MÄLARDALENS HÖGSKOLA
ESKILSTUNA VÄSTERÅS

ECONOMIC MODELLING OF FLOATING OFFSHORE WIND POWER

Calculation of Levelized cost of energy

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ABSTRACT

Floating offshore wind power is a relatively new technology that enables wind turbines to float above the sea level, tied by anchors at the seabed. The purpose of this work is to develop an economic model for the technology in order to calculate the total cost of a planned wind farm. Cost data are retrieved from reports and academic journals available online. Based on these data, a model in Microsoft Excel is developed which calculates the Levelized cost of energy (LCOE) for floating wind power plants as a function of several input values. As an addition to this model, financing offshore projects are described using literature study and by doing interviews with three major companies, currently investing in offshore wind. As a result, the model allows the user to calculate Capital expenditures, Operating expenditures and LCOE for projects at any given size and at any given site. The current LCOE for a large floating offshore wind farm is indicated to be in the range of 138-147 £/MWh. The outline from interviews was that today there is no shortage of capital for funding wind projects. However, in order to attract capital, the governmental regulatory of that market has to be suitable since it has a crucial impact on price risks of a project.

Keywords: Floating offshore wind, Levelized cost of energy, Financing, Cost structure, Funding structure, Weighted average capital cost, Capital expenditure, Economic model, Operating expenditure.

PREFACE

This work is written for the degree of Master of Science in industrial economics at Mälardalen University in Västerås, Sweden. The research conducted in this degree project has been under the supervision of Jan Sandberg in the department of Business, Society and Engineering from January to June 2017.

The degree project is at the request of Flowocean, a startup company in floating wind industry. It is of high importance for the company to estimate costs accurately at different stages in its offshore projects and thereby their request for this work. The purpose of the study and research question was formulated together with my supervisor Urban Joelsson, CEO of Flowocean.

I am grateful to employees at Flowocean that were involved in this project. I would like to especially thank my supervisor Urban Joelsson for his supervision and support throughout the work. A special gratitude goes to Jan Sandberg at Mälardalen University for his guidance. And also to Cristoffer Kos at Flowocean for valuable conversations and advice during the project.

I would like to thank also all the participants in the interviews who shared valuable information regarding financing of wind projects: Jonas Ekman at Statkraft, Lars Andersen at DONG Energy and Linus Hägg at Arise.

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Shayan Heidari

MÄLARDALENS HÖGSKOLA
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FLOW OCEAN

SUMMARY

The installed capacity of wind power has increased steadily the last decade. Most of the development has been taken place in the onshore wind industry. However, the installed capacity of offshore wind has also increased the last couple of years. The offshore market has so far been dominated by countries with shallow water near coasts and established maritime industries. With increased inaccessibility to locations that are suitable for installation of fixed-bottom offshore, the interest for floating offshore wind has increased. Floating wind power is a relatively new technology that enables the wind turbines to float above the sea level while tied at the seabed with anchors. The main opportunities with floating offshore wind power compared to traditional offshore wind concepts is the eliminating of depth constraint in deep waters, enabling access to areas with strong wind resources, proximity to populated regions near coasts, easing turbine installation offshore and they also have less impact on the environment since only the anchors are installed at the seabed.

There are today only a few floating concepts that have been demonstrated at large scale. This degree project has been written in collaboration with Flowocean. Flowocean is a Swedish-based floating wind startup company with its own technology and is currently planning to launch its first full-scale demonstration plant and further to begin commercial operations globally. It is crucial for Flowocean to estimate costs accurately at various stages in an offshore wind project and thereby they requested this work.

The purpose of this project degree is to develop an improved economic model for the floating wind power industry in order to enable operators in the market to calculate the total cost of a planned floating wind power farm with greater certainty. Cost data are retrieved from reports and academic journals available online. Using these data, an economic model in Microsoft Excel is developed which calculates the Levelized cost of energy (LCOE) for floating wind power plants as a function of different input values regarding technical specifications and site conditions. Further, different parameters of the model are analyzed using sensitivity analyses. As an addition to the LCOE-model, a second part is added. In this part, the financial structures of offshore wind projects are described and studied in more detail by doing three interviews with major companies, currently investing in offshore wind.

The outcome of this work is mainly a LCOE calculator specific for floating wind projects, which is developed in Microsoft Excel and is attached to this degree project as a digital appendix. A series of simulations are performed using the developed model in Excel. Three benchmark farm are designed for comparing the results from the model with different floating concepts. The chosen floating concepts in these simulations are Spar-buoy with drag-embedded anchors, Semi-submersible with drag-embedded anchors and Tension Leg Platform with driven pile anchors. The benchmark farm has a capacity of 490 MW and consists of 70 turbines. The calculated CAPEX values for the benchmark wind farm are in the range of 1,5-1,7 billion £, with spar-buoy as the cheapest concept. The OPEX values are in the range of 51-57 million £/year, with semi-submersible having the lowest annual cost. Finally, the Levelized cost of energy (LCOE) is calculated for all three concepts which resulted in the range of 138-147 £/MWh with again spar-buoy as the cheapest alternative. Further, various sensitivity analyses were run to gain a better understanding of relationship between the input values and the calculated LCOE.

The most important identified cost drivers in these analyses are turbine capacity, capacity factor, wind farm availability and cost of capital.

In the second part of the degree project, several interviews are done with active players in the industry to get a better understanding of the financing of wind projects. Three interviews are selected to be included in this work. The outline provided by these interviews was that today there is no shortage of capital for funding wind projects, capital can be found for the right price. However, in order to attract capital to a specific project, the governmental regulatory of that market has to be suitable since it has a crucial impact on risks of a project. Price mechanisms such as CfD or Feed-in tariffs are preferred since they provide revenue predictability and ease handling price risks.

It can be discussed whether the model is presenting accurate cost estimations or not. The output of the model contains high level of uncertainty since the underlying data is retrieved from available reports and not based on industry raw data. However, both LCOE values and the cost structure of the projects are acceptable compared with actual investment data and values indicated in other studies. It is also important to mention that the floating wind market is still immature and there are various concepts under development with totally different design. The costs of each design may vary greatly depending on the manufacturing, installation and maintenance procedure. Therefore, to divide all concepts in the market into three main substructures is a rough generalization and the costs should be adjusted accordingly by the user.

As conclusion, it can be claimed that offshore wind is considered to become a competitive renewable energy source in the future. Floating offshore wind is suitable in locations where there is deep water near coastlines, there are decent wind resources and suitable infrastructure. In these areas is floating offshore wind considered to grow and play a substantial role for a sustainable power production in the coming future.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Abbreviation	Description
AC	Alternating current
AEP	Annual energy production
CAPEX	Capital Expenditure
CfD	Contract for difference
DC	Direct current
EMRP	Expected market risk premium
FID	Final investment decision
GW	Gigawatt
HVAC	High-voltage alternating current
HVDC	High-voltage direct current
JV	Joint venture
kV	Kilovolt
kW	Kilowatt
LCOE	Levelized cost of energy
MW	Megawatt
MWh	Megawatt-hour
O&M	Operations and Maintenance
OPEX	Operations and Maintenance expenditures
PPA	Power purchase agreement
R&D	Research and development
RFR	Risk-free rate
UK	United Kingdom of Great Britain and Northern Ireland
USA	United States of America
SPV	Special Purpose Vehicle
TLP	Tension Leg Platform
UJV	Unincorporated Joint venture
WACC	Weighted Average Cost of Capital

1 INTRODUCTION

In this chapter a brief summary of wind power's history, an outline of the market today and also, the aim of this work is presented and described.

1.1 Background

Ever since the industrial revolution fossil fuels have dominated the energy supply globally, which has resulted in a gradual increase of carbon dioxide emissions. It has been confirmed that the majority of global anthropogenic greenhouse gas emissions are due to the usage of fossil fuels. These emissions are continuing to grow as a result of this, the carbon dioxide concentrations have been estimated by the end of 2010 to have increased to 390 ppm above preindustrial levels. There are several measures available to lower these emissions while still satisfying the demand for energy. Such as energy conservation and efficiency, development of renewable energies, nuclear and carbon capture and storage (CCS) methods (Edenhofer, o.a., 2011).

Although the concept of wind power has existed for thousands of years, it was not until 1888 in Ohio, that the first wind turbine to generate electricity was installed. This occurred during the 1880s. In this decade a series of technological inventions emerged, including the development of generator. Thus, wind power can be regarded as one of the early applications of these inventions.

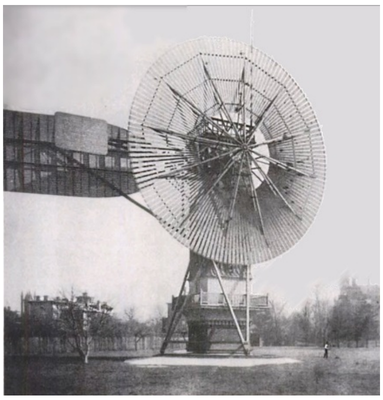


Figure 1. Charles F. Brush's 60 foot, 80 000 pound turbine in 1888. Adapted from "Wind Energy in America: A History", by: Robert W. Righter, 1996, University of Oklahoma Press, page 44.

In the coming years, the technology was developed further by Denmark, France, Germany and UK which enabled to demonstrate that the large-scale wind turbines could actually work. An important event related to wind power is the 1973 oil crisis. During this period, USA made huge research and development efforts in this area which resulted later years in the first large-scale wind energy generation in California, where over 1.7 GW were installed between 1981 and 1990. However, in the meantime, Northern Europe took the lead of development of wind power due to increased electricity costs and optimal wind resources in the region. This lead eventually to the formation of a stable market in Europe and since 1990 the region has been the main scene for major developers in the industry worldwide (Kaldellis & Zafirakis, 2011).

The total cumulative installed wind capacity at the end of year 2015 is estimated to be over 432 GW worldwide (GWEC, 2016). Today, wind turbines are fabricated in several different sizes and styles and are mainly categorized as horizontal or vertical. The power production is affected by a number of factors, such as turbine capacity and height of the turbine, the diameter of the rotors and also the wind speed (IRENA, 2012).

Moving wind power offshore has the advantages of both reaching higher average mean wind speed and ability to build larger turbines with larger swept area and therefore obtain higher electricity outputs. Offshore wind farms are also less constrained by siting issues that are usually applied on land (IRENA, 2012).

The technology for offshore wind power has so far been dominated by fixed-bottom foundations. The growth of offshore wind capacity has been increasing steadily, at the end of 2015 the global cumulative installed offshore wind capacity was over 12 GW (GWEC, 2016).

United Kingdom is currently the market leader within the offshore wind power sector with over 5 GW installed capacity (GWEC, 2016). The capacity is expected to reach the remarkable level of 20-55 GW by 2050. Most of the installed capacity for offshore wind power in the UK is currently fixed-bottom structures and are located in shallow water depths (<40m) and close to shore (<30km). Considering the decrease of access to shallow waters near the shores in the future, the fixed-bottom technology for offshore wind power has potential to limit over the long-term in some markets. This creates a need for a new technology that enables projects to move further from shore into deeper waters (James & Costa Ros, 2015).

As a solution to this challenge, several concepts for floating wind power plants have been developed with the potential to utilize deep water sites with fewer complications compared to the traditional fixed-bottom structures. Moving further from shore brings technical challenges regarding power transmission, installation and operation and maintenance activities. The cost for the fixed-bottom foundations assumes also to increase as moving into deeper waters (James & Costa Ros, 2015).

Although its potential, development of floating technology is still in its initial phase and hasn’t been demonstrated at large scale yet. The main challenge for the operators in the market today is to make cost reductions from existing prototypes to commercial models in order to prove the feasibility of the concepts. Subsequently, the technology will attract investment for commercial deployment and this will benefit the industry from the learning factors and economies of scale that will be developed in turn (James & Costa Ros, 2015).

The market today consists of 30+ developers with floating concepts under development. However, only a few concepts have been demonstrated at large scale offshore. (James & Costa Ros, 2015) Flowocean is a Swedish-based floating wind power startup company with its own proprietary technology that has been engaged in R&D activities for almost ten years and is now ready for commercial launch. This degree project has been written in collaboration with

Flowocean. The company has been assisting throughout the work, all necessary knowledge of the processes that the company executes has been shared and described systematically.

Flowocean is currently planning to launch its first full-scale demonstration plant and further to commence commercial operations globally. One area of importance for the company's success is the ability to estimate costs accurately at different stages in its offshore wind power projects and hence their support in this work.

1.2 Purpose

The main purpose of this study is to develop an improved economic model for the floating wind power industry in order to enable actors in the market to calculate the total cost of a planned floating wind power farm with greater certainty. It is of great importance that the developed model is general for all types of floating wind power plants and can easily be used by any company around the world. The model aims to enable suppliers to give better offers to customers, and for developers and investors to evaluate investment risks more accurately.

As an addition to this model, financing of offshore wind projects has been studied in more detail. The reason for this is to gain a better understanding of financial structures that occur in offshore projects and also find out which impact cost of capital has on the total cost of a project.

1.3 Research questions

- Is it possible to develop an economic model for calculating LCOE from floating wind power plants at any given wind farm and any given site? How would such a model need to look like?
- What funding structures occur in the offshore market and what trends can be seen regarding financing of projects?

1.4 Delimitation

The created model is designed primarily for floating wind power plants. It will possibly be compared to some extent with fixed-bottom wind power concepts but is developed solely for floating wind power.

The cost of developing a wind power plant depends on numerous factors. In order to create a simplified and practical model, only a limited number of parameters will be selected and examined further. The number of these factors and their complexity has been adapted to the project time frame.

The developed economic model is able to provide the user with a total cost estimation for projects of different sizes. However, the model is not suitable for pricing of wind power since that subject requires further information about business strategy, political and other negotiating factors.

1.5 Contribution to current research

Due to the new technology of floating wind power structures, there are not many reports and studies in the field compared with several other energy sources. However, it is an exciting new field and there are many R&D activities going on in this area.

The main goal of this study is to develop a model to calculate total costs of a floating wind power plant. Regarding cost estimations and equations in the floating wind market, mainly two reports were used: Bjerkseter & Ågotnes (2013) and Beiter, et al. (2016). The first mentioned report is a thesis work written by Norwegian students where costs of floating wind farms is estimated based on literature study and market insight. The other report is written by NREL and analyzes cost structures of offshore wind projects in the US using various data sources and industry collaboration.

In the second part of the report, financial aspects of wind projects are analyzed. To understand this field, EWEA (2013) and PricewaterhouseCoopers (2012) were used as main references. The first report is written by EWEA and describes financing of offshore wind projects systematically. The other report is prepared by PricewaterhouseCoopers and describes more profound technical aspects of financing offshore wind projects.

This degree project is a combination of these two fields of study. The developed model is able to take various parameters, including financial parameters as input values and calculate LCOE of a power plant as output. The market is developing rapidly and therefore updated data for cost estimations are strived for during the work.

2 METHODOLOGY

This degree project is mainly based on literature study at the initial phases, the significant factors that affect the total cost of wind power plants according to other studies have been identified and described thoroughly. The literature study is based on available reports, reviews and academic journals published by several organizations and researchers.

Meetings and interviews have been held with Urban Joelsson, CEO of Flowocean in order to identify important cost driving factors and for gaining the necessary base of knowledge in the field of floating wind power.

Cost estimates and functions used in the model were retrieved from existing reports and academic journals. Using these cost estimates, an economic model in Microsoft Excel has been developed. In the model, it is possible to calculate the LCOE for floating wind power plants as a function of different input values regarding technical specifications and site conditions. The exchange used in this work is pound sterling since many of the cost estimations were from British sources and were given in pound. All cost estimations can be found in Appendix 1.

The formula used for LCOE calculation is retrieved from PricewaterhouseCoopers (2012) and is the following:

$$LCOE = \frac{Sum\ of\ lifetime\ discounted\ generation\ costs\ (£)}{Sum\ of\ discounted\ lifetime\ electricity\ output\ (MWh)}$$

Equation 1 – Levelized cost of energy

Where generation cost includes all CAPEX and OPEX that occur over the lifecycle of the project which is 20 years in this case. CAPEX includes more specifically the cost for project development, turbine, substructure, mooring system, electrical infrastructure, installation, insurance and contingency. Revenue from salvage value and decommissioning costs are neglected in this work. Electricity output is the net metered output at the offshore substation after all losses. All components of the formula will be described throughout the work.

Further, different parameters of the model have been analyzed using sensitivity analyses. Based on these analyses, key cost drivers of a wind project are identified and described in more detail.

As an addition to the LCOE-model, a second part was added to the work. In this part, the financial structures of offshore wind projects are described and studied in more detail by doing interviews with major companies, currently investing in offshore wind. The financing of projects is initially described in the literature study. Based on the findings from the literature study, five interview questions were asked during telephone interviews to get more insight about the financial market of offshore wind. The full transcripts of the interviews can be found in Appendix 2.

By using the LCOE-model and summary from the interviews, the questions related to this degree project are answered and a final conclusion was reached.

3 LITERATURE STUDY

A brief description of the floating wind power market is included in this part of the report, followed by a breakdown of cost structure of floating wind projects.

3.1 From near shore to deeper waters

Due to supportive energy policies, technology advancements and related cost reductions the annual installed capacity of wind power has increased steadily during the last decade. Wind energy is predicted to play a major role in global electricity supply as well as reduction of greenhouse gas emissions in the future. Most of this development in the industry has taken place in the onshore wind industry. However, the installed capacity of offshore wind power has also increased in recent years, mostly in Europe (Wiser, o.a., 2016).

At Horns Rev off the coast of Denmark, the first utility-scale offshore wind farm was grid-connected in year 2002. Since that year till the end of 2015, the global capacity of offshore wind energy has increased from 0,26 GW to 12,7 GW, which can be seen in the figure below (IRENA, 2016).

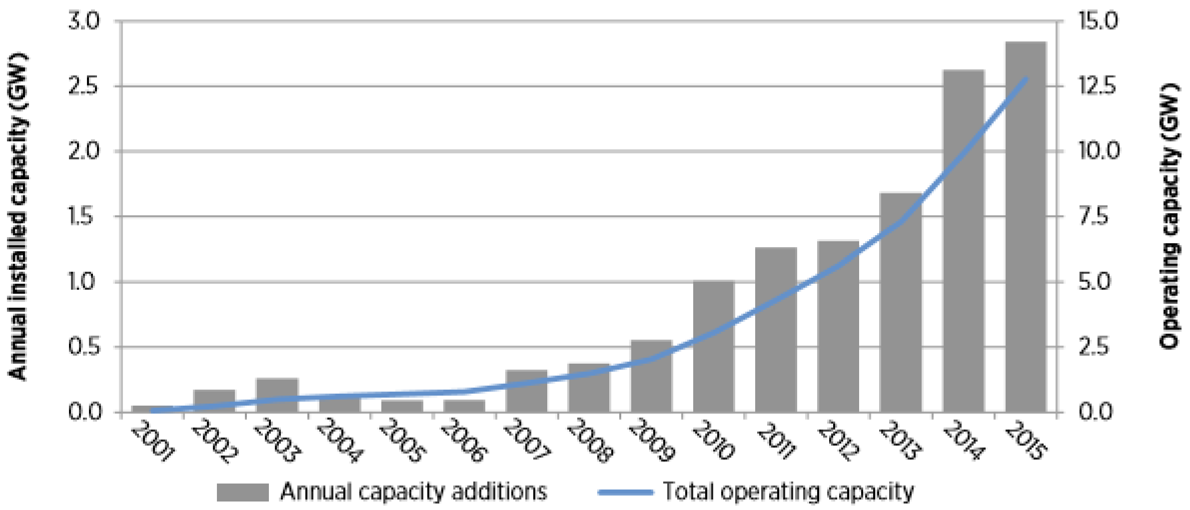


Figure 2. Global annual installed capacity and operating capacity for offshore wind farms, 2001-2015. Adapted from: "Innovation Outlook: Offshore Wind", International Renewable Energy Agency, 2016, Abu Dhabi.

The increased interest in offshore wind energy is due to the advantages associated with this renewable energy source. Compared to onshore wind power, offshore installations can access greater and steadier wind resources. In populated areas, it has less social impact than onshore wind power, regarding operating noise and visual burden. Another advantage with offshore wind power is the possibility to utilize many of the technologies which already have been used by the onshore wind industry for decades (IRENA, 2016).

Since the beginning of this century, most of the offshore wind projects have moved farther from shore and into deeper waters. In these areas, the wind speeds are usually higher, thus manufacturers have developed special turbines for the offshore market with higher rated power and more suitable for the harsh conditions out at sea. The supply chain has also undergone improvements, the installation methods have become more sophisticated and the offshore installation vessels are more efficient. Specialized wind turbine components that were costly in the early stages of the market are now replaced by more affordable standard components, which are produced in greater numbers thus utilizing economics of scale (IRENA, 2016).

So far, the market has been dominated by countries with shallow coasts, water depths of less than 50 meters, and with established maritime industries, such as oil and gas. With increasing inaccessibility to suitable places for installation of fixed-bottom foundations and growing pressure on countries to decarbonize their energy portfolios, the interest for floating offshore wind is increasing (James & Costa Ros, 2015).

3.2 The global market

Development of floating foundations opens up a whole new market with vast opportunities in deep waters offshore. The main opportunities with floating concepts are firstly the eliminating of the depth constraint of existing fixed-bottom foundations. They enable access to areas with strong wind resources and proximity to populated regions. Another opportunity is easing turbine installations in deep waters and offering a lower cost alternative compared to fixed-bottom foundations. Also, they offer environmental benefits since the installation has less impact on the seabed compared with fixed-bottom designs (IRENA, 2016).

Considering these advantages, the appetite for growth of floating wind power is high in several countries that have limited places with shallow waters for installing fixed-bottom foundations. The potential is especially high in Japan, several European countries and the United States.

3.2.1 Europe

Europe is the biggest global market for offshore wind energy. More than 91% of all offshore installations were located in European countries at the end of 2015 (GWEC, 2016).

The potential for further development of floating wind power in Europe is vast. Based on the table and figure on the next page, the North Sea and the Atlantic coastline is suitable for floating wind installation since the waters are deep, while the wind resources are high and suitable for floating wind power concepts.

Table 1. Offshore wind resource and potential floating wind capacity in Europe, USA, and Japan. Adapted from: "Floating offshore wind: Market and technology review", by: R. James, M. Costa Ros, 2015, Carbon trust.

