AALBORG UNIVERSITY
DENMARK

Operational Risk Management for Far Offshore Wind Farms

4th Semester

MSc in Risk and Safety Management

Master Thesis

January 10th 2018

AALBORG UNIVERSITY
DENMARK

AALBORG UNIVERSITY

STUDENT REPORT

Title:

Operational Risk Management for Far Offshore Wind Farms

Theme:
Master Thesis

Project Period:
Fall Semester 2017

Project Group:
RISK4-1-F17

Participants:
Thomas Broeng Sønderby

Adrian-Alexandru Otel

Mohammed Hassan

Supervisors:
Anders Schmidt Kristiansen

Michael Havbro Faber

Page Numbers: 79

Date of Completion:
January 10th, 2018

ABSTRACT

The development of far offshore wind farms requires new logistical solutions on how to operate and maintain wind turbines. One method involves the use of computer based simulation as means of analyzing the effects of operation and maintenance procedures when moving further out.

This method allows various scenarios to be performed, while also identifying key operational and safety specifications. The aim of the study was to investigate how moving further offshore affects the risk picture regarding emergency response and O&M. A combination of quantitative and qualitative methods was chosen to provide a more complete understanding of our research problem.

The results showed an increase in risk when moving further offshore, due to Important factors such as weather, distance to shore and the size of the components. An accurate visualization of the actual O&M procedure was provided by using the simulation software MAINTYS. The results of our research can prove helpful for future investigations in the field of far offshore energy production, while also considering computer based simulations as an option for the planning and development of project.

AALBORG UNIVERSITY
DENMARK

AALBORG UNIVERSITY
DENMARK

Preface

Our interest for this topic came after reading an article about the Dutch power grid company TenneT wanting to build an artificial island for far offshore wind turbines in the North Sea. Afterwards, we became interested in working with this subject of far offshore and shared resources and incorporate our knowledge from our studies in Risk and Safety Management.

The report is aimed towards students and professionals with interest in exploring the opportunities for far offshore wind farms, and get insight on the operation and maintenance simulation software for offshore wind called MAINTSYS.

This report is written as part of the Risk and Safety Management 4th semester master thesis at Aalborg University Esbjerg, in the period between 01/09/17 to 10/01/18, and counts for 30 ECTS.

We would like to thank our supervisors Anders Schmidt Kristensen, and Michael Havbro Faber from Aalborg University for their help and supervision throughout the completion of the project.

We would like to acknowledge the help of Christian Fabricius from AMU Vest, Miriam Marchante from Dong and Sam Millard from Codan Forsikring for helping with material and interviews.

Furthermore, we would like to thank Michael Bjerrum from Shoreline, for providing us the support and access to the simulation software MAINTYS.

Blank pages in the report are left purposely

Thomas Broeng Sønderby

tsonde10@student.aau.dk

Adrian-Alexandru Otel

aotel16@student.aau.dk

Mohammed Hassan

Mhassa16@student.aau.dk

AALBORG UNIVERSITY
DENMARK

Acronyms

BST	Basic Safety Training
CBS	Computer Based Simulation
CMS	Computerized Maintenance System
CTV	Crew Transfer Vessel
DEA	Danish Energy Agency
DMA	Danish Maritime Organization
DWEA	Danish Working Environment Act
EM	Emergency Management
EU	European Union
GWO	Global Wind Organization
HLV	Heavy Lift Vessel
HSE	Health and Safety Executive
IMO	International Maritime Organization
KPI	Key Performance Indicator
NIMBY	Not in My Backyard
MARPOL	Marine Pollution
MTTR	Mean Time to Repair
O&M	Operation and Maintenance
OREI	Offshore Renewable Energy Installation
SOLAS	Safety of Lives at Sea
SOV	Service Operation Vessel
SPS	Special Purpose Ships
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TF	Transport Facility
WT	Wind Turbine

Table of Contents

AALBORG UNIVERSITY
DENMARK

1 Introduction

Wind turbines have become a familiar sight for many people around the world, and their purpose is fairly simple, which is to harvest energy from the wind. With fossil fuels running low and becoming troubling to exploit because of economic aspects, other sources of energy must be identified. Many countries are therefore turning away from fossil fuels, which has seen a 13 % reduction worldwide since the 1970s[1]. Although the cost might be higher in some cases, the environmental impact of alternative energy sources is considerably lower and brings lots of advantages in the long run. As a result, the European Union's Renewable Energy Directive has set a binding target of 20% final energy consumption from renewable sources by 2020[2]. In order to achieve this, European countries have set their own national renewable targets, ranging from 10% in Malta, to 49 % in Sweden[2]. The message from Maroš Šefčovič (European Commission Vice-President for Energy Union) at the European Wind Energy Conference in Paris was, that wind energy is the renewable energy technology that is expected to provide the largest contribution to the EU's 2020 renewable energy targets and beyond[3]. According to the European Wind Energy Association, EU currently has approx. 140 GW of wind power, of which 13 GW are located offshore, which could rise to 210 GW by 2020 and 350 GW by 2030. These levels of capacity would then cover 14% of the EU's electricity demand in 2020 and up to 24% of the demand in 2030[3]. Offshore wind is therefore one of the most stable sources of renewable energy currently in the EU, and especially for the countries located near the North Sea[4].

Over the last years, the Wind Industry has begun considering moving further offshore, as there is a huge potential for generating power[5]. As offshore wind farms are built further out - 60, 80, and even 100km from shore , the challenges to risks and safety associated with maintaining these assets increase[6]. This also poses problems with how logistics are handled and managed at the far offshore locations, leading to new ways of handling operation and maintenance procedures, through the use of substations as seen in the Oil and Gas Sector. Suppliers in the Wind Industry have started using computer based simulations (CBS) to analyze the risks[7].

The far offshore aspects of the Wind Industry were deemed an initiating interest, as it is a complex area with various hazards to both HSE and O&M procedures. This complexity would be interesting to analyze using risk management tools and CBS, to discover the implications from transitioning from offshore to far offshore.

1.1 The Development of Wind Power

The developments of modern wind turbines started in the 1980's, and were led by manufactures such as Bonus, Vestas and Nordbank. They produced a series of three-bladed turbines of 55 kW which were exported to California in the beginning of the 1980`s.

Today, wind energy is one of the most commonly used forms of renewable energy around the world. It is also the energy form that has come nearest at being competitive with other conventional forms of energy production. Denmark's position as one of the most energy efficient countries in the world is the result of the several years targeted efforts and close collaboration between the stakeholders in the field to reduce energy consumption. As countries around the world managed to switch their energy supply from oil to renewable energy, it created an interest in Danish energy solutions, and made the Danish Energy Sector a vital strategic partner for other interested countries.

Through the 1990s, wind turbines grew from kW to MW-size. This meant that fewer turbines could now ensure the increased need of wind energy. As the turbines grew in size, it became more suitable to place them offshore. The figure below illustrates the gradual evolution of the size of Danish wind turbines from 1980 until 2005—with capacity (kW) and rotor diameter (m) indicated.

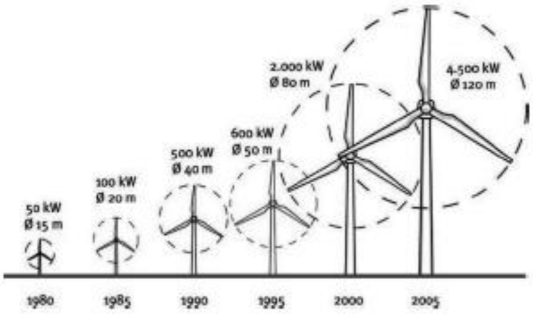


Figure 1 The evolution of the size of Wind Turbines [8]

1.2 Wind Power goes offshore

The wind resources offshore are on average nearly 50 percent better, compared to onshore[5] . On the other hand, it is more expensive to install and operate offshore wind farms since the process must be carried out at sea. The installation, operation and maintenance procedures get more difficult to perform due to harsher weather conditions and increased distances.

However, there is a huge potential for generating power on offshore wind farms in the North Sea[5]. Offshore offers a vast space with no neighbors to disturb, which makes it possible to place numerous large-scale wind turbines. The North Sea furthermore has a geographical advantage, which gives the surrounding countries a huge potential for electricity production offshore. Shallow water, and a solid strong wind makes the North Sea the perfect location for offshore wind farms.

There has been a gradual development of the Offshore Wind Industry, where the distance to shore has increased, as it has gained more experience as shown in Figure 2.

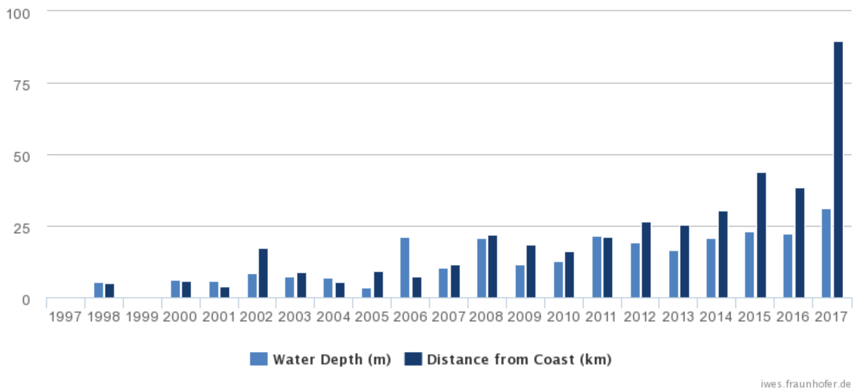


Figure 2 New turbine installations by average distance from coast, and water depth [9]

1.3 Benefits of Far Offshore Wind Farms

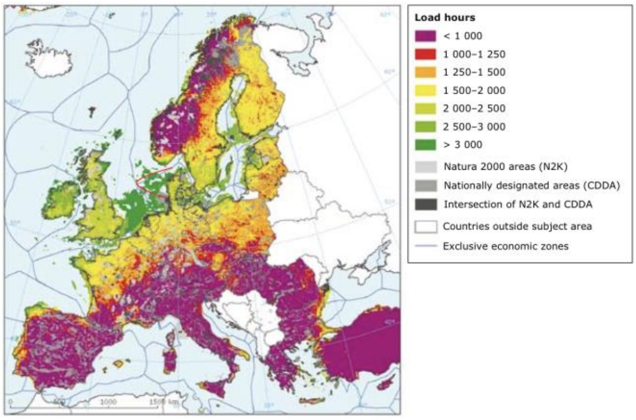
The technological developments allow for bigger and more reliable wind turbines, and previous obstacles are now not an issue. This allows project holders to take advantage of the possibilities of moving further offshore. In order to understand the possibilities behind moving wind turbines further offshore, it is important to recognize the contribution it will bring along. This chapter will investigate some the benefits of moving the wind turbines further offshore.

1.3.1 Wind Potential

As the development of offshore wind energy is less established than onshore wind energy, a lot of experience can be gained from developments on land[10]. However, as the operations offshore occur at sea, they also encounter several additional challenges. One of the reasoning of moving offshore was because of the wind potentials. The wind resources are a lot stronger at sea, up to 50 % more compared to onshore[5]. Additionally, the further wind turbines are located from the coast, the better are the wind potentials. According to Senior Wind Analyst Miriam Marchante from Dong, an increase of 0.1 m/s every 10 km can be expected (see APPENDIX 2). This is very attractive, and could potentially encourage more countries to harness this opportunity as an initiative to achieve and even improve the targets set by EU.

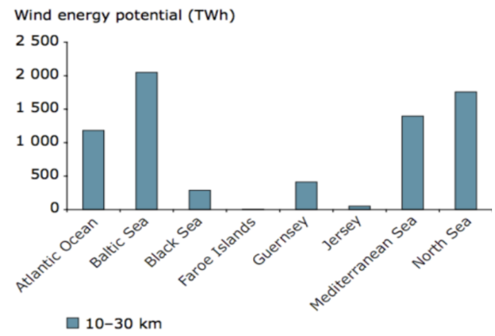
1.3.2 Location

The placement of wind turbines also plays a huge part of attaining better wind potentials. The North Sea has an advantage of attaining huge power generation from offshore wind projects. Denmark has a geographical advantage when it comes to cost-effective installation and operation of large-scale offshore wind farms in that the quality of the wind conditions exceeds those of the neighboring countries[5].



Source: EEA, 2008.

Figure 3 Full load-hour potential in Europe [70]



Source: EEA, 2008.

Figure 4 Offshore wind potential [14]

Figure 4 illustrates the wind energy potential across Europe. As it can be seen in Figure 3, the wind power generation potential is highest at the Baltic- and North Sea. Additionally, Figure 3 shows that the potential full load hour is highest in the North Sea region, exceeding more than 3000 load hours. To sum it up, the possibilities and potential for the countries around the North Sea are among the greatest in relation to the other nations in Europe.

1.3.3 Public resistance

Public support is important in order to expand wind energy. Some opponents of wind power claim that wind turbines are damaging the nature and bird life, and do at times succeed in influencing the decision-making process.

The wind turbines occasionally kill birds, however, studies show that the risk of birds bumping into the turbines is minimal[11]. One of these is an American study from 2009 which used bird mortality data from EU and US and estimated the number of killed birds per GWh, to find out which energy source was responsible for destroying the most bird life offshore.

The study concluded that wind farms and nuclear power plant were each responsible for 0,3 and 0,4 bird deaths per GWh, whereas fossil fuels are responsible for about 5,3 deaths per GWh[11].

The other aspect is that wind proposals sometimes face strong opposition at the local level. Although surveys generally show strong public support for wind energy, some developments do suffer from the Not in My Backyard (NIMBY) syndrome. Nimbyism is an *"intense, sometimes emotional and often adamant local opposition to site proposals that residents believe will result in adverse impacts"*[12]. The objection of these critics is mostly directed at the noise, visual disturbance, skepticism of the objectives and lack of local ownership as motives for their opposition against wind farms. So, to overcome these oppositions, a solution could easily be placing offshore wind farms further offshore, and thereby avoid these objections from critics.

1.3.4 Available offshore area

There's generally a misconception of the possibilities of constructing offshore wind farms. Some view the ocean as being capable of hosting as many wind turbines as needed, which is not the case.

The current technology limits the potential for offshore wind generation, as the developments so far do not support the construction of wind turbines in areas with a depth of more than 50 meters. These areas are therefore not applicable, and therefore aren't available for constructing wind turbines with current methods.

As seen in **Figure 5** [13], the majority of the North Sea has a water depth less than 60 m, both near shore and far offshore.

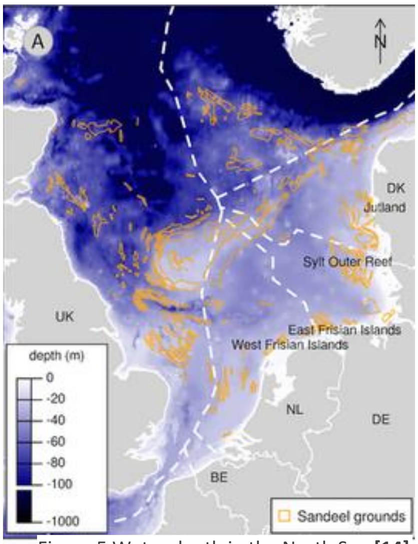


Figure 5 Water depth in the North Sea **[14]**

As stated earlier, due to technological limitation, the available offshore areas are a lot less than the total offshore area when you exclude, maritime routes, military use of offshore areas, oil and gas exploration, and tourist zones[14].

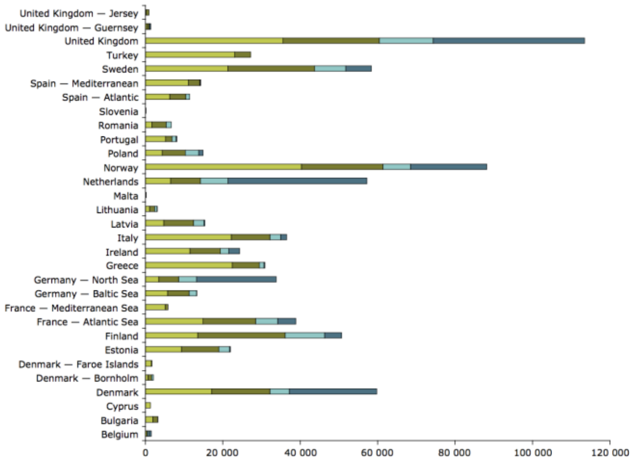


Figure 7 - Available offshore area (km2) for wind energy farms within national jurisdictions [14]

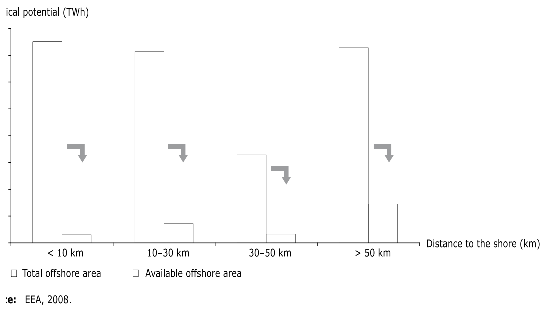


Figure 6 Available offshore area [14]

Figure 7[14]shows the total offshore area compared with the available offshore area. As seen in Figure 6, the further distance from shore, the more available area there is. This is another reason why moving further offshore would be more beneficial, and reasonable for project holders in the future.

So, as previously described, the benefits of moving further offshore are clearly advantageous especially for North Sea. Not only does it mitigate the complications made by the NIMBY syndrome, but moving further offshore also contributes on achieving EU's renewable energy objectives faster than it would otherwise. In the next paragraph, we will discuss the concept of sharing resources offshore, and what value it brings for project owners.

1.4 Shared Resources

In this chapter, a brief introduction will be given to what is meant by shared resources, and a description of the different methods around shared resources.

According to the International Energy Agency, the current price fall of fossil fuel has discouraged the Oil and Gas Industry in developing new oil fields[15]. In order for renewable energy sources to become competitive, they need to reduce their production costs. According to an energy-comparison made by Windpower, the wind energy is well placed to take advantage of the future price hikes in oil and gas. A way for offshore wind power to become more cost competitive is to introduce shared resources. What is meant by shared resources is the sharing of: vessels, technicians, helicopters, equipment and spare parts. It's essentially anything of value that's not being utilized. Up to 1/3 of the total cost of energy from offshore wind production is contributed by operation and maintenance (O&M)[16]. An estimate of lifetime costs of energy can be seen in Figure 8[17], where the O&M costs are broken down into key aspects. As stated earlier, there is a need for improvement, if wind power is to secure its place among other energy sources. One way to improve, is to make the O&M procedures more efficient. In the next paragraph a description of two possible methods of sharing resources is exemplified.

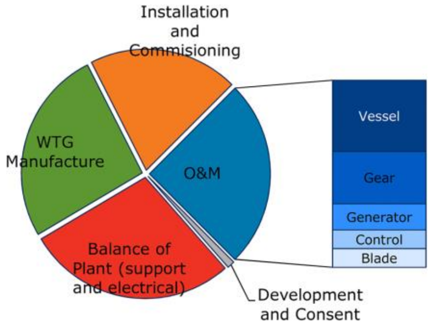


Figure 8 - Principal cost drivers for offshore wind 17]

1.4.1 Business to Business

A Business to Business model refers to business that is conducted between companies. Offshore Sharing Solutions is a company that provides other companies the opportunity to reduce their operating costs by allowing them to use their solution to do business with each other. Their focus is to make the Energy Industry more efficient by using spare capacities that are already available. They offer services such as vessels, rigs, helicopters, infrastructure, inventory and labor. They do not provide any of these services by themselves, but allow companies to use their platform to exchange resources.