Country/Region	Share of offshore wind resource in deep water locations (>60m depth)	Potential floating wind capacity
Europe	80%	4,000 GW
USA	60%	2,450 GW
Japan	80%	500 GW

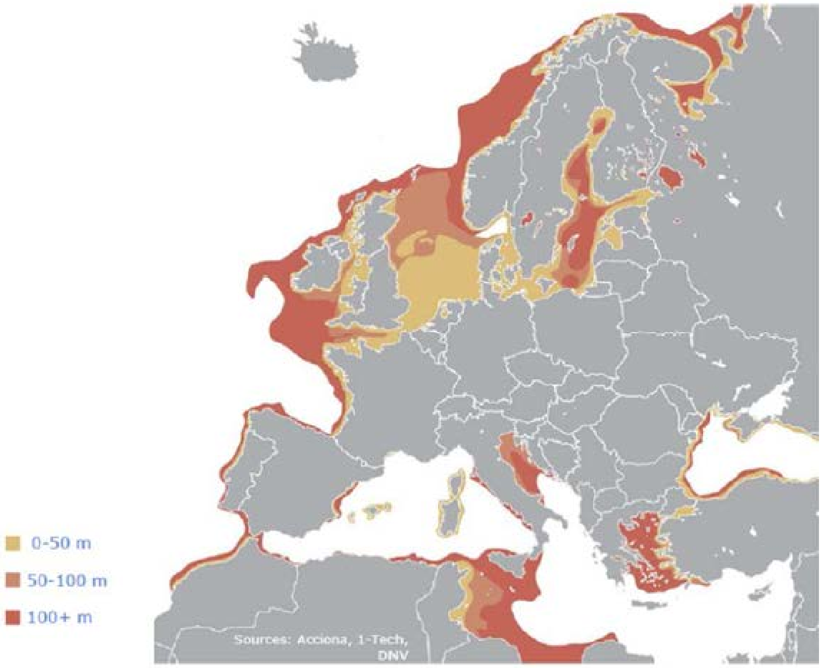


Figure 3. Sea depth around Europe. Adapted from: "Floating wind technology: future development", by: Johan Slätte, 2014, DNV GL.

Today is the UK the world leading country with over 5 GW installed offshore capacity (WindEurope, 2017). The country possesses great potential in the North Sea with huge wind resources in deep waters. The highest wind speeds are in Scottish waters and off the southwest coast of the UK where deep-water areas are plenty (James & Costa Ros, 2015).

The UK can position themselves as the market leader in the floating wind power technology as they are in the offshore industry today. The operators possess great experience earlier from the oil & gas, maritime and offshore industry, together with governmental incentives and support frameworks the potential for success is vast (DNV, 2012).

According to EWEA (2013), the depths of the North Sea varies between 50 m and 220 m. For instance, deploying 6 MW wind turbines in this area could generate today's EU electricity demand four times over. In the Atlantic and the Mediterranean, the potential is even greater. Portugal with a vast maritime area, together with France and Spain, have deep waters close to shore in Atlantic Seas. Therefore, a big potential for offshore wind power exists in these areas.

By far, the UK has the greatest experience of offshore wind industry in the world, but the technology is still immature and the race is ongoing with numerous European countries trying to take the lead in the European market.

Current projects in Europe

Europe is home to a couple floating wind pioneers who already have built prototypes and have proven their designs. There exist also several companies who are still developing their concepts and might make a breakthrough in the market in future.

The Hywind concept developed by Statoil is the first floating offshore wind turbine being deployed in the world. The Hywind Demo has been installed since 2009, ten kilometers off the coast of Norway. A few years later in 2015, the company made the decision to build the world's first floating wind farm in Aberdeenshire in Scotland. The park will cover 4 square kilometers at water depths of 95-120 meters. The distance to shore is 25 km and the wind speed estimates to be around 10 meters per second. The 30 MW wind farm planned to be in production from late 2017, this will mark a step forward for offshore wind technology (Statoil, 2015).

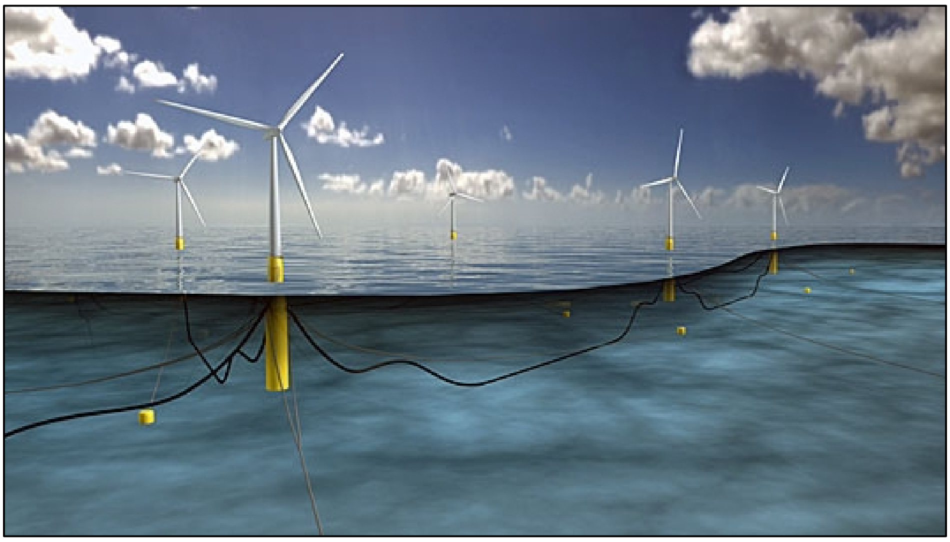


Figure 4. Hywind Scotland. Adapted from: " Statoil to build the world's first floating wind farm: Hywind Scotland", by: Statoil, 2015.

WindFloat by Principle Power is also one of the more mature floating concepts being developed in the industry. The company installed a 2 MW prototype, 5 km off the coast of Aguçadoura in Portugal in 2011. The system has produced 16 GWh of electricity and was decommissioned in 2016 after completing all of its project objectives. Principle Power has now multiple follow-up projects that are under development for pre-commercializing WindFloat units. Including, a 25 MW wind farm located in Viana do Castelo in Portugal, a 24 MW project in Leucate in France and a smaller 6 MW project in Japan (Principle Power, 2017).

Another challenger worth mentioning is the French company Ideol. They have a concept under construction called Floatgen that will be commissioned in late 2017 off the coast of Le Coisic in France. The capacity of the turbine will be 2 MW and the depth of the unit 33 meters. The project will evaluate the performance of the solution under real conditions and offer a start point for serial production. The company is planning further to develop a 24 MW wind farm off the coast of Gruissan in France in the next coming years (Ideol, 2017).

3.2.2 United States

Even though the offshore wind market is not as mature in the US at it is in Europe, the potential is big for further development of floating technology in this market. It is estimated that the technical wind resource potential along the coastline and the Great Lake waters exceed 4000 GW. There are huge opportunities in these areas since 60 % of the offshore sites available in this area are in deep waters (>60m). Floating wind power is the only realistic solution at many locations in the US (DNV, 2012).

More than 80 % of the US electricity demand exist in coastal states, therefore offshore wind can make a big impact on the clean energy mix goal of the country. The National Offshore Wind Strategy has set a target goal of 54 GW of offshore capacity in the US to be developed by 2030 with a cost of £0,05/kWh (Mast, Rawlinson, & Sixtensson, 2015).

Current projects in US

At this point, most research & development activities in the US are occurring at the University of Maine. So far, DeepCwind Consortium Research Program have developed VolturnUS floating concrete structure which can support wind turbines in depth of 45 meters or more. A 6 MW prototype of this concept was built in 2013 in a 1/8 scale and became the first grid-connected floating wind turbine in the US. Maine Aqua Ventus is now leading a project called New England Aqua Ventus which plans to develop two 6 MW VolturnUS units on Monhegan Island. The project has been selected by the US Department of Energy to receive £25.9 million in construction funding. The deployment of the project is planned for 2019 and will probably be the first full-scale floating wind project in the US (The University of Maine, 2017).

Figure 5. New England Aqua Ventus, Adapted from: "Maine Aqua Ventus", the image is fully credited to the University of Maine. Retrieved from: http://maineaquaventus.com/

Another exciting project in the US is the planning of an 816 MW wind farm in Hawaiian waters. Alpha Wind Energy, a Danish company plans to install 102 units of Principle Power's Windfloat foundations in water depths of nearly 1000 meters. The project is currently going through lease acquisition process (Tsanova, 2015).

3.2.3 Japan

Analyses performed by Govindji, James, & Carvallo (2014) indicates that Japan has potential to generate 600 GW wind power, with most of this from floating technologies. Japan is one of the countries that could leap in leading the floating wind market since it has a very suitable geographic condition for installing floating designs. It has deep waters and limited land available for onshore for wind farms (DNV, 2012).

Another advantage for the Japanese is their great experience in offshore floating structures from other markets such as shipbuilding industry. Together with consistent emphasis on R&D and a long-lived culture of mass production, it is one of the most suitable markets for commercialization of this technology (DNV, 2012).

Since the Fukushima nuclear disaster in 2011, Japan has closed most of its nuclear reactors. This has led to a lot of spending on imported liquid natural gas to replace the lost power generation from nuclear. Therefore, the focus on alternative solutions in energy generation, such as floating wind power, has increased in recent years (Nilsson & Westin, 2014).

The increased price of electricity has created a political agenda towards renewable energy sources in Japan. Since March 2014 an offshore wind feed-in-tariff of approximately 252 pound/MWh has been introduced in Japan. The purpose of the tariff is to support the development of offshore wind in Japan and support easier project financing (Mast, Rawlinson, & Sixtensson, 2015).

Current projects in Japan

The Japanese Government has a long-term goal to install up to 1 GW of offshore floating wind capacity. To reach this goal a R&D approach is under process called Fukushima FORWARD. The project is divided into two phases. The first phase is headed by Marubeni Corporation and resulted 2013 in installing one 2 MW turbine on a four-column foundation together with the world's first floating substation. The second phase of the project consists of installing two floating platforms, carrying a Mitsubishi 7 MW turbine and a 5 MW Hitachi turbine. The project has become a hub for research in floating wind power technology and places Japan at the forefront in this field (James & Costa Ros, 2015).

Figure 6. Fukushima FORWARD, Adapted from: http://www.fukushima-forward.jp/english/photo/index.html

3.3 Deep water foundations

Most concepts for floating foundations have already been deployed offshore in the oil and gas sector and have been used commercially at large scale. These foundations have already been proven in tough operating environments earlier. However, they tend to require adaptation to wind power to accommodate different dynamic characteristics and a different loading pattern (IRENA, 2016).

According to Mast, Rawlinson, & Sixtensson (2015), there are basically three stability philosophies in the market which floating structures can be classified within: ballast (Spar-buoy), mooring (TLP) and buoyancy (Semi-submersible).

3.3.1 Spar-buoy

In these structures, an enormous cylindrical buoy is used which stabilizes the turbine by using ballast. The lower parts of the foundation are heavy while the upper parts are usually empty, near the surface. In this way, the center of gravity is lower in the water than the center of buoyancy (EWEA, 2013).

Spar-buoys are created based on this principle. Due to simple structure design, the spar-buoys are easy to construct and provides good stability in the water. However, the large structure creates logistical challenges during the process of assembly, transport and installation. The design can also have the constraint to be deployed in waters of at least with 100 m depth.

The most mature concept in the spar-buoy category is Statoil's Hywind foundation. The development of the concept started in 2001 and has so far commissioned a 2 MW prototype and planning to soon deploy the world's first floating wind farm (Mast, Rawlinson, & Sixtensson, 2015).

Figure 7. Turbine Spar illustration, by: Josh Bauer, 2013, NREL.

3.3.2 Tension Leg Platform (TLP)

In these concepts, by using tensioned mooring lines stability is achieved. TLP concepts are submerged structures that pulls the foundation up above water surface, while the mooring lines pull the structure down toward the sea bed. The tension of mooring lines is of great importance in these concepts since a failure will eventually lead to tipping of the whole structure (Nilsson & Westin, 2014).

GICON SOF with origins from Germany, is the only operator in the market with a full scale TLP demonstration so far. It demonstrated a 2.3 MW turbine in Germany in 2016 (IRENA, 2016).

Figure 8. Turbine TLP illustration, by: Josh Bauer, 2013, NREL.

3.3.3 Semi-submersible

Stability in these structures is achieved by distributed buoyancy. It is a combination of the two previous designs. These foundations consist typically by several columns linked to each other that provides ballast and flotation stability. The structure is tied with mooring lines to keep the structure in position. These foundations are suitable in different site conditions since the draft is low and constraints regarding soil conditions are few (DNV, 2012).

WindFloat developed by Principle Power is the most mature semi-submersible concept in the market. The structure is built of three columns with a single turbine mounted on one of these. It has an active ballast system meaning that water is pumped between columns in order to keep the platform upright when the wind direction changes (Mast, Rawlinson, & Sixtensson, 2015).

The company has so far commissioned a 2 MW prototype in Aguçadoura, Portugal. Larger projects are currently under development, including in Portugal, France and Japan (Principle Power, 2017).

Figure 9. Turbine Semi illustration, by: Josh Bauer, 2013, NREL.

3.3.4 Comparison of concepts

Currently, there is no clear winning concept in the floating wind industry. Each concept has its own strengths and weaknesses due to different conditions at a specific site.

The table on the next page summarizes strengths and weaknesses of each structure type. The statements are according to DNV (2012), IRENA (2016) and James & Costa Ros (2015).

Table 2. Pros & cons with each substructure type. By: DNV (2012), IRENA (2016) and James & Costa Ros (2015).

Type	Pros	Cons
Spar-buoy	• Simple structure, suited for serial fabrication • Lower installed mooring cost and independent of soil conditions • Highly stable structure with tendency for lower critical wave-induced motions • Few moving parts or complicated components	• Due to the large draft of the structure, the possibility for in-shore assembly and maintenance limits • Spar-buoys need deeper water compared to other concepts (>100 meters) • The structure requires dynamic positioning vessels an heavy-lift cranes during offshore installation
TLP	• Low mass and thereby production cost • Can be assembled onshore or in a dry-dock • Few components, easy to inspect. • Highly stable	• Less technological experience • Complex anchoring, installation and maintenance • High loads on the anchoring and mooring system
Semi-submersible	• Operational in shallow water depth due to low draft • Can be assembled on-shore or in a dry-dock • It can easily be towed back to shore with conventional tugs during major repairs • Lower installed mooring cost	• High production cost due to heavy and complex structure • Difficult to fabricate • Might have larger wave-induced motions compared with other foundations

3.4 Cost structure

In this chapter, the cost structure for an offshore floating wind farm is broken down into different cost categories. Each category is in turn described regarding the development in the market today, and which cost reduction possibilities may be considered in the future.

3.4.1 Wind farm development

The costs included in this category considers the development costs of a project, which are activities prior to construction and acquisition of components to be included in the wind farm. They cover the processes from the start of a project until the final investment decision (FID). The development of a project can take years before the commissioning of the wind farm. It usually starts 7 to 10 years before the year of first turbine installation (IRENA, 2016).

During these years, many tasks should be conducted to prove the feasibility of the project. The development cost is not the biggest cost item in a wind farm project. However, greater investment in this field will be beneficial and enable cost savings later in the project. According to FOWIND (2016), the development costs can be derived into four main categories: Site surveys, consent and planning, design and engineering and commercial and legal work.

Site surveys are required to understand the conditions of both offshore and onshore sites nearby the wind farm. Hence, contractors need operating experience from both areas. In this stage, trained personnel such as engineers, surveyors and geophysicists are essential. Also, capital equipment such as vessels are crucial during the operation of surveys (FOWIND, 2016).

Next category in the development process is the approval of the project. To acquire consent, an environmental impact assessment is required, which covers both human and natural receptors. However, the planning process is special for each country and depends on where the wind farm is planning to be developed (FOWIND, 2016).

Design and engineering tasks are required in order to develop a floating wind farm project. Typically, developers perform these tasks in-house since they're unique for each wind turbine concept and cannot be implemented from other projects. The number of tasks in this category are vast (see figure 10), and it can be helpful to contract an Owner's engineer for assistance of engineering and commercial tasks (FOWIND, 2016).

Figure 10. Development activities. Adapted from "Supply Chain, Port infrastructure and Logistics Study", by: FOWIND, 2016.

Large-scale wind farm projects often require a substantial amount of legal and commercial work since the final decision involves large size capital investments and many stakeholders are involved. The developer manages typically these processes in-house, while legal firms support all steps of the process (FOWIND, 2016).

3.4.2 Turbines

During the recent years, specific designs of offshore wind turbines have emerged. These turbines are bigger than the one used for onshore. They are also improved regarding to reliability and durability in maritime harsh environments. In 2016, the five major turbine manufacturer globally were Siemens, followed by MHI Vestas, Senvion, ALSTOM and Areva Gamesa (FOWIND, 2016).

Some components of a turbine are shown in the figure below. The total cost of a wind turbine includes three major parts; Rotor, Nacelle and Tower.

Figure 11. Illustration of wind turbine, by: Josh Bauer, 2013, NREL.

Rotor

The rotor includes the blades, a cast iron hub, auxiliary systems, blade bearings and a weatherproof hub cover. The blades are usually manufactured by using glass fiber in full-length molds. By the end of 2015, all commercial deployed wind turbines were of three-blade upwind configurations. The largest rotors had 75 meters long blades (IRENA, 2016).

Nacelle

The components included in the nacelle are the drivetrain, the power take-off system, the auxiliary systems as well as control and monitoring systems. They are located inside the weatherproof cover. Three different concepts of drivetrains exist in commercial offshore turbines:

- Three-stage gearbox with high speed generator,
- Lower-ratio gearbox and mid-speed generator and
- Low-speed direct-drive permanent magnet generator without the need of a gearbox.

It is uncertain which concept offers the lowest cost of energy based on operational cost considerations as well as reliability (IRENA, 2016).

Tower

Wind turbine towers are steel tubes made in two or three parts which are bolted together. Internal ladders, personnel lift and sometimes power electronics and step-up AC transformer are included in towers. Offshore towers are very similar to those used in onshore turbines regarding both design and manufacturing (IRENA, 2016).

3.4.3 Substructures

So far, only a handful of prototype projects in the floating wind market have been deployed and hence there is a lack of data and information about production time and total costs of these substructures. If the floating wind market progresses from prototype stage to further commercial stages, it is obvious that the large scale production costs will decrease due to economics of scale and automation.

The substructure is the innovative solution of each company and distinguishes them from competitors. Currently, Statoil and Principle Power are the companies that have developed their concepts furthest and are leading the market. However, the race is still ongoing and any company with the best substructure as solution regarding costs and simplicity is able to take the lead in the future.

In chapter 3.3, the three dominant floating wind structures are described in detail. These are semi-submersible platform, spar-buoy and tension leg platform.

3.4.4 Mooring system

With floating wind structures, a mooring system is attached to keep the structure in a fixed position at a specific location. It consists of moorings and a set of anchors.

Moorings

There exist several different mooring configurations but the most used configuration are catenary and taut-leg mooring systems. Catenary configurations are usually used with semi-submersible and spar-buoy concepts and taut-leg configurations with TLP concepts.

The main difference between these configurations is the loading at anchoring point, as it can be seen in the figures. The catenary system has horizontal loading with the lower part of the chain rests on the seabed and taut-leg with a vertical loading. This leads to limited horizontal movement and creates excellent stability for the taut-leg system but some degree of horizontal movement for the catenary (James & Costa Ros, 2015).

The restoring forces for the taut-leg system are generated by elasticity of the mooring lines that are attached to the substructure and can withstand both horizontal and vertical loads. The catenary system however, generates most of the restoring forces horizontally through the weight of the mooring lines. Therefore, a large mass or a buoyancy element should be attached to the system to create vertical forces (Bjerkseter & Ågotnes, 2013).

An advantage with the catenary system is the simple installation procedure compared with the challenging installation of taut-leg systems. The disadvantage however, is the disruption of seafloor compared with taut-leg systems since the lower part of the catenary chains rests on the seabed and results in a large footprint (James & Costa Ros, 2015).

Anchors

There exist several different anchor solutions in the market for floating wind turbines. The choice of anchors is dependent on seabed conditions, the mooring configuration and the holding capacity that is required for the substructure. The four most common anchor types are drag-embedded, driven pile, suction pile and gravity anchor. These are all proven concepts and been used in the marine and oil & gas markets previously.

Drag-embedded anchors are used often with the catenary mooring configurations to handle the horizontal loadings on the mooring chains. The taut-leg mooring configurations however, often use the three other anchor types to cope with the vertical loadings. (James & Costa Ros, 2015)

The most widely used anchors are the drag-embedded, together with catenary mooring configurations. These are mostly used in soft soils, in harder soil conditions they are harder to penetrate. Therefore, gravity and driven pile anchors are being used more in soft soil conditions. In general, the installation process for drag-embedded and suctions piles anchors is less complicated than the other two and are also easier to remove after decommissioning.

3.4.5 Electrical interconnection

This chapter describes the electrical infrastructure in floating wind farms that connect the farm to the onshore electrical grid. The offshore electrical interconnection usually consists of: array cables, offshore substation and subsea export cables (IRENA, 2016).

Array cables

Array cables in a wind farm collect the power from strings of wind turbines and connect them further to an offshore substation. These cables usually consist of three-phase power conductors of either copper or aluminum. They are designed to function in hostile environments and therefore need to meet strength and temperature requirements necessary (IRENA, 2016).

To date, typically 33 kV array cables have been used in offshore wind projects. Although, in the future it is considered that 66 kV cables will be utilized for wind turbines with larger capacity (FOWIND, 2016).

The array layout of the wind farm is highly site-specific operation and need to be optimized by using reliable software tools. By increasing the distance between turbines in a wind farm, the wake effects will be lower while the energy production will increase per turbine. On the other hand, the capital expenditure as well as operational expenditure will increase (Bjerkseter & Ågotnes, 2013).

Offshore substation

Offshore substations are used to reduce electrical losses by increasing the voltage before the power is exported to shore from the wind farm. The voltage of array cable strings steps up to 220 kV for AC and to between 320 and 800 kV for DC export cables from substation to the shore. Typically, two or more AC offshore substations are installed at larger wind farms to decrease the impact of a single point of failure. It is also possible to use a single substation with two or more transformers (IRENA, 2016).

In smaller projects, there is no need for an offshore substation due to high costs. If the capacity of the wind farm is 100 MW or less or the distance is less than 15 km to shore or if the voltage at the collection point is the same as the grid voltage, then offshore substation can be avoided (Douglas-Westwood, 2010).

Export cables

The export cables connect the wind farm to the onshore electrical grid. These cables can either be AC or DC depending on voltage type and level. AC export cables consists of three phase conductors and are rated up to 220 kV. DC export cables on the other hand are usually two single-core conductors and are rated up to 400 kV (IRENA, 2016).

HVAC cables are usually limited to 150 km offshore due to reactive power flow. For that reason, HVDC is used for longer distance transmissions with less losses but with the disadvantage of higher price tag (The Crown Estate, 2010).

The figure below presents an analysis by (Beiter, et al., 2016). The graph demonstrates the total cost of the electric export system as function of site to cable landfall. It is apparent the HVDC transmission is preferred for longer transmission distances, over 100 km.