1.4.2 Joint Venture

A Joint Venture is a business arrangement in which two or more parties agree to pool their resources for the purpose of accomplishing a specific task[18].

This could be done by installing a substation offshore that would allow these companies to share accommodations, technicians and spare parts. This would additionally reduce the response time, especially for far offshore locations as its located closer to the wind turbines. Another option could be to build an artificial island, such as the proposed project at Dogger Bank. The Dutch power grid has come up with the plan to build a power hub for far offshore wind farms.

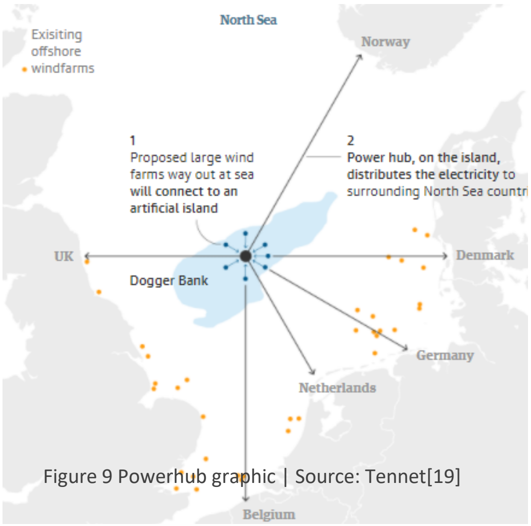


Figure 9 Powerhub graphic | Source: Tennet[19]

Rob van der Hage who's responsible for the offshore wind grid development programme said that:

> "It's crucial for industry to continue with the cost reduction path. The big challenge we are facing towards 2030 and 2050 is onshore wind is hampered by local opposition and nearshore is nearly full. It's logical we are looking at areas further offshore."

This island could therefore potentially make offshore wind even more cost competitive in the future. Denmark together with Germany have made an agreement with the Dutch power grid to investigate the possibilities of constructing the island in the North Sea[19].

AALBORG UNIVERSITY
DENMARK

1.5 Problem description

1.5.1 Operation and maintenance

The focus of the Wind Industry has so far been on the development and creation of wind farms. However, as wind farms are popping up all over the world, and the number of active wind turbines continues to raise, the focus and awareness needs to be shifted on the challenges of operating and maintaining these systems.

As the number and sizes of wind turbine continues to grow, it becomes imperative to build these further from shore[20]. Further distances require new logistical solutions, and rethinking how O&M procedures are performed. From an Emergency management (response) point of view, it is therefore interesting to know how moving further offshore influences the safety of the O&M personnel and vessels.

1.5.2 Emergency response concerning offshore wind installations

Along with the development of offshore wind come big obstacles which determine the companies to take into consideration cutting down the costs. Cutting cost is a significant challenge to the Wind Industry. The main concern is that companies tend to compromise on safety when wanting to make the operation more financially efficient.[21] The main issue is to encourage the Wind Industry to take into consideration safety and human factors when they are improving their cost perspective.

The safety of the personnel involved in operations should be of critical importance. An integral part is making and maintaining the workplace as safe as possible. This can only be achieved by recognizing that situations may arise, from time to time, which require training and familiarization with the methods of dealing with various emergencies.

It is a common understanding within the Energy Industry that Wind Energy is a young industry, that has plenty to learn when it comes to health and safety. Compared to other offshore industries like oil and gas which has spent 40 years to get where they are now, it can be seen that offshore wind has a way to go. There is a great deal of work going on in different countries, but also from different groups of companies, in trying to put health and safety in the forefront.[22]

In order to reach their efficiency targets many projects are being developed far offshore as the wind assessments and the conditions for an improved efficiency are more appealing when moving further away from the coastline. Along with this transition additional safety challenges have emerged. Some of the key challenges are related to both operation and maintenance strategies and the relevant emergency response procedures for these strategies.

1.6 Problem formulation

As previously described, the opportunities of moving further offshore are great, and could hold a vital significance for electricity production in the future. Being further out from the coast requires thoughtfulness of how to protect personnel and limit the risk of them getting hurt. It is known that up to 1/3 of the total cost of energy from offshore wind comes from O&M. Having this in mind, it is fair to question how companies would cope with this transitioning in regard to operation and maintenance, legislation, emergency response, and so on. This has resulted in the initiating question:

How does transitioning from offshore to far offshore affect the risk picture related to operation and maintenance of wind farms, and can this be analyzed using computer based simulations

The risk picture comes as a result of a risk analysis process where the likelihood and the consequences of the hazards identified in the Offshore O&M procedures are considered. The hazards are identified using considerations about Occupational Health and Safety, structural integrity and environmental issues. Concerning the structural integrity, the analysis doesn't focus specifically on elements of material structure and resistance but has a more qualitative approach trying to identify in which extent the functionality of the devices is affected. Analyzing the risk picture means developing a process of comparison between the relative risk factor present in both offshore and far offshore sectors.

The following sub-questions will enable us to answer our main question.

- How is legislation and standards handled at offshore windfarms in the North Sea?
- How is O&M currently performed at offshore wind farms, and how is this affected when moving far offshore?
- How does the transition affect risk- and emergency management?
- Can CBS be used as a valid method for analyzing shared resources and O&M procedures?

1.7 Problem delimitation

The constructed delimitations of this thesis are as follows:

- To only focus is on the operation and maintenance procedures of offshore wind farms, and not in the planning & development, structure installation, commissioning and decommissioning phases.
- Focus on the emergency response phase, and not the recovery, mitigation and preparedness phases.
- Focus on the North Sea area
- The use of computer based simulation program (MAINTSYS)
    - Primarily focus on availability and downtown of the wind turbines, while not looking into the wind output and economical aspects.

The researchers have limited this research to only focus on the O&M phase, due to the enormous share O&M has in relation to the other phrases, and because of the opportunities of introducing shared resources as means of reducing these expenses.

The emergency response phase was chosen because of the interest to investigate how moving further offshore might affect emergency response procedures. Instead of a general covering of emergency management, a thorough study of emergency response was desired by the authors.

The North Sea area was chosen because of its high wind power generation potential, and for the reason that the proposed far offshore Hornsea projects are being located there.

The computer based simulation chosen for this project, was provided to us by Micheal Bjerrum from Shoreline. To perform a simulation of how O&M procedures were going to change when moving further offshore, a CBS called MAINTSYS was selected, as Shoreline provided us free access to the simulation.

2 Methodology

2.1 Introduction

This chapter seeks to present the research methodologies applied for the thesis. In order to obtain accurate results of our research, a combination of both quantitative and qualitative approaches has been applied to the project. This chapter will also explain how the data and information gathered to answer our problem formulation was collected. Furthermore, a reasoning of our chosen approach to the project regarding data sources and data collection techniques will be given.

2.2 Research method – Qualitative versus Quantitative

The method chosen for this project was a mixed method research, which consists of both qualitative and quantitative research methods. By combining these methods, it has been tried to minimize both their weaknesses, as they complement each other's shortcoming, and thereby achieve more suitable results. In this context, the project seeks to investigate how some people within the Wind Industry view far offshore wind turbines, and if they think the risk picture will change. To get an insight into this, it would be necessary to perform a qualitative study, in order to understand the underlying reasons, opinions, and motivations behind their view. We therefore made a visit to AMU vest in Esbjerg, to get an understanding of how technicians were trained in preparation for the Global Wind Organization (GWO) Basic Safety Training (BST) when working at heights.

An operation and maintenance simulation software for offshore wind has also been used as a quantitative method to analyze the changes of moving wind turbines further offshore. Simulation is a flexible methodology, and can be used to analyze how systems behave, and how it would change if some elements of the system are changed. In our case, we simulate how current offshore wind farms perform, and afterwards investigate how far offshore wind farms impact the overall risk picture regarding the O&M procedures. Therefore, simulation is one of the most commonly used quantitative methods, not only because of its flexibility, but because it can produce so many useful results without having to disturb the existing systems.

Therefore, mixing these two methods enables us to strengthen our results and gives the project a more well-founded result.

2.3 Definition of Terms

To ensure a common understanding of the terms used in this report, a brief description will be given of some of the recurrent terms, to create an underlying basis for the reader.

Offshore	- Offshore is defined as being in-between **0 – 75 km** from the nearest coastline. (see Appendix 1)
Far Offshore	- Far offshore wind farms are defined as being more than **> 75 km** from the nearest coastline
Shared Resources	- Shared resources are defined as a joint venture between different stakeholders in order to make O&M procedures more efficient.

2.4 Data collection method and tools

Again, a combination of quantitative and qualitative data collection methods was used to answer our problem formulation. To begin with, our intention was to primarily use a qualitative approach to interview our respondents, but due to scheduling, it became necessary to include a quantitative approach as a backup.

First, to get an understanding of the technicians and how they work with safety, we visited the AMU VEST center where offshore wind technicians get their safety certification. We followed a team of technicians in their BST in working at heights. This provided us with an understanding of some of the requirements technicians need to have in order to work offshore. This was followed by a semi structured interview with team leader and instructor Christian Fabricius about his views on safety requirements and the future of far offshore wind farms.

As stated earlier, due to scheduling we weren't able to interview Senior Wind Specialist Miriam Marchante from Dong. Therefore, a questionnaire where sent out to Miriam Marchante about the potentials and risks associated with far offshore wind farms.

In addition to our primary data, as mentioned above, we also supplemented our data with secondary data for the research. Secondary data consists of all the data that has not been collected by us, or data that has already been interpreted by someone else such as: books, reports, websites, journals and newspapers.

2.5 Research Limitations

The research had the following challenges/limitations:

- Despite making multiple enquiries to companies to cooperate with us in our research, it turned out to be harder than initially assumed. The reason for this being that many of these companies where busy negotiating major deals[23].Although collaborations with specialized companies exist in the development of the project, we lacked on companies which would enable us to gain access internal data for our analysis.
- Again, it would be preferred to have conducted an in-depth interview with Senior Wind Specialist Miriam Marchante from Dong, but as stated earlier it was not possible.
- The field of far offshore wind is at the moment quite new, and therefore little-researched. The implication of this has given us statistical/data limitations. It would be preferred to have data of failure rates for far offshore wind turbines, but due to lack of information, we were compelled to use available offshore data for our simulation.
- The O&M simulation software MAINTSYS used in this report also possess several limitations. As the simulation software is recently developed, we faced some challenges in regard to the flexibility of the program. We would have preferred to be able to customize some of the inputs, in order to modify the simulation into exploring our desired focus area. Nonetheless, we were able to make the simulations as realistic as possible.

3 Legislation and standards

When dealing with the legislative instances in the Offshore Wind Energy Sector, there are several factors to consider. Everything from the occupational health and safety of the workers, to the regulations of vessels and the environment. Furthermore, the legislation is handled on both national and international levels, depending on the type of work being done.

The analysis will only cover relevant legislation and standards, that deal with the work being performed during the operational phase of the wind farm, as well as that which is relevant for emergency management. As such areas such as construction, onshore operations, decommissioning etc. will not be covered.

3.1 Legislation, Standards and regulations

Most of the legislation only covers the general terms and conditions that should be dealt with, and not specifically how they should be dealt with in regards to the Offshore Wind Energy Sector. As a result of this a large part of the industry is covered by standards and regulations, both on national and international levels, that regulate anything from vessel to design, to working conditions. In order to get a better overview, a general investigation of these conditions has been made.

3.1.1 North Sea regulations

The report “Summary Report On North Sea Regulation and Standards”[24] by the Danish Maritime Authority (DMA), covers various national regulations and standards for vessels and crew in Denmark, the UK, Germany and the Netherlands. The report covers differences in the legislative approaches in regard to construction, operation, safety and crew competence of vessels and covers relevant industry standards in the Offshore Wind Industry.

This chapter will cover the basics of which standards, legislation and conventions are used in the field, but will not go into detail about the contents and requirements, as that would be a project on its own.

3.1.2 National authorities

When dealing with the Offshore Wind Industry, different national agencies are involved in the process of regulating and granting permits, assessing the impact of new projects and regulating the work. Below is a summary of the different national agencies that are involved in the processes.

Denmark	United Kingdom	Germany	Netherlands
No national guidance specific to wind farms	Methodology for Assessing the Marine Navigational Safety & Emergency Response Risks of Offshore Renewable Energy Installations (OREI)	Studies must be performed in order to produce the required protection and safety concept	Assessment Framework for Defining Safe Distances between Shipping Lanes and Offshore Wind Farms

Figure 10 National requirements for marine/navigational safety and emergency studies [24]

Regulator	Denmark	United Kingdom	Germany	Netherlands
Flag/Port State	DMA	MCA	BG Verkehr	NSI
Coastal State	DEA	DECC/MMO*	BSH/WSV†	RWS
Safety regulator	DWEA	HSE	BSH/BG Verkehr	SSM

* Some responsibilities are devolved in Scotland
† Within 12nm of the coast, state agencies have de jure responsibility, though de facto the direction of offshore wind policy is set by BSH.

Figure 11 National administrations and competent authorities (for Offshore Wind) [24]

3.1.3 Vessel design

The vessels used in the Offshore Wind Industry vary depending on what tasks they are designed to perform. Vessels are categorized as either Convention or Non-Convention vessels.

The term *convention* refers to whether a vessel is subject to the requirements of international maritime conventions, such as Safety of lives at sea (SOLAS), international maritime organization (IMO) Convention on Load Lines. As such the two terms are defined as:

*"**Non-convention**: Vessel not trading internationally, less than 24m in Load Line length and less than 500GT. **Convention**: A cargo vessel engaged on international voyages and > 24m GT (subject to Load Line) and/or > 500 GT (subject to SOLAS) and/or carrying more than 12 passengers (passenger vessel).* [24]"

With non-convention vessels being regulated by flag state (national) legislation, and convention vessels being regulated by international regulations. The table below, describes which requirements vessels generally must follow in the different countries. With SPS code, being the Special Purpose Ships code.

The classification is split between regular maintenance vessels and self-elevating units, such as HLVs.

Type	Denmark	United Kingdom	Germany	Netherlands
'Typical'	Convention or SPS Code on case-by-case assessment.	Convention or SPS Code **/8/**	Convention or SPS Code	Convention or SPS Code
Walk-to-work	SPS Code	SPS Code or Passenger (Convention)	SPS Code or OSV Guidelines will be accepted, subject to risk assessment	SPS Code

Figure 12 National requirements for wind farm maintenance vessel design and construction [24]

Unit	Denmark	United Kingdom	Germany	Netherlands
Unmanned	Convention **/9/**	Convention	National safety certificate and MODU Code **/10/**	National safety certificate **/11/**
Manned	Convention **/9/**	Convention or MODU Code (case-by-case) **/12/**	National safety certificate and MODU Code **/10/**	National safety certificate or SPS Code (for > 12 special personnel)
Self-propelled	Convention and SPS Code (case-by-case)*	Convention (and SPS Code for > 12 special personnel) **/8/** and additional MODU Code requirements **/12/**	Convention (and SPS Code for > 12 special personnel) and additional MODU Code requirements	Convention or SPS Code†

* Further application of MODU Code is optional, either by issue of MODU Safety Certificate or a Statement of Compliance
† MODU Code may be applied if required by operator's risk assessment, but is not mandatory

Figure 13 National requirements for self-elevating unit design and construction [24]

The tables cover the basics of the requirements for crafts, but there are areas which are not covered, such as service craft vessels and small service craft vessels, which follow additional codes such as IMO High Speed Craft Code.

3.1.4 Personnel

When dealing with the people working at sea and aboard the vessels, it is important to distinguish between industry personnel and maritime personnel. Maritime personnel cover the personnel operating the vessels, such as officers, crew members etc. while the industry personnel are passengers not engaged in activity or business on the vessel, but rather being transported to do work at offshore installations or structures.

The industry personnel have a variety of options when it comes to training.

OPITO BOSIET	GWO Basic Safety	STCW Personal Survival Techniques
• No entry to water at height requirement • No requirement to right a capsized liferaft	• No mustered entry to liferaft • Includes emergency descent from height • Includes marine transfer training	• No helicopter rescue techniques

Figure 14 Main differences between sea survival standard practical demonstrations

Though there is a trend within the industry towards wider application of the GWO standard.

3.2 GWO

The GWO, which is an association of wind turbine owners and manufacturers, has designed a basic safety training (BST) program, to support an injury free work environment, and describes their goals as:

"The Global Wind Organisation (GWO) is an association of Wind Turbine owners and manufacturers with the aim of supporting an injury-free work environment in the wind industry. An objective of GWO is to develop common industry training and best practice Standards for health and safety as a vital and necessary way forward to reduce risks for personnel in the wind industry working on site and to reducing environmental risks across Europe and the globe."

The BST program consists of 5 different courses, that GWO recommends. The courses are:

Duration of BST Modules

Modules	Duration
First Aid	16 hours
Manual Handling	4 hours
Fire Awareness	4 hours
Working at Heights	16 hours
Sea Survival	12 hours

Figure 15 GWO Basic Safety Training course overview [25]

A person who has undergone the BST course, should be competent with basic safety in the Wind Industry, and have the required knowledge to stop unsafe work situations, where they are responsible for safety.

The training program is covered by a curriculum, for each of the courses, covering lecture hours and subjects to cover as shown in Figure 15. If there is national legislation that sets demands that are not covered in the program, these must be incorporated.

The certificates earned from the BST program is valid for 2 years, after which a refresher courses must be taken[25].

The training consists of both classroom and practical training. To get a better overview of how the training was being conducted we visited Amu Vest, where we were allowed to follow some of the courses, both classroom but also the practical training, for the working at heights course. The course takes two days to complete, while we followed the course participants for the major part of day one.

Figure 16 Instructor Christian Fabricius (red hardhat) showing how to secure his glider to the wire, before climbing the up the ladder. Picture taken by authors

The training in general is focused around the practical training, which is where the course participants can try out their equipment, different working conditions and methods. The training is centered around learning base principles of how to use a harness and anchor points and following the instructions stated on the equipment, so that they are working within safe limits.

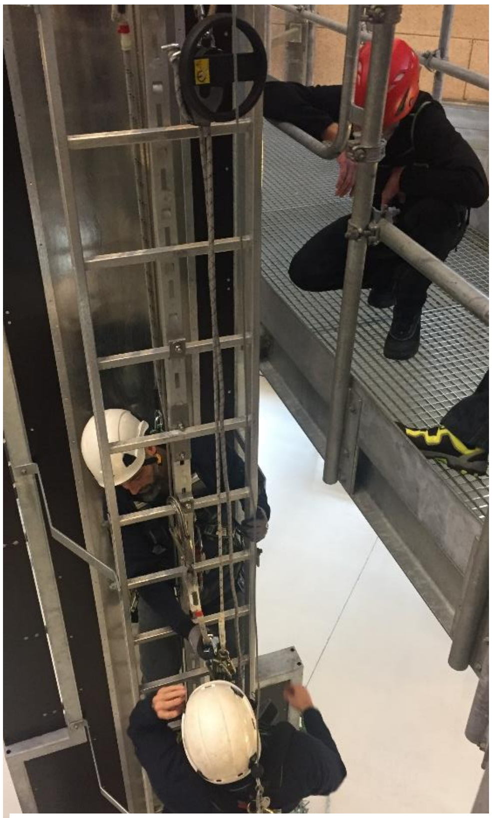


Figure 17 Two of the course participants performing a rescue at heights. The one inside the ladder system is performing the rescue, with the other pretending to be injured. Picture taken by authors.