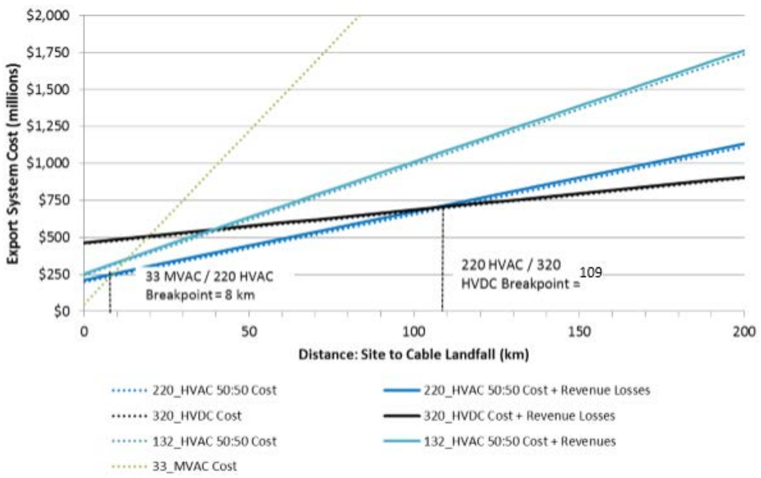


Figure 12. Summary of export system parameter study results for floating technology. Adapted from: "A Spatial-Economic CostReduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030", by: Beiter, et al., 2016, NREL.

Onshore substation

To increase the power from the export cables to the transmission voltage and connect the wind farm to the onshore transmission network an onshore substation is needed. Onshore substation will likewise convert the power from the export cables to three phase AC if it is delivered by HVDC cables. The onshore substations are almost identical to substations that are being used for power generation with other technologies and the costs are estimated to be approximately half of costs for the offshore bottom-fixed substations (The Crown Estate, 2010).

3.4.6 Installation

The installation process of floating wind structures is rather different compared with conventional bottom-fixed concepts. Therefore, existing literature study regarding installation processes are not useful in the floating market.

The biggest advantage of floating wind turbines over fixed-bottom concepts is that the need for operational handling at sea is dramatically reduced, which eases the process regarding weather window and requirements for expensive installation vessels. Therefore, it is desirable for every concept to maximize the number of operations onshore or at the portside. As it is apparent from the figure below, many concepts today are possible to be assembled onshore and later towed to the installation point. However, moorings, anchors and electric cables are usually still assembled offshore (James & Costa Ros, 2015).

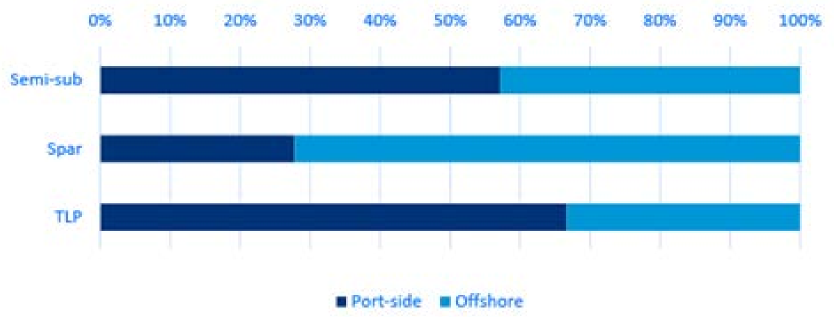


Figure 13. Port-side vs. offshore assembly by typology. Adapted from: "Floating offshore wind: Market and technology review", by: R. James, M. Costa Ros, 2015, Carbon trust

Another major benefit with floating wind concepts is that there is no need for large jack-up and dynamic positioning installation vessels. These can cost approximately 150 000 £ per day, compared with the tug boats that are used by floating concepts which are ca 80 % cheaper at only 30 000 £ per day (James & Costa Ros, 2015).

Different floating concepts have their own requirements regarding vessel requirement such as tugs and barges during installation process. As it is apparent from figure 14 the semi-submersibles have the lowest vessel requirement compared to other concepts. Spar buoy concepts require heavy-lift dynamic positioning vessels to assembly the turbine as well as barges to transport the large foundation to a sheltered area to be erected. TLP concepts requires also barges for transportation of the foundation to the installation site (James & Costa Ros, 2015).

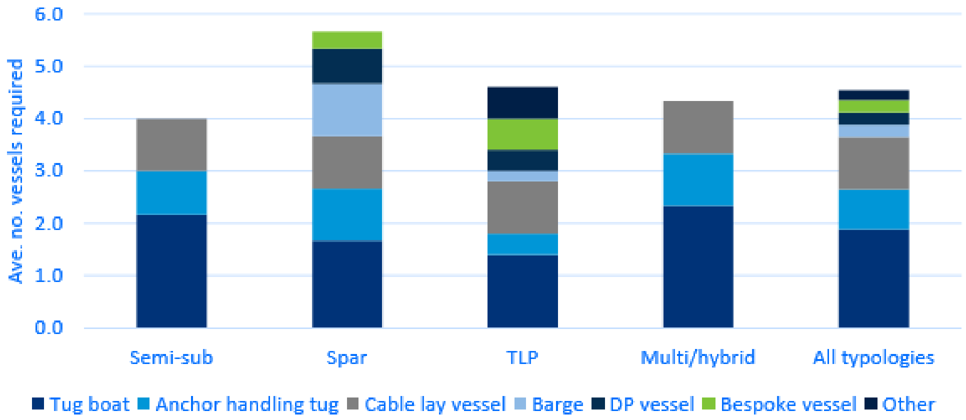


Figure 14. Vessel requirement during installation for floating wind structures. Adapted from: "Floating offshore wind: Market and technology review", by: R. James, M. Costa Ros, 2015, Carbon trust.

Installation time of a wind turbine is dependent on the number of offshore operations, level of met-ocean limitation that is constrained by the significant wave and the complexity of the installation process. Installation time is a key cost driver in wind projects and it will have a crucial role in future from prototype of concepts to commercial stages of concepts. Based on analysis from James & Costa Ros (2015), the installation time will be halved from prototype to commercial production as the processes are optimized.

According to James & Costa Ros (2015), the most important cost drivers for installation is time consumed and vessels types to be used. As it is apparent from the figure 15, the installation costs for spar-buoy concepts are higher relative to other concepts because of hiring expensive heavy life crane vessels for assembly of turbines. On the other hand, the installation time of TLP concepts are rather higher than the other two due to complex installation process.

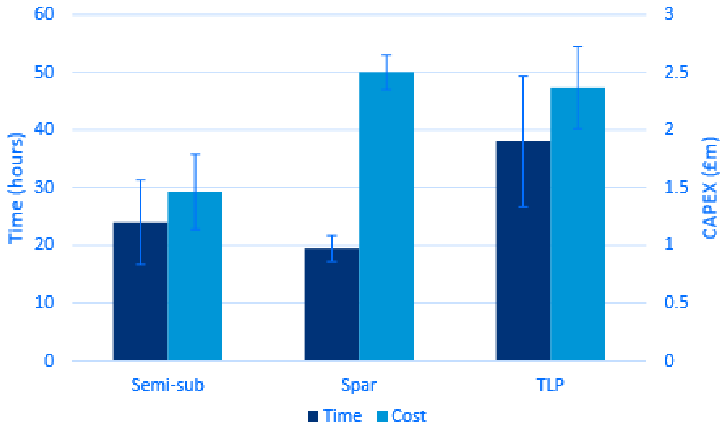


Figure 15. Installation time vs. cost. Adapted from: "Floating offshore wind: Market and technology review", by: R. James & M. Costa Ros, 2015, Carbon trust.

3.4.7 Operation and Maintenance

Operation and maintenance expenditures cover all the costs that occurs throughout the life of the turbine, nominally 20 years. These costs account for approximately one quarter of the total cost of a wind project during its lifetime. Activities that contribute to management of the asset are included in the operations category. Activities included in this category are for instance remote monitoring of the plant, marketing, sales, administration and other back office tasks. These activities stand for a small share of the total O&M expenditure. The largest proportion of the costs are included in the maintenance activities. These are the up-keep and repair activities of the plant. In turn, these activities are divided into preventive maintenance and corrective maintenance. Proactive repair or replacement of various components of the wind turbine based on routine inspections or as a response from condition monitoring systems are expressed as preventative maintenance. Corrective maintenance on the other hand, includes reactive repair of failed or damaged components in the plant (GL Garrad Hassan, 2013).

The costs associated with proactive activities can be determined with small uncertainties, since these efforts can be planned. However, costs related to reactive activities are much more difficult to predict and therefore the uncertainties are much larger. Considering this, it is wise to perform proactive maintenance activities on other components of the plant every time a bigger maintenance operation is executed on a wind turbine (Bjerkseter & Ågotnes, 2013).

There exist three kind of different contracts for wind farm owners to choose from in order to manage operation and maintenance activities. These are hand-off, light-touch and hands-on. With the hands-off approach, the wind farm owner signs a full package contract with the wind turbine manufacturer covering all balance of plant, day-to-day operations management, planned and unplanned maintenance. The light-touch approach means a contract with the manufacturer that only is responsible for the maintenance and service on the wind turbine. Other services, such as electric balance of plant, foundations, onshore operations base, and transport support are covered by other providers. And the hands-on approach means that the owner recruits a team of specialist technicians for operation and maintenance activities. In turn, the team works in partnership with specialist subcontractors such as manufacturers and vessel operators. In this way, the owner of the farm attempt to take on more risk but has opportunity to minimize the costs and maximize the energy production (IRENA, 2016).

There are many strategies to transport technicians from land to the offshore wind turbine. Every wind turbine project has different site characteristics and thereby the optimal strategy differs for every project. According to GL Garrad Hassan (2013), the main factors that determine the optimal logistics solution are:

- Distance from onshore facilities
- Average sea state
- Number, size and reliability of turbines
- Offshore substation design

The distance from shore is the primary factor in determining the most cost-effective approach for O&M activities. As sites are being developed further from shore, especially with the floating wind concepts, new strategies are shaping that are suitable for offshore wind sites far away. They are presented in figure 16. The typical logistic solution in the offshore wind market is currently with conventional workboats and less well-established helicopter services. Workboats are cheaper and can carry many technicians from shore to the turbine. However, the response time and accessibility of these services are limited by the sea condition and response times. Helicopters on the other hand, are more expensive and do not have the possibility to carry many passengers. But these can respond quickly and are less dependent on the sea condition (GL Garrad Hassan, 2013).

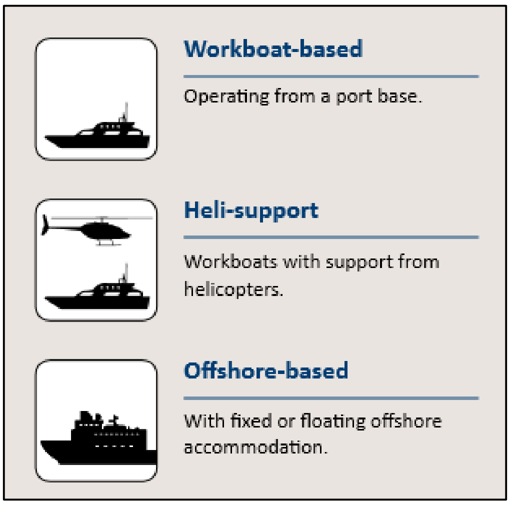


Figure 16. Broad strategic approaches to offshore logistics. Adapted from: "A Guide to UK Offshore Wind Operations and Maintenance. by: GL Garrad Hassan, 2013, Scottish Enterprise and The Crown Estate.

In the case of floating wind turbines, they are usually placed much further from shore compared to fixed-bottom turbines. If the transit distances become so great to access the turbines the operations will require to be based offshore. The base can be either fixed accommodation modules or boats such as motherships, offshore support vessels or jack-ups. As it is apparent from figure 17, the transition point from the support of only workboats and helicopter to offshore bases appears at approximately 74 km (GL Garrad Hassan, 2013).

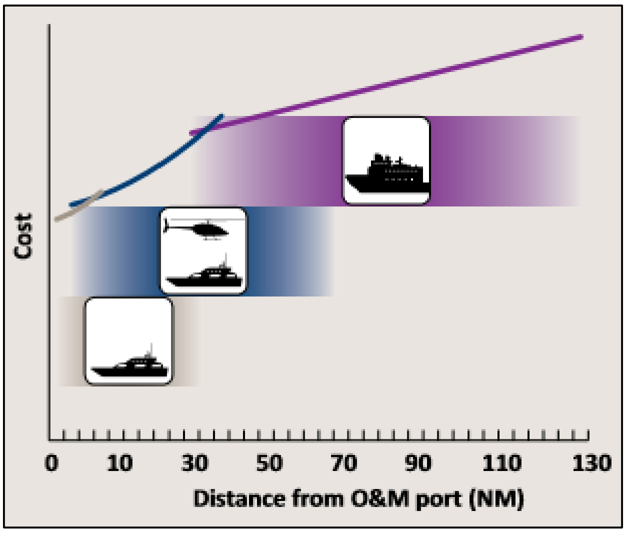


Figure 17. Illustration of lowest cost O&M strategy as a function of distance from O&M port. Adapted from: "A Guide to UK Offshore Wind Operations and Maintenance. by: GL Garrad Hassan, 2013, Scottish Enterprise and The Crown Estate.

An advantage with most of floating wind structures is that in the case of major repairs, the structure can be towed back to shore for portside repairs using only inexpensive tug boats and barges. This is a huge benefit, compared with fixed-bottom offshore wind turbines that require large and expensive heavy lift vessels. However, this benefit differs for each floating concept due to sea conditions and limitation that exists. Spar buoys still require heavy lift vessels due to its large structure. Semi-submersible concepts can be towed back to shore and usually have bigger tolerance in harsh sea condition. While TLP concepts are more sensitive to this and require costly bespoke barges (James & Costa Ros, 2015).

3.4.8 Financial factors

Due to complexity and immaturity of offshore wind projects, many of these have earlier resulted in running over the budget. To prevent this from happening, some financial factors are introduced.

Contingency

Many risks involved in offshore wind projects are difficult to identify and manage appropriately, such as seabed condition risks, design risks and delays. It is acceptable to ensure that all risks in a project are not covered by the developer. However, to prevent cost overruns in projects, developers have to include a contingency in financial evaluations. Contingency is needed to cover the risks estimated in cost models and also to avoid negotiating new financing during the development of a project (PricewaterhouseCoopers, 2012).

The contingency level in the model for this work is set at 10% of CAPEX and is assumed to be spent during the construction phase.

Insurance

Although insurance has a small share of total costs of a wind power project, it has a crucial role in supporting the investment by providing protection against unwanted events such as delays and physical damage during assembly, transport, construction and running stages of a project (PricewaterhouseCoopers, 2012).

In this degree project, insurance costs are divided into two groups, insurance during construction and operating phase insurance. There are several different types of insurances existing in the market with diverse risk premium based on the scope of the insurance. For construction phase, there are Construction All Risks (CAR), Delays in startup (DSU) and Third party liability. Moreover, for operating phase, there are Operating all Risks, Machinery Breakdown, Business Interruption and Third party liability (PricewaterhouseCoopers, 2012).

In the model developed for this work, a general insurance type has been chosen rather than a specific one. The cost calculations can be found in Appendix 1.

3.4.9 Decommissioning

Various activities that are related to decommissioning and removal of wind farm components are included in this category. Usually all components except cables are transported back to shore and are delivered as scrap metal (Bjerkseter & Ågotnes, 2013).

Floating wind concepts entail benefits regarding decommissioning of wind turbines and are simpler compared with fixed-bottom concepts that require specialized vessels and equipment. For floating structures, the full structure can be towed back to shore as soon as moorings are cut from the anchors (James & Costa Ros, 2015).

This offers cost savings to developers and in some cases it can even generate revenue at the end of a project. According to Bjerkseter (2013), the return value from scrap metal of the components will in most cases with floating wind concepts exceed the costs for removing and disassembly.

This is of course dependent on the distance from shore, the complexity of decommissioning and the scrap metal prices, but as a rough estimate it can be stated that decommissioning is cost-neutral and therefore is not included in the calculations of this work.

3.5 Financing wind projects

The costs of offshore wind projects depend significantly on the technology used and the site chosen, which has been described in the previous chapters. However, the sources of capital for floating and fixed-bottom projects are estimated to be similar. In this chapter, financing of wind projects is described based on current fixed-bottom offshore wind projects that have been developed recent years.

The offshore industry is continuing to grow strongly. The total investment value of offshore projects in Europe year 2016 was € 22.6 billion, which is an increase of 39 % compared with the year before (WindEurope, 2017).

Historically in the offshore industry, power producers have been the main investors by using their balance sheets. Regarding to figure 18, power producers in 2016 represented approximately 67 % of the total equity investor share of the market. However, as the market matures, new investors are entering the market and becoming active in different stages of financing the offshore wind projects. These entrants are for instance financial, corporate and institutional investors (WindEurope, 2017).

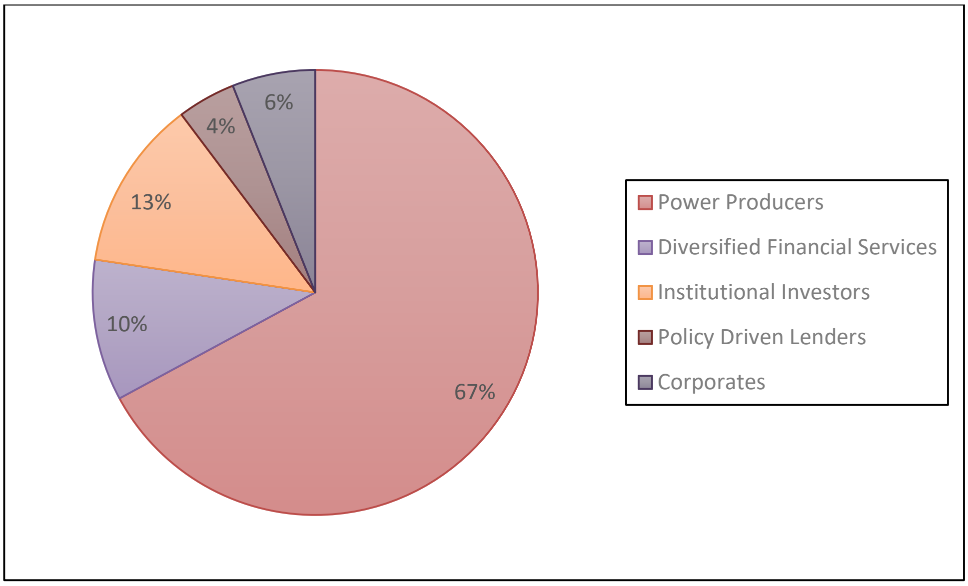


Figure 18. Market segmentation of major equity investors in 2016. Adapted from: "The European offshore wind industry", by: WindEurope, 2017.

Funding structure

Offshore wind projects are funded with either equity or debt by investors. The funding structure defines how these two elements work together. Due to the increased size of offshore wind projects, groups of different lenders are required continually. There are several different funding structures which can be applied in wind projects to make the investment more attractive to potential investors due to commercial, financial and tax reasons. According to EWEA (2013), these are the funding structures used in the offshore industry:

Sponsor equity

These funding structures are often called as “on balance sheet” and funded by a single company. A project sponsor in these cases has full ownership of a wind project, which has the benefit of simplicity and full control of the project. This funding structure is typical for large power producers that have the balance sheet strength to afford the required investment. This model was characteristic in the early stages of offshore wind development (EWEA, 2013).

SPV

Special Purpose Vehicle or Incorporated joint ventures are traditionally held on the balance sheet as an investment under the relevant accounting rules or are joined as a subsidiary into the accounts of the shareholder’s group. Tax losses cannot be transferred to the shareholder’s group, unlike unincorporated joint ventures. One example of this kind of funding structure is Scara, a JV company by Statoil and Statkraft that operates Sheringham Shoal in the UK (EWEA, 2013).

SPV with debt finance

This funding structure counts on future cash flows generated by the project for repayment. Project’s assets, rights and interest are held as secondary security or collateral. When the lenders are repaid just from the cash flow or in the case of project failure, from the value of sold assets, this funding structure is usually called “off balance sheet” and non-recourse (EWEA, 2013).

Unincorporated Joint venture

This funding structure allows each investor to transfer all the profits and losses in its SPV in its group accounts independent of the size of the interest in the project. Interests of each investor are set in operating agreements which outline the investor’s percentage interest in the project and its governance. Commonly, an operating company is required for practical or legal reasons to hold assets or licenses that cannot be held by the investors mutually (EWEA, 2013)

This kind of funding structure has some tax-driven benefits. It has also benefit in that regard that it allows each investor to pursue different ownership and financing options independent of their partners. No partner has overall control in UJV and there is a need for unanimity in decision-making (PricewaterhouseCoopers, 2012).

Incorporated joint venture with debt

This funding structure is similar to traditional unincorporated JV but is typically created for tax purposes to allocate different risks or to distribute PPA liability (EWEA, 2013).

Risk profile

To convince stakeholders to invest in offshore wind power, the market must compete for capital with other markets and the attractiveness should be bigger than other available technologies. The offshore wind market is growing strongly but the risk profile is still relatively high, especially in comparison with other infrastructure projects. The table below retrieved from Moné, Stehly, Maples, & Settle (2015), summarizes the risks that are associated with offshore projects and mitigation strategy for each.

Table 3. Offshore Project Risk Categories and Mitigation Strategies. Adapted from: "2014 Cost of Wind Energy Review", by: Moné, Stehly, Maples & Settle, 2015, NREL.

Risk category	Examples	Mitigation strategies
Development risk	• Project viability • Debt vs equity ratios	• Community engagement • Robust project management • Sponsor commitments • Due diligence to ensure that all permits, licenses and authorizations are in force
Financing risk	• Attract sufficient debt/equity • Once operational, debt must cover payment obligations	• Planning, engaging likely financiers early • Diligent permitting/contract structuring • Fixed price for generated power • Conservative, validated estimates
Construction risk	• Delays and cost overruns • Responsibility for problems (liability)	• Analysis of downside scenarios • Preparation of contingency fund • Insurance • Strong contracts • Due diligence to validate design, engineering
Operations risk	• Lower availability • Cost overruns	• Smart warranty design with emphasis on revenue protection • Long-term service agreement • OEM commitment • Insurance • Conservative planning and budgeting • Due diligence to validate assumptions
Volume risk	• Energy production lower than expected	• Conservative wind resource estimates • Insurance • Priority dispatch agreement • Due diligence to validate assumptions
Price risk	• Lower price than forecast	• Fixed price contract (PPA or feed-in tariff) • Conservative projections

Reducing these risks by different measures and re-allocate who stands for the risks involved can help to lower the LCOE by reducing the capital cost that the investors require. These risk reductions can also help to attract different types of investors that are not currently active in the market. On the contrary, cost uncertainties will affect the excepted return on equity which results in a higher LCOE.

Accelerate the funding

The interest for offshore wind has grown strongly in recent years and there are no indications that it will stop. Offshore market has become an attractive investment opportunity for equity and debt providers (IRENA, 2016).

According to PricewaterhouseCoopers (2012), there are several cost reduction opportunities in the offshore wind market such as maximizing the necessary volume of capital and reduction of risk premiums. In order to achieve these opportunities, a number of prerequisites are necessary for the market. These are Policy and regulation, Risk reduction and Facilitating new ways of funding.

Policy and regulation

Investors require visibility on the long-term growth of the industry before investing in the market. The government's obligation is to provide a clear statement on the ambition of growth in wind power, including volume targets and interaction with cost reduction to the sector (PricewaterhouseCoopers, 2012).