The training is primarily centered around how to ascend and descend within a turbine, using the ladders and how to rescue an injured person who is on a ladder. The current training methods favor older turbine models. When instructor Christian Fabricius was asked about how they prepared for newer larger wind turbines, he stated that they currently don't. The current training is centered around evacuating a person downwards to the bottom of the wind turbine. In newer and larger turbines this becomes problematic as turbines have sections in the tower, where there are floor hatches that people must be evacuated through, which is currently not part of the course. Furthermore, in some of the newer turbines it is standard to evacuate people upwards, rather than downwards, so that helicopters can be used in the evacuation, which is not trained either[26].

The training requires everyone to go through the procedures themselves, while under supervision. If mistakes are made, they are thoroughly discussed by the instructors, who use them as example that can be learnt from. There is focus on how to properly perform tasks and actions, as to train the muscle memory of the trainees and to teach them rule of thumb principals with the equipment.

The education is accessible by anyone and does not prerequisite any knowledge of prior work in the field. If the course participant fails the class, they can take the course again and there is no limit to how many times a participant can attempt. However, the instructors stated, that they at times have had trainees who were not suited to work in the field and advise them against continuing.

Amu Vest who are providing the GWO BST course, are subject to audits from GWO Audit & Compliance committee and must follow their instructions and provide sufficient documentation to be able to perform the courses. This requires Amu Vest to have qualified instructors, valid documentation for the training equipment and training facilities among others[27].

GWO makes use of a training committee to maintain and improve their training programs. The committee members, work in the industry themselves and use their personal knowledge and experience to improve the GWO program. The members are represented by companies such as MHI Vestas and Siemens Gamesa[27].

4 Stakeholder Analysis

After identifying the boards of legislation for developing an offshore and far offshore wind project, the next step is to perform a stakeholder analysis.

Because the project focuses on comparing the risks and safety aspects involved in two distinctive wind projects it is important to try to understand the participation that stakeholders have on the development of the two projects. As it was discovered when analyzing the legislation chapter there are no major differences between the boards of governmental decisioning that influence the two projects. Because of that a single analysis will be performed and the result will be considered from the point of view of both projects.

This analysis will allow to identify all the stakeholders involved in the two projects. It will also determine their position in terms of influence and interest along with the degree of importance for the success of the project

The first step is to identify the major stakeholders by researching previous wind projects in the North Sea and considering some theoretical aspects keeping in mind important factors like:

The extent to which they are or not affected by the project[28]

- Importance for the project
- Influence
- Interests
- Level of participation

For this reason, it is important to identify the persons, organizations or institutions that have an influence on the construction and operation of the wind parks also keeping in mind to consider the administrative, governmental and social institutions that might have an influence on the success of the projects.

In Figure 18 the general main stakeholders relevant for a wind project are identified:

Figure 18 Internal and external stakeholders relevant for an Offshore/ Far Offshore Wind Project. Made by authors using[28]

As it can be observed the stakeholders are classified as internal and external entities, depending on their level and type of participation in the project.

The internal stakeholders are entities within the wind projects

Owners	**Stockholders**
	Board of directors

	Venture capital
Management	Direct management
	Functional management
Team members	Unions
	Families
Sponsors	
Functional departments	Accounting
	Human resources
	Engineering
	Marketing

Table 1 Internal stakeholders

The external stakeholders are entities not within the project itself but who care about and are affected by its performance:

Media	
Community	Citizens
	Social interest groups
	Boards and clubs
Competitors	
Government	Legal system
	Legislators
	Regulators

Table 2 External stakeholders

As seen in the Figure 18 there can be considered another group of stakeholders which can be identified as both internal or external like:

- Vendors
    - Suppliers
- Customers
    - Clients

With the help of these statuary theoretical categories of stakeholders it is possible to identify the actual groups, organizations and institutions related to developing a wind project either offshore or far offshore. In order to go more into depth with the analysis the stakeholders will be evaluated by distributing them into types of entities or organizations as: [28]

Administrative organizations that have responsibilities or competences for the area or the activities that might be affected by the construction of a wind farm:

- Environmental impact: Environmental Protection Agencies
- Authorization of the project: Energy Agencies, Labor Agency, Maritime Agencies
- Technical and economic analyses on the need for the project: Energy Agencies
- Town councils

Social organizations which will have an influence over the project:

- Environmental associations
- Trade unions
- Consumer and residents' associations
- Competing companies
- The academic community

Economic activities which might be potentially affected:

- Tourism
- Merchant shipping
- Fishing

Agents and financial organizations linked to the project:

- Investors
- Costumers
- Local transport companies
- Local supply companies

After identifying the stakeholders, it is possible to arrange them in a diagram:

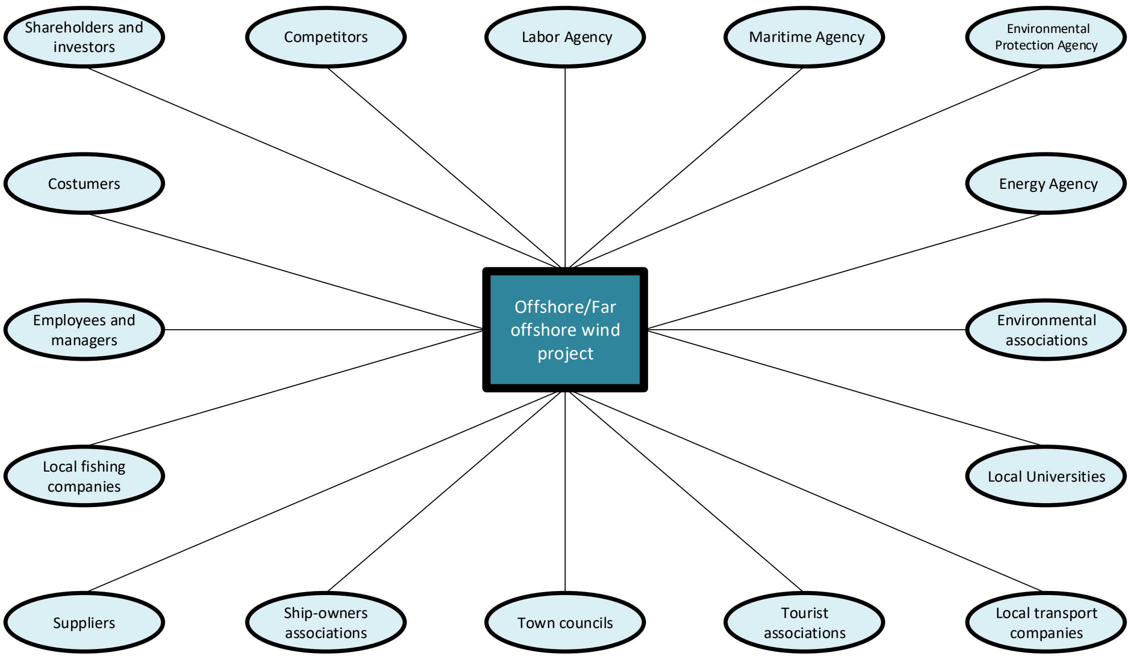


Figure 19 Stakeholder diagram for Offshore/Far Offshore Wind Project. Made by authors using[29]

4.1 Evaluation of stakeholder's interests, impact level over the project and relative priority

After the process of identifying all potential stakeholders is finished the next step is to document their needs and assess each stakeholder's level of interest. Once this information is available, they can be categorized as primary, secondary or tertiary stakeholders.

When presented with the project every stakeholder will have different expectations from it meaning that every stakeholder will try to act in its own interest. Trying to identify these interests is very important for developing an insight on their value and estimate how much every stakeholder will influence the project.

Stakeholder	Interests	Estimated project impact	Estimated priority
Shareholders and investors	Develop an efficient wind project attractive for technological and financial reasons. Structurally reduce uncertainty and increase trust in investments in sustainable energy	H	1
Costumers	Availability of cheap and green energy	M	1
Employees and managers	Security of a long lasting collaboration	M	1

AALBORG UNIVERSITY
DENMARK

Local fishing companies	Assurance about possible changes of the usual fishing routes taken by the fishing vessels Assurance about possible changes of the ecosystems which could affect their activity.	M	1
Suppliers	Interest in a constant development of new projects	H	2
Ship-owners association	Assurance about possible changes of the usual shipping routes.	H	2
Town councils	Low disruption of the normal fishing and touristic activities	M	2
Tourist associations	Low disruption of the normal touristic activities	M	2
Local transport companies	Assurance about possible changes of the usual shipping routes. Enlarging the customer portfolio	M	2
Local Universities	Favorable and helpful stand concerning the research and evaluation of the wind project.	M	2
Environmental associations	Assurance that the areas with high environmental value will not be disrupted	H	2
Energy Agencies	Requirements of research and study material which will allow certification.	M	3
Environmental Protection Agencies	Requirements of research and study material which will allow to develop knowledge about the impact on the environment	M	3
Maritime Agencies	Requirements of research and study material on the effect on shipping activities and the degree of safety.	M	3
Labor Agencies	Requirements of research and study material oh health and safety issues combined with numbers about work force and the appropriate working conditions	M	3
Media	Availability of coverage upon major events during and upon completion of the wind project.	M	3
Competitors	Methods of collaboration Effect on their activity in relationship with costumers	M	3

Table 3 Evaluation of stakeholders interest [29]

Table 3 describes an evaluation of the stakeholder's interests. The possible impact and priority considering the wind projects are estimated considering the level of influence as well as the degree of decisional power.

It can be seen that the highest priority is awarded to the entities which are directly affected by the projects development. The investors, clients and the fishing companies are susceptible of gaining or loosing assets in a direct or personal way. They are the true beneficiaries of the projects, issues that can affect them both positively or in a negative way.

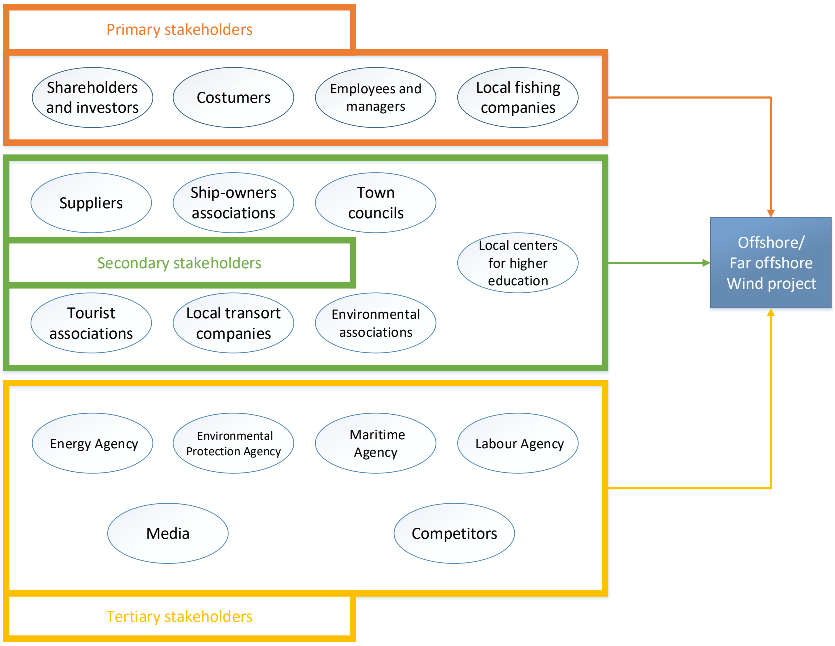


Figure 20 Primary, Secondary and Tertiary stakeholders, Made by authors using[28]

The next category of stakeholders characterized as being secondary is considered to be affected indirectly by the development of the two wind projects. Of course entities like the suppliers, town councils or various commercial associations are also important for the completion of the projects. Although they don't hold a primary role, their level of assistance regarding administrative and financial processes is very important.

The last group of stakeholders is represented by entities which are affected more indirectly than the ones considered secondary. This group consists of administrative governmental organizations together with media and part of the businesses which will endure a degree of competition on the market when the projects are completed. Despite this, it's important to engage tertiary stakeholders, as their opinions and perceptions can determine whether a project succeeds or fails. Communication between the different types of stakeholders assure the success of the project because the methods of working for the same goal are well known. On the other hand, lack of communication can cause a disruption in the activities within the projects.

4.2 Analyzing stakeholder importance and influence

Dependent on their level of power and influence any stakeholder can have a positive or negative action on the development of an Offshore Wind Project. Because of this factor, it is important to determine as close as possible their actual level of power and influence and the interactions between them. This action will help to minimize the risk of having to deal with unanticipated reactions from the different stakeholders which can have the effect of harming the project.

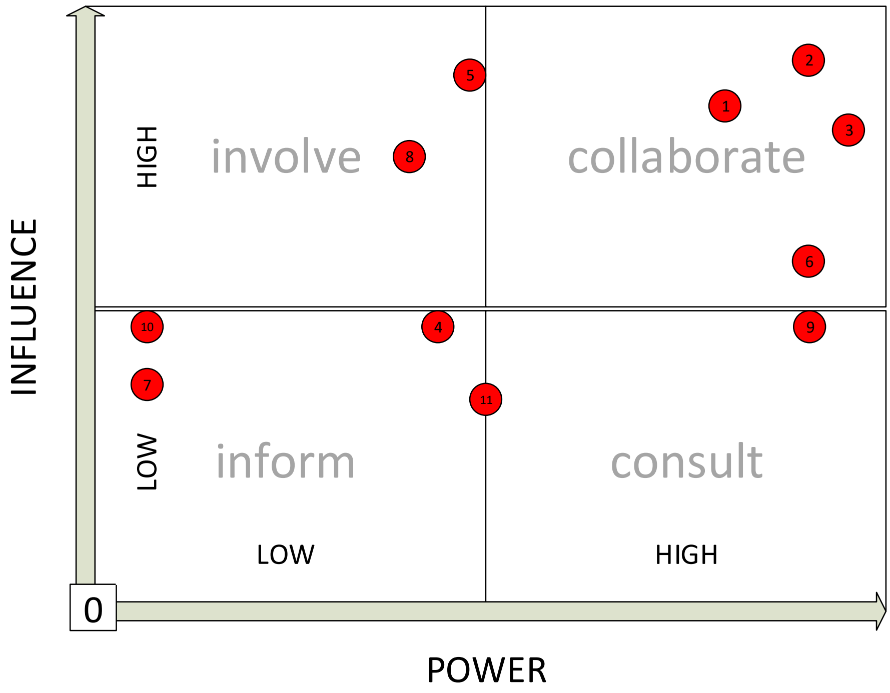


Figure 21 Stakeholder power/influence matrix for Offshore Wind Projects from The North Sea. Made by authors using[29]

In Figure 21 a visualization of a power/influence matrix can be observed suitable for an Offshore Wind Project. The matrix is a suitable tool to analyze the stakeholders after the entities have previously been identified. With the help of the matrix it is possible to get an overview on each and every stakeholders interest and the estimated power they have to emphasize their authority. It also gives information about their level and ways of interaction.

No	Stakeholder	Examples of entities from The North Sea region

AALBORG UNIVERSITY
DENMARK

1	Shareholders and investors	STATOIL, DONG ENERGY, VATTENFALL
2	Costumers	Individual and corporate users
3	Employees and managers	Workers from different departments: HR, Technical, Management
4	Local companies	Fisheries, touristic activities providers
5	Suppliers	WT manufacturers: VESTAS, SIEMENS/GAMESA, ENERCON Service providers: ESVAGT, A2SEA, SVETZER
6	Town councils	ESBJERG COMUNNE, GRIMSBY CITY HALL, ABERDEEN, BREMEN
7	Local universities	UNIVERSITY REASECHERRS
8	Environmental associations	International Union for Conservation of Nature, Greenpeace
9	Legislators	IMO, ILO, IACS
10	Media	BBC,DR, ZDF
11	Unions	3F, IDA

Table 4 Examples of stakeholders involved in and Offshore Wind Project in The North Sea

Considering also Table 4 it can be observed that the numbers from the matrix correspond to different stakeholders previously identified. The table also offers examples of real stakeholders which exercise their influence on The Wind Industry in The North Sea area. It is now possible to determine the level and ways of interaction between the different stakeholders.

As expected most of the primary stakeholders identified are expected to have an elevated level of collaboration in their activities. The shareholders and investors need to collaborate with their employees and keep a close eye on the demands and necessities of the public and private costumers as well as the town councils. The different suppliers need to be constantly consulted together with the different environmental organizations as the environment represents a delicate matter when considering an Offshore Wind Project. In order to assure a peaceful and safe working environment a process of consultation must be put in place with the unions and legislators in order to comply with every legal aspect imposed by the entities from the region. Finally, every action which concerns the public must be made known by using different channels of communication provided also by media. All the local companies must be informed of every plan and change of action which may interact with their domain of activity.

5 Operation and maintenance (O&M)

After the commissioning of the wind turbines follows the O&M phase, where the goal of this activity is to ensure the project achieves the desired objective, this includes making sure the project has a good balance between the running cost and electricity output. O&M occurs throughout the life of the project, modern wind turbines are designed, so it can produce electricity for about 20 years[30]. O&M is more and less the same as inspection, repairs, and maintenance as seen in the Offshore Oil and Gas Sector. To fully understand O&M, we start with a description of the term, and outline some key concepts, then the different equipment's and strategies for O&M activities will be considered.

Operation

Operations includes the day to day activities, and relates to the activities connected to the handling of the asset, such as remote monitoring, environmental monitoring, electricity sales, marketing, administration and other back office tasks[31]. For the most parts, it is the wind farm owner or the suppliers of the turbines that cover these expenses, which is a significantly smaller part than maintenance.

Maintenance

Maintenance includes the repair and service of the wind farm, and accounts for the largest portion of O&M effort, cost and risk[31].The purpose is to maintain and service the physical plant and systems. Maintenance can be split into two parts; preventative maintenance and unscheduled corrective maintenance.

- Preventative maintenance
  Proactive repair/work carried out to avoid breakdown or malfunction. Based on information from monitoring systems, or routine inspections can provide a list of worn components which then can be repaired or replaced. It includes actions such as routine surveys, inspections, adjustments, parts replacement, and cleaning which are fulfilled specially to mitigate any faults from occurring. This maintenance effort is therefore the most cost-effective solution[31].

- Unscheduled corrective maintenance
  Unscheduled corrective maintenance refers to the reactive maintenance done after an equipment breaks down or malfunction. It can also be performed in groups when multiple or other issues that affects a large number of wind turbines need to be corrected. Despite of maintenance or repair cost, the bulk of the expense will be due to the down time of the wind turbines during maintenance work[31].

The two most essential aspects of operation and maintenance is, 1. To ensure the safety of the personal and, 2. Is the financial return of the project. For the majority of project owners the objective is to maximize the output of valuable electricity for sale – at least cost – can be thought of as driving the decision making in the O&M sector[31]. Offshore conditions contribute to making O&M procedures becoming more difficult. For example, a wind farm may become inaccessible during the winter, due to harsh sea, wind and visibility conditions[32]. Besides weather conditions, other factors such as access, availability, distance to shore, WT size and maintenance strategy do have a major influence on the cost of offshore wind projects. In the following section, we will examine some of the most important factors in offshore wind O&M.

5.1 O&M costs

Offshore wind farms generally operate with large wind turbines, which capital cost is currently estimated at £1.2 million pr. MW, whereas onshore wind turbines are at £0,62 million pr. MW[33].

Figure 22 illustrates the typical systems costs for an offshore wind farm in shallow waters. Most of the cost for offshore wind farms can be attributed to the turbine, support structure and O&M. Given that offshore wind project are more complex, so are the cost also in the high region compared to onshore projects. That's the reason O&M cost constitutes a substantial percentage of the total costs of a wind turbine. To put it numbers, the O&M percentage costs for offshore wind farms can vary from 18% to 23 % which is much higher than the estimated 12 % for onshore projects[32].

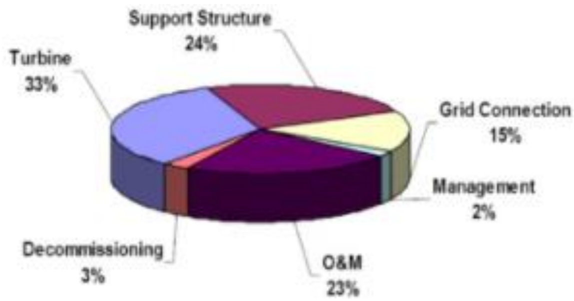


Figure 22 Typical cost breakdown for an offshore wind farm in shallow water [35]

Manufacturers and other stakeholders who directly or indirectly are involved in O&M have because of this, begun increasingly to focus on how to lower these costs by developing new turbine designs and new O&M strategies, to minimize service visits and reduce turbine downtime. Especially on the technological developments, which will consist of future wind turbine models with higher focus on:

- Enhanced remote diagnostic to improve logistical issues, and reduce unscheduled maintenance.
- Design wind turbines that are more reliable, and thereby reduce unwanted/unscheduled maintenance.
- Lastly, improvements connected to the components of the wind turbine, such as gearboxes and generators.

Other non-technical areas for cost reduction could be greater synergies; resource sharing. This would allow neighboring projects to share their resources, and thereby reduce the cost and benefit both parties. a concluding remark is that, to achieve the lowest cost of energy, you must maximize availability and minimize unscheduled maintenance. Doing this would result in the lowest cost of energy for an offshore wind farm [32].

5.2 Availability

One important factor to measure the performance of a project is known as availability, which is one of the most popular Key Performance Indicators (KPI) used to track the performance of a wind farm, and very useful to operators, financiers and turbine manufacturers when comparing turbine and project performance[33]. The International Electrotechnical Commission defines turbine availability as;

"the fraction of a given operating period in which a wind turbine generating system is performing its intended services within the design specification"[33]

In other words, the availability is the amount of time that a turbine, or a wind farm, is technically able to produce electricity over a certain period. Its therefore the amount of time electricity is lost during downtime or malfunction.

Today, current offshore wind farms achieve availability between 90 % and 95 %, with few variations depending on the project, whereas onshore wind farms typically achieve 97 % availability[31].

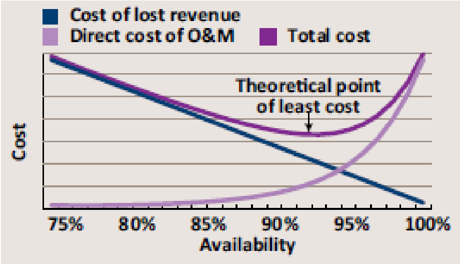


Figure 23 - Balance between cost and lost revenue[31]

Figure 23 illustrates an assessment of the O&M cost as a function of wind turbine availability. It shows that, even when lost revenue draws closer to zero as availability reaches hundred percent, the cost of attaining this grows exponentially. It means that if less is invested in O&M, the outcome would be a deficient in performance from the wind turbine, and conversely if too much is invested in O&M, it would result in less return on investment. The graph also illustrates the theoretical optimal point, in which the total cost curve is at its the lowest point [31]. In the following paragraph, we will explore the relationship between reliability and availability.

5.2.1 Relationship between reliability and availability

In order to achieve the best availability in wind turbines, an analysis of the different reliability of wind turbine technologies has to be produced, and knowing the cost of investment and O&M, will improve the decision making of which wind turbine arrangement to go after. But without additional support to maintain reliability in service, it is difficult to achieve high availability[33]. As described earlier, having a high availability depends hugely on having a high reliable offshore wind farm, but also on:

- **Offshore environment**
  The environment has a huge impact on achieving good performance offshore. Low wind speed can result in less energy outcome, whereas higher wind speed can lead to increased wave height, and limit the access to the wind turbines.
- **Detection**
  As access is limited to offshore wind farms due to their location, it is not possible to achieve good availability unless systems are put in place to remotely detect any decline on performance and intervene before it gets worse. There is therefore a need to install reliable and accurate systems in order to achieve the best results.
- **Asset management**
  Lastly, the whole wind farm asset will need to be managed holistically in order to maintain the assets over its planned life. But also, ensure the handling of longer-term worsening and replacement of larger components, such as blades, gearboxes, and generators[33].

5.3 Access

The difficulty of transporting the technicians on and off the wind turbine to do a job, in case of a failure, is something that affects the overall downtime. The two main aspects that influence the approach taken to gaining access are:

- *Transit time*
  It's the time it takes to transport the service crew from the O&M structure to the wind turbines. Given the location of offshore wind turbines, the amount of time spent on actual maintenance work is much less than the time it takes the crew reach the wind turbines, and as offshore wind farms continue to move further offshore, so will the transit time increase.

- *Accessibility*
  This is the stretch of time a turbine can safely be accessed from a crew transfer vessel (CTV) or a service operation vessel (SOV) and is concurrently dependent on the sea conditions offshore. One aspect

influencing accessibility is the wave height. For instance, if a project has a wave height greater than 3m 30% of the time, would mean that a SOV operating in a wave height blow 3 m could be said to have 70 % accessibility.

These two aspects of access are to some extent dependent of the environmental conditions offshore. It also depends on the location of the wind farm, as longer distances from shore usually intensifies conditions for SOV's and CTV's. Particularly in the event of a critical unscheduled maintenance, where sea conditions can hinder vessels from intervening, which may result in a prolonged down time. The approach to O&M, should therefore be to minimize the transit time and increase accessibility for the wind turbines, to reduce the overall costs connected to lost production.

5.4 Offshore Logistics

When dealing with major components such as wind turbines, it's important to have the coordination under control. Having the right equipment for the technicians, to better utilize them when needed is crucial. The main aspects that influence which offshore logistic approach is the most suitable are[31]:

I. HSE and regulatory factors
II. Response time
III. Flexibility
IV. Vessels
V. Equipment
VI. Weather conditions
VII. Cost

Besides these aspects, there are also other characteristics that have an impact on which offshore O&M strategy to utilize. These are factors are[31]:

I. Distance from shore
II. Typical sea conditions
III. The quantity and quality of the turbines

As offshore wind farms are built further from shore, new strategies must be deployed. This means that strategies customized for near shore farms must be modified for far offshore projects.

5.5 O&M Equipment

Part of the O&M phase is to utilize the most suitable equipment for the project. As projects differ from each other, it is important to tailor the approach to the specific project instead of adapting to preexisting procedures. In this paragraph, we will discuss the different equipment technicians use to access and repair the wind farms, and also investigate the advantages and disadvantages of the different approaches. The approaches that will be investigated include:

I. Vessels without access system – where technicians climb from the vessel to the platform
II. Vessels with access system – where technicians can walk directly to the tower from the vessel
III. Helicopters – where technicians are flown directly to the nacelle
IV. Fixed installations – substations where technicians are accommodated

The systems will be discussed further in the sections below.

5.5.1 Vessels without access system

The most commonly used vessel currently for offshore wind farms are the workboats. They have a cruising speed of 20 knots, and thus takes them ½ to 1 hour to get on site [32]. The facilities onboard are designed to ensure the wellbeing of the personnel. These workboats are financially less expensive, and can accommodate as many as 12 personnel and 2 crews [32]. These vessels are usually used for near shore wind farms, from 10-20 km from shore [32]. Figure 24 illustrates workboats which are used for a medium sized wind farm. Due to safety worries and the fact that offshore wind farms are being built further from shore, new ways of accessing sites are being explored. One of its weaknesses is being restricted by harsh sea conditions which then effects the response time and accessibility to the site. Other disadvantages are:

Figure 24- Example of an access transfer boat [71]

- Dependent on the weather, and restricted by wave high, making it difficult to achieve more than 98 % accessibility.
- Hazardous transfer for technicians from the vessel to the tower
- Limited to small tools/equipment's due to the size of the vessel

Some of the advantages of using small vessels would be:

- Low fuel costs due to the size of the vessel
- Perfect for the transportation of smaller parts / equipment
- It's a well-tested vessel in the industry for near shore sites

5.5.2 Vessels with access system

As previously explained, we know that workboats have its shortage when it comes to accessing the wind turbines. In order to increase the accessibility, the industry has gradually shifted their focus from which best vessels to employ to also considering which transfer system is most suitable for the task. Having access systems that not only increases accessibility to the sites, but also ensuring their employees safer access than previous, is important to an industry where safety is highly regarded.

Figure 25 illustrates a vessel with access system, where the vessel acts as a platform for O&M procedures, transport, housing for the technicians and means of accessing offshore wind farms. The vessel can accommodate 60 people in single cabins, of which 40 dedicated to service technicians [34]. It also has the ability to stay at sea for 5 to 7 weeks depending on sea conditions and fuel consumption.


Figure 25 - Vessel with access system [72]

These vessels are not limited for far offshore operations, but can also be utilized for near shore wind farm. Due to the economics of these large vessels, it is not suitable at the moment to employ these for near shore wind farms as these vessels are very expensive. Other disadvantages are:

- They consume a huge amount of fuel compared with the workboats and helicopters
- Expensive in operation when not employed

Some of the advantages are:

- The capacity of the vessel to bring big equipment and heavy components
- Weather conditions do not limit (as much) the operation or accessibility to the turbines
- Operations can last longer due to the duration of the vessel when deployed, and the facilities onboard for the crew.

Helicopters

Another way of handling O&M procedures are with the help of helicopters. Helicopters are relatively expensive, and limited to carry only few technicians and small equipment. As stated earlier, if accessibility is low due to weather conditions, and there's an urgent need for technicians to perform repair or maintenance work, then a helicopter might be a tenable solution. Helicopters are quick, and significantly faster than the vessels, and in addition, they do not have any regard to sea conditions when operating offshore. To give a comparison, it takes workboat up to 6 hours to reach the Dogger Bank wind site in the North Sea with wave heights being less than 1,5 m or wind speeds less than 10 m/s, whereas it takes a helicopter 25 minutes to reach the same point[35]. It should be noted that helicopters have usually been used for near shore wind farms, 20 km from shore, such as Horn Rev in Denmark. Operators tend to employ helicopters as stand by transfer system for workboats when they are not able to operate due to harsh weather conditions.

Helicopters have been tried and tested in the oil and gas sector for some time, but are relatively new to the offshore wind O&M industry. While some operators have implemented helicopters like at Horns Rev in Denmark, others have concerns regarding the safety risks and the regulatory implications of their use. The oil and gas industry has tried to reduce helicopter transfer for their personnel, because statistically, it's the most dangerous means of transportation in the industry [36] .Some projects have contracts in place for helicopters in the case of an emergency for search and rescue services[37]. The advantages of using helicopters are:

- Quick access to wind turbines for minor repairs and maintenance
- Can operate when workboats are restricted due to weather condition
- Can be deployed for emergency situations

The disadvantages are as follows:

- Installment of helidecks on all wind turbines are very costly
- Restricted to day light, and may be restricted mostly in winter
- Risky

5.5.3 Fixed installations

Fixed installations or substation are already deployed in some offshore wind farms. They are known from the oil and gas sector, where their personnel where accommodated. Horns Rev II has a substation near their site, to quickly access the wind turbines for O&M procedures. It's an accommodation module with 24 rooms, galley, canteen, TV-room, changing room, offices, PAGA, Tele/data and entertainment [38]. These substations are very suitable for far offshore wind farms, to reduce the time used for transportation of small equipment's and personnel. It also gives the technicians the possibility to take advantage of being close to the site, and perform their duties on short weather windows.

Figure 26- Fixed installation [73]

The advantages for fixed installations are:

- Pre-tested in the oil and gas industry
- High level of accessibility
- Take advantage of short weather windows

The disadvantages are as follows:

- The costs for building this are high
- That its fixed

5.5.4 Jack up vessels

Jack up vessels are mostly deployed during the construction phase of a wind farm. But, when needed to perform major maintenance or repair work that requires heavy lifting, then they will be vital in the O&M phase. These vessels are mobile, and are therefore not fixed at one location for longer periods. They provide a foundation for personnel to easy access the wind turbines, without extended transportation. The advantages of a jack up vessel is:

- It has the capacity to carry heavy spare parts and equipment
- Stable foundation for heavy work
- Experience from the oil and gas sector

Figure 27 - Jack up vessel [76]

The disadvantages are as follows:

- Cost
- Its only able to work at one wind turbine at a time
- It requires a decent weather for the commissioning and decommissioning between locations

Sub-conclusion

The overall conclusion that can be drawn from this is that in order to make O&M more cost-effective in the future as wind parks are moving further out, is to shift from how O&M previously were handled into thinking in new ways. As previously explained not a lot will change in regard to the operation of wind turbines, as most of this is done onshore. Nonetheless, some improvements might be beneficial in the sense to mitigate unscheduled corrective maintenance of the wind turbines. As wind parks move further offshore, the need for preventive maintenance measures increases. This is required in order to reduce the time spent on transferring technicians to the sites. The less time technicians spend on accessing the wind turbines, the less risk they are exposed to. One of these improvements could be enhancing remote diagnostic to better detect failures and inconsistencies earlier than previous. This would allow companies to better utilize their resources, and implement cost-effective maintenance strategies for their sites. Another approach of reducing unscheduled maintenance is to simply design more reliable wind turbines. The manufacturers of wind turbines can therefore also assist in the reduction of unscheduled maintenance. Because, having more reliable wind turbines leads to a decrease in maintenance, and thus obtain higher availability.

6 Computer Based Simulation

One of the goals of this report is to test whether, computer based simulation can be used to analyze the risk of offshore and far offshore projects. To answer that question, it is important to take the validity of the simulation software being used, into account.

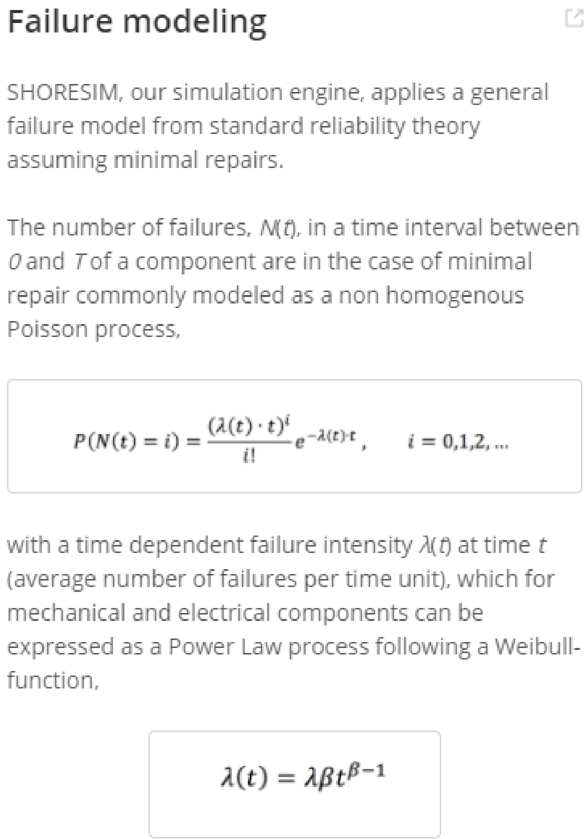
The simulation software being used in this project is Shoreline MAINTSYS, which is an O&M simulation tool, that simulates an entire wind farm throughout the operational phase. The simulation uses input data for vessels, wind turbines, technicians and economics to give data on resources used and generated, as well as expected availability, downtime, utilization of assets, etc. in the form of KPIs.

The program makes use of public data, in the form of available ports, types of vessels and turbines, while also allowing user specific inputs, making it possible to control the parameters of the different agents. The program also allows for simulating weather conditions, such as wind speeds, wave heights and visibility, through historical weather inputs and through randomized weather.

MAINTSYS started out as a PhD project at the university of Stavanger and the Norwegian Centre of Offshore Wind Energy[39] in 2012. One of the first processes, was to verify and validate the system. This was done through the published paper, “Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms”[40], which deals with, the validation and verification of the software. This was done through a series of comparison to other similar simulation software and not through and actual case study for an O&M project. The comparison was done on a set number of parameters, that would be evaluated across all the different software, and then used to determine if MAINTSYS was operating within acceptable parameters based on that.

Several models were tested, and it was concluded that the models can be regarded as verified. However, the software cannot be regarded as fully validated, as that would require an actual project to compare the results with.

The software is also supported by a library of articles that go over the functionality of the software and gives descriptions of the different functions and methods being used, as reference to how the program works and operates. For instance, this can be for failure modeling, as described in *Figure 28*, which shows a section of the description for failure modeling.


Failure modeling

SHORESIM, our simulation engine, applies a general failure model from standard reliability theory assuming minimal repairs.

The number of failures, *N*(*t*), in a time interval between *0* and *T* of a component are in the case of minimal repair commonly modeled as a non homogenous Poisson process,

$$P(N(t)=i)=\frac{(\lambda(t)\cdot t)^i}{i!}e^{-\lambda(t)\cdot t}, \qquad i=0,1,2,\ldots$$

with a time dependent failure intensity *λ*(*t*) at time *t* (average number of failures per time unit), which for mechanical and electrical components can be expressed as a Power Law process following a Weibull-function,

$$\lambda(t)=\lambda\beta t^{\beta-1}$$

Figure 28 Shoreline failure modeling technical description

6.1 Simulation model

The program makes use of a both microscopic and macroscopic simulation elements. The major elements of the simulation, namely the vessels, wind turbines and helicopters are run as a microscopic simulation where the input can be controlled and changed, and their current position and status can be viewed. This is displayed in a mode where the simulation is visualized and can be viewed in “real time”. In this manner it is possible to see the movement of each of the elements and view when events occur and when they are solved. This can be seen in Figure 29, which shows the overview of a project and Figure 30, where the project is zoomed in on the wind farm itself.

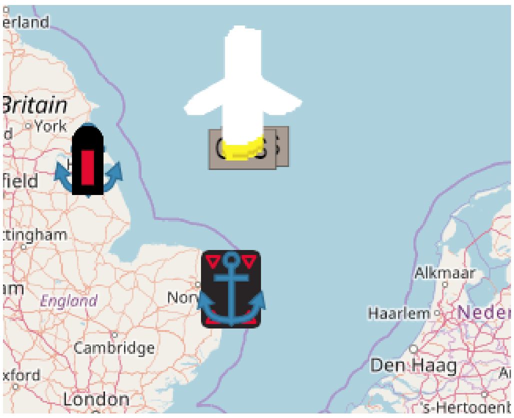


Figure 29 Project overview, showing wind farm location, selected ports and vessels

AALBORG UNIVERSITY
DENMARK

When dealing with other aspects of the program, it operates as a macroscopic simulation. Several of the inputs controls actions such as weather, technicians, costs etc., which does not have any visible attributes during the visual simulation. These inputs all affect the output sections of the program, in the form of KPI's, statistics etc. For instance, it is possible to get an overview of technician availability for project. This gives information about technicians as a hole, where no information can be given about any single individual.