Stakeholders desire stable, predictable and consistent regulation with long-term stability in pricing. Stability is considered to be of greater importance than increasing the level of support itself. Clear and simple support structure enables investors to evaluate the economics of a project earlier in the development phase. By avoiding making frequent adjustments in support structures, third party capital providers are able to easier assess long-term cash flows of a project (EWEA, 2013).

Risk reduction

Risk reduction measures have a big impact on reducing the cost of capital by decreasing risk premiums, mainly during installation and O&M. There are several different measures that could eventually lead to reducing risks in the offshore wind projects. According to PricewaterhouseCoopers (2012), some of these measures are:

- Greater cooperation between stakeholders on industry best practice
- Development of standardized installation methodologies to reduce project delays/cost overruns
- Move away from multi-contracting to a more transparent, less complex contracting structure
- Industry to focus on deployment of a proven technology
- Equipment suppliers need to offer service and warranty periods longer than the typical 5 years
- Promote early grid investment by generators and underwrite stranded asset risk
- Longer term O&M contracts would reduce cost uncertainties

Facilitating new ways of funding

A number of financial structures are being considered in the market for funding offshore projects. These are SPV, Unincorporated Joint venture (UJV) and Fixed-price power purchase agreement (PPA). In circumstances when the existing and new shareholders have the same approach to raise debt, an SPV is suitable. However, when shareholders have a tendency to have independent financing strategies on their assets, UJV or PPA is more suitable (PricewaterhouseCoopers, 2012).

The finance models are moving towards high-level debt models, which are leading to lower LCOE. (IRENA, 2016) By following the European offshore market, it is estimated by analysts that financing of projects will shift more toward debt financing as the market matures and lenders achieve experience with the sector, while utilities and sponsors require more capital. Several large-project financing banks are already active in the market and are associating with smaller banks to enter the area (Moné, Stehly, Maples, & Settle, 2015).

Apart from project finance models with equity and debt, there are some possibilities for new investors to enter the market. These are either Financial or non-financial investors.

Non-financial investors such as utility firms, supply chain companies or developers in the oil and gas sector, are potential entrants to the market. These companies can invest either directly into development projects or into operational projects, which allows them to integrate back into new projects as the level of their expertise increases. These companies are likely to invest in the offshore market if the potential financial returns are attractive enough compared to other investing opportunities and also if the risks around the regulatory framework and construction are understood and can be manageable (PricewaterhouseCoopers, 2012).

Potential new financial investors can include pension, insurance and sovereign wealth funds. According to (PricewaterhouseCoopers, 2012), it is unlikely that these funds will invest into offshore wind projects unless the projects are at operational level and projects are further de-risked.

3.5.1 Weighted average capital cost

One important cost driver of an offshore wind project is the cost of capital. It signifies the rate of return that the investors need to earn on the capital that has been invested to compensate them for both the timing delay during the project and the risks that are associated with cash flows during the operations.

The reason why the cost of capital is a key cost driver of the overall LCOE for offshore wind is the high ratio of capital costs to operational costs. It depends also on how long the investment period is expected to be in the wind projects.

In this work, this cost is expressed as Weighted Average Cost of Capital (WACC) which is defined as following according to Investopedia (2015):

$$WACC = \left(\frac{Equity}{Total\ Cost}\right) * Cost\ of\ Equity + \left(\frac{Debt}{Total\ Capital}\right) * Cost\ of\ Debt * (1 - Tax\ Rate)$$

Equation 2. Weighted average cost of capital (WACC)

Cost of Equity

The most common way to evaluate the cost of equity is by using Capital Asset Pricing Model (CAPM), which estimates the cost of equity by adding the risk-free rate with an additional premium for exposing the investment to systematic risk. According to

PricewaterhouseCoopers (2012), this risk is expressed as product of investment's beta and the market risk premium:

$$K_e = RFR + beta * (EMRP)$$

Equation 3. Cost of equity

Where:

- K_e = cost of equity
- RFR = risk-free rate
- EMRP = expected market risk premium

The return that an investor requires on an asset with minor risk is called risk-free rate. This return is usually based on the yield on a government bond during the power plant's operational life which in this case is 20 years (PricewaterhouseCoopers, 2012).

Since the exchange rate in the Excel model is in sterling pounds, financial factors that are related to the UK market will be estimated in this chapter. These values can differ in different markets around the world. The figure below, represents the decrease of 20 year UK government bond yields in the last 10 years. The average value during these years is 3,36 % which will be used in this model.

Figure 19. UK 20-Year Bond Yield Streaming Chart. Retrieved from: https://uk.investing.com/rates-bonds/uk-20-year-bond-yield-streaming-chart

EMRP represents the added return that the investors expect by investing in equities rather than risk-free assets, such as government bonds. The EMRP is often estimated over the long-term, it is not possible to observe it directly from market data. Typically, a mixture of two evidences are used to calculate the rate of EMRP. These two evidences are ex-ante evidence which are derivations from current market data and ex-post evidences which are based on historical return. In our case, EMRP with 6 % premium is used (PricewaterhouseCoopers, 2012).

Beta is another parameter in the calculation of the cost of equity. It is a measure for calculating the systematic risk related to an investment compared with the average risk of investing in the equity market. This factor is multiplied with EMRP to estimate the overall risk premium for equity (PricewaterhouseCoopers, 2012).

A common method to estimate the beta value is to calculate the historical relationship between listed comparator company equity returns and the returns gained from the overall stock market. Since there are not many floating wind power developers that are listed, an alternative approach is to compare companies with activities that are estimated to have the same risk grade as offshore wind projects and use the average beta from this group of companies as a representation for the offshore wind's beta (PricewaterhouseCoopers, 2012). In the model for this work, a beta value of 1,3 has been selected which seems to be reasonable for the immature floating wind market.

Cost of debt

There are not many projects in the offshore industry that have used debt as a source of funding. However, this may change in the future as the market matures and the number of projects increases and thus, the additional need of capital (PricewaterhouseCoopers, 2012).

The cost of debt is estimated as a margin over LIBOR (London Inter-Bank Offered Rate), which is the interest rate that the high-credit quality banks are charging for short-term financing. To exchange these interest payments with each other, interest rate swaps are commonly used. These are derivative contracts and are traded over-the-counter. By using these swaps, the floating-rate payments based on LIBOR are exchanged into fixed-rate payments (PIMCO, 2017). A fixed rate of 9% cost of debt is assumed in the developed LCOE model.

Estimation of WACC

Based on the parameters explained in this chapter the WACC was calculated for the developed model. The WACC is simplified and was estimated at a constant rate for the whole lifecycle of the project, which means no gearing was taken into consideration in the model. The WACC resulted in a 10 % fixed rate.

3.6 Levelized cost of energy

The aim of this degree project is to develop a model for calculating the costs of floating wind power projects. A common approach for calculating the cost of energy is by using LCOE (Levelized cost of energy). LCOE allows different technologies for power production to be compared with each other by considering all life cycle costs of a project.

The formula used for LCOE calculation has previously stated in the methodology chapter. It is retrieved from PricewaterhouseCoopers (2012) and is the following:

$$LCOE = \frac{Sum\ of\ lifetime\ discounted\ generation\ costs\ (£)}{Sum\ of\ discounted\ lifetime\ electricity\ output\ (MWh)}$$

Equation 3. Levelized cost of energy

Where generation cost includes all CAPEX and OPEX that occur over the lifecycle of the project which is 20 years in this case. Electricity output is the net metered output at the offshore substation after all losses.

3.6.1 Annual energy production

Wind turbines are rated with various power output levels when delivered. However, they will not generate electricity at their rated power at all times. The generation of power depends on weather conditions, mechanical and electric losses (Bjerkseter & Ågotnes, 2013).

A measure for estimating energy production is the capacity factor. It is the ratio of the actual energy produced in a given period over the theoretical potential energy that could possibly be delivered if the power plant was operated continuously at full rated power output over the same period (Smith, Stehly, & Musial, 2015).

Capacity factor has historically gradually improved. The reason to this is mainly the location of the projects and also the improving of turbine technology. The offshore wind projects are shifting more and more into open-sea conditions, which makes it possible to access more energy dense and consistent wind resources. The turbine technology has also improved a lot during the last decade due to the development of larger rotor-to-generator ratios, which makes it possible to capture more energy in a given site. Taller hub height design makes it possible to access higher wind speeds because of wind shear effects (Smith, Stehly, & Musial, 2015).

Net capacity factor in the LCOE-model takes into account other losses as well such as electrical, aerodynamic and other losses caused by the environment. The table below presents net annual energy production in the model.

Table 4. Net annual energy production.

Gross energy production (MWh/MW/year)	**8 760**
Capacity factor	50%
Wind farm availability	95%
Aerodynamic array losses	7%
Electrical array losses	1%
Other losses	3%
Net capacity factor	42%
Net energy production (Mwh/MW/year)	3 716

4 RESULTS

The following chapter presents the result that has been accomplished throughout the work.

4.1 Current market

In the early stages of the work, there was a lot of focus on collecting data and information regarding costs and pricing related to floating wind projects. During this process, over 60 companies were contacted without any success to collect data. It wasn't possible to reach some of the companies via phone and a few didn't respond back to e-mail inquiries. However, several firms were reached and replied back to the request but they all refused to share data about the power plants with us.

These companies explained further that the market for floating wind power is still immature and therefore it isn't possible to share data and information about cost and other technical specifications of the power plants must be kept confidential considering its sensitivity.

At this point, some developers in the floating market have successfully commissioned demonstrator plants and are planning to build larger multi-unit wind farms. Therefore, it is crucial to keep sensitive information about their prototypes away from the competitors since the race is still ongoing in the market and there isn't any dominating actor yet.

After the discussions with companies, the market can be described as rather closed at the moment with too little transparency. However, the companies were helpful and provided the research with several reports and information that is available online for the public, which has further contributed to the developing of the economic model in Excel.

4.2 Economic model

An economic model has been developed as a part of this work to calculate LCOE for floating wind projects. The model has been developed using Microsoft Excel and is attached to this paper as a digital appendix.

Due to lack of cost data of floating wind projects, most of the cost data that the model is based on are related to projects with fixed-bottom foundations and therefore may include some uncertainties. The model doesn't take into account economics of scale either since it is mainly based on cost data that is per MW. More detailed information about these values and methods used in the model are described in appendix 1.

Benchmark wind farm

The developed LCOE model is able to calculate costs for various wind farms depending on the input parameters. The substructure can be chosen between Spar-buoy, Semi-submersible and TLP that all have been described earlier in this paper. The anchors are either Drag-embedded or Driven piles. The time from final investment decision to works completion date is set to 5 years in the model and the operational life of the turbines are 20 years.

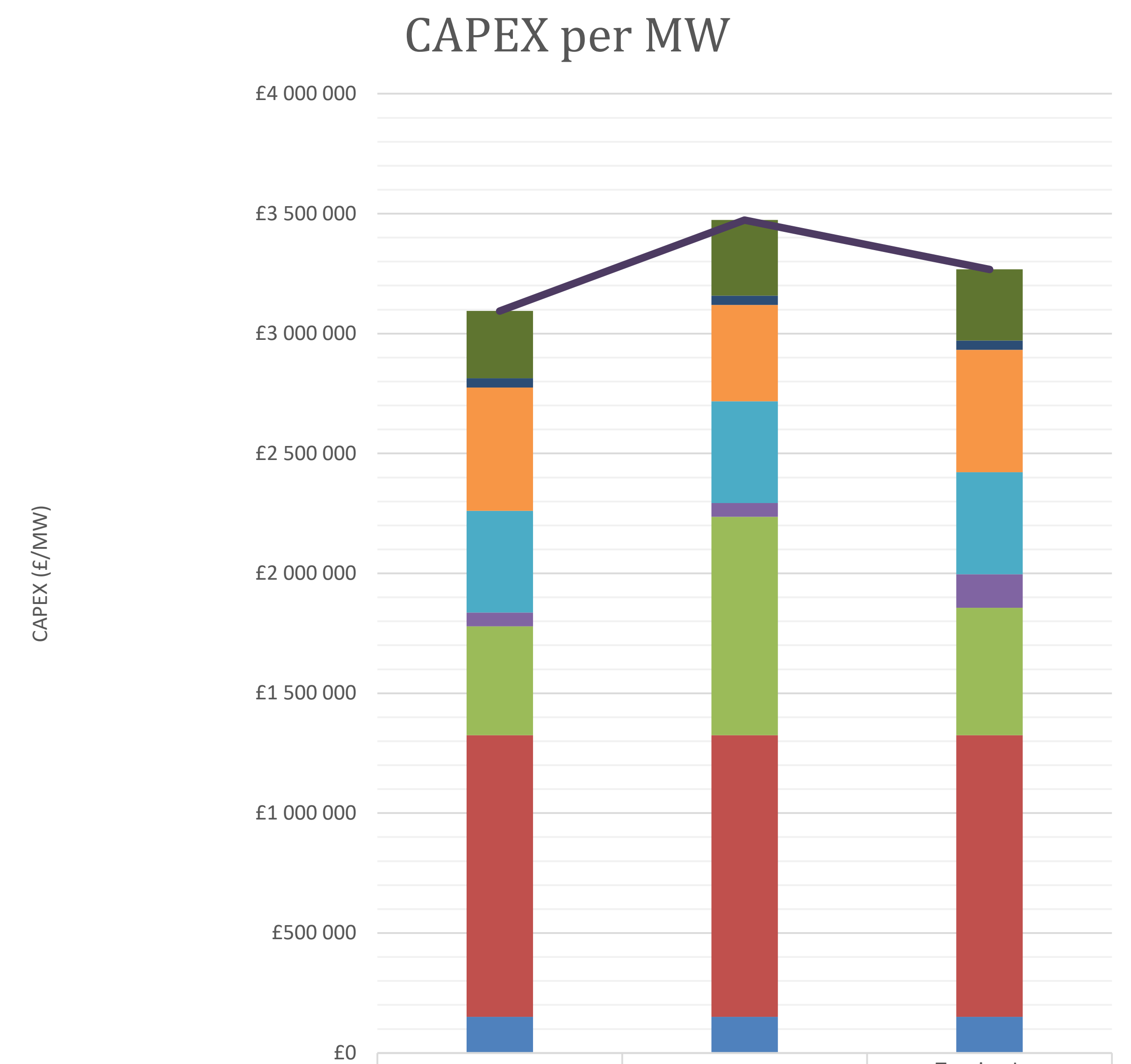
In this section our benchmark wind farm and its costs are presented:

Table 5. Benchmark farm in the LCOE-model.

Technical data	
Turbine capacity (MW)	7
Number of units in farm	70
Total wind farm desired output (MW)	490
Wind Farm site data	
Distance to O&M port (km)	50
Distance from staging port to inshore assembly area (km)	10
Distance from inshore assembly area to project site (km)	40
Water depth (m)	100
Energy production	
Capacity factor	*50%*
Wind farm availability	*95%*
Aerodynamic array losses	*7%*
Electrical array losses	*1%*
Other losses	*3%*
Financing	
Equity	
% of total financing	*80%*
Risk-free rate	*3,4%*
Beta	*1,30*
EMRP	*6,0%*
Cost (%)	*11,2%*
Debt	
% of total financing	*20%*
Cost (%)	*9%*
Corporate tax rate	*35%*
WACC - Weighted average cost of capital	10,10%

In this simulation, the weight of the substructure and specification about the anchors were selected as unknown. It was also chosen that the wind farm will have its own electrical infrastructure. Simulations with Spar-buoy and Semi-submersible concepts were chosen to have 3 Drag-embedded anchors and simulation with TLP concept had 5 driven pile anchors.

The following are the outputs of the simulation:



	Spar-buoy	Semi-submersible	Tension Leg Platform
Contingency	£281 314	£315 771	£297 043
Other costs	£0	£0	£0
Insurance during construction	£38 000	£38 000	£38 000
Installation	£514 000	£402 000	£511 000
Electrical interconnection	£425 000	£425 000	£425 000
Mooring system	£57 000	£57 000	£140 000
Substructure	£454 143	£910 714	£531 429
Turbine	£1 175 000	£1 175 000	£1 175 000
Project development	£150 000	£150 000	£150 000
Total CAPEX	£3 094 457	£3 473 486	£3 267 471

Figure 20. CAPEX per MW for three different floating concepts.

The figure below, presents total CAPEX comparison between different substructure types with the benchmark values that were stated above. The result from the model shows that the semi-submersible concept causes highest capital expenditures, followed by TLP and Spar-buoy as the least expensive alternative.

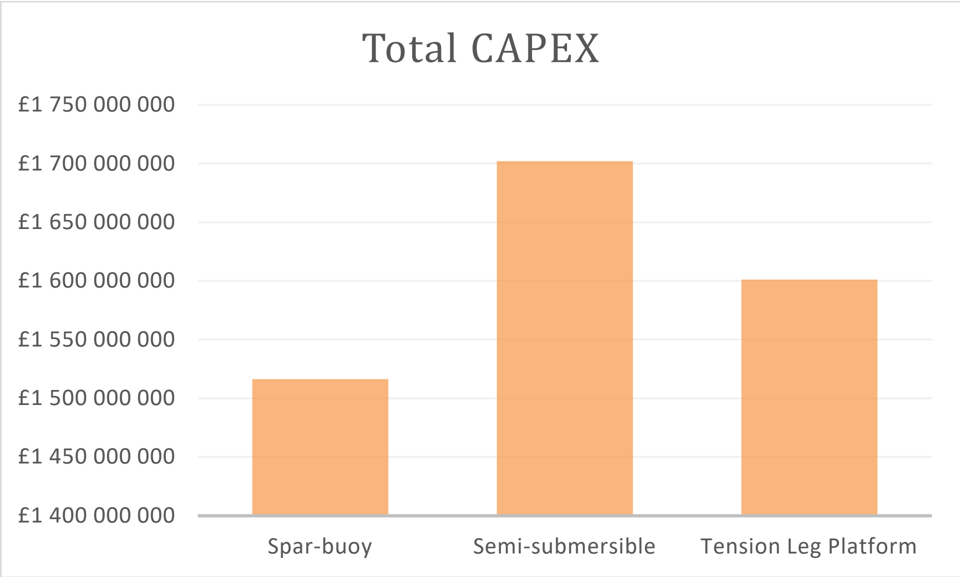


Figure 21. Total CAPEX for the 490 MW benchmark wind farms.

Regarding OPEX however, Semi-submersible concepts change ranking with spar-buoys and are the alternative with lowest annual OPEX, which can be seen in the figure below.

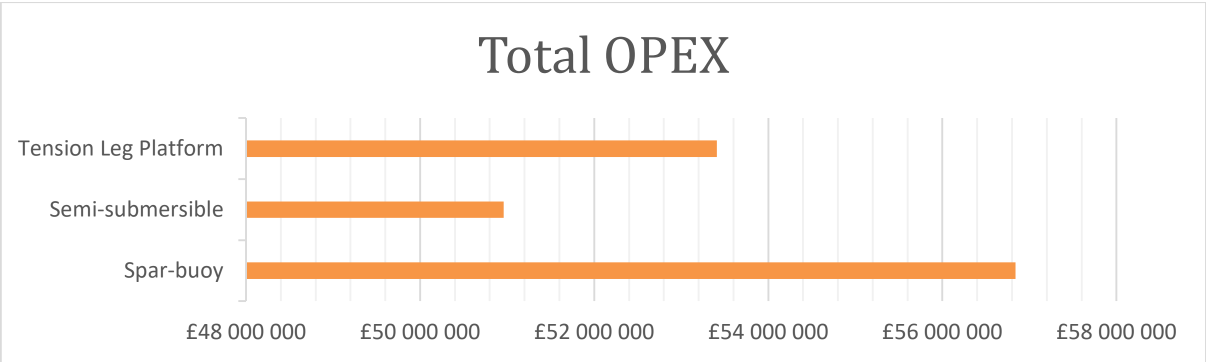


Figure 22. Total annual OPEX for the 490 MW benchmark wind farms.

Finally, the figure on the next page presents the LCOE values for different concepts, resulting in Semi-submersible as the most expensive concept and Spar-buoys as the cheapest.

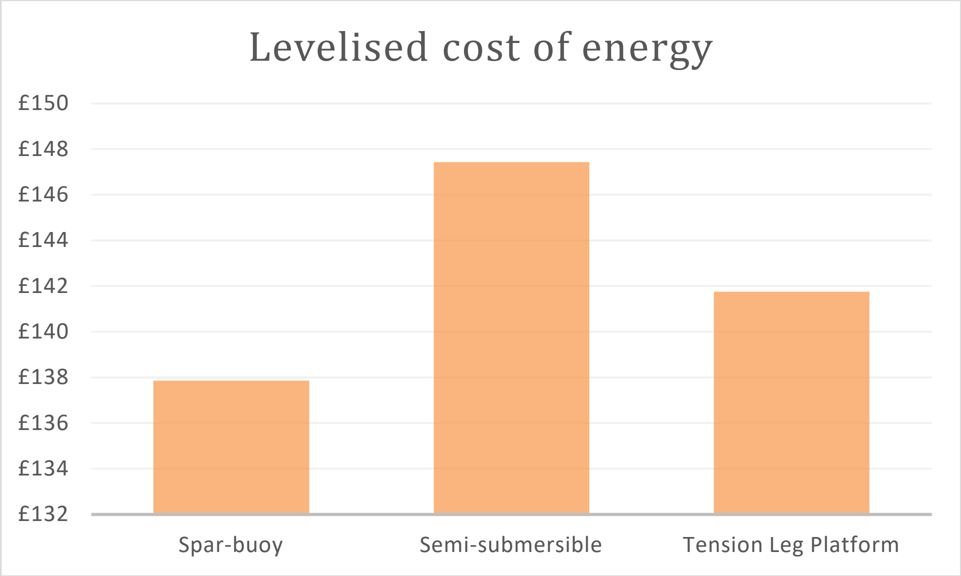


Figure 23. LCOE for three different floating concepts.

In addition to the output values above, cash flow calculations are performed in the model, which also derives the Levelized cost of energy.

4.2.1 Sensitivity analysis

A series of sensitivity analyses were performed using the model to gain a better understanding of the relationship between the input variables and Levelized cost of energy as output. The analyses were executed by changing an input variable while the other variables were held constant.

Analyses were done for all three floating concepts and the input variables were the same as in the benchmark wind farm. The following are the result of these analyses with related figure to each:

The turbine cost in the model is derived from a linear function. However, the turbine capacity doesn't affect only the turbine purchase price but it is involved in many other parameters such as substructure construction, installation and maintenance. The turbine capacity is a key cost driver in the developed model.