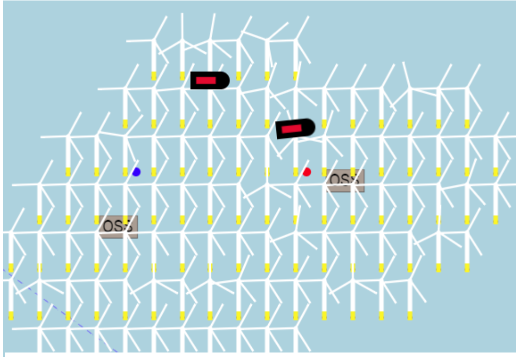


Figure 30 Visualized simulation in Shoreline MAINTSYS

6.1.1 Input and output

The program allows for inputs in two major categories, which each has their own subcategories. The two primary areas are:

- Wind farms: This area defines the parameters for the wind farm, such as location, turbine type, sub stations etc. All of these have subcategories that affect the simulation, such as failure rates, technicians required, scheduled maintenance, operating costs etc.
- Vessels: Here it is described which types of vessels are used for the wind farm. There are 4 primary options, SOV, Heavy Lift Vessel (HLV), CTV and helicopter.

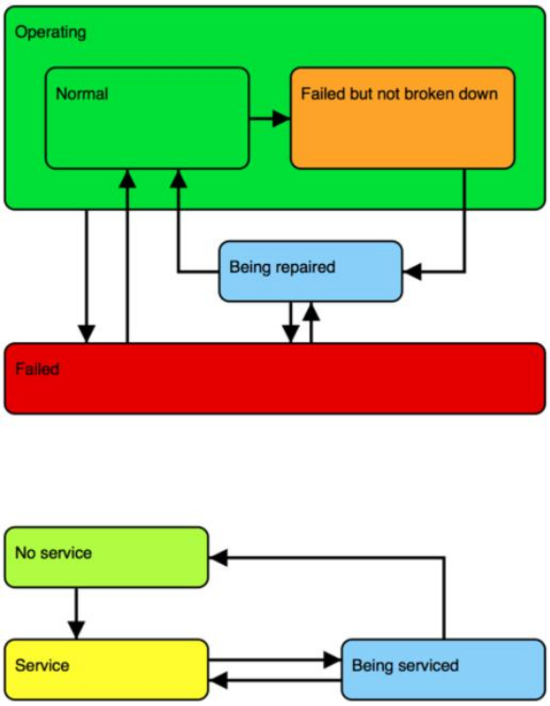
The program uses an agent based approach to simulating the conditions at the wind farms. Every vessel type, the turbines, technicians, planning work orders etc. act as their own agents, and controlled by statecharts, which indicate what possible actions they will take next, based on what state or process they are currently in.

As for the agents themselves they are influenced by inputs that determine how, and under which conditions they operate. The input varies between the different agent types. In general, it can be split into three major categories:

- Vessels: Cruising speeds, safe operation parameters such as significant wave height and visibility, activity durations such as connecting to turbines, transferring personnel etc.
- Turbines: Component failure, scheduled maintenance, hub height, power curve.
- Technicians: Number of technicians, working hours, different types of shifts/ seasonal workers.

For instance, one of the input sections can be seen in *Figure 32*, which is used to model different failures for the wind turbines.

Figure 31 Statechart for wind turbine, indicating the different states it can be in, and which states they can lead to. Image taken from the simulation program.



AALBORG UNIVERSITY
DENMARK

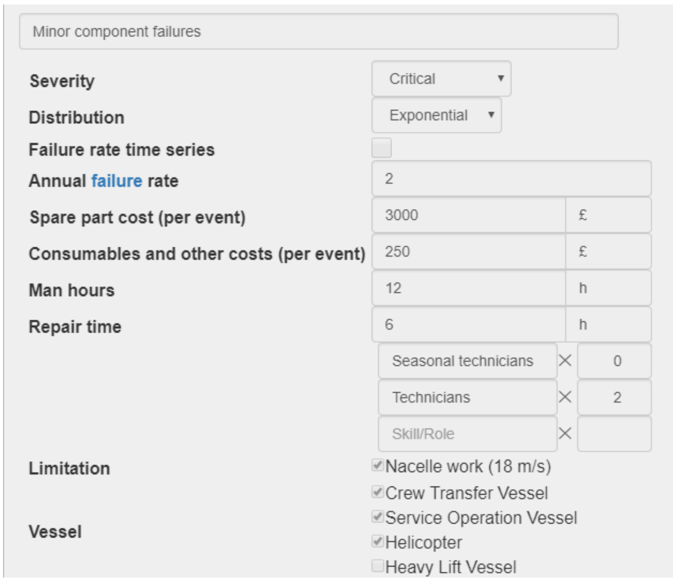


Figure 32 Input section for component failure for wind turbines

The output of the simulation comes in two different sections. MAINTSYS generates charts automatically for specified areas, such as availability, root causes for downtime, vessel and technician utilization etc. while also allowing for an excel export, where the data for each turbine, vessel etc. can be downloaded and viewed for all days throughout the simulation.

6.2 Simulation scenario

As described in the previous chapter, MAINTSYS offers many functions and output options. When setting up the simulation scenario, it is therefore important to use the right input to get the correct output. As described in previous section Shoreline MAINTSYS uses inputs in 2 major areas; turbines and vessels. The required information for each of these areas will be analyzed and researched in order to get sufficient data to do a simulation on how shared resources can be used in the Offshore Wind Energy Sector. But before doing the actual simulation, a simulation of a known and currently operational wind farm will be performed in order to get a reference point and a better understanding of the software.

The first step is to identify which wind farms to simulate. When dealing with far offshore, there hasn't yet been built any wind farms yet, but several are planned, with one having begun construction. The Hornsea projects off the east cost of the UK is planned to be a zone with 4 wind farm projects, respectively Hornsea project one to four as shown in *Figure 33*.

For the reference case, we will be using London Array as a comparison case. London Array and Hornsea One are both projects that are located of the east coast of the UK. London Array has 175 turbines[41] compared to Hornsea one, which has 174[42], while Hornsea Two, is still being planned and will have a between 91 and 231[43] turbines depending on the turbine capacity.

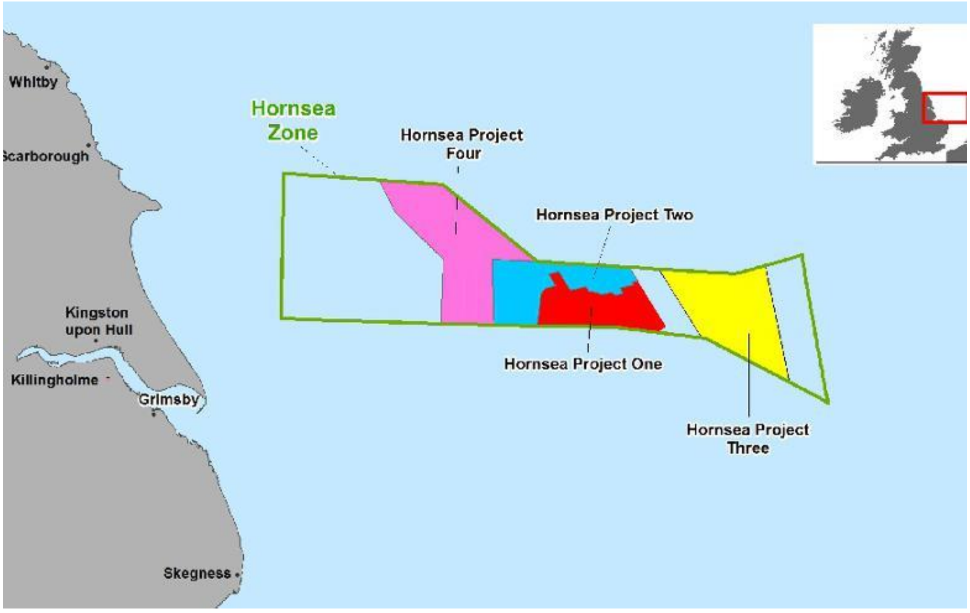


Figure 33 Planned area for Hornsea projects one through four[44]

Both of the projects are planned to be operated from an O&M base in Grimsby, and by using offshore stations or bases[45].

Wind farm	London Array	Hornsea Project One	Hornsea Project Two
Turbine model	SWT-3.6-120	SWT-7.0-154	Undecided (8MW estimated)
O&M base	Ramsgate, UK	Grimsby, UK	Grimsby, UK
Latitude	51.626	53.883	53.940
Longitude	1.496	1.922	1.688
Number of turbines	175	174	173(estimate)
Area [km²]	122	407	462
Depth Range [m]	0-23	24-37	30-40
Distance from shore (to center) [km]	27,6	114,5	107,5
Substations	2	4	4

Table 5 General information for wind farms. **[41], [42], [43]**

AALBORG UNIVERSITY DENMARK

6.3 Types of vessels used in the simulation:

Crew Transfer Vessel

The CTV are the primary method for transporting technicians from harbor or offshore bases to the wind turbines. CTVs have become a specialist vessel used in the wind industry, and carries up to 12 passengers and generally have a cruising speed of 15-25 kn, and can deliver technician to the turbines at 1,5m of significant wave height[46].

The capabilities vary from model to model, but most CTVs allow for cargo transport in the range of 1 to 30 tonnes, depending on the size of the vessel.

CTVs are built for one-day trips, where the ship leaves and returns to harbor in the same day. The method for moving technicians from the CTV to the turbine varies from model to model. But generally, there are 2 methods being used. The "bump and jump" method, where the CTV contacts its bow to the turbine and uses thrust to maintain its position, leaving the CTV somewhat stable. This allows the technicians to access the ladder to the turbine.

Figure 34 CTV performing bump and jump [74]

The second method is "walk to work", where the CTV uses a compensating bridging mechanism. This will allow the vessel to connect the bridge with the turbine, and create a gangway that stays level, for the technicians to walk on to access the turbine. This method though is rarely used on CTVs as it requires a larger vessel.

Service Operation Vessel

A SOV is a service station at sea, that carries technicians and spare parts much like the CTVs. The difference is that the SOVs are capable of staying at seas for longer periods of time, in the range of 4-5 weeks, between going back to harbor[47]. Depending on the size of the SOV, they can also perform certain crane operation and carry smaller CTVs. At the same time most SOVs make use of the "walk to work" method, and are capable of operating at higher significant wave heights. Upwards of 4m, depending on the ship[48].

Figure 35 3D rendition of one of the new SOVs ordered by Dong, to be used at Hornsea [75]**.**

Heavy Lift Vessel

HLVs are used throughout the construction phase and operational phase, when moving heavy pieces of equipment or components. The capabilities of HLVs varies depending on the specifications of the ship, as many of them are purpose built. They come in different models. The most common used type in the wind industry is the jack up vessels, as shown in Figure 36.

Figure 36 Heavy lift vessel using jack up. [76]

6.4 Data used

6.4.1 Technicians

The number of technicians used for the wind farms have been determined by looking at public data from the two projects. [49] notes that the proportion of turbine technicians to other operational staff is approximately 60%. Given this, we have determined the number of technicians used for each project.

London array uses a 90-person team to operate and maintain the wind farm[50], which leads to 54 technicians, following the 60% principle.

The Hornsea projects will be operated and maintained through a new offshore hub in Grimsby, which will employ at least 200 workers in the offshore service and maintenance industry. Along with this Dong has ordered two new SOVs to be used on Hornsea one and two and two other nearby wind farms, Race Bank and Westmost Rough. Each of the SOVs will accommodate 60 maintenance crew workers, giving us 120 technicians for the Hornsea projects.

The technicians will operate on a 07:00 to 19:00 work shift schedule[51].

6.4.2 Vessels

The data used for vessels, in the simulations are collected through papers or databases. Much of the data is collected through 4C Offshore ltd[52], who specializes in consultancy in the offshore energy market. As such they have databases of public available data for several wind farms. This data can be used to determine factors as those described earlier. They also provide information on which vessels have been used on given wind farms.

This information is used to get an overview of how many vessels can be expected to be used during the simulations. For the London Array project, the use of CTVs and HLVs was analyzed over a period of 7 years, from the start of the operational phase, until current date. The data lists periods of time in which companies and vessels have been contracted to London Array. The data comes in the form of a list of companies and vessels, and in which period they have been contracted to the project as shown in the *Figure 37*

Operations and Maintenance Vessels (including Crew Transfer) (130)

Vessel	Role	Organisation
Login	Vessel-Crew Transfer	CWind Ltd *(Global Marine Systems Ltd)* *Client: Upgrade* *Period: 04-Sep-2015 to 12-Sep-2015* Ocean Warrior was working on the site during this period.
Login	Vessel-Crew Transfer	Turbine Transfers Limited *(Holyhead Towing Company Ltd)* *Client: Upgrade* *Period: 14-Jul-2012 to 23-Aug-2012* Wylfa Head provided crew transfer services.

Figure 37 Overview of vessels used at London Array, from 4C Offshore

This data was gathered and used to create a gantt-diagram for the entire project, which can be seen in appendix 3. Using this gantt-diagram it was possible to see how many vessels had been connected to the project on any given day, since the operational phase started.

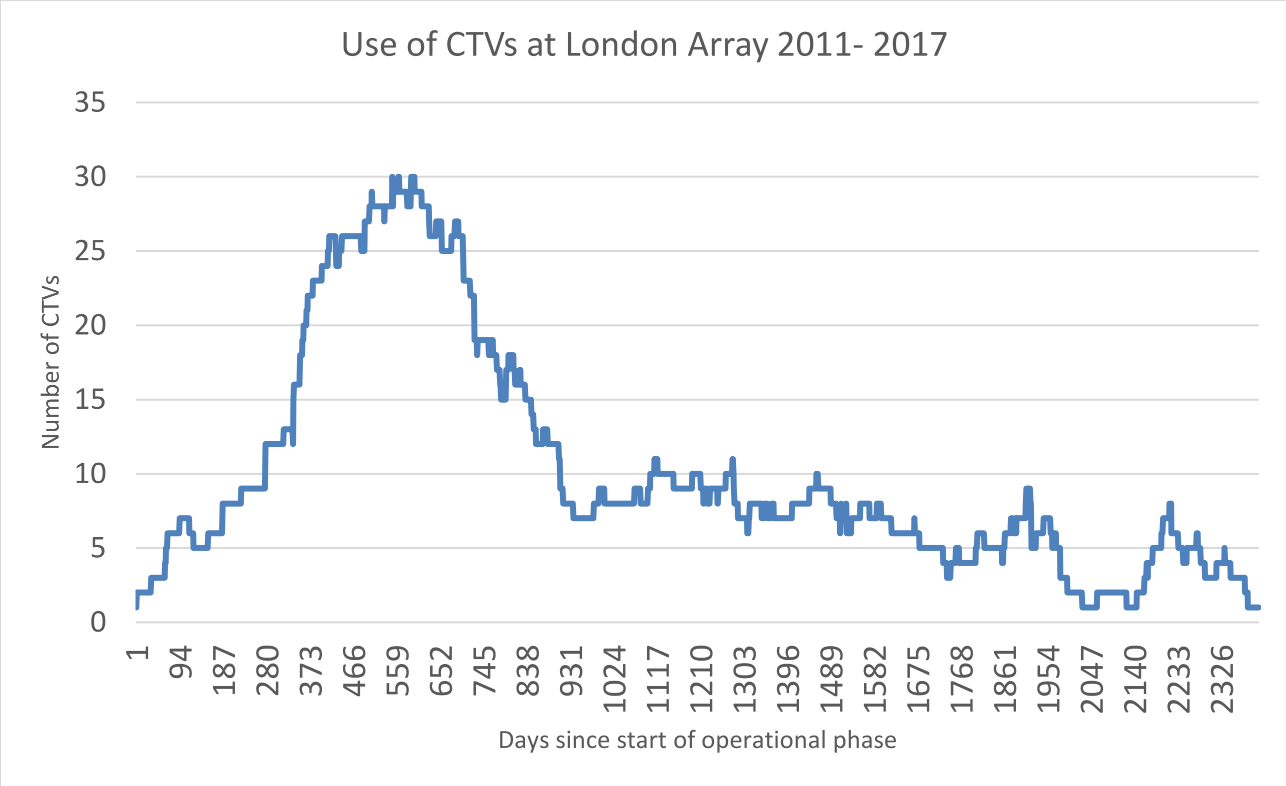


Figure 38 Number of CTVs used at London Array throughout the project period. Starting at day 1, the 30/04/2011 and ending at day 2334, the 30/11/2017.

Going by this method a mean of 10 CTVs were available at throughout the period. Though, the graph does have a spike in the number of CTV during the first 900 days of operation. This is most likely due to the commissioning period, which took place until April 2013[50], after which the wind farm was switched into service. Seeing as we are only interested in the actual operational phase, we will be using the data points from after this date, which is after the 909th day. With this method we get a mean of 6 CTVs. It should also be noted that the number of CTVs registered, is how many different vessels that were contracted to work on the project at any given time. This does not mean all of the vessels were in operation at any given time.

The same method was used to determine how many HLVs was used for London Array during the operational phase. HLVs are used less frequently as they are expensive to contract and most of the work can be done without their services. Throughout the operational phase there was never more than 1 HLV contracted, with a mean of 0,27.

There is no available data for helicopters or SOVs for the project. Though there were used 4 different accommodation vessels, or hotel vessels, during the commissioning period.

6.4.3 Failure rates

Going into the simulation, we will need to gather data about current offshore wind farms, and their failure rates and repair time.

One of the most important parts when it comes to planning O&M for wind turbines, is information about the probability of component failures and the time it takes to repair them[48]. Over the years, as the wind industry has grown, several initiatives has been established to collect data on the component failures in wind turbines and how it affects the availability of the turbines. One of the problems with collecting and gathering data in the offshore industry, is that it is still relatively new. Onshore turbines have matured as an industry over the years, and there have been several government funded projects and initiatives leading to public data. This data has been used to analyze the failure rate and MTTR for wind parks and develop and optimize O&M strategies.

Even though there have been several successful offshore wind farms that have met their goals in availability and power prices, much of the data is not publicly accessible due to competition and a still developing industry[48]. Furthermore, when moving far offshore the industry is going into new territory, where the experience and data gathered from previous projects, may not be enough to tell what can be expected and how it should be prepared for.

One method for doing this is looking at onshore projects and the data that has been gathered from these as it has been done with previous studies [48], [49].

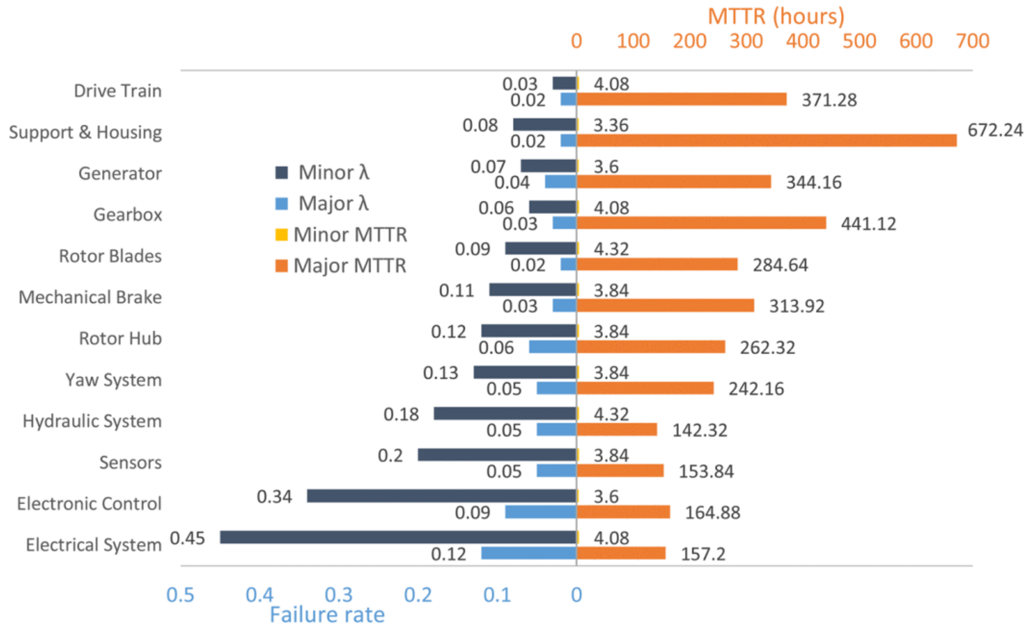


Figure 39 Failure rates and MTTR for onshore[48]

The failure rates and MTTR repair as described in *Figure 39* are used in Shoreline, as component failures for the turbines. The differences in Minor and Major failures, allows for a more detailed modelling of components, where the tasks can be described in different ways, requiring different vessels and times to do the repairs. The drive train, blades, gearbox, generator and structure generally requires HLVs to do major repairs [48].

This was used to create the input for component failures in MAINTSYS, as seen in the *Table 6*.

Failure	**Minor**				**Major**			
Component	**λ**	**MTTR**	**Severity**	**Vessel**	**λ**	**MTTR**	**Severity**	**Vessel**
Drive Train	0,03	4,08	Non Crit	CTV	0,02	371,28	Critical	HLV
Support and housing	0,08	3,36	Non Crit	CTV	0,02	672,24	Non Crit	CTV
Generator	0,07	3,6	Non Crit	CTV	0,04	344,16	Critical	HLV
Gearbox	0,06	4,08	Non Crit	CTV	0,03	441,12	Critical	HLV
Rotor Blades	0,09	4,32	Non Crit	CTV	0,02	284,64	Non Crit	HLV
Mechanical Brake	0,11	3,84	Non Crit	CTV	0,03	313,92	Critical	CTV

Rotor Hub	0,12	3,84	Non Crit	CTV	0,06	262,32	Non Crit	CTV
Yaw System	0,13	3,84	Non Crit	CTV	0,05	242,16	Non Crit	CTV
Hydraulic System	0,18	4,32	Non Crit	CTV	0,05	142,32	Non Crit	CTV
Sensors	0,2	3,84	Non Crit	CTV	0,05	153,84	Non Crit	CTV
Electronic Control	0,34	3,6	Non Crit	CTV	0,09	164,88	Non Crit	CTV
Electrical System	0,45	4,08	Non Crit	CTV	0,12	157,2	Non Crit	CTV

Table 6 Input data for component failures in simulations, showing which severity and vessel is required to repair the failure.

6.4.4 Weather

MAINTSYS allows for simulating the weather conditions of the wind farm. This can be done through various methods, using either historical data, which mimics the weather based on the input. Another model is using a weather randomizer, based on "A Multivariate Markov Weather Model for O&M Simulation of Offshore Wind Parks"[53] which uses a Markov Weather Model to simulate the weather based on historical input supplied to MAINTSYS. Regardless of which option is chosen, the software needs an input of actual historical weather data. For this we have used the baseline weather data supplied by MAINTSYS.

6.5 Simulation scenarios

Using the data collected in the previous sections, two simulation scenarios has been setup for MAINTSYS. One for London Array and one for Hornsea one and two combined.

Simulation	London Array	Hornsea one and two
General information	See Table 5 page 34	See Table 5 page 34
Failure rates and MTTR	See *Table 6* page 39	See *Table 6* page 39
Technicians	54	120
CTVs	6	8
SOVs	0	2
HLVs	2*	4*

Table 7 Simulation scenarios

* it was planned to only use 1 HLV for London Array 2 for Hornsea one and two, though this had to be changed during the simulation process to get accurate simulations. The reason for this will be discussed later along with the simulation results.

The simulations do not include any input on economy or power generation of the turbines, and solely focus on the O&M aspects related to usage of the assets and the results in the form of availability and root causes for downtime.

The annual maintenance of the turbines was scheduled during the summer period the year, where it is easiest to access the turbines, and where there is the lowest energy production.

To simulate shared resources, the Hornsea project one and two, where simulated as one project. All of the assigned vessels and technicians were not assigned to a specific site, but rather bound to a SOV, using the mother vessel function in MAINTSYS, which allows the CTVs to return to a SOV, rather than the harbor. The SOVs were given an off-duty location near the wind farms, allowing them to return to this position when no work was being done, rather than returning to harbor. The SOVs are capable of staying at sea for 28 days in the simulation, between harbor visits.

6.6 Simulation Results

In the following chapter the results from the simulations will be discussed and analyzed. Each simulation yielded a series of data in downtime and availability.

The simulations were performed as multi run simulations, with a simulation period of 2 years, running it 50 times. It would have been optimal to run the simulation for longer periods, similar to the actual operation of wind farms, in the range of 10-20 years, but due to limitations with the simulation software, no more than 2 years was possible.

The simulations have been recorded and uploaded to Youtube and can be seen on the following links. The simulations shown in the videos show both the visual simulation method and the multi run method, which was used to gather data.

London Array Simulation (Opens browser)[54]

Hornsea one and two Simulation (Opens browser)[55]

6.6.1 London Array

The London Array simulation delivers a stable result with consistent downtime throughout the year as shown in *Figure 40*.

Absolute downtime pr. turbine pr. year		
	Relative	**Absolute, [hr]**
Waiting on weather	5,62%	25,83
No available vessel	31,59%	145,29
Time on wind turbine	26,87%	123,55
Scheduled maintenance	14,74%	67,78
Waiting to be handled	20,70%	95,19
Other	0,48%	2,21
Total	100%	459,85

Table 8 Downtime for London Array

Availability	
Jan	95,83%
Feb	96,09%
Mar	96,33%
Apr	96,47%
May	96,26%
Jun	94,67%
Jul	93,91%
Aug	93,67%
Sep	92,99%
Oct	92,14%
Nov	91,37%
Dec	91,35%
Annual	94,24%

Table 9 Availability for London Array

Figure 40 Turbine status for London Array

6.6.2 Hornsea one and two

The Hornsea simulation delivers a less stable result than that of London Array. There is a visible buildup of work orders that are not completed leading to failed turbines as shown in *Figure 41*.

Absolute downtime pr. turbine pr. year		
	Relative	**Absolute, [hr]**
Waiting on weather	3,66%	18,94
No available vessel	30,52%	157,98
Time on wind turbine	18,86%	97,62
Scheduled maintenance	13,87%	71,77
Waiting to be handled	31,90%	165,13
Other	1,19%	6,17
Total	100%	517,64

Table 11 Downtime for Hornsea one and two

Availability	
Jan	95,59%
Feb	95,03%
Mar	94,71%
Apr	94,27%
May	93,76%
Jun	91,25%
Jul	90,58%
Aug	90,16%
Sep	89,48%
Oct	88,63%
Nov	88,58%
Dec	89,44%

Table 10 Availability for Hornsea one and two

Figure 41 Turbine status for Hornsea one and two

6.6.3 Analyzing the results

The availability we get from our results can be compared to what is currently achievable and what has been historically recorded in the Offshore Wind Industry. The early offshore wind farm had an average availability of 80,2%[48], though this were among the first wind farms, where there were problems with transitioning from onshore to offshore. Much of the technology and equipment being used was the same, which cause a series of problems with large components that had to be replaced. Newer projects, such as Nysted Offshore Wind Farm, which finished construction in 2003 has achieved an availability of 96,5%[56]. London Array announced in 2015, that they had achieved a 98% availability during the winter period of the year[57], though there are no mentioning of the overall availability for the project. Along with these measurements, Dong has also stated that on sea an availability of 97-98 % could be achievable[23][56].

The availability achieved through the simulations are lower than what would be expected, if comparing it to what was achieved from London Array and what should be achievable according to Dong. Though the data used to perform the simulations, come from older onshore sites, so it isn't purely representative of the conditions that should be expected at sea. By now, it could be assumed that the operation of offshore wind farms has matured significantly compared to the older sites, which leads to more developed maintenance strategies and monitoring through computerized maintenance systems (CMS).

One of the biggest causes for downtime in the simulations is no available vessels. The biggest contributor to this are the HLVs, which cause 91% of the no available vessel downtime for London Array, and 99% at Hornsea one and two. The primary reason for this downtime is the lead time associated with the HLVs. The lead time being the time it takes to acquire a HLV, get the necessary equipment and spare parts etc. that are necessary to do the required repairs. This downtime in the simulation is partly due to the difference between the simulated scenario and how it is done in the real world, and due to the way, the input data is used. In the real world, the HLVs are primarily used during the summer season, where production is at its lowest, and the sea conditions are the most accessible. This can also be seen from 4C Offshore's public data on the use of vessels in the operational phase of London Array[58].

Vessel	Start date	End Date	Contractor	Total days
HLV	01-02-2011	30-04-2011	Red 7 Marine Ltd	89
HLV	16-06-2013	19-06-2013	ZITION A/S	4
HLV	04-07-2013	12-11-2013	Hyperbaric Consult ApS	132
HLV	07-05-2014	22-09-2014	Menas UK	139
HLV	06-10-2014	07-10-2014	A2SEA A/S	2
HLV	27-04-2015	11-05-2015	A2SEA A/S	15
HLV	06-06-2015	08-06-2015	A2SEA A/S	3
HLV	02-12-2015	02-12-2015	Iceni Marine Services	1
HLV	16-05-2016	18-05-2016	ZITION A/S	3
HLV	15-09-2016	21-09-2016	ZITION A/S	7
HLV	28-01-2017	30-06-2017	A2SEA A/S	154

Table 12 HLV use at London Array

The data used for the simulations does not specify whether a failure causes production to stop, or what measures are needed to repair them. This leads to situations where a major failure in the simulation shuts down production and requires a HLV for the entire repair job. In reality a major failure would not have this effect, as a failure often would be detected ahead through various sensors or CMS and would not always cause a shutdown of the entire system. Neither does the entire repair job require a HLV to be present throughout the entire process. The HLV will be used to change or repair spare parts, while technicians do the rest of the work. The technicians can still access the turbine afterwards and finish the jobs without the HLV being present. This leads to an unrealistic high use of the HLV vessel, which is why there were also used double the required amount in the simulations.

Even though this was done, there was a buildup of uncompleted work orders, of turbines that had failed and shut down production, just waiting to be handled by HLVs. This was most prominent in the Hornsea simulation, as seen in *Figure 41* page 42, where it is visible that the failed turbines are growing as shown by the red indicator in the figure.

The downtime of the turbines in the simulations shows a higher downtime on the Hornsea project than on London Array. This is primarily due to the problems with HLVs. As there is a notably difference in the waiting to be handled post.

One positive thing to note from the Hornsea one and two simulation are the reductions in waiting for weather and waiting for vessel. As mentioned earlier, 93% of the waiting for vessel time at London Array came from HLVs, while it was 99% of the time at Hornsea one and two. This gives an indication of the CTVs being more efficient and quicker at responding to failures at the Hornsea project.

The differences in Time on Wind Turbine, indicates that the technicians spend less time on the turbines at the Hornsea one and two, than they do at London Array. This is again due to the problems with HLVs. As there is a bigger buildup of work orders waiting to be handled, requiring HLVs, the time being spent on the turbines will naturally decrease. As the same failure and MTTR data is being used for both simulations, the number of absolute hours spent on each turbine, should be approximately the same. The difference that we hoped to see, would be in the relative measurements, meaning the technicians would spend more time on the turbines, and less waiting for vessels and handling.

6.7 Sub conclusion

The simulations were made by primarily using public data. This data was gathered through available information on the use of vessels and technicians, while also using failure rates and repair times based on onshore data. The data gathered, was primarily gathered for London Array, and then used at the Hornsea project, to test the differences in the two scenarios. The simulation results for London Array yielded somewhat stable results, with an availability close to what could be expected for the project, whereas the Hornsea project had problems with a buildup of work orders, which led to an increasing number of turbines not being available. The problem is partly due to problems with modelling HLVs and using outdated data on failure rates and MTTR. Through the simulations, there is a small reduction in the downtime due to weather and CTVs.

7 Emergency Management

The purpose of this analysis is to investigate the various stages of Emergency Response Management as part of a global Emergency Management Procedure and understand the methods that can be applied. The methods investigated are relevant to offshore incidents in the Wind Industry Sector comparing situations which have applicability for both offshore and far offshore wind parks.

Emergency Management is a process of constant development, because effective emergency responses are vital in ensuring the health, safety and the wellbeing of the offshore wind workforce.[59]

Working in the Offshore Wind Sector can be challenging, because of the changing working conditions. Therefore, it is important to be aware of what might go wrong and how to mitigate these events.

Figure 42 Emergency management cycle[60]

The Emergency Management cycle as seen in Figure 42 can successfully be applied in this case to analyze the Emergency Response for offshore and far offshore wind parks. The Cycle covers all four phases of an emergency scenario. Leaders in organizations need to know their roles and responsibilities in each phase of the emergency management cycle and lead their organization through them.

The scope is to describe the procedures and the proper lines of communications, between all relevant stakeholders involved in the offshore wind projects, in order to ensure that any emergency situation is resolved as quickly and safely as possible. This description applies to all vessels and personnel involved in an offshore wind project in the operation and maintenance phase.

This chapter will cover the following elements of Emergency Response:[59]

- Emergency response management
- Command and communication
- Training/drills for emergencies
- Temporary refuge details
- Details of evacuation and escape equipment
- Means of recovery to a place of safety

For researching and developing a structured Emergency Response Analysis, the term emergency should be well defined. An emergency in the Offshore Wind Sector is considered to be an abnormal situation already developed or that has the possibility to develop into a major accident. Here are the incidents considered to be the primary emergency situations in the Offshore Wind Sector:[59]

- Serious personnel injuries / fatalities and subsequent evacuation

- Fire / explosion on-board the vessels of transport
- Collision between vessels or between vessels and WT
- Major failure of the vessel structure
- Major failure or loss of equipment
- Personnel missing
- Pollution
- Severe environment / weather conditions
- Acts of terrorism

The emergencies can be classified in: [61]

Minor emergencies: A minor emergency is one which can be dealt with, either totally or requires response from a limited number of personnel to provide technical advice and support.

Major emergencies: A major emergency is one which affects the safety of the transport vessel and associated equipment, personnel and the environment, which requires contact with the Management of the Company.

Emergency Response Policy

The amendments stated in the policy should adopt a proactive approach to risk management and loss prevention as part of its business and philosophy. The safety of the personnel, involved on-board the transport vessels and WT, should be of critical importance. An integral part of the policy of making and maintaining the workplace as safe as possible is recognizing that situations may arise, from time to time, which require training and familiarization with the methods of dealing with various emergencies. In a situation that demands evacuation of personnel from the vessels or WT it is important to ensure that the evacuated personnel are transferred, as quickly as is reasonably practicable, to a place of safety, onshore or offshore. In the event of an offshore emergency, an Emergency Response Team, headed by Management Onshore, will be mobilized to advise and assist Offshore Management. This Team will align with the relevant authorities, employees' relatives, the media and the client representatives as required.[59]

Every operator in the Offshore Wind Sector should be committed to following the emergency response philosophy and objectives. One objective considers that the operator should ensure the safety of the personnel involved in offshore operations. The activities performed should also have a zero or minimal environmental impact. In case of an emergency situation, all operations should be carried out without unnecessary damage to installation or equipment. During an emergency, the prime responsibility of all concerned is to maintain the safety of those not affected by the incident. Because the situation could escalate, an important issue is also maintaining the safety of those responding to the incident and rescuing personnel, particularly those who may have been injured.

7.1 Emergency response procedures and strategies

Using a bow-tie model some measures for prevention and mitigation are formulated in order to develop some strategies which will allow to strengthen the emergency response system. In both cases some predefined procedures have to be taken into account. These procedures come as result of experience in the field and standardization. As it can be observed in the bow-tie model from Figure 43, the most important issues for Emergency Response Management are related to key factors like preparedness, design of equipment, training and communication. Bow-Tie is one of many barrier risk models available to assist the identification and management of risk. The Bow-Tie clearly displays the links between the potential causes, preventative and mitigative controls and consequences of a major incident. It is also a visual tool which effectively depicts risk providing an opportunity to identify and assess the key safety barriers either in place or lacking between a safety event and an unsafe outcome.

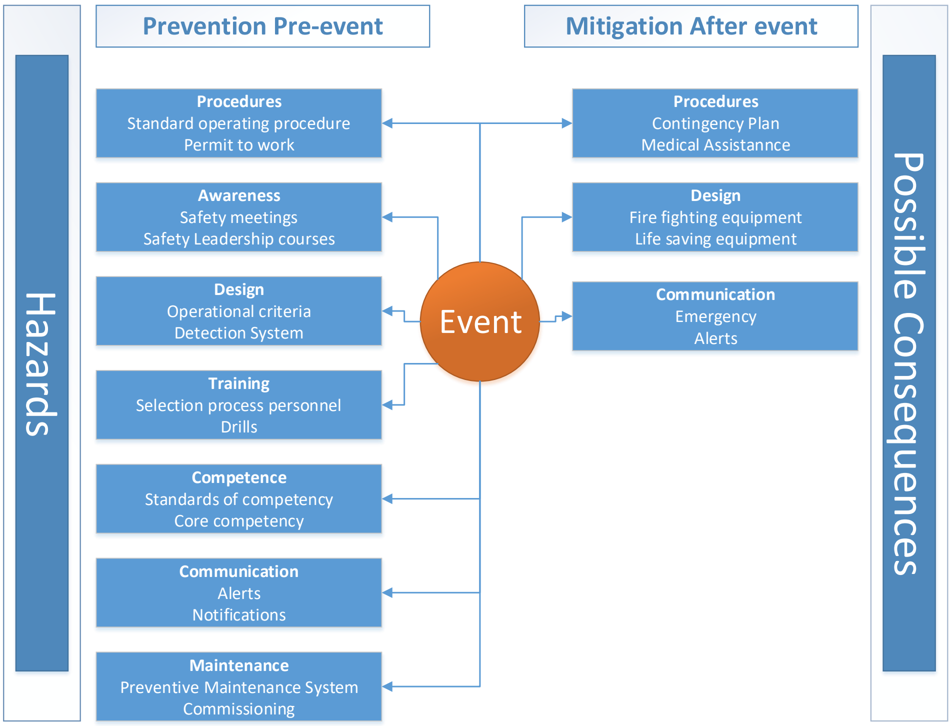


Figure 43 Bowtie model for emergency situation in the Wind Energy Sector. Made by authors using[62]

7.2 Evacuation, Escape, Rescue and Recovery Process[59]

7.2.1 Evacuation

Evacuation will only be required if the hazardous event threatens either the integrity of the WT or the life-support function of the Transport Facility. For most of the incidents, the safest course of action will be to remain on the WT until the incident is brought under control. In this case, the WT itself, or the Transport Facility, is considered to be the place of safety.

7.2.1.1 Primary Means of Evacuation – Helicopter

The primary means of evacuation to a place of safety is by helicopter. Evacuation by helicopter may take place as the result of a marine event where it has been determined that the installation will be lost, but there will be sufficient time to carry out the evacuation by helicopter. The probability of a successful evacuation by helicopter depends on the availability of an appropriate aircraft and the ability to land on a helideck on board one of the transport vessels. In certain circumstances evacuation may be attempted by helicopter winching. In such circumstances, the personnel should be instructed to the appropriate muster location. Assuming a lifting time of 2 minutes, with 2 personnel per lift, this would be a much more time-consuming activity than a normal helicopter evacuation. The time to load a helicopter with 14 passengers would therefore be of the order of 15 minutes.