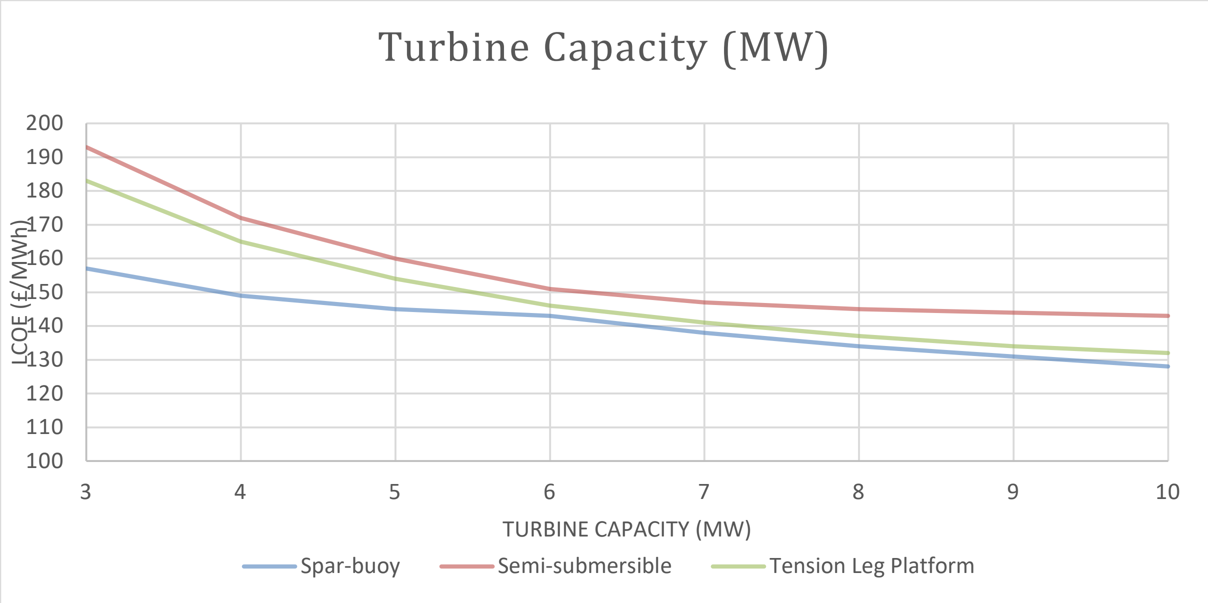


Figure 24. LCOE as a function of Turbine Capacity.

As it is apparent from the graph, reduction of building own electric infrastructure has great cost saving potential for all three cases. The LCOE values are calculated by taking in account a transmission fee which is charged by the Offshore Transmission Network Owner (OFTO) instead of building own substation and purchasing export cables.

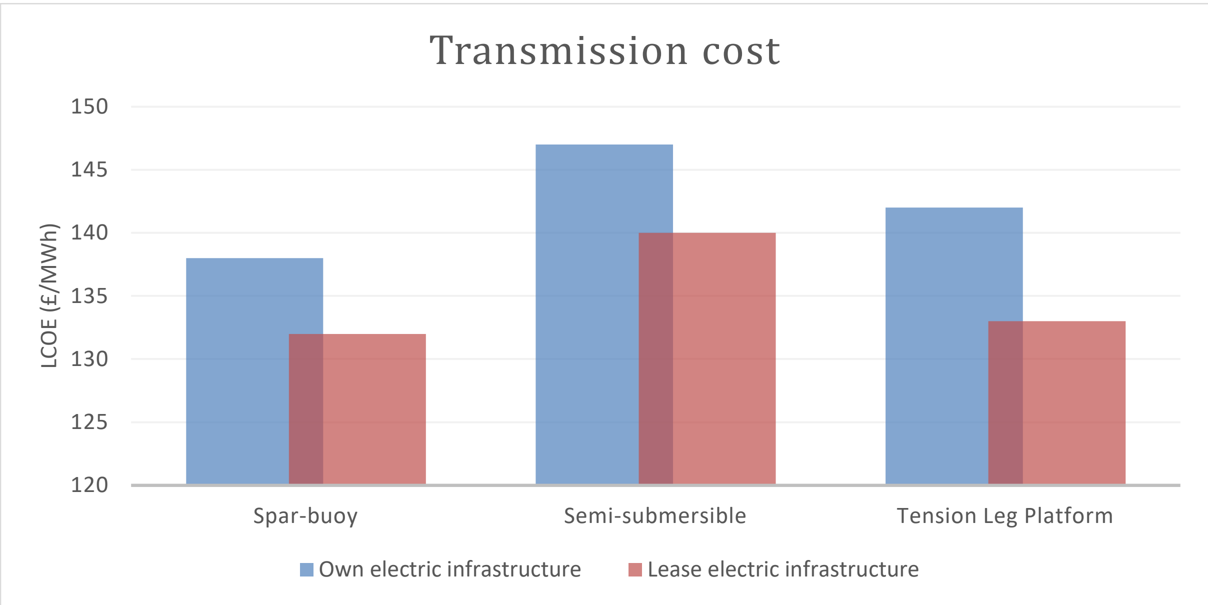


Figure 25. LCOE as a function of Transmission cost.

The Distance to port is cost driver to installation and O&M costs in the model. The variable does not have a strong influence on the final LCOE in the model. However, this might not be true in reality since the installation process of different floating concepts varies greatly and therefore the costs associated with the barges and equipment used can be more fluctuating.

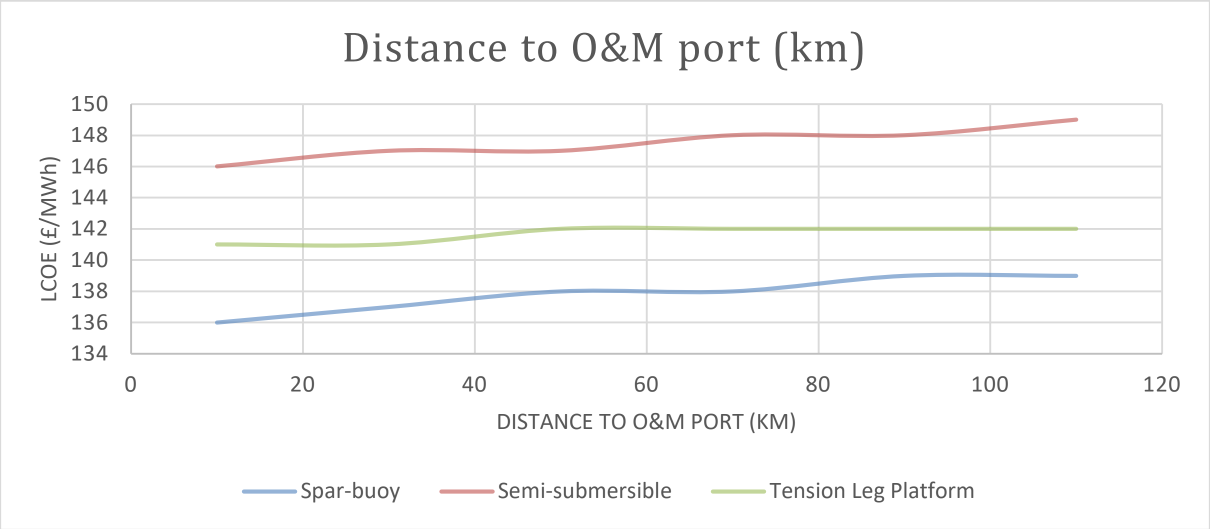


Figure 26. LCOE as a function of Distance to O&M port.

The capacity factor is another major cost driver in the LCOE model. Higher capacity factor allows higher annual energy production. Offshore wind projects have in the recent years been shifting away from the shore which allows the turbines to access more robust wind resources. The wind turbines' rotor-to-generator ratio have also increased recent years which allows them to capture a larger amount of energy in a given wind resource. These factors have contributed to a larger capacity factor in offshore wind projects the recent years (Moné, Stehly, Maples, & Settle, 2015) According to the graph below, it can be stated that higher capacity factor reduces the cost of energy. However, it should be noted that higher capacity factor causes higher installation and O&M costs if the wind turbine is located far away from the port. The higher capacity factor can also lead to higher wind turbine purchase price because of the larger structure as well as more advanced technology.

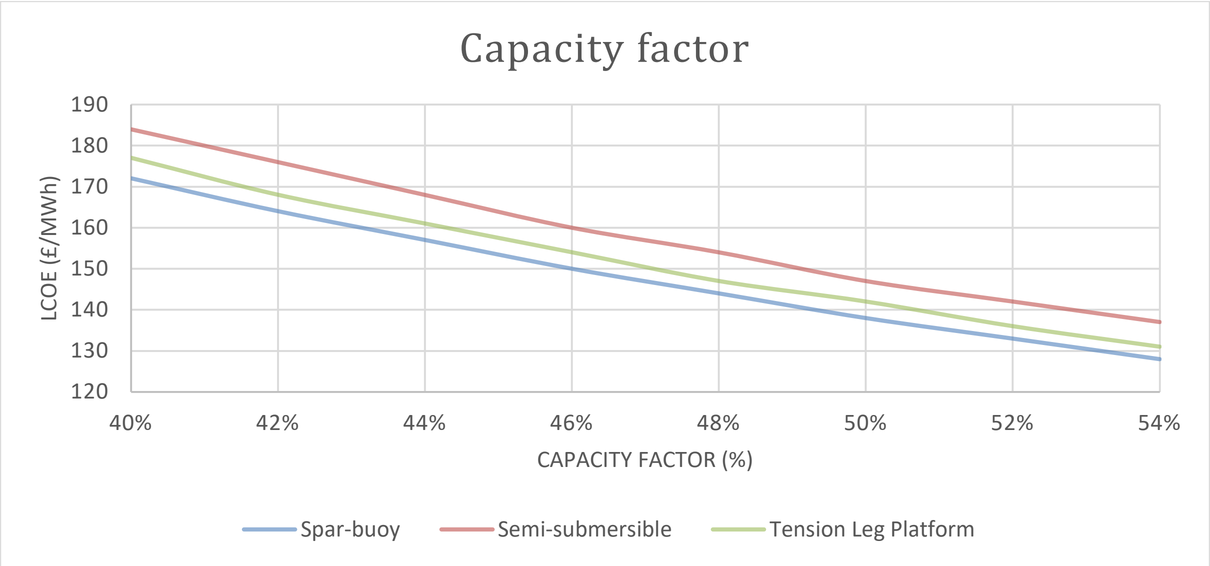


Figure 27. LCOE as a function of Capacity factor.

The impact of turbine availability is presented in the graph above. As the turbine and grid technology improves the availability percentage increases as well. In the benchmark wind farm, this rate was set as 95 % which agrees with the most values in reports related to offshore wind projects.

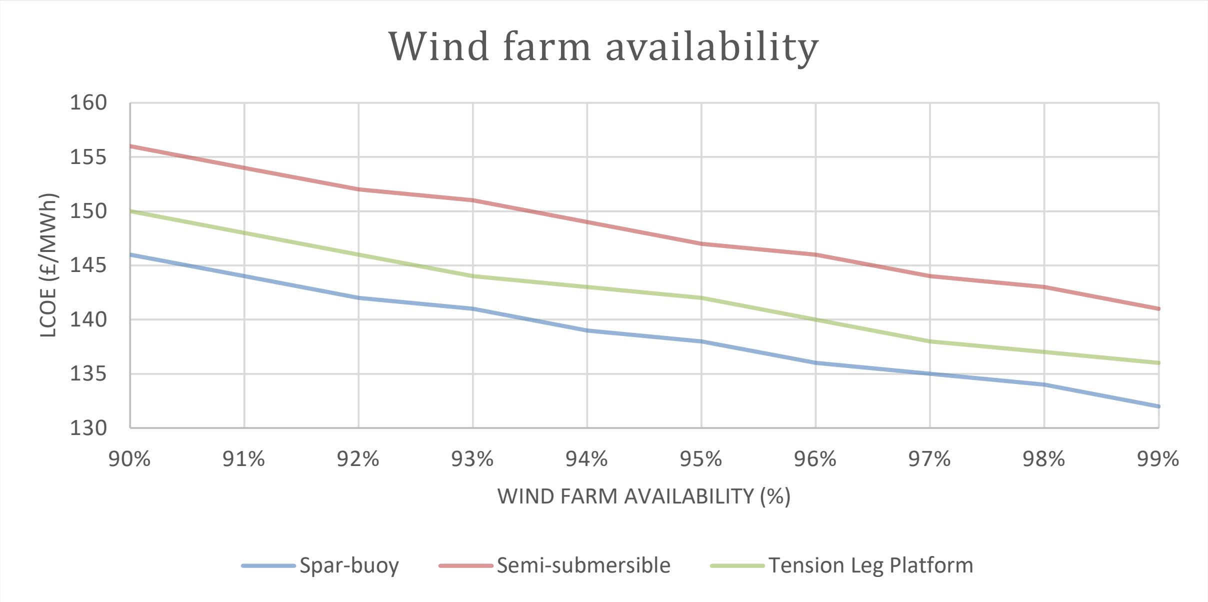


Figure 28. LCOE as a function of Wind farm availability.

Beta measures the systematic risk related to an investment compared to the average risk of investing in the equity market. As the floating wind market matures in future, the beta value tends to decline because of fewer risks involved in the projects.

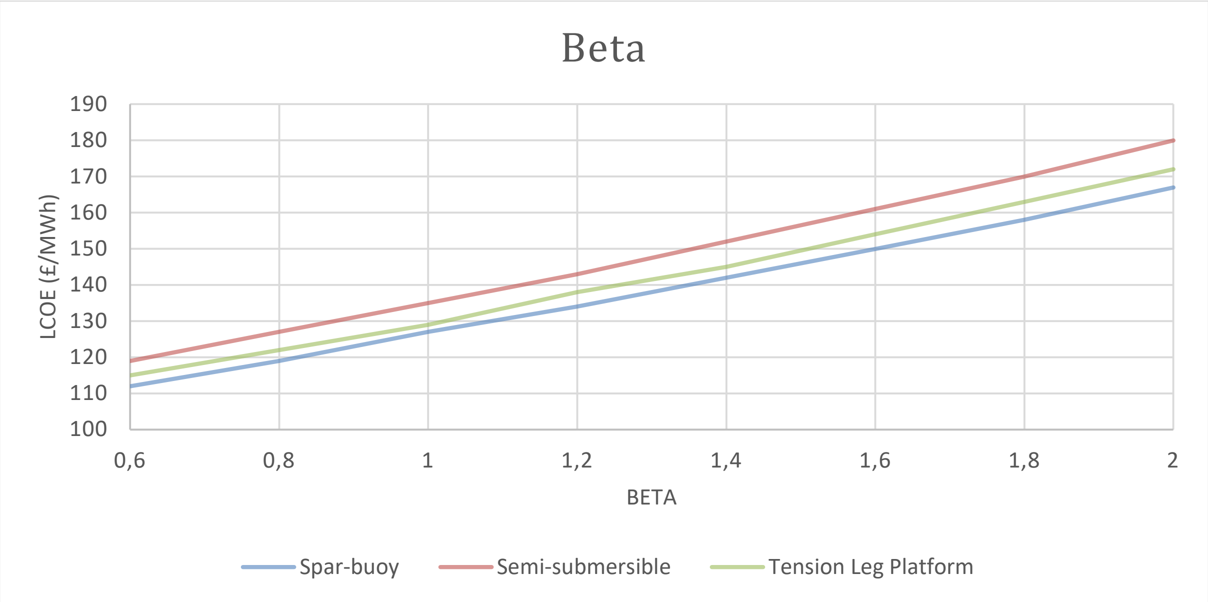


Figure 29. LCOE as a function of Beta value.

With decreasing beta value, debt costs tend to lower as the market matures. Banks are likely to require a lower return on the invested capital as the industry gains experience and risks are handled better. According to figure 27 and 28, it can be stated that cost of capital has a major impact on the final LCOE for offshore wind projects.

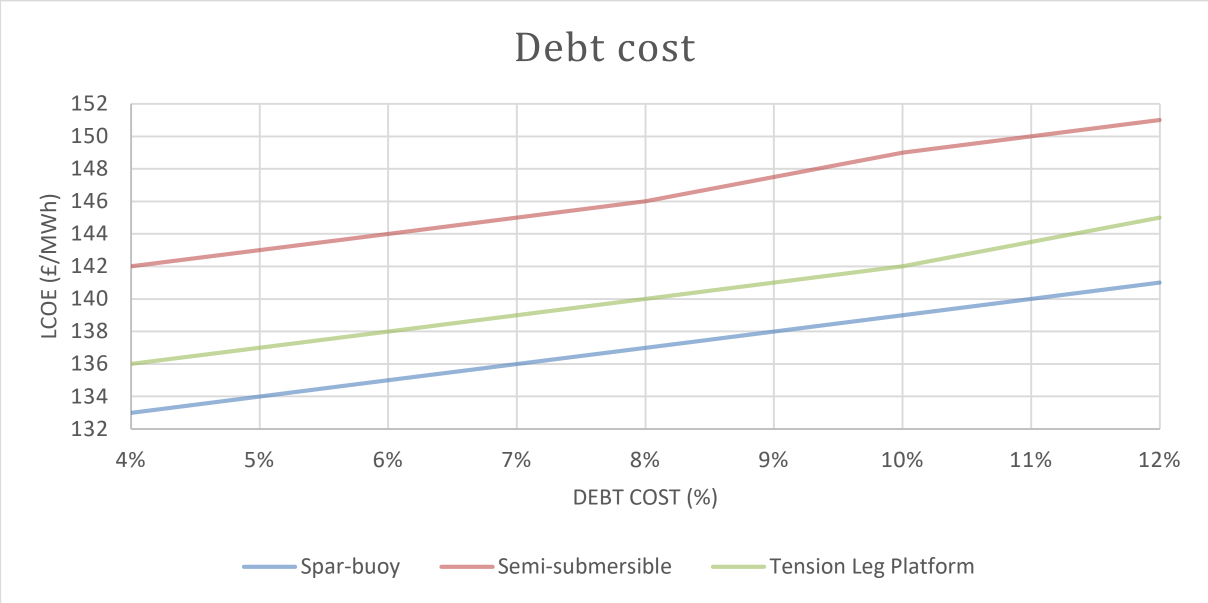


Figure 30. LCOE as a function of Debt cost.

4.3 Market insight

As an addition to the LCOE model that was described in the previous chapter, several interviews were done with active operators in the wind market. The interviews were related to the financial aspects of wind projects, described previously in chapter 3.5.

The following interviewees are:

- Jonas Ekman, Head of Project Finance, Statkraft
- Allan Bødskov Andersen, Head of Group Treasury & Risk Management, DONG Energy
- Linus Hägg, CFO, Arise

The structure of this chapter is intended to be similar to chapter 3.5 in this degree project. Interview questions are based on the content of that chapter and the outcome is intended to be more profound information about the financing of wind projects and how the various projects actually are financed in reality.

4.3.1 Funding structure

In this section, funding structure of various offshore wind projects are described.

Statkraft

Statkraft has to date invested in four larger offshore wind projects:

- Sheringham Shoal – 317 MW
- Dudgeon – 402 MW
- Triton Knoll – 900 MW
- Dogger bank – 4800 MW (four separable sub-projects)

All projects have the financial structure of SPV and are owned together with other stakeholders. Sheringham Shoal is a project that has been in operation since 2012 and is funded entirely by equity and is owned 40 % by Statkraft and the remaining by Statoil and green investment bank in the UK (Ekman, 2017).

Dudgeon is another project by Statkraft. It will be completed and ready for commercial operation in autumn 2017. Statkraft owns 30% of the project with equity, Statoil and Masdar, which is Abu-Dhabi's sovereign wealth fund, own the remaining equity stake. The funding of this project consists of 75 % debt on asset company level and 25% equity (Ekman, 2017).

Triton Knoll is a larger offshore wind project, which is still under development and is intended to bid in the auction for CfD in the UK during summer 2017. Statkraft owns 50 % equity stake but plans to sell this project before construction, probably using non-recourse leverage on asset company level (Ekman, 2017).

The last project Dogger Bank is a collection of four large-scale sub-projects that are still in the development phase. The projects were until recently owned with 25 % equity stake by Statkraft but the company sold their share in 2017 to the other stakeholders (Ekman, 2017).

Statkraft's preference has generally been to invest along with other partners in SPV, mainly due to the size of the investments but also to be able to learn from the partners, especially in the beginning. Instruments used are generally pure equity and shareholder loans. Though Statkraft's default position is for debt to be issued at a top level, i.e. senior debt with recourse to Statkraft AS, non-recourse senior debt on asset company level is considered on a case-by-case basis. For instance, in project Dudgeon non-recourse leverage occurs on asset company level and it anticipates to occur at Triton Knoll as well when the project is sold (Ekman, 2017).

Historically, small projects have been funded entirely by equity from one sponsor without any external debt. But as the investment grows in size the more capital will be needed to fund such projects and hence joint ventures with several partners take form in the market. Same funding structure trend can be seen in the floating offshore wind projects as the market develops (Ekman, 2017).

DONG Energy

Offshore wind is DONG Energy's primary strategic focus. The company has strong experience in the field and the investors are very pleased with investments in the offshore wind market. Offshore wind is considered to become one of the most competitive renewable energy sources (Andersen, 2017).

Commonly, no special funding structures are used. DONG funds projects "on balance sheet" and owns 50 % share of developed projects. The remaining 50 % divests to other partners and a premium is charged to the divested share that covers the construction cost of the project. The premium has been a significant contribution for DONG to expand its business and be able to continue building new projects in offshore wind. It is still possible for DONG to invest in projects "on balance" and there is still good interest from partners to buy into their projects (Andersen, 2017).

Typically, no bank funding is used in DONG offshore wind projects. It is rather common to use corporate bond market and hybrid bond market on the debt side (Andersen, 2017).

Arise

Arise is currently an active developer in the land-based wind industry in Sweden. The company owns approximately 241 MW in Sweden in operation and has new projects under development. However, the new projects are sold to other stakeholders when these are fully developed and ready for operation. An example of these stakeholders is insurance companies and infrastructure funds (Hägg, 2017).

The preferred funding structure of wind projects is sponsor equity. It is easier to manage an asset that is completely owned by a single investor. However, on larger projects, it is necessary that several stakeholders join as partners due to the size of the investment (Hägg, 2017).

4.3.2 Risk Profile

Participators were asked which risks are the greatest in the market and how can these be prevented.

Statkraft

The perception of risk profile in offshore wind has evolved a lot over the years and is continually doing so since offshore wind is still an immature market (Ekman, 2017).

Risk profile described by Moné, Stehly, Maples, & Settle (2015) was discussed and commented:

- The development risk considers to be the greatest risk of a project due to substantial expenditures that occur in this phase without any clarity that the project will be executed in the future. There are several setbacks that can prevent the project such as adjustment in regulatory, wind turbine price increase and reach obstacles in environmental impact assessment.

- Financing risk is the lowest risk in offshore projects. Although the project capacities have increased steadily during the years, capital can always be found for the right price. The increased market size has led to a stretch both for project finance debt markets and equity sponsor balance sheets. However, it is apparent from increased competition in the market that there is no shortage of capital in the market.

- Construction risk in generally one of the greatest risk in offshore projects due to complexity of construction, the hostile environment of the projects and dependency of weather and wind. But the industry has come a long way, the market is learning quickly and best practice is developing. Therefore, stakeholders have got increasingly comfortable with construction risks.