7.2.1.2 Secondary Means of Evacuation – Lifeboat

Evacuation by Totally Enclosed Motor Propelled Survival Craft (TEMPSC) may be considered where the means of helicopter evacuation is not available or where the facilities, such as the helideck, are not present. The success of evacuation by TEMPSC depends on the following accident scenario specific features:

- Accessibility of lifeboat stations via egress routes
- Lifeboat availability (lifeboats might be impaired due to the incident)
- Success of launching lifeboats
- Success of lifeboats moving away from the installation (weather dependent)
- Recovery of evacuees to the stand-by vessel, or another place of safety

7.2.2 Escape

If the lifeboats are impaired, or fail to operate successfully, personnel will have to use other escape methods.

7.2.2.1 Liferafts

These rafts are safety devices that automatically inflate. All are fitted with a hydrostatic release, which will be activated by hydrostatic pressure when the liferaft is in the sea. The success of escape by liferaft depends upon:

- Accessibility of liferafts
- Liferaft availability
- Launch success
- Rescue success by fast rescue craft
- Success of recovery to the stand-by vessel.

If liferafts cannot be utilized, personnel can escape directly to the sea by use of personal descent devices, located at the life raft stations. As a last resort, jumping directly to the sea could be attempted from anywhere on the WT or transport vessel

7.2.2.2 Survival Suits

All personnel on the WT and vessels are provided with survival suits, stored at the Muster Stations. The purpose of the survival suits is to ensure the survival of personnel who have to escape to the sea until they can be rescued. Although it is intended that the suits will preserve life until all personnel can be rescued by the emergency response and rescue vessel, survival time will depend on water temperature, sea state, integrity of the suit and the physical state of the wearer.

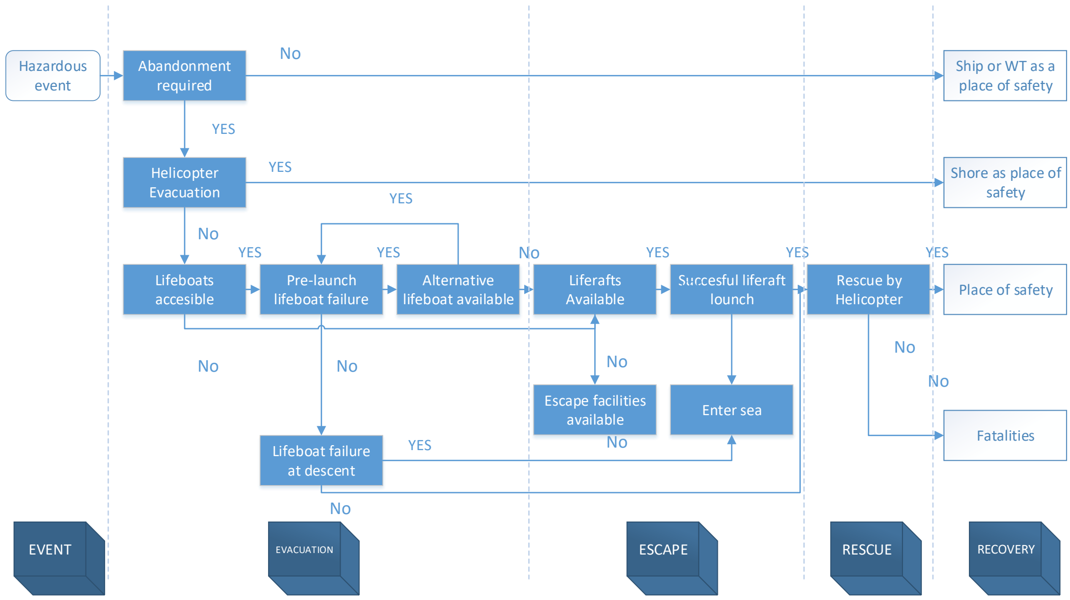


Figure 44 Flowchart visualization of the Evacuation, Escape, Rescue and Recovery Process. Made by author using [63]

In Figure 44 a flowchart of the Evacuation, Escape, Rescue and Recovery Process is illustrated. The flowchart starts with the initial event. The next step is the evacuation process. The decision is to abandon or not the WT or transport vessel. If the conditions either on the WT or transport vessel are not safe they will have to evacuate using the primary means of evacuation namely a helicopter. If the helicopter is not an option, the staff on board will have to evacuate to the lifeboats. If the evacuation process is successful, they will have escaped the WT or transport vessel and will be rescued by a helicopter or nearby boats. The last phase is the recovery one, this will either show the fatalities or the number of rescued personnel

7.3 Emergency Response Training

This process is represented by ensuring that the individuals are competent to fulfil their roles, including their roles in an emergency. With respect to emergency response, all personnel should receive instruction in: Combined firefighting/survival issues, Medical first aid procedures, Confined space rescue, Rescue at height. A number of specialized companies are certified in providing the relevant safety courses depending on the type of work the employee needs to perform.

All emergency training is managed by the Health and Safety Department who makes sure that all training is maintained up to date. The personnel on board should be trained and have adequate knowledge to perform the following tasks: [22][64]

- Shut down all fans and ventilation systems
- Operate relevant safety equipment
- Prepare all TEMPSCs and life rafts for launching and starting
- Extinguish fires
- Direct personnel to their appointed stations
- Conduct search and rescue
- Shut down all heat sources
- Start fire pumps, hydrants, foam equipment
- Stretcher loading and patient movement
- Power on and off the electrical system

Where helicopters are being used to transport personnel to/from the installation, all personnel are required to have completed helicopter escape training prior to being permitted to travel. In exceptional circumstances, authorization may be given to travel without this training.

7.4 Drills and Exercises

The Health and Safety Department is responsible for drills being carried out on the WT installation, and in conjunction with transport vessels during combined operations. Regular drills will provide all personnel with practical experience, test all aspects of the plan, and allow the continual assessment of individuals and groups with emergency response duties.

Following the drill/exercise, a debriefing will be held to evaluate the results and initiate changes required for subsequent drills. Base management will be involved with drill/exercise assessment when onboard. The periodic crew safety meeting includes an assessment of the weekly periodic drills. Any actions or recommendations from assessments and investigations are agreed and ratified prior to implementation or inclusion into this procedure. Scenarios which are based on the identified major accidents are exercised at frequent intervals. This includes: [22][64]

- Fire and explosion
- Dropped object
- Helicopter crash
- Marine emergency/vessel collision
- Structural failure.

7.5 Communication

The communications set up in place should be adequate to manage all identified potential emergencies. It is important that the messages are very clear and give reliable information about emergencies. This will help to better manage the situation and decrease the level of risk. The communication process is divided into two important parts namely: internal communication and external communication. A relevant issue about these two communication lines are that there should be a permanent correlation between them. As the messages represent major events in the mitigation of emergency situations the way of interpreting is very important.

In Figure 45 an example of a communication flowchart is illustrated.

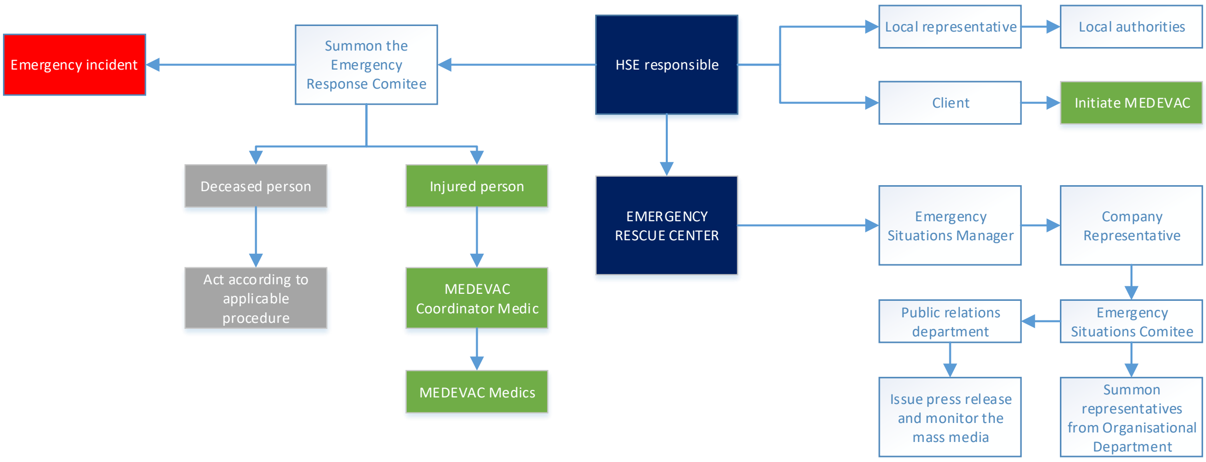


Figure 45 Emergency communication flowchart for emergency response procedures in the Offshore Wind Industry. Made by author using [63]

This flowchart shows that the HSE responsible has the overall mission to communicate information to the other branches. For example, the HSE responsible will contact the Emergency Response Committee if a major incident has occurred. Then the Committee will contact the MEDEVAC if they have injured personnel on board the transport vessel or WT. The Emergency Rescue Center will then coordinate efforts with the Emergency Situation Manager, the Company Representative and the Emergency Situations Committee, making sure that all internal and external stakeholders are in contact

7.6 Primary differences between emergency response procedures offshore vs far offshore

For reaching the purpose of the project it is important to see how the Emergency Response Procedures influence the wind projects analyzed before in the simulation chapter. For both the offshore and far offshore projects, the policy and strategies remain the same as emergency response shares the same goals. Also, the predetermined methods of preparedness and mitigation will specify the same recommendations.

In the simulation chapter, we visualize how the O&M procedures are carried out considering three Wind Projects situated at 27.6 km, 114.5 km and 107.5 km distance from the coastline. This distance represents a very important parameter when developing the emergency response procedures as it has a huge influence on aspects which concern choosing the appropriate means of evacuation in case of an unvented incident. Due to different weather conditions choosing the suitable means of evacuation can become a challenging process as well as an important one. It can be observed that there is a distance of almost 80 km between the offshore and far offshore projects. The process of escape, evacuate, rescue and recovery will have to follow different inputs determined by this distance to shore.

The difference between a successful and a misfortunate intervention stands in understanding how much influence does a parameter such as weather or distance to shore have on the intervention. If we take a look at the means of evacuation represented by the helicopter and medical vessels it is understandable that the intervention needs to consider certain characteristics like:

- *Distance to shore*: The time it takes for the helicopter or medical vessel to reach an injured person.

This time makes a difference on the result of the intervention. If arrived too late the severity of the hazards consequences could proof disastrous resulting in fatalities or extensive destruction of facilities. Considering that the time to reach an injured person will be higher in time when considering the far offshore projects it can be suggested that the emergency response procedure possesses an elevated level of risk. As a counter measure, some intervention means of evacuation will be stationed on substations situated closer to the far offshore wind projects.

- Weather conditions
    - Wind Direction and Speed: unsuitable wind speeds will be unsuitable for proper maneuvering of the intervention means of evacuation
    - Visibility: the presence of precipitation and fog will have to be countered with additional care when performing the maneuvers
    - Sea State: rough sea and heavy currents have a very adverse action on the intervention procedure

All these parameters are highly interactive with each other. The weather conditions become harsher when moving further away from the coastline. This aspect combined with the different distance to shore make the far offshore interventions more challenging. Special care needs to be taken also when following predetermined protocols as the conditions change rapidly in the far offshore sector. As an example, could be considered the one regarding the means of intervention. Even if the availability exists some missions can be aborted because of rapidly changing conditions like sea state or visibility in the far offshore sector.

The use of substations as means of shared resources could have a homogenizing effect on the emergency response procedures in both offshore and far offshore sectors. This effect will come as a result of minimizing the negative impact of parameters like weather or distance to shore.

8 Risk Management

In concordance with the simulation chapter a risk management study is performed in order to identify possible differences between the relative risk factor when considering the two wind parks.

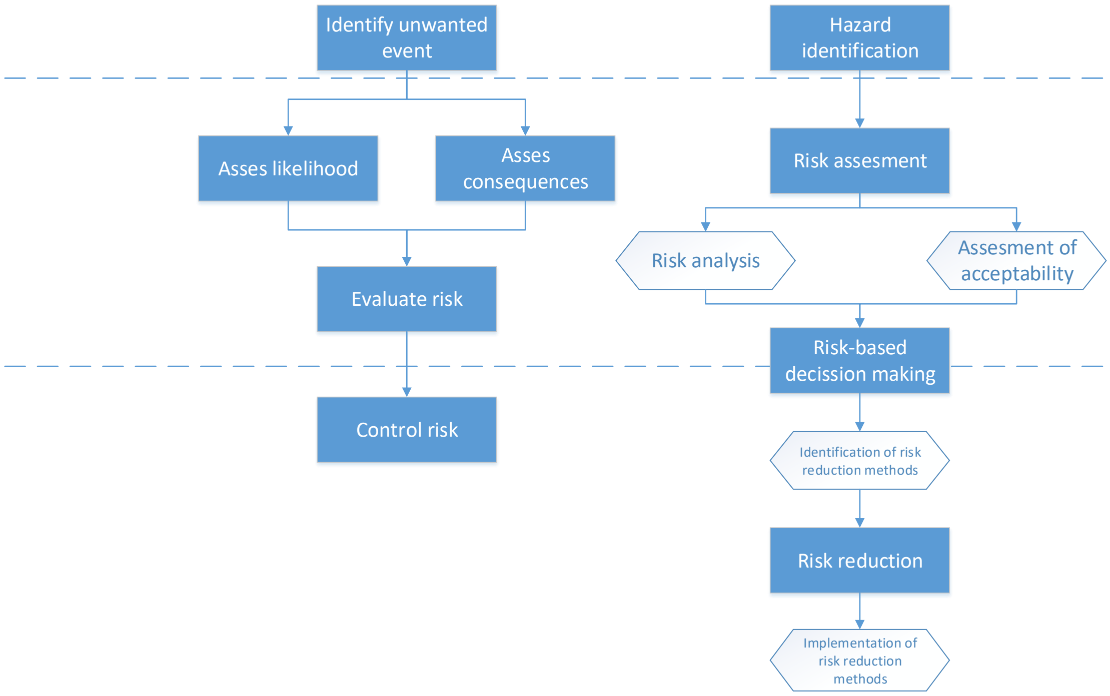


Figure 46: Risk management flowchart. Made by authors using[62]

As described in Figure 46 this process is performed following a series of analysis methods which will allow to identify the major hazards present in the Offshore Wind Industry. After the hazard identification process the next step is to try to evaluate the risk. This is done in a qualitative manor using a risk matrix. After determining the impact of each hazard present in the O&M procedures some mitigation methods will be described and analyzed from the point of view of influence on the risk reduction process.

8.1 Hazard identification

The hazard identification process starts by trying to find and describe each operation performed in the O&M process in the Offshore Wind Industry. The identification is performed for both wind parks as the operations are similar.

In Table 13 the main operations related to O&M procedures in The Offshore Wind Energy Sector are described. By analyzing the operations, it is possible to identify the main hazards considering aspects which have an effect on occupational health and safety, structural integrity, environment and reputation of the companies. The information is gathered using research on published technical data and by personal experience of the authors. The major hazards will be later used for the risk assessment process.

Table 13 - Hazard identification for O&M procedures in the Wind Energy Sector. Made By authors using [65]

Operation		Operation description	Hazards
Access and egress	Transfers to and from vessels	The operation is performed in a direct step-over manor from the vessel to the WT with the help of ladders.	Falls onto the vessel Falls into the sea Injuries from dropped objects during transfer Stranding High levels of vibration
	Mechanized access	Usage of gangways or platforms the assist the transfer from the vessel to the ladder with the vessel holding position against vertical fenders linked to the ladder.	Failure of mechanical or structural components Failure of sensor and control systems
	Helicopter hoist access	Winching operation by usage of a hoist dropped from the helicopter to the WT	Injuries of workers when landing on platforms Static discharge Increased level of noise and vibration Dropped objects between the helicopter and hoist platform
Cable wiring		Operation and maintenance of the high voltage cable networks for collecting and transmitting the generated power into a substation	Injury when handling the cables through different stages (vessel to vessel, land to vessel etc.) Loss of vessel stability when handling the cables
Operations in confined spaces		Operations in places which are enclosed like parts of the WT Tower and nacelle	Loss of consciousness Drowning Incidents caused by fire or explosion
Electrical operations		Operating and maintaining High and Low voltage systems as well as temporary installations(generators) and portable equipment used by technicians.	Electrical shock Internal burns Fire and smoke

		Arc flash Explosion
Operations which affect Ergonomics	Operations in the WT witch are performed in a restricted space or a forced adoption of an awkward working position	Long term musculoskeletal disorders
Operations which include the risk of fire	The risk of fire is present in most stages of operation and maintenance as the different activities present the appropriate conditions for ignition like usage of combustion materials and sources of fuel for a fire	Burns Asphyxiation and death Carbon monoxide release Explosions and arc flashes
Operations with hazardous substances	Operations which include the usage of hazardous substances like lubricants and coolants as well as cleaning fluids. Welding and resin repairing operations.	Injuries by any form of contact with hazardous substances which can have minor, moderate or major consequences depending on the severity and duration of the effects
Lifting operations	O&M activities involve a wide range of lifting operations like lifting of equipment or major components	Risk of dropped objects
Meteorological aspects	All operations in the offshore sector are performed under the threat of unsuitable weather conditions. Adverse conditions can increase the probability of incidents happening.	Injury from excessive wave, current action. Stranding Lightning Low visibility Discomfort from extreme cold or warm temperatures
Navigation related operations	O&M operations in the offshore sector rely on a number of navigational operations which allow the transport of technicians and support for the relevant to the ongoing tasks.	Ship collision Man overboard Pollution Interference with commercial shipping lines

Noise	A large number of operations can introduce noise exposure like use of power tools, transfers from helicopters and vessels as well as noisy power sources like generators or compressors.	Permanent or temporary hearing loss or damage
Ports and mobilization	During the O&M STAGE there are a series of important operations that need to be performed like: Fleet access for supplying and resupplying Material handling Maintenance operations on the designated ships	Collision Dropped objects Pollution Fire hazard Tripping hazard Arguments from different safety cultures adopted by different operators.
Remote working	Usually the O&M operations are performed with small teams deployed at the offshore site meaning that the workers will be remote from immediate support and supervision	Incident severity incensement on behalf of longer period of intervention.
Subsea operations	In the O&M stage a series of diving operations are used for the inspection and repair procedures of any devices or equipment situated underwater	Mechanical hazards Injury from differential pressure Dropped objects Hearing damage Electric shock Entrapment
Vessel selection	Because the O&M procedures involve a large number of vessels it is important that the tasks attributed are not exceeding the capability of the vessel or the competence of its crew.	Vessel collision Vessel capsizing Minor, moderate, major personnel injury

Work at height	There is a multitude of situations where the operations are considered to be performed at height starting from operations in different parts of the WT device or onboard the vessels. A place is considered at height if a person can get injured falling from it.	Falls from heights Falling objects
Vibration	While working offshore personnel may be exposed to different forms of vibration like: Hand-arm vibration (use of certain tools) Whole body vibration	Temporary or long term injuries due to vibration

8.2 Risk assessment

The hazard identification is followed by a risk assessment process which starts with a risk analysis. Again, the results will be considered for both wind parks as the hazards considered are similar.