- Operation risks are difficult to predict and therefore it is unknown if these risks are underplayed or exaggerated. The track record of the industry is quite limited since there are not many turbines operated offshore in 10-20 years' time. As stakeholders getting more comfortable with construction risks, operations are getting a higher degree of attention these days.

- Volume risks are mostly manageable and Statkraft is confident with the prognoses considering wind resources and production volumes. It is one of the lowest risks in offshore projects.

- Price risks are crucial in the sense that if price mechanisms are not found in a specific country, offshore wind will not exist in that market. Price mechanisms such as CFD or Feed-in tariffs provide a crucial role in providing for revenue predictability and managing price risks.

DONG Energy

It is considered that construction risk is the greatest risk in the offshore wind market. Since investors put all their capital upfront and the revenues are later followed by a long tail of income, it is of huge importance that projects are delivered on time and budget during construction (Andersen, 2017).

Another important risk in the industry has been operating risks. Earlier, there were various operational issues in the industry but they have been dealt with quickly and it has proven to not be a major problem anymore. The turbine technology for instance, is developing rapidly. Issues that occurred 15 years ago do not exist today (Andersen, 2017).

One of the lowest risks in offshore projects is the volume risk. DONG Energy's experience with the operation of wind farms has been accorded to their expectations. Forecasts of wind resources have been very accurate as well as wind farm availability well predicted to 95 % (Andersen, 2017).

Arise

There are different risks during different phases of a wind project. However, greatest risks in wind projects are occurring during the development phase. Many risks are involved in projects that are still under development since anything can happen during this period. After the development phase, there remain some construction and volume risks but they are considered to be slightly lower than development risks since most parameters are set (Hägg, 2017).

Apart from technical risks, price risks are also crucial in wind projects. In Sweden, there is a market-based support system for renewable electricity production called electricity certificates. It exists some level of uncertainty in pricing since the system is market-based and is not at a fixed level such as feed-in tariffs (Hägg, 2017).

Arise as a developer of wind projects are willing to take technical risks during development and construction phase. However, stakeholders whom projects are sold to are often investors with low yield requirement and therefore tend to not take high risks after construction. They usually withstand some level of volume risk by having skilled consultants for predicting wind resources. But to cope with the high price risks some measures are often used such as bilateral physical supply contracts with a larger investing counterpart, for instance with Google and IKEA (Hägg, 2017).

4.3.3 Accelerate the funding & trends in the market

In this section, various aspects that the participates had regarding the future of offshore wind power are described.

Statkraft

Statkraft decided in December 2015 to stop investing in the offshore wind due to project’s capital intensive nature. The competition has intensified since investments in previous projects in Sheringham Shoal and Dudgeon and the company doesn’t consider to have sufficient enough investing capacity to reach a leading market position and instead are focusing on the company’s main competence which is hydropower. However, there are vast opportunities in the offshore wind market but considering Statkraft’s position in the value chain which is a capital intensive one, the opportunities are not suited for them. The increased competition in offshore wind market in the two last years has led that some other major utility companies other than Statkraft are stopping to invest in the market. This trend is apparent from the extreme drop of auction prices recent years (Ekman, 2017).

An approach for the industry to collaborate and attracting more capital to projects is having companies getting specialized in a project’s different stages. Rather than having an owner investing with the intention to hold the asset through its lifetime, it is expected that market participants are getting focused on different project stages. Smaller companies focus for instance on the earlier part of the project since they require less capital. When the project has achieved required key consents and permits, they can then pass the baton to larger utilities, construction companies or wind turbine suppliers to construct the project. And in the end of the chain, there are long-term passive owners such as pension funds or sovereign wealth funds together with a utility or an independent power producer retaining an equity stake during the operations phase to actively manage the asset. The same trend predicted for offshore wind industry has previously been seen in the real estate market, where smaller developers acquire necessary permits for the building, in the next step a larger property developer takes over the project and after the construction, the asset is sold to financial investors such as pension funds (Ekman, 2017).

Further, (Ekman, 2017) explains that today there is no shortage of capital for funding offshore projects in general, at least passive capital. However, it can be the case that on the equity side there is a shortage of active capital, competence to manage risks of an asset. Especially, during the development and construction phase of a project. We might get to a situation in future where we will see a price differential between active and passive capital (Ekman, 2017).

On the debt side, banks are much more comfortable with risks involved in a project compared with 4-5 years ago and it is getting increasingly more common with debt in funding of offshore projects. Another reason is offshore wind projects' high return on invested capital. Banks are constantly searching for profitable projects with high yield to invest in and offshore wind projects with manageable risks nowadays is a better choice compared with for instance onshore wind. However, floating wind industry still needs a track record until commercial banks get comfortable to invest in these project but this might change in the coming years (Ekman, 2017).

DONG Energy

The market is changing dramatically in several aspects. As the costs are decreasing, we see many countries such as US and Taiwan, that have suitable wind resources and are located near coastlines entering offshore wind market as new players. The competition is also increasing in more mature markets such as UK, Germany and Denmark and Netherlands. New projects are allocated in these countries by auction bidding, which has fueled the cost reduction in the industry but it has at the same time led to decreased return on capital in these investments (Andersen, 2017).

Regarding trends in financing of offshore projects, it predicts that DONG will still be able to fund the projects "on balance sheet" but also an increased interest from pension funds and infrastructure funds are expected which are low-interest investors (Andersen, 2017).

An apparent trend in the market is consortiums that are forming as new actors entering the offshore wind market in order to promote investments in the industry. An example is Green Investment Bank which is a public institution in the UK (Andersen, 2017).

Arise

In general, there is no shortage of capital to invest in wind projects globally. However, the challenge is to attract these investments to a particular market. Sweden has today record low-interest rates and the Swedish wind industry has delivered fine projects with high load factors compared with other European countries. But it still remains a challenge to attract investors into the market since there are high price risks regarding revenues of the projects. Infrastructure investors involved can't withstand high risks that the electricity certificate system carries but need more predictable revenue streams. This has also led to an increased share of equity compared with debt in the Swedish and Norwegian market (Hägg, 2017).

4.3.4 Summary of interviews

As it is apparent from the interviews, it is common today that several partners collaborate with each other by creating various financial structures such as SPV to fund larger wind projects. However, in the beginning of industry it was more common with only one owner who funded the whole project on equity. The same trend can be anticipated in the floating wind market. Now in a premature market, companies shall themselves fund the projects as sponsor equity but in future as the wind farm capacities increase the financial structures will get more complex.

The most important components in the risk profile can be summarized into technical risks including development and construction risks and also price risks which include risks in regulatory and governmental support systems. Development and construction risks are important especially in the wind industry since investors in the market put all their capital upfront and the revenues will be streaming in several years ahead. If the projects are not delivered on time and budget, the consequences will be huge. Regarding price risks, they are crucial in the sense that in countries where the regulator is not suitable for renewable energy projects, the investments will simply not take place in that market. Price mechanisms such as CFD or Feed-in tariffs are preferred since they provide revenue predictability and ease managing price risks.

The competition in the offshore wind market has increased dramatically the last couple of years. This is apparent from the extreme drop in auction prices, which has led that several major companies are lowering their investments in the offshore market. Two approaches are named by the participants in order to improve the market and attract more capital into the market. The first one is the specialization of companies throughout the value chain. Instead of having an owner hold the asset through its whole lifetime, different companies focus on project's different parts and pass the baton as the project is moving forward. Another approach is the new trend seen by having companies create consortiums to promote investments in the industry, an example of such consortiums is Green Investment Bank in the UK. However, it can be stated that today there is in general no shortage of capital to invest in wind projects, capital can be found for the right price.

5 DISCUSSION

This chapter is divided into two sections. The first subchapter addresses discussion about the economic model and the second the financing of wind projects.

5.1 Economic model

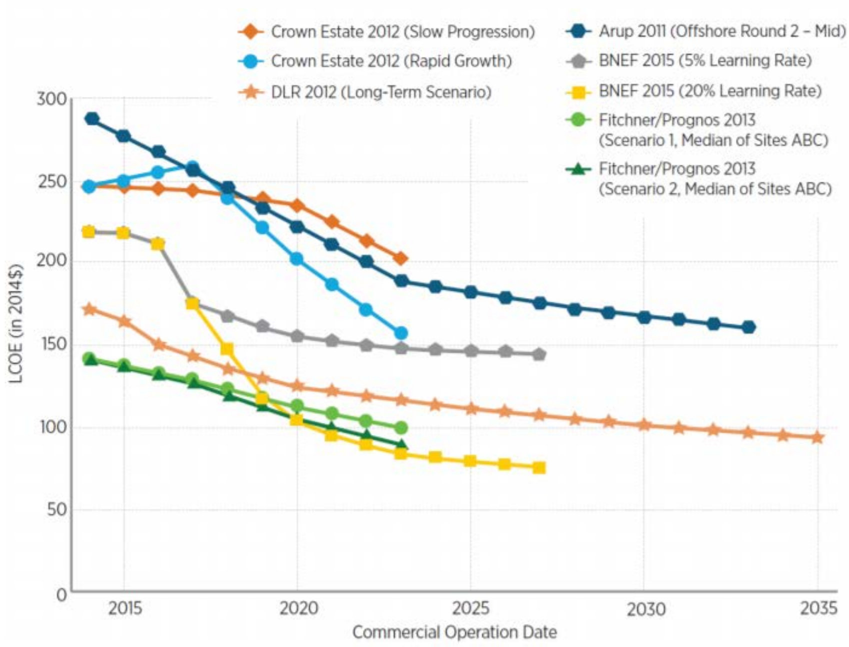
The floating wind power market is still immature, there are various concepts under development with totally different technical specifications. The total cost of each structure may vary widely regarding steel consumption, construction, installation and maintenance. To divide floating concepts into three categories is a rough generalization. In reality, many concepts are intermediates between Spar-buoy, Semi-submersible and Tension Leg Platform categories and therefore it is difficult to fit them all into one single calculation model.

The developed LCOE-model can be used by companies and enterprises to estimate the total cost of planned floating wind power plants depending on technical details of the wind farm and specific site conditions. The model can also be used to determine which input parameters have the biggest impact on total cost of the project and get a better understanding of the cost structure. Another application of this model is to predict future cash flow of the business during the total lifetime of the project which is estimated to be 20 years.

The output of the model contains a high level of uncertainties since the underlying data of the model is retrieved from reports and scientific studies and is not based on industry raw data as it was intended from the beginning of the work. Due to the high level of uncertainty of the model and difficulty to classify various concepts into three categories only, the LCOE output of the model might need to be adjusted by the project developers to give a fairer picture of the cost structure of a project. This can be done in the model by, either increase or decrease each cost category in percentages to adjust the total costs.

Another factor that might affect the final result is the exchange rates used throughout the work. It would be preferable to convert each cost to 2017-Pound by taking into account how much the financial values in the industry have inflated over time. Instead, in this work the values are converted to British pounds by using the historical average exchange rates.

Both LCOE values and the cost structure of the projects simulated by the developed model are fairly acceptable compared to actual investment data and values indicated in other studies. The figure on the next page presents LCOE estimations from various sources. The LCOE value from this degree project can be positioned inside the margins.



Figur 31. Groups of major international LCOE estimates for offshore wind (2014–2035). Data for the image obtained from The Crown Estate (2012), DLR (2012), ARUP (2011), Bloomberg New Energy Finance (2015), and Fitchner and Prognos (2013). Adapted from: "A Spatial-Economic CostReduction Pathway Analysis for U.S. Offshore Wind Energy Development from 2015–2030", by: Beiter, et al., 2016, NREL.

It was decided not to validate the final LCOE and CAPEX result since, there are not much information about projects available online and the investment costs that are given in some cases might include other factors that are not studied in this work such as negotiating costs or political factors.

5.2 Financing

In the second part of the work, financial structure of projects, risks profile and coming trends in the wind industry is explained in the literature study and investigated further by interviewing active operators in the wind industry. Regarding floating wind power, the financing of projects under development are similar to earlier projects in the beginning of the offshore market and are predicted to be funded mainly by sponsor equity, “on balance sheet”. However, as the market grows other types of funding structures may occur, such as SPV. This can be observed already today with Statoil’s latest projects, Hywind 1 and 2. The first demonstration project was funded solely by Statoil and the second larger 30 MW project is funded in partnership with Masdar which is a wealth sovereign fund (Statoil, 2017).

An important point mentioned several times throughout the interviews were the fact that governmental regulatory has a great impact on the growth and in some cases, the existence of wind projects in a specific country. Stable and consistent price mechanisms regulated by the government are prerequisites for profitability in renewable energy projects. Due to the fact that wind power plants are operated under a long period of time, a stable and predictable regulation with stability in the long-term is desirable by investors. This statement should be carefully noted by companies who are entering the floating wind market. An example of a market where support regulatory is not working well but other factors for investment are suitable is the current Swedish market.

Despite regulatory and other prerequisites for investment, other geographical conditions should be suitable for making floating wind power a preferable alternative compared with other energy sources. In locations where there are large populations living near coastlines, the water depth is shallow, maritime industries are established and wind resources are substantial, floating wind power have the potential to be highly scalable and may play a major role in future energy production in those markets.

6 CONCLUSIONS

The interest for offshore wind is increasing globally as a sustainable solution to decarbonize the energy portfolios. Due to the decrease of access to shallow waters near coastlines, a need for a new technology that allows projects move further from shore into deep waters has been created.

In this degree project, an LCOE model has been developed based on several data sources to evaluate the cost of floating wind power plants at any given site with various sizes and technical specifications. As an addition to this model, financing of wind projects has been described thoroughly and interviews have been done with investors in the wind industry to evaluate the current market and predict coming trends in the industry.

The LCOE model has been developed in Microsoft Excel and is attached to this work as a digital appendix. Three different floating concepts have been analyzed throughout the degree project and these can be selected as substructures in the LCOE model. The cost structure of wind projects during development, construction, installation and operation has been described in the work. The developed model allows the user to calculate CAPEX, OPEX and LCOE for projects at any given size and at any given site.

A series of simulations were run using the LCOE model based on a 490 MW benchmark farm including 70 turbines. It can be concluded from these simulations that CAPEX value was highest for the wind farm with Semi-submersible, following by Tension Leg Platform and the cheapest alternative Spar-buoy. However, regarding OPEX, the Spar-buoys are the most expensive alternative following by Tension Leg Platforms and Semi-submersible. Finally, LCOE for all three substructures were calculated. Based on the simulations, it was indicated that lowest LCOE is at 138 £/MWh with Spar-buoy substructures, following by Tension Leg Platforms at 142 £/MWh and the most expensive substructure Semi-submersible at 147 £/MWh.

Further, sensitivity analyses were performed to analyze different cost drivers of floating offshore wind projects. The most important identified cost drivers were turbine capacity, capacity factor, wind farm availability and cost of capital.

Finally, financing of wind projects was analyzed as an addition to the LCOE model for gaining a better understanding of the risks involved with these projects and also the impact of the cost of capital on LCOE of this technology. Three interviews were done with active operators in the wind industry and the outline from these interviews was that today there is no shortage of capital for funding wind projects, however in order to attract capital to a specific project the governmental regulatory of that market has to be suitable since it has a crucial impact on risks of a project.

As a conclusion, it can be stated that offshore floating wind is considered to become one of the most competitive renewable energy sources in future. In locations where there are deep waters near coastlines, robust wind resources and suitable infrastructure, floating offshore wind power considers to grow and in future play an important role in a green and sustainable power production.

7 FURTHER WORK

The economic model developed in this degree project gives an estimate for total costs of a given wind farm. The model is developed by using assumptions and available data in reports and other studies online. For this reason, many improvements can be made in the calculations.

The most desirable approach would be to develop the model based on raw cost data from demonstration power plants. By having cost data and technical specifications of each power plant, a statistical analysis should be performed to find the relationship between total costs and the specifications and site condition of each project. This approach was intended to be done in this degree project but it was not possible to gather any data due to confidentiality reasons.

An aspect that is not considered at all in this project is the economics of scale. LCOE for floating wind farms tends to decrease as the size of projects increase. This may be due to automation processes, development of supply chain, lower cost for the electrical infrastructure and simply because of best practice. These aspects should be investigated.

Two areas that should be improved in this work are substructure production costs and installation costs. The cost for substructures should be studied in more detail by estimating welding costs from production facilities such as docks. Installation costs should be estimated by investigating costs that occur during lifting and installation operations by vessels.

Additionally, financing of wind projects should be studied in more detail. This can be done by identifying risks associated with different phases of a project and studied, calculating the cost of capital dependent on various financing structures which may occur in partnerships and finally, calculating the profitability of projects by considering revenues in a project, business strategy and other political and socioeconomic factors.

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APPENDIX 1: COST ESTIMATIONS

The following chapter describes the cost estimations that have been to develop the LCOE-model. Due to lack of access to raw data in the market these costs are retrieved from reports and studies available online.

Project development

It is possible that the costs are slightly lower for floating wind turbines since the impact of the foundations are less on the seabed and thus may some surveys be less comprehensive.

These costs below are estimated for wind farm projects with 500 MW capacity. For smaller demonstration projects the costs may be lower. It should also be noted that some data have included engineering and management costs in the project development costs while some other have not done that.

Source	Cost (£/MW)
(KIC InnoEnergy, 2016)	80 360
(Department of Energy & Climate Change, 2015)	200 000
(Howard, 2012)	189 000
(Moné, Stehly, Maples, & Settle, 2015)	146 900
(Scottish Enterprise, 2011)	202 000
(The Crown Estate, 2010)	120 000
(Beiter, et al., 2016)	145 000
(Hurley & Nordstrom, 2014)	113 000
Average value	150 000

All costs are converted to pound sterling at the actual year.

Turbine

The total turbine costs are presented in the table below. Cost data of some sources are intended for larger 8 MW wind turbines and some for smaller. Hence, the cost of the turbines is calculated per MW for each turbine. Some sources might have included the tower cost in this section and some might not.

Source	Turbine capacity (MW)	Cost (£/MW)
(KIC InnoEnergy, 2016)	8	1 118 000
(Department of Energy & Climate Change, 2015)	8	1 207 000
(Howard, 2012)	8	1 024 000
(Moné, Stehly, Maples, & Settle, 2015)	3,39	1 269 000
(Scottish Enterprise, 2011)	-	1 277 000
(The Crown Estate, 2010)	5	1 200 000
(Beiter, et al., 2016)	6	1 117 000
(Hurley & Nordstrom, 2014)	6	1 132 000
Average cost (£/MW)		1 175 000

All costs are converted to pound sterling at the actual year.

Substructure

Due to lack of data in floating wind power market, especially regarding the platform costs, it is extremely difficult to calculate the exact cost of platform for different concepts.

The costs presented at table below are retrieved from various sources. Each concept represents a floating wind structure.

Cost data related to Hywind and WindFloat are retrieved from (Bjerkseter & Ågotnes, 2013), these are collected in their report from different sources and are based mainly on material and manufacturing costs.

Glosten released year 2014 a report about the costs structure of its concept PelaStar written by (Hurley & Nordstrom, 2014), the values are retrieved from that source. The report is prepared by Glosten themselves and should therefore be viewed with thoughtfulness.

Source	Concept	Cost (£)
(Bjerkseter & Ågotnes, 2013)	Hywind	3 179 000
(Bjerkseter & Ågotnes, 2013)	WindFloat	6 375 000
(Bjerkseter & Ågotnes, 2013)	TLP	3 720 000

All costs are converted to pound sterling at the actual year.

General function

More general, the cost of substructures can be broken down to different components based on the fabrication complexity. The spar-buoys concepts are broken down to stiffened column, tapered column and outfitting. While, the semi-submersible concepts are broken down to stiffened columns, truss members, heave plates and outfitting. (Beiter, et al., 2016)

The tables below presents the costs connected to each component.

Spar-buoy component costs

Component	Cost/ton (£)
Stiffened column	2 309
Tapered column	3 123
Outfitting	5 365

All costs are converted to pound sterling at the actual year.

Source: (Beiter, et al., 2016)

Semi-submersible component costs

Component	Cost/ton (£)
Stiffened column	2 309
Truss members	4 625
Heave plates	3 885
Outfitting	5 365

All costs are converted to pound sterling at the actual year.

Source: (Beiter, et al., 2016)

Mooring system

Same approach as substructures is used when estimating the costs for the mooring and anchor costs. It is possible to choose either drag-embedded or driven piles as anchors in the project. The cost of moorings is calculated per installed anchor. The mooring cost vary a lot based on the type of substructure and the wire used. The approximate value is given in the table below.

Values are retrieved from (Bjerkseter & Ågotnes, 2013) and (Hurley & Nordstrom, 2014).

Source	(Bjerkseter & Ågotnes, 2013)	(Hurley & Nordstrom, 2014)	Average cost (£)
Type	Drag-embedded	Driven pile	-
Anchor cost (£/anchor)	97 000	160 000	-
Mooring cost (£/anchor)	34 000	41 000	36 000

All costs are converted to pound sterling at the actual year.

General function

Two general functions can be applied to calculate the total cost of mooring and anchors of a floating wind structure. (Beiter, et al., 2016)

$$Chain\ cost = (0{,}0591 * MBL - 87{,}69) * L$$

Where MBL is the chain minimum breaking load expressed in kN and L is the length of the mooring chain in meters.

$$Drag - embedded\ anchor\ cost = 10{,}198 * MBL$$

In this function, stands MBL for chain minimum breaking load as well. The tool used to derive this functions, calculates the cost of anchors as a function of chain tension at the anchors and doesn't consider the holding capacity of the anchor in various soil parameters. (Beiter, et al., 2016)

Electric infrastructure

The electric infrastructure for offshore wind projects can be structured in many different ways and the decision of which structure is the most optimal solution for a specific wind farm is highly site-specific. The costs are dependent on the transmission distance, water depth and plant capacity among other factors.

At the table below, total electrical interconnection costs are presented from different sources for 500 MW wind farm projects with fixed-bottom foundations. Generally, the cost of cables, offshore substation and onshore substations are summed up in this category.

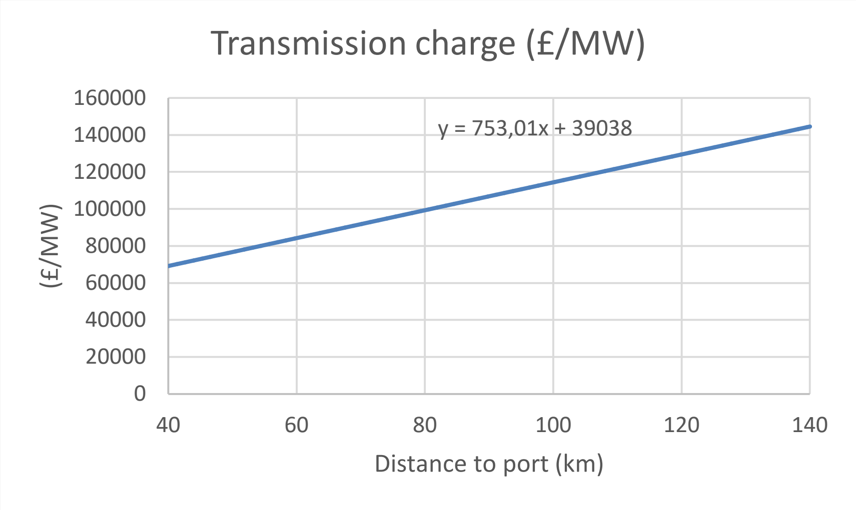
Source	Turbine capacity (MW)	Distance to shore (km)	Water Depth (m)	Cost (£/MW)
(Moné, Stehly, Maples, & Settle, 2015)	3,39	20	15	496 000
(The Crown Estate, 2010)	-	-	-	340 000
(RenewableUK, 2012)	-	150	35	422 000
(Scottish Enterprise, 2011)	-	-	-	442 000
Average cost (£/MW)				425 000

Some opportunities consider to exist in order to reduce the costs for the electrical interconnection of offshore windfarms. Joint collaboration between offshore industry and government could assess ways to develop a transmission network based on the costs from table X (above) and charge the companies that get connected to the system.

The table below, presents the OPEX annual costs for the transmission charges the project's economic life time.

Source	Turbine capacity (MW)	Distance to shore (km)	Water Depth (m)	Transmission charges (£/MW/year)
(Howard, 2012)	6	125	35	133 000
(Hurley & Nordstrom, 2014)	6	40	75	69 000
(Hurley & Nordstrom, 2014)	6	70	75	92 000
(Hurley & Nordstrom, 2014)	6	130	75	137 000

Based on these values, a graph were plotted in Excel that describes the relationship between the distance from shore and the transmission cost. For projects that are further from the port, the transmission charges are higher.



Installation

The costs for different concepts vary largely due to different design and production process. Regarding detailed calculations that were made by (Bjerkseter & Ågotnes, 2013), it is preferable for all concepts to use two lifts during installations, which results in the values below.

The installation of mooring system is also included in the total installation cost. The type of anchor that has been considered in each calculation is described in the previous sections.

Installation cost per turbine.

Source	(Bjerkseter & Ågotnes, 2013)	(Department of Energy & Climate Change, 2015)	(Hurley & Nordstrom, 2014)	Average value
Spar-buoy	810 000 £	-	-	810 000 £
Semi-submersible	736 000 £	-	-	736 000 £
TLP	816 000 £	1 115 000 £	1 654 000£	1 207 000 £

The installation cost of electrical infrastructure is retrieved mainly from reports that has been based on wind farms with fixed-bottom foundations. The costs are considered to be similar for floating wind concepts.

Electric infrastructure (£/MW)

Source	Array cable laying	Export cable laying	Offshore substation installation	Onshore substation installation	Construction ports
(The Crown Estate, 2010)	120 000	160 000	20 000	-	26 000
(Scottish Enterprise, 2011)	115 200	152 600	28 000	18 600	34 200

(Howard, 2012)	112 000	-	-	-	-
(Beiter, et al., 2016)	-	-	-	-	22 000
(Moné, Stehly, Maples, & Settle, 2015)	-	-	-	-	15 000
Average value	115 700	156 000	24 000	18 600	23 400

General functions

The equations below describe the installation cost for a 6 MW and a 10 MW turbine on floating structures. Spar-buoy and semi-submersible concepts are included in these calculations. The costs are modeled based on a 600 MW floating wind power plant. (Beiter, et al., 2016)

Variable	Description
C_t	Turbine installation cost
C_s	Substructure installation cost
C_{ps}	Port and staging cost
D_p	Distance from staging port to project site
Da	Distance from staging port to inshore assembly area
D_{as}	Distance from inshore assembly area to project site
W_d	Maximum water depth at project site

The following set of equations estimate costs for the 6-MW turbine case installed on a spar substructure:

$$Cs = 83062187 + 88643 \cdot Da + 65900 \cdot Dp$$

$$Ct = 149900000 + 41598 \cdot Da + 245417 \cdot Das$$

$$Cps = 26525267 + 25367 \cdot Da + 21667 \cdot Das$$

The following set of equations estimate costs for the 6-MW turbine case installed on a semisubmersible substructure:

$$Cs = 18408000 + 7875 \cdot Wd + 24821 \cdot D_p$$

$$Ct = 48170500 + 95833 \cdot Dp$$

$$Cps = 12627913 + 2375 \cdot Wd + 22565 \cdot D_p$$

The following set of equations estimate costs for the 10-MW turbine case installed on a spar substructure:

$$Cs = 94577688 + 90048 \cdot Da + 85033 \cdot Dp$$

$Ct = 1.75e^{8} + 73499 \cdot Da + 290417 \cdot Das$

$Cps = 28101577 + 27188 \cdot Da + 21667 \cdot Das$

The following set of equations estimate costs for the 10-MW turbine case installed on a semisubmersible substructure:

$Cs = 23658000 + 11625 \cdot Wd + 35450 \cdot Dp$

$Ct = 59608000 + 120833 \cdot Dp$

$Cps = 15896470 + 2975 \cdot Wd + 28266 \cdot Dp$

A linear interpolation relationship is developed by Beiter, o.a., (2016) to estimate the costs through turbine sizes of 3-10 MW:

$$X_c = \begin{cases} 3 \leq TR \leq 6, \left|\frac{TR-3}{3}\right| C_6 + \left|\frac{TR-6}{3}\right| C_3 \\ 6 < TR \leq 10 \left|\frac{TR-6}{4}\right| C_{10} + \left|\frac{TR-10}{4}\right| C_6 \end{cases}$$

Where:

X_c = interpolated installation cost

TR = turbine rating in megawatts

C_3 = 3-MW turbine installation cost function

C_6 = 6 -MW turbine installation cost function

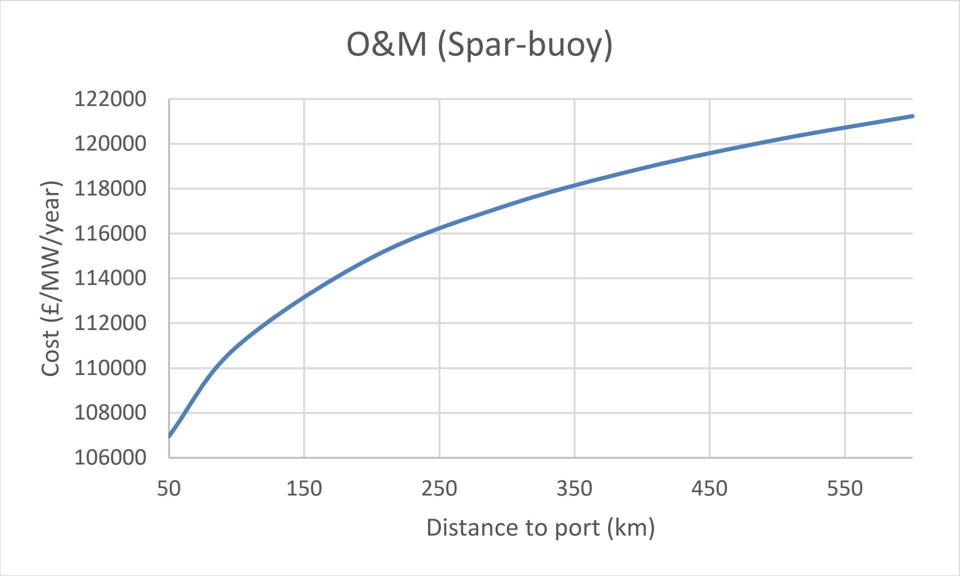
C_{10} = 10-MW turbine installation cost function

Source: (Beiter, et al., 2016)

OPEX

The cost data below are retrieved from (Beiter, et al., 2016) and consider the OPEX costs for a 600 MW wind farm with semi-submersible units and a similar with spar-buoys. In both cases during larger corrective maintenance, a strategy similar to a reversal of the installation process is considered. During this process turbines are towed to port or suitable inshore assembly area for having the major components replaced. Other inceptions and repair activities are considered to be take place at the project site.

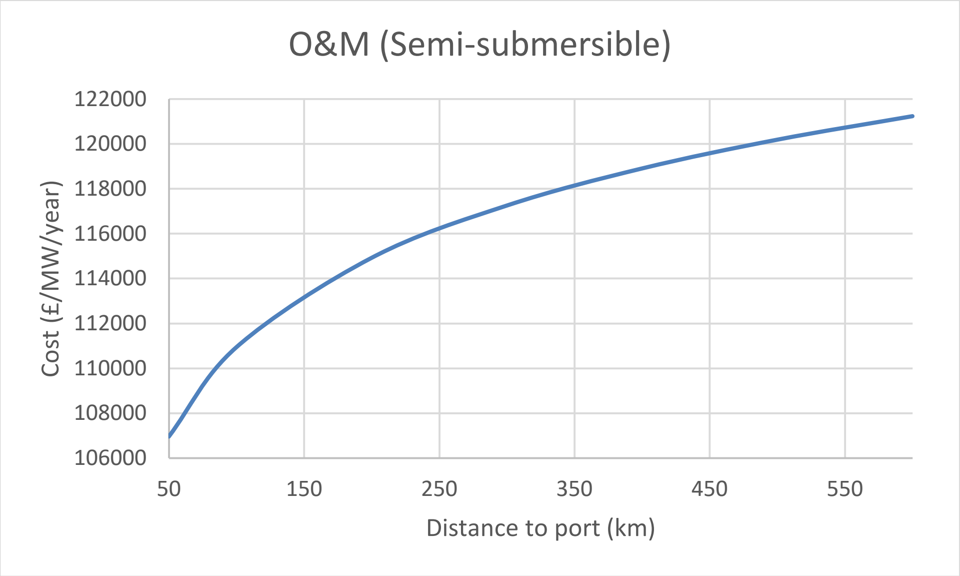
The met ocean conditions in both cases are considered as moderate. Which implies mean significant height wave of 1,39 m and mean wind speed of 7,32 m/s.



The equation used for plotting the graph is:

$$OPEX = 4{,}6556 * \ln(D) + 68{,}513$$

Where D is the distance to port, entered in km.



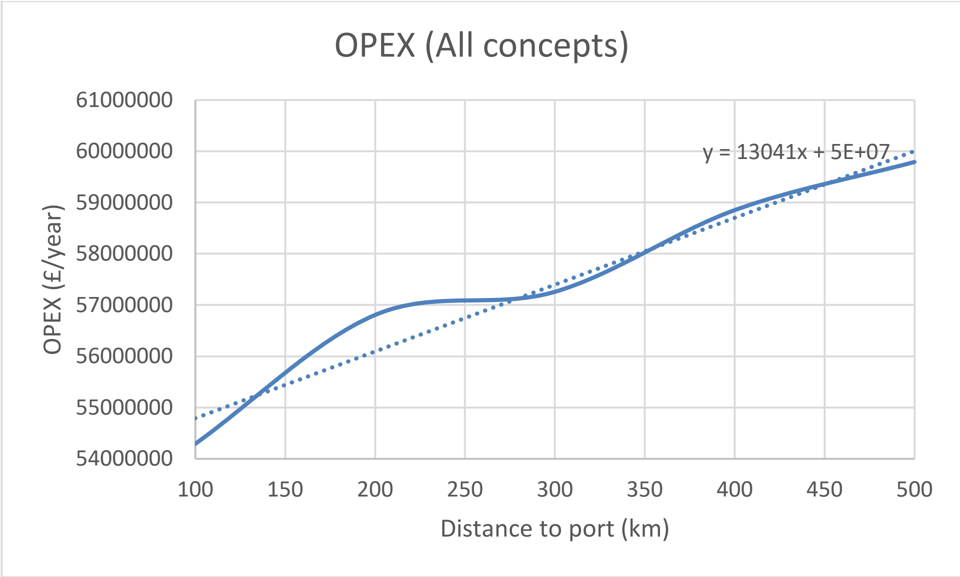
The equation used for plotting the graph is:

$$OPEX = 4{,}5907 * \ln(D) + 48{,}827$$

Where D is the distance to port, entered in km.

Also, detailed calculations were performed by (Bjerkseter & Ågotnes, 2013), using the OMCE-calculator developed by Energy Research Centre of the Netherlands. The wind farm capacity for this study was 500 MW and consequently the lower OPEX cost.

Using the values from this study, an equation was derived from Excel that describes the relationship between O&M costs and distance from shore.



In the LCOE-model, an average value of the cost equations from (Beiter, et al., 2016) and (Bjerkseter & Ågotnes, 2013) is calculated for spar-buoy and semi-submersible concepts. For the TLP concept however, calculations are based solely on equation from (Bjerkseter & Ågotnes, 2013).

Insurance

Insurance has a small share of total costs for this wind farm cost analysis. However, it has a important role by supporting the investment. The insurance costs in this work are divided in two groups: Insurance during construction which takes place from FID to WCD and Operating phase insurance over the economic life time of the project which is 20 years.

Source	Operating phase insurance (£/year/MW)	Insurance during construction (£/MW)
(Department of Energy & Climate Change, 2015)	17 000	-
(Howard, 2012)	18 000	-
(Moné, Stehly, Maples, & Settle, 2015)	-	35 000
(PricewaterhouseCoopers, 2012)	12 000	40 000
Average cost (£/MW)	15 600	38 000

Exchange rate

The inserted cost values in the model were retrieved from various sources that used different currencies. In this model all currencies are converted into pound sterling since the majority of sources used this currency as standard.

The values were converted to British pounds using historical average exchange rate of that year. These values were retrieved from (OFX, 2017) and are presented in the following table.

Year	From	To	Rate
2016	$	£	0,74
2016	€	£	0,82
2015	$	£	0,65
2015	€	£	0,73
2014	$	£	0,61
2014	€	£	0,81
2013	$	£	0,64
2013	€	£	0,85

APPENDIX 2: INTERVIEW TRANSCRIPTS

E-mail – Jonas Ekman - Statkraft

1- Has your company invested in offshore wind power projects?
If yes, what was your experience? Any coming projects in wind power?
If no, do you see any opportunities in the offshore wind power market?

Yes, we have invested in four offshore wind projects, all in the UK, all incorporated JVs (i.e. SPVs):

- Sheringham Shoal - 317MW, in operations since 2012, 40% equity stake, no leverage on AssetCo level
- Dudgeon - 402MW, commercial operations expected from autumn 2017, 30% equity stake, non-recourse leverage on AssetCo level
- Triton Knoll - Up to 900MW, in development, i.e. pre-construction, 50% equity stake, Statkraft intends to sell pre-construction, will probably use non-recourse leverage on AssetCo level post development phase
- Dogger Bank - Up to 4*1200MW, consists of four separable sub-projects, in development, 25% equity stake, project sold in 2017Q1

The investments this far have been successful, but it is certainly the case that the competition has intensified since our investments in Sheringham Shoal and Dudgeon. Statkraft decided in December 2015 not to invest further in offshore wind due to Statkraft's investment capacity not being considered sufficient to gain a leading position in the offshore wind market. Thus, though there are vast opportunities in the offshore wind market, Statkraft's position in the value chain is a capital intensive one, and thus the opportunities are not for us.

2- Which are the greatest risks involved in offshore wind projects and how can these be addressed and prevented? (Development, financing, construction, operations, volume or price risks?)

Considering that large scale offshore wind is not yet a fully mature industry, the perception of where the greatest risks are to be found are continually evolving, though generally I would say that:

- The development phase is the riskiest phase since very substantial development expenditure is incurred with very limited visibility over whether the final investment case will make sense.
- I would consider the financing risk significantly smaller than the other mentioned risks. Though project sizes have become a stretch both for project finance debt markets and equity sponsor balance sheets, capital can always be found for the right price.
- The construction risk is generally very substantial, but the market is learning quickly and best practice is developing. Stakeholders have got increasingly comfortable with the construction risk.
- It is hard to say to what extent the operations risk is underplayed or exaggerated. The track record of the industry is still quite limited, so we do not yet know how the turbines will perform

in 10-20 years' time. It seems operations get a higher degree of attention these days when stakeholders get increasingly comfortable with the construction risk.

- The volume risk is generally manageable, and I would consider it less of a risk compared to the construction risk.
- Most markets have moved to price mechanisms such as contracts for difference, feed-in tariffs to manage the price risk for offshore wind projects. These mechanisms provide a crucial role in providing for revenue predictability. Without these mechanisms the offshore wind market would not have developed as fast, and in general, jurisdictions/geographies where these mechanisms are not to be found, offshore wind is probably not a very appealing business case.

3- What kind of financial structure do you prefer to invest in regarding offshore wind power? (Sponsor equity, Joint venture, SPV)

Due to the size of the investments, Statkraft's preference has generally been to invest along with partners in an incorporated JV (SPV). Instruments used are generally pure equity and shareholder loans. Though Statkraft's default position is for debt to be issued at top level, i.e. senior debt with recourse to Statkraft AS, non-recourse senior debt on AssetCo level is considered on a case by case basis.

4- How can players in the industry and finance market collaborate to address these challenges and attract more capital to projects?

Rather than having an owner investing with an intention to be there for the full lifecycle of the asset, I would expect that different market participants will increasingly get focused on different stages of the lifecycle, such as early development, pre-construction, construction or operations. I.e., specialization, like in most industries. The skills needed for the different stages of the lifecycle are quite different, and so are the capital requirements. Parties focusing on the early stages do not need as much capital as in the later stages, and they can then pass on the baton to utilities, construction companies, WTG suppliers/operators and other developers (of which a few more financially oriented) to construct the asset, after which some owners recycle capital by selling off to long term, passive investors such as pension funds and sovereign wealth funds, but with a utility or an independent power producer retaining an equity stake during the operations phase to secure an operations capable owner to be able to actively manage the asset. After the development phase, I would expect that most assets will have multiple owners since few firms have the capital or the risk appetite to take on an asset on their own. That said, as long as the ownership is spread out over several equity sponsors, for many assets also using leverage on asset or HoldCo level, I would not say there is a general shortage of capital. The balance sheets of utilities are constrained, but you can always find third party capital for the right price - looking at the pricing of debt and equity in the sector, the supply of capital does not seem to fall short of demand. If there is a shortage of capital, I would rather think that the shortage is for active capital, competent to manage the risks of an asset. Passive capital is abundant. If that is the case, it may be that we get to a situation where we will see a price differential between active and passive capital. With the ownership of each asset being shared with multiple owners, economies of scale are difficult to realize on the owner level, which is likely to be a driver for an ever increasing use of subcontractors that can realize economies of scale over multiple assets, creating business opportunities for specialized sub-contractors.

5- What trends do you anticipate in financing of offshore wind projects in the coming years? (equity vs debt)

Due to constraints of the balance sheets of European utilities, financial equity will increase in importance along with non-recourse bank debt. For the debt markets, bank debt will continue to be the dominant debt source - I doubt that the bond market will get comfortable/competitive anytime soon to take on construction risk, but it will constitute a refinancing alternative for operational projects. Investments will predominantly be in countries with stable, favorable revenue mechanisms such as CfDs and FiTs.

Phone interview – Jonas Ekman – Statkraft

1- Has your company invested in offshore wind power projects?
If yes, what was your experience? Any coming projects in wind power?
If no, do you see any opportunities in the offshore wind power market?

(Swedish) De projekten som vi har investerat i är fyra stycken offshore vind projekt. Alla är i Storbritannien. Alla är i form av egna bolag dvs. SPV. I alla så investerar vi tillsammans med andra ägare. Det första projektet som vi investerade vi Sheringham Shoal, det är ett projekt på 317 MW. Det äger vi tillsammans med Statoil och Green investment bank i UK. Det har varit i drift sedan 2012 och vi har 40 % av equityn där. Det ligger ingen extern debt i det bolaget.

Nästa projekt är Dudgeon, vilket är större. Det är precis i slutet av byggtiden. Nu är nästan alla turbiner uppe och snurrar. Vi beräknar att den ska vara i full kommersiell drift under hösten. Där äger vi 30 % av equity. Det äger vi tillsammans med Masdar, Abu Dhabis Sovereign wealth fund och Statoil. Det här projektet har debt på asset company level och finansieras på 75% debt och 25% equity ungefär.

Sedan så har vi Triton Knoll som är ett ganska stort projekt, 2-3 gånger de tidigare nämnda projekten. Detta projekt är fortfarande under utveckling och ska bidda i den auktionen för Contract For Difference (CfD) som sker i UK här under sommaren. Vi äger 50 % av equityn i det projektet men vår avsikt med det projektet är att vi kommer sälja den equityn när bygget sätter igång av det projektet.

Den sista, Dogger Bank, är en samling av fyra stycken väldigt stora projekt. Där vi fram till väldigt nyligen ägt 25% men vi sålde det till de andra ägarna. Anledningen till försäljningen är att i december 2015 beslutade Statkraft att inte investera vidare i offshore vind pga. den extremt kapitalintensiva branschen och statkraft egentligen inte har tillräckligt med investeringskapacitet för att uppnå en ledande marknadsposition inom branschen. Och därför beslutades att inte investera vidare utan fokusera på Statkrafts huvudkompetens som är vattenkraft.

Ser det så ut generellt i världen? kan det bero på regelverket från land till land?

Det varierar extremt mycket från land till land. Om vi ser på utbyggnaden av offshore vind så är det koncentrerat till ett extremt fåtal länder. Historiskt har Danmark varit först ute. Sen har vi sett Tyskland, UK, Nederländerna de senaste åren. Men det är koncentrerat till ett fåtal länder och det beror helt enkelt på vilket system man har i landet för revenues. Om det är feed-in tariff eller CfD eller liknande. Om det är ett land som inte erbjuder stabila revenues över lång tid så är det väldigt svårt att finna det attraktivt att bygga offshore vind i det landet.

Det är Statkrafts position. Vi har väl sett liknande uttalanden från vissa andra aktörer. Jag tror det var EON, tyska utilityn, som gick ut och sa de funderade på om offshore vind var något för dem med tanke på hur konkurrensutsatt har marknaden blivit de senaste två åren. Om vi ser de auktionspriser som projekt vinner så har de gått ner ganska dramatiskt de senaste två åren och det är vissa aktörer som funderar om det är en tillräckligt lönsam bransch att vara i.

2- Which are the greatest risks involved in offshore wind projects and how can these be addressed and prevented? (Development, financing, construction, operations, volume or price risks?)

Dessa risker du nämnt är en bra kategorisering tycker jag. Jag skulle jag säga att tolkningen av vilka risker som är störst har förändrats ganska mycket över tiden. Men generellt, på grund av de väldigt stora utvecklingskostnaderna som man måste lägga ner innan man ens kan börja bygga så är development risken väldigt stor. Man kan råka ut för ett antal bakslag som gör att projektet inte kan hända. Det finns politisk risk att man ändrar i stödsystemet för vindkraft. Man har ingen aning om hur prisutvecklingen för turbiner och offshore arbetet kommer att utvecklas de närmaste åren. Om det kan vara så att man upptäcker något problem i miljökonsekvensbeskrivning som gör att siten inte skulle kunna användas för vindkraft. Så att development risken egentligen är den största risken där det finns väldigt många skäl för att ett ska projekt kapsla isär innan man ens har börjat bygga nåt.

Vad det gäller finansieringsrisken skulle jag säga den är minst jämfört med de andra. För även om projektstorlekarna bara ökat och ökat. Det blir lite av en stretch för marknadskapaciteten vad det gäller tillgången till lånemarknaden. Om vi säger lånemarknaden för ett projekt i UK kan svälja max 1,5 miljard pund eller nåt liknande. Där finns det en risk. Vanligen vill man också ha med en utility som äger. De flesta utility idag har ont om pengar. Där finns det en begränsning. Däremot generellt, tillgång till kapital finns det ingen brist om. Som vi diskuterade tidigare ser vi väldigt stark konkurrens på marknaden och konkurrerad lönsamhet i de senaste auktionerna. Det tyder ju på att det finns ingen brist på kapital egentligen. Supply för kapital möter definitivt demand.

Projektstorleken gör att man måste ha många aktörer inne i strukturen. Många på ägarsidan, på equity och det blir vanligt att lägga in debt i strukturen också.

Har denna trend något att göra med att bankerna blir mer bekväma med riskerna i och med att marknaden mognas?

Det är definitivt så att banker är mer villiga att låna ut till offshore vind projekt idag jämfört med låt oss säga för 4-5 år sen. Dels har det att göra med att marknaden har utvecklats och riskbilderna har blivit mer och mer klar vilket gör att bankerna blir mer och mer bekväma med riskerna. Den andra komponenten är att de flesta banker har svårt idag att finnas någonstans lönsamt att bli av med sina pengar. de får oftast för låg avkastning i långivning. Offshore vind ger en bättre avkastning jämfört med att finansiera landbaserad vind exempelvis. Det beror på att offshore risk innehar högre risker.

Vi går vidare med riskprofilen. Konstruktionsrisken är definitivt framträdande och det handlar om offshore arbete som är väldigt komplicerat. Man är väldigt beroende av väder och vind. Väder och vind kan välta den bästa av planer. Man är väldigt beroende av specialfartyg. Det finns inte många såna fartyg i världen och missar man en sån... det är alltså en väldigt väsentlig konstruktionsrisk. Men man ska samtidigt konstatera att det har hänt väldigt mycket. Marknaden lär sig väldigt snabbt och det etableras best practice för hur man gör. Vi har på två av projekten arbetat tillsammans med Statoil. Deras erfarenhet av offshore arbete inom Oil and gas har ju varit väldigt värdefullt. Det har det absolut.

Om vi går över till operationsrisk så är det lite svårt att värdera egentligen. Det är fortfarande en ung bransch och det finns inte så många offshore vindparker som har varit i drift ett antal år. Vem vet hur offshore turbiner kommer fungera om 15-20 år. Det här är ju en långsiktig investering och för att räkna hem caset så måste ju turbinen kunna leverera definitivt mer än 20 år. Det är svårt att veta hur pass bra de kommer prestera så långt bort. Jag vet faktiskt inte idag om vi underskattar eller överskattar operationsriskerna. Vi vet inte riktigt egentligen.

Kan försäkringar hjälpa investerarna i det fallet?

Egentligen inte. Då måste försäkringsbolagen prissätta försäkringarna. De har inte mer information än vad vi har. Så det tror jag inte är nån produkt som skulle funka.

Volymrisken för produktionen, där är vi ganska trygga med de prognoser som generellt görs. Vindstudier och produktionsstudier har blivit ganska avancerade. Egentligen är det ingen av de större riskerna utan vi är ganska bekväma med det.

Den sista risken, prisrisken. Det är så enkelt att om ett land inte har feed-in tariffer eller CfD eller liknande då är vi inte intresserade. Det tror jag gäller de flesta aktörer inom branschen. Finns det inte möjlighet att få förutsägbarhet i revenues då är det inte så intressant. Om vi exempelvis tar Sverige, ska vi bygga offshore vind baserat på spotpris på el plus elcertifikat, det är inte intressant.

Vilket stödsystem önskas helst?

Auktioner tycker vi generellt sett fungerar ganska bra. Alternativt, erbjuda en generell nivå på feed-in tariff eller CfD och sedan får alla som önskar bygga ett projekt på den nivån. Nackdelen med det är att staten inte kan förutsäga hur många som kommer att vilja bygga ut för det priset.

3- What kind of financial structure do you prefer to invest in regarding offshore wind power? (Sponsor equity, Joint venture, SPV)

Såsom vi har resonerat hittills om offshore vind så har det varit så att vi har önskat att investera tillsammans med andra partners och det är dels på grund av storleken på investeringar, det är väl det största skälet. Sedan till en början så var det också för att lära sig av andra. Projektstorlekarna är helt enkelt för stora annars.

De pengar som vi investerar är då antigen bara rent aktiekapital eller aktieägarlån. Statkrafts grundposition egentligen är att vi föredrar att inte lägga ner nån leverage på tillgångsnivån utan koncentrera leverage hos Statkraft moderbolag istället för nere på projektnivån. Med det sagt, på case by case basis så utvärderar vi att lägga debt även på tillgångsnivån och det är ju såsom du såg ovan så är det nånting som redan har skett en del på offshore vind projekten. På Dudgeon så har vi non-recourse debt på asset nivå och på Triton har vi ambitionen att lägga non-recourse på asset nivå. Nu kommer vi sälja det innan det finansieras. Men det är generellt sett så att pga. storleken på projekten så har det blivit ganska vanligt i marknaden att lägga debt på asset nivå just för att det är såna stora volymer och när det gäller financial sponsors på equity så uppskattar de generellt när debt läggs i strukturen.

Hur har det varit historiskt?

Historiskt så har det varit vanligt med små projekt, en ägare. Man ägde bara projektet utan att ha några externa lån, bara equity. Men sen ju mer projekten ökade i storlek, ju mer insåg man att det här har jag inte råd med själv och måste få in kapital på annat håll.

Är det så på den flytande offshore vindmarknaden nu?

Om jag förstått rätt det man gör nu på flytande sidan är väl lite som testanläggningar. Då har man ju kanske råd att göra det själv. Om det är 4-5 turbiner så har man kanske råd att ta det själv. Men om det är 100 turbiner så blir det lite värre.

4- How can players in the industry and finance market collaborate to address these challenges and attract more capital to projects?

Jag tror egentligen att den här branschen utvecklas fortfarande relativt snabbt men man ser ju att den mognar mer och mer. Vissa teorier finns kring vad då som kan hända se när en bransch mognar mer och mer. Så om vi säger så historiskt, en aktör tar och äger en tillgång från ax till limpa genom hela livscykeln, det tror jag är nånting som man kommer att gå bort ifrån mer och mer. Jag tror att aktörer kommer mer och mer specialisera sig inom branschen så att vi får en specialisering på det område som de olika aktörerna hanterar.

Om vi tar under tidig utvecklingsfas av ett projekt när man håller på söker tillstånd och gör biologiska undersökningar, behöver man då inte vara ett stort företag och ha mycket kapital. Sen när projektet mognat och har key consents och permits så säljer man det vidare till nån som har mer kapital.

Sen har vi vissa företag som specialisera sig på att hantera byggperioden och byggrisker och sedan har man långsiktiga ägare som därefter träder in och håller tillgången långsiktigt.

Jag skulle väl dra nån parallell till hur fastighetsbranschen fungerar. Då är fastighetsbranschen segmenterat på ett liknande sätt där man har små utvecklare som utvecklar projekt så att de får alla tillstånd sedan får en större fastighetsutvecklare köpa projektet av dem. Fastighetsutvecklaren har projektet över byggtiden men sen efteråt säljer de det till pensionskapitalet.

Jag skulle inte bli förvånad om en liknande utveckling får branschen så att man specialiserar sig. Det leder ju också till tidig utveckling och det behövs inte lika mycket kapital däremot under byggtiden där behövs det mycket kapital men också kompentens för att aktivt kunna arrangera riskerna. Pensionskapitalet är en mindre lämplig ägare här. Där kan det finnas ägare i olika former av utlitiy, byggfirmor, turbinleverantörer eller specialiserade utvecklare. Sen efter byggskedet så kan vissa av de här aktörerna sälja till pensionskapitalet när man har de-riskat tillgången så att det inte finns alltför mycket risk kvar. Men pensionskapitalet behöver även i slutskedet nån form av ägare som kan aktivt hantera riskerna. Pensionsfonden har inte kompetens.

Hur ser det ut idag?

Det har väl börjat gå i den riktningen. De senaste åren har det mer och mer blivit vanligt att energiföretag som Vattenfall eller Statkraft eller EON säljer ett antal procent av equityn i operating assets till finansiellt passivt investerare. Jag tror att det kommer gå ännu längre så att det blir en ytterligare ökad specialisering egentligen där man fokuserar på olika delar av livscykeln. Om vi tar pensionsfonder, de är inte så väl lämpade för att hantera byggperioden pga. sitt sätt att de inte ägnar så mycket tid på att hantera en tillgång. De vill lägga alla pengar på bordet dag en och inte sprida ut kapitalinjektionerna under byggtiden. Lite såna problem.

Egentligen när det kommer till kapitalsidan skulle jag säga att idag finns det ingen generell brist på kapital, i synnerhet passivt kapital finns det inte brist om. Det finns mycket kapital där ute som söker avkastning. Det som möjligen är brist på är kapital som kan arbeta som aktiv ägare, framför allt under utvecklingsfasen och byggfasen. Det är det som är lite klurigt i och med pensionsfonderna inte kan hantera det så bra. Det är då på equity sidan.

Ser vi på debt sidan, där har ju bankmarknaden blivit ganska bekväm med riskerna och det är väl den primära källan för debt. På global basis, så finns det kanske ett tjugotal banker som har rimlig erfarenhet av offshore vind sen så finns det ett antal till som är mer case by case basis.

Är debt alltid att föredra jämfört med equity med tanke på låga räntor?

Det beror på vad man är ute efter. Det är olika för olika aktörer. Vissa är ute efter det för att de helt enkelt inte har tillräckligt med kapital själva. Därför måste de ha med debt i strukturen andra vill ha det för uppsyn av return of equity i investeringen. Andra aktörer kan vilja ha det så att de vill lägga in ett mindre belopp och att få en riskavlastning ifall projektet klappar ihop, de förlorar då bara equityn som de lagt in. Det finns lite olika drivers för olika aktörer.

När det kommer till obligationsmarknaden så har det varit bara nåt projekt som har finansierats med obligation. Under operations så har de finansierat sig med obligation. Men att obligationsmarknaden skulle bli bekväm med byggrisken och att de skulle prisa det på ett konkurrenskraftigt sätt det tror jag inte skulle hända. Inte på de närmsta tio åren.

5- What trends do you anticipate in financing of offshore wind projects in the coming years? (equity vs debt)

Egentligen tror jag investeringarna från institutionella investerare framför allt i projekt i operations fas, kommer att öka. Också användningen av leverage på asset nivå kommer att öka, det är leverage som man lägger på asset nivå, det kommer att vara banklån snarare än obligationer pga. jag tror att obligationsmarknaden kommer inte att vara särskilt konkurrenskraftig jämfört med bankmarknaden.

Investeringarna kommer att fortsätta att vara i geografier där det finns en stabil intäktsmekanism såsom CfD eller feed-in tariffer.

Och flytande offshore vind måste få tillräckligt mycket track record för att kunna sänka riskbilden och få investerarna att bli bekväma. Det finns ju fortfarande en väg att vandra i innan bankerna blir bekväma med flytande, det kommer ta några år till. Detsamma gäller ju mer finansiellt orienterad en equity investerare är som en pensionsfond, då föredrar de nog nåt gammalt beprövat än något nytt och fränt. Ju mer erfarenhet från branschen som man har desto större vilja kan det finnas att testa nåt nytt.

Phone interview – Lars Andersen – DONG Energy

1- Has your company invested in offshore wind power projects?
If yes, what was your experience? Any coming projects in wind power?
If no, do you see any opportunities in the offshore wind power market?
You can say that offshore wind is our primary strategic focus, we have very good and strong experience with offshore wind. And we believe, it has developed to one of the most competitive renewable energy sources right now. We are very pleased with our investments in offshore wind.

Based on the competition that is increasing in offshore wind, is the market changing or do you still have the same position?
The market is changing quite dramatically in several aspects. After that we have seen costs coming down, many countries are pursuing offshore wind, those who have coastlines and wind speed and sea bed conditions that are suitable for offshore wind. For instance, we are moving into Taiwan and US which are new markets for offshore wind. So the market for offshore wind is growing.

Another important development is also that the competition is increasing in particular in the mature markets where Germany, UK, Denmark and Netherlands are tending an auction process where they allocate new projects. That has fueled the cost agenda within the offshore wind technology. But it has also decreased our returns. So I guessed that is probably the most pronounced change that we are seeing right now.

Is the regulatory the main driver of the market?
I think the primary driver for the market is cost reductions. That's what makes the technology attractive in developer's point of view and also the market's and government's point of view. All in the market such as nuclear are reaching its technical lifetime in coming 10-15 years and they have to be replaced with something else. With cost reductions we can see offshore wind play an important role in the energy mix. It is not the only technology but in broad.

2- Which are the greatest risks involved in offshore wind projects and how can these be addressed and prevented? (Development, financing, construction, operations, volume or price risks?)

I would say that the most important risk is probably construction risk and being able to deliver the projects on time and budget. It is a technology where you put all your money upfront and you are returned by a long tail of income after that. So, a large part of cost is driven by construction and your CAPEX. So being able to deliver on time and budget is crucial for securing the economics of parks. Surely, there are some operational issues but they are dealt with as we are going forward and these risks are usually shared with providers of technology such as turbine tower and so on. And this has proven to not be a major problem.
Turbines had many problems before but not today. And I can also say that our experience with operating of farms has been accorded to our expectations. Availability of above 90 %, we have quite accurate wind speed forecasts as well.

3- What kind of financial structure do you prefer to invest in regarding offshore wind power? (Sponsor equity, Joint venture, SPV)

We have a strategy where we keep 50 % of the wind farms and we divest the other 50 % to investors. The part we build or keep is funded on balance sheet. And we also get a premium on top of our construction cost when we divest the other 50 % and that premium help fund our own bid as well. It is a significant contribution to continue our offshore wind dominance. So that is how it is funded, we do not use special funding structures.

Is your balance sheet getting restricted?
It is still possible (to invest on balance sheet). We still see very good interest in buying into our projects. Our investor's return requirement has declined and as a result we have improved our economics in constructing and operating offshore wind.

Is it more usual nowadays with debt in financial structures?
Yes, but we really do not bank finance our activities. We use the corporate bond and hybrid bond market and we finance on a general DONG energy level and not specially on offshore wind. Some of our partners they typically finance their share of the park by means of the project financing. There you also see a declining credit margin and banks becoming more comfortable with this technology.

4- How can players in the industry and finance market collaborate to address these challenges and attract more capital to projects?

We see certain institutions or clubs that are forming when they enter into offshore wind. They form a consortium which provides loans to the partners that are entering into offshore wind farms. That is one development we see. Our German insurance companies have done their financing that way. We also see for example in UK, green investment bank which is a public institution that targets to enable more investments into green technologies. They have also a catalyst of financing. We have also been helped by low interest firms in general which means that pension funds have been very interested in investing in offshore wind and our infrastructure projects.

5- What trends do you anticipate in financing of offshore wind projects in the coming years? (equity vs debt)

I think we, Dong energy, will continue financing our share of the projects out on our balance sheet by corporate funding mainly. We expect to continue to see very high interest in offshore by pension funds and infrastructure funds to invest in offshore wind. We see more infrastructure investors and more strategic investors coming to offshore wind and that's basically around the globe. We have partners with Danish and European partners but also Asian and Northern America.

Do you anticipate companies in offshore industry becoming specialized in different stages of the supply chain?

Yes, it is possible. I think it is unlikely it will be our strategy though. We see very much ourselves as a utility that procures power at transition phase where we are going from coal to wind. But it is very likely that industry will specialize and the value chain becoming more granular (?). I guess today the main components within offshore wind is already sort of quite granular. You have turbine manufacturers, the cable manufacturers and the tower and foundation manufacturers. And we see good competition within each part of the supply chain. That's also been helpful in order to drive costs down of course. I think it is likely to see more players in each part of the supply chain as the industry will likely grow the coming years.

Is the grow of offshore wind dependent solely by the revenue mechanisms or are there other political and regulatory factors?

Of course, it needs to be political support and a regime to support offshore wind but other than that, you need of course, physical conditions in place. You need to have some coastline and preferably close to load sender, close to big cities and industry areas. And you need to have fairly shallow water as well. With the foundations we have today we cannot go to very deep sea levels. And you also need decent wind speeds. In those places where these conditions are fulfilled, it is natural to look towards offshore wind. But if you go to Sahara Desert, something else is more natural to pull up there.

Is floating wind power something that would be interesting in future?

We don't have floating foundations. I cannot rule out that it would be interesting in future. Right now, we have plenty of opportunities with our current foundation technology. Using monopiles is the cheapest way to build offshore wind. We ourselves are also working on jacket foundations and developing those. That will also allow us to go into deeper waters and bigger turbines.

Phone interview – Linus Hägg – Arise

1- Has your company invested in offshore wind power projects?
If yes, what was your experience? Any coming projects in wind power?
If no, do you see any opportunities in the offshore wind power market?

Nej, bara landbaserad. Om vi tittar på landbaserad o havsbaserad vindkraft så är LCOE högre för havsbaserad än för landbaserad. Givet att vi har så stora markområden, kan vi bygga industriskala eller utility scale på land i Sverige. Så det känns irrationellt att bygga en dyrare energityp än att utnyttja en billigare energityp. I många andra länder så bygger man mycket till havs men det har att göra med att det inte heller finns plats för att bygga storskaligt på land. Då är det klart att man är tvingad till en högre energikostnad. Men jag tycker att i Sverige, ur vårt perspektiv, vi är inte tvingade till en högre energikostnad för vi har mycket land.

Sen kan det mycket väl, att man bygger om energisystemet helt o hållet. Så att kärnkraft på riktigt blir urfasad över några decennier framöver. Då måste man ha havsbaserad, då är det aktuellt det också. Men jämför man hav och land, så länge man har resurser på land ska man utnyttja det.

2- Which are the greatest risks involved in offshore wind projects and how can these be addressed and prevented? (Development, financing, construction, operations, volume or price risks?)

Det finns olika risker i olika faser. Det är klart att i ett utvecklingsprojekt finns det helt andra risker än i ett projekt som är byggfärdigt. Ett projekt under utveckling har ju en väldigt hög risk på sig för allt möjligt kan hända innan det är färdigt utvecklat. Ett projekt som är färdigt för att byggas, alla tillstånd är på plats, allt är upphandlat etc. då är det byggrisk och produktionsrisk kvar. Om vi pratar bara teknik så att säga. Och sedan projekt i drift, då har man ingen byggrisk men kanske produktionsrisk. Det är en kategori av risker.

En annan kategori är prisrisker. Vi har elcertifikatsystemet som är marknadsbaserat. Det är ingen fast feed-in tariff. Så att om man bortser från utvecklingsrisken och teknikrisken så är det den största risken. Det kan man hantera på lite olika sätt.

Handlar det om utvecklingsrisken så är det utvecklaren som oss som tar hand om den. Byggrisk det tar vi också. Nu bygger vi inte till egen räkning längre utan vi säljer projekt när de är byggfärdiga till investerare. Och det är oftast investerare med ganska lågt avkastningskrav vilket innebär att de inte får ta speciellt mycket risk. Dvs de får inte ta utvecklingsrisk, de får ta väldigt lite byggrisk om någon, möjligen får de ta produktionsrisk dvs du har en bra vindmätning med bra konsulter som har räknat på det men du har ännu ingen proven production. Den risken kan de ta. Men sen behöver de klappa prisrisken när de väl är där. Det kan man göra på lite olika sätt. Det kan man göra med bilaterala elhedgar med en stor motpart. Som tex. Google som har gjort lite såna dealar i Sverige. Du kan göra olika typer av hedgar för att ta bort mer eller mindre risken på elsidan.

Så Arise äger för tillfället inga egna projekt?

Jo, vi äger 241 MW ungefär som är driftsatt. Däremot projekt som vi utvecklar nu, de finansierar vi egentligen inte själva utan där har vi utvecklat de färdigt, upphandlat och allt och de är byggfärdiga. Då söker vi istället en investerare som försäkringsbolag eller infrastrukturfond eller något liknande.

3- What kind of financial structure do you prefer to invest in regarding offshore wind power? (Sponsor equity, Joint venture, SPV)

Det är enklast att äga det själv. Man behöver ibland vara partners för att det är för stora projekt osv. Annars är det enklast att äga det själv tycker jag. Om man ska ha belåning, ska man ha en rimlig belåning på det. Det är enklast att äga det själv men samtidigt kan man lära sig av andra. Så det är från fall till fall.

4- How can players in the industry and finance market collaborate to address these challenges and attract more capital to projects?

Det finns otroligt mycket kapital för att investera i alternativa tillgångar som infrastruktur och vindkraft. Men frågan är hur man kan locka det kapitalet. Utmaningen i Sverige är ju inte att vi inte har bra projekt utan vi har väldigt bra projekt om vi tittar på Load factor osv jämfört med många andra länder i Europa. Problemet är att vi har marknadsrisk på intäktssidan och de här infrastrukturinvesterarna vill inte ta såna risker utan behöver mer förutsägbara intäktströmmar. Att marknaden fortsätter utveckla, gör att det blir enklare att göra hedgar och det mer kostnadseffektivt.

Hade man valt att göra ett annat supportsystem som auktion, skulle det vara att föredra. Det blir mer förutsägbart. Vi har idag rekordlåga räntor som driver in massvis med kapital till den här sektorn, kapital som aldrig har varit såhär billigt som det är nu. Hade det funnits mer förutsägbara spelregler så är det klart att, inte bara vi aktörer i vindkraftsbranschen utan Sverige i sin omställning till mer grön energi, det kommer aldrig vara billigare att göra det nu. Men vi har inte riktigt systemet på plats för att locka allt detta billiga kapital.

5- What trends do you anticipate in financing of offshore wind projects in the coming years? (equity vs debt)

Vad som har skett är att marknaden har blivit så tuff. Det har inneburit att det är mindre och mindre lån i projekten och det förekommer mer och mer equity finansieringar i Sverige och Norge. När det gäller riktigt stora projekt då måste man ha med lån också för det blir för mycket equity. Givet hur kurvan ser ut så är det svårt att få större mängd lån. Kanske därför har equity investerarna blivit starkare för den delen.

Är inte bankerna bekväma med teknologin i och med att marknaden mognar och riskerna minskas?

Det är inte det som är huvudproblemet just nu. Bankerna är komfortabla med de större leverantörerna vi har i Norden; Vestas, Siemens, GE etc. Det är klart går du på ny teknik hela tiden är det kanske inte så bra men bankerna är relativt komfortabla med det. Det är mycket jobb med tekniska konsulter för att etablera och verifiera hit och dit. Det finns processer för att få bankerna att få komfort. Den stora biten för att locka kapital, antingen eget kapital eller lånat kapital är hur man hanterar prisrisken och hur marknaden är designat och det kommer fortsätta vara en utmaning här i alla fall.

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