Table 15 describes the identified hazards and the analysis performed in order to identify the risk factor. In the risk analysis the hazards identified before are considered starting with research on the cause of each hazard. This is very important as the risk mitigation methods described later will be strongly linked with the causes. This will be followed by an assessment over the likelihood and consequences. After establishing the causes, a conclusion about the effect of each hazard can be drawn. The effects are discussed and formulated considering OHS, Structural integrity and reputation aspects. The conclusion on the severity of the effects will help prioritize the risk by using a risk matrix in which the severity and likelihood of each hazard is evaluated in order to determine a risk factor as it can be observed in Table 14.

Figure 47 Risk evaluation and tolerability for hazards in the Offshore Wind Sector. Made by authors using[62]

SEVERITY					
Slight Health Effect/Injury	1	4	3	2	1
Minor Health Effect/Injury	2	8	6	4	2
Major Health Effect/Injury	3	12	9	6	3
Single Fatality	4	16	12	8	4
Multiple Fatalities	5	20	15	10	5
PROBABILITY		4	3	2	1
		Happens several times per year in Offshore Wind Industry	Incident has occurred in Offshore Wind Industry	Heard of in Electricity Industry	Never heard of in Electricity Industry

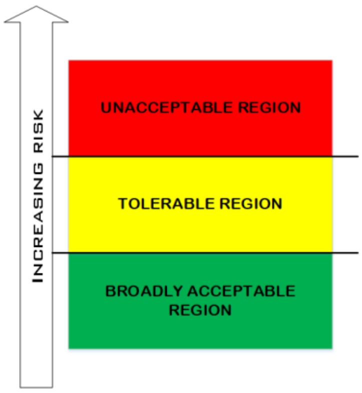


Table 14 Risk Matrix for hazards encountered in the Offshore Wind Industry. Made by authors using[62]

As seen in the Table 14 the risk factor is calculated by a process of multiplication between the indices of the probability and the severity considered for each hazard. The results will be interpreted for each hazard placing it in an acceptable tolerable or unacceptable region. Considering these three regions as seen Figure 47 it is possible to prioritize the risks and give special attention to their level of danger.

AALBORG UNIVERSITY
DENMARK

Table 15 Risk evaluation for hazards encountered in The Offshore Wind Energy Sector. Made by Author

No	Hazard	Cause of hazard	Effect of hazard on			Hazard likelihood	Hazard criticality	Risk evaluation
			OHS	Structural integrity	Reputation			
1	Falls and tripping	Excessive movement of transfer vessels due to weather or faulty maneuvering Failure of mechanized transfer facilities Unsuitable hoisting equipment Faulty storage of transfer cables Inappropriate safety measures when working at heights	Major health effect/single fatality	none	Local impact	4	4	16
2	Dropped objects	Excessive movement of transfer vessels due to weather or faulty maneuvering Failure of mechanical or structural components Failure of sensor and control systems Faulty helicopter maneuvering operations Faulty material handling Inappropriate usage of cranes and lifting facilities	Major health effect/multiple fatalities	Localized damage	Local impact	4	5	20
3	Vibration	Failure to comply with safety recommendations for different vibration levels	Temporary or long term injuries due to vibration Minor Health Effect/Injury	Slight damage	Limited impact	4	2	8
4	Failure of sensor and control systems	Inappropriate maintenance strategy	None	Localized Damage	Limited impact	4	2	8
5	Static discharge	the helicopter has not been earthed	Major health effect/single fatality	Slight Damage	Local impact	3	4	12
6	Noise	Failure to use protection against noise when operating power tools or when transferring from vessels or helicopters	Hearing damage Minor Health Effect/Injury	none	Limited impact	4	2	8

7	Fire and smoke or explosion	Faulty usage of tools and materials in confined spaces Faulty usage of tools and materials in electrical operations Inappropriate training for handling combustion and fuel sources and materials	Major health effect/multiple fatalities	Extensive Damage	National impact	3	5	15
8	Loss of consciousness	Faulty ventilation equipment in confined operating rooms Inappropriate handling of dangerous substances	Major health effect/single fatality	none	Local impact	3	4	12
9	Electrical shock	Faulty usage of tools, materials and installations in electrical operations	Major health effect/single fatality	none	Local impact	3	4	12
10	Drowning	Faulty diving equipment Inappropriate measures of intervention in man overboard operations	Major health effect/single fatality	none	Local impact	3	4	12
11	Burns	Faulty usage of tools, materials and installations in electrical operations Fire and explosions	Major health effect/single fatality	none	Local impact	3	4	12
12	Ergonomics	Operations which negatively affect the natural ergonomic posture of workers like operations in confined spaces	Major health effect	none	Limited impact	3	3	9
13	Asphyxiation and death	Fire and explosion Faulty ventilation equipment in confined operating rooms Inappropriate handling of dangerous substances	Major health effect/single fatality	None	Local impact	3	4	12
14	Carbon monoxide release	Fire and explosion	Major health effect/multiple fatalities	none	Local impact	3	5	15
15	Hazardous substances	Faulty handling of hazardous substances	Major health effect/multiple fatalities	none	Local impact	3	5	15

16	Excessive wave, current action	Adverse meteorological conditions	Major health effect/multiple fatalities	Major Damage	National impact	4	5	20
17	Stranding	Adverse meteorological conditions	Minor Health Effect/Injury	none	Local impact	4	1	4
18	Lightning	Adverse meteorological conditions	Major health effect/single fatality	Localized Damage	none	4	4	16
19	Low visibility	Adverse meteorological conditions	none	none	none	4	1	4
20	Extreme cold or warm temperatures	Adverse meteorological conditions	Minor Health Effect/Injury	Slight Damage	none	4	2	12
21	Man overboard	Excessive movement of transfer vessels due to weather or faulty maneuvering Failure of mechanized transfer facilities Unsuitable hoisting equipment	Major health effect/single fatality	none	National impact	3	4	12
22	Pollution	Inappropriate refueling and vessel waste disposal operations Inappropriate disposal of polluting substances used for WT maintenance operations	none	none	National impact	3	3	9
23	Entrapment	Failure of mechanized transfer facilities Failure of mechanical or structural components Failure of sensor and control systems Cable and rope entrapment in diving operations	Major health effect/single fatality	none	Local impact	3	4	12
24	Vessel collision	Faulty maneuvering of vessels	Major health effect/multiple fatalities	Extensive Damage	National impact	3	5	15
25	Vessel capsizing	Faulty maneuvering of vessels	Major health effect/multiple fatalities	Extensive Damage	National impact	3	5	15
26	Different safety cultures	Failure to homogenize safety cultures between different operators and associations.	none	none	none	3	1	3

27	Interference with commercial shipping lines	Faulty communication strategy Inappropriate localization and survey operations	none	none	Local impact	3	1	3

8.3 Risk Control

For the hazards considered to belong in the acceptable region with the risk evaluation indices from 1yo 4, it is recommended to tolerate the risk. In this approach, the decision is made that the risk is at an acceptable level. There is no further action taken with this approach. Only it is recommended to monitor the activities.

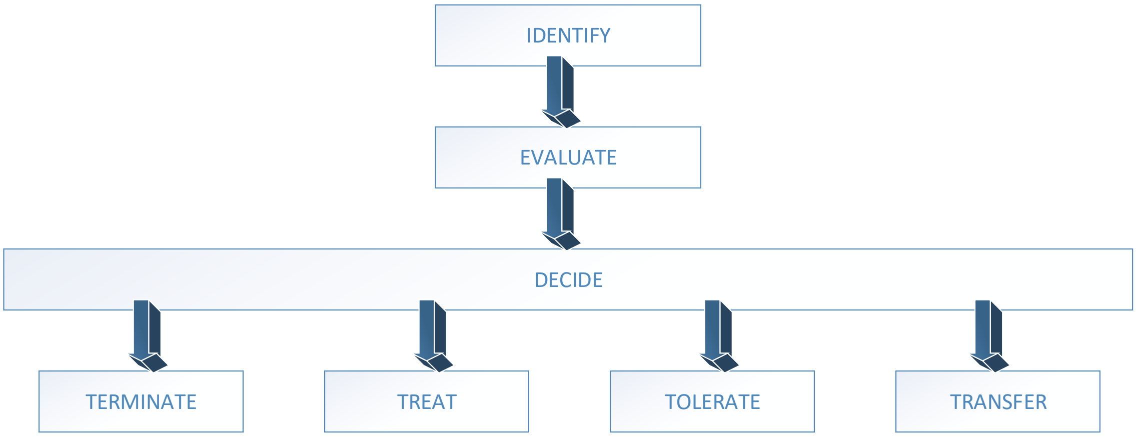


Figure 48 Methods of risk control Made by authors using [33]

Every other hazard that exceeds the indices of 4 needs to be treated with attention. Mitigation methods need to be identified in order to control the risks. As seen in Table 16 Relative risk factor offshore vs. far offshore, it is possible to keep the risk at a level considered as low as reasonable practicable if the correct mitigation methods are adopted. This approaches focus is on reducing the likelihood or consequences of the risk to a level that is acceptable. This is different from avoidance, because it is considered that eliminating the risk is not an option due to time or costs.[66]

Some of the hazards which go above the indices 4 can be controlled by transferring the risks. In this approach the risk is transferred or shared to another party. An example of transferring risks is outsourcing. The third party needs to consider the risks and should agree with the obligation that this activity brings with it.[67]

In the last stage for the hazards that start and go above the indices 12 it is recommended to take into account an avoidance strategy in which the risk is eliminated by terminating the operations. With this approach, the decision is made not to proceed with the activities, because the risks are too high. When an activity is avoided, it means that all the processes related are stopped. A different activity is chosen to avoid the unacceptable risk, but it will still meet the requirements of the business. [67]

Table 16 Relative risk factor offshore vs. far offshore Made by authors using [22][65].

Risk evaluation	Hazards	Mitigation methods	Relative risk factor offshore/far offshore	Comments
20	Dropped objects	Helicopter condition monitoring systems Use of automatic weather stations and trained observers for planning O&M operations. Regular inspections on lifting equipment and devices.	higher	Personnel working both offshore and far offshore must climb ladders or operate lifts many times a day, facing falls hazards or exposure to dropped objects. Because the components of far offshore WT are larger and heavier and because the meteorological conditions disturb more the vessel maneuvering the relative risk factor is considered to be higher
	Excessive meteorological phenomenon	Implement an effective forecasting regime for predicting suitable weather windows. Awareness that different operations have different weather sensitivities.	higher	Far offshore wind parks are subject to more extreme meteorological phenomenon. As a result of changes in weather conditions, workers on far offshore facilities can become stranded on wind turbines for a longer period of time.
16	Falls and tripping	Planned access and egress procedure Training for emergencies and rescue situations Inspections on the competence of the teams that carry out different tasks.	similar	Because the O&M procedures are similar in both sectors the hazards present a similar risk factor
	Lightning	Providing lightning protection and refuge Providing lightning detection equipment.	similar	
15	Fire and smoke or explosion	Providing the Communication lines for demanding help Training on types, usage and locations of manual fire extinguishers; and any automatic fire extinguishing systems Steps to be taken to control the risk	similar	
	Carbon monoxide release		similar	
	Hazardous substances	Controlling the exposure to the hazardous substance Providing necessary information, instruction or training Management of workplace exposure and, where the risk analysis identifies this requirement.	similar	
	Vessel collision	Providing accurate information about meteorological conditions Monitoring of all marine activities, including movements of vessels in the vicinity; Control of access, and tracking of personnel and vessels	higher	The number of vessels used in the far offshore sector is larger in order to cope with the greater distance to shore Also the maneuvering is more difficult due to harsher weather conditions.
	Vessel capsizing		higher	

		Emergency co-ordination with other sea users and emergency service providers		Larger components make it also more difficult to maneuver increasing the relative risk factor in the far offshore sector.
12	Static discharge	Regular inspection of all electrical equipment Control on the design in concordance with European Codes Assuring that the layout of panels, WTGs and other devices, platforms and substations allow safe access for future inspection and maintenance requirements.	similar	Electrical hazards from O&M procedures inside the turbine present the same dangers either offshore or far offshore The level of risk when performing the operations is considered to be similar
	Loss of consciousness		similar	
	Electrical shock		similar	
	Burns		similar	
	Asphyxiation and death		similar	
	Drowning	Providing safety equipment for emergency intervention Proper planning of subsea operations Providing rapid means of intervention on and under water	similar	During the transfer by either helicopter or CTV and subsea operations the hazards of man overboard and drowning present the same risk factor.
	Man overboard			
	Extreme cold or warm temperatures	Implement an effective forecasting regime for predicting suitable weather windows. Awareness that different operations have different weather sensitivities.	higher	Far offshore wind parks are subject to more extreme meteorological phenomenon.
	Entrapment	Careful planning of all operations which present the hazard of entrapment by assuring the means of escape. Training for managing entrapment situations considering also the diving operations as a possible means of entrapment.	similar	Because the O&M procedures are similar in both sectors the hazard of entrapment presents a similar risk factor
9	Ergonomics	Limit the hours in which workers have to perform their activities in confined spaces	similar	Workers confront awkward postures, which can lead to short term sprains and fatigue, as well as long-term injuries. The procedures are similar so the risk factor is considered to be similar.
	Pollution	Respect prevision in MARPOL convention Keep a strict record on the substances used in the maintenance process like oils and gases which may present a hazard for the environment assuring proper disposal procedures.	similar	Because the O&M procedures are similar in both sectors the hazard of pollution presents a similar risk factor
8	Vibration	Providing properly maintained and suitable tools for the tasks Limiting the duration of exposure to processes which present the risk of vibration. Suitable vessel selection, to lower the impact of vibration forces Appropriate maneuvering of vessels	higher	The risk factor is considered higher in the far offshore sector because: Heavier WT components meaning that the tools used to maneuver present a higher vibration level Because of the meteorological aspects the vessels have a harder time to maneuver
	Failure of sensor and control systems	Regular inspection of sensor and control systems.	similar	

		Implementing a preventive maintenance strategy for the sensors and control systems		
	Noise	Where possible eliminate the source of loud noise by using different types of tools and devices which don't present a noise hazard Limit workers' exposure to noise by reducing the time spent in noisy areas or operations	higher	The risk factor is considered higher in the far offshore sector because: • Heavier WT components meaning that the tools used to maneuver present a higher noise level
4	Stranding	Implement an effective forecasting regime for predicting suitable weather windows. Awareness that different operations have different weather sensitivities. Provide appropriate stranding refuge	higher	The presence of harsher weather conditions favors the conditions for stranding in the far offshore sector. For the same reason the visibility will be affected more so the risk of low visibility becomes higher
	Low visibility		higher	
3	Different safety cultures	Establish communication lines for presenting and homogenizing safety cultures	similar	
	Interference with commercial shipping lines	Proper communication between CTV and other sea users of the designated area Appropriate and efficient surveys on maritime traffic	similar	

Table 16 examines the relative risk factor during the O&M procedures for both offshore and far offshore facilities. While offshore and far offshore wind farms share many common hazards, the far offshore environment presents additional factors which increase in severity and determine an elevate risk factor.

Although the mitigation methods are addressed to reduce the consequence of the hazards, there are a couple of major factors which make the far offshore sector to increase in attention when it comes to safety aspects like:

- Environmental factors

  In the far offshore sector the extreme meteorological phenomenon become more common. The wave height increases, the current force becomes stronger and the visibility decreases. Because of this the transportation procedures become more dangerous. The usage of vessels and helicopters will determine much more troubling working conditions as maneuvering these facilities becomes harder. This decreased maneuverability can determine an elevated relative risk factor as the likelihood and consequences of possible incidents increases in severity.

- WT components are bigger and heavier

  Maneuvering the larger and heavier components means that the personnel is exposed to more disruptive effects of noise and vibration. This means that the levels of noise and vibration have to be carefully monitored and measures need to be taken in order to decrease this harmful exposure. If the hazards cannot be avoided due to engineering reasons the shifts in which the personnel work need to be shortened to a period in which the danger is considered as low as reasonable practicable. The increased size and weight also present additional problems in the transportation procedures. Maneuvering vessels and cranes becomes more difficult with increased loads.

  The combination of the two factors can prove very challenging when trying to address issues related to risk and safety in the Offshore Wind Sector. This could determine very problematic situations when moving further offshore. The relative risk factor of certain hazards like dropped objects, marine incidents or extreme weather incidents increases and the mitigation methods used for the near offshore projects will have to suffer improvements. All these improvements need to keep the risk level at a level which is considered as low as reasonable practicable.

9 Discussion

The following paragraph will discuss how the choices made in this research contributed to making our results more reliable, while also discussing the difficulties and limitation created by the very same. Next follows a discussion of the performed simulation and EM/Risk Management parts, with the purpose of debating whether moving further offshore increases or decreases the overall risk picture. In this regard, the following points will be considered:

- Methods used
- MAINTSYS
- Results

Methods used

The mix method research applied in this study enabled us to combine both qualitative and quantitative methods. This method was selected to achieve more suitable and reliable results, as they complement each other's shortcomings. Though it can be discussed whether it is the best approach. The disadvantages of using mixed methods are that the analysis could become quite superficial. It could be argued that choosing one of these methods would allow us to get a more in-depth study of our subject area. However, we are convinced that being able to understand both the quantitative and qualitative methods views on our subject, gives us a holistic insight to our research. Being able to combine both expert opinion and the use of a simulation software to grasp how far offshore will develop in the future, will give us the best results from both approaches.

MAINTSYS

The operation and maintenance simulation software MAINTSYS applied in this study was provided to us by Michael Bjerrum from Shoreline. The program has proven to be very valuable for interested parties within the industry, hence our interest for the program began. The simulation enabled us to analyze different scenarios regarding offshore and far offshore wind farms. The program is very user friendly and allowed us to go into details with the modification of the scenarios. The simulation is therefore reliant on the data which are inserted in the program. And, as we are dependent on public available data, it could be debated whether the outcome is as reliable as we would have liked it to be. To fully exploit the program, it requires specific data on the desired scenario, in order to get precise results. However, as our focus was primarily on the changes far offshore wind brings, and not on the wind outcome, we feel convinced our simulation replicates closely real conditions. Following is a discussion of the results of our simulation and Risk Management.

Results

Risk Management

Because the Wind Industry is evolving in a rapid pace it is important to take a look at the possible risks that may emerge from this fast development. Being always on the hunt for increased efficiency, the companies operating in the Wind Sector could easily fall into the trap of underestimating the hazards which arise from the action of moving the wind parks further offshore. That's why it is very important to understand the risk and try to develop research scenarios which replicate real conditions as much as possible. Starting with understanding every hazard it is possible to perform a risk assessment and get ideas about the relative risk factor in both Offshore and Far Offshore Sector. Even though most of the hazards are similar, the risk factor is higher in The Far Offshore sector as some parameters like weather conditions and the size of the components make the job of reducing the risk at an ALARP level, a very challenging one.

Nevertheless, the analysis is performed using qualitative methods meaning the data come as a result of a deterministic approach. It could be very interesting if the results could be compared using a probabilistic approach in which the probability of certain hazards developing into incidents could be analyzed. Unfortunately, the process of gathering specific data from the operators is a very difficult one. On top of this, The Far Offshore Wind Sector has been considered for use, only for a few years which makes it very difficult to perform a quantitative risk analysis. The approach is to discover if the risk picture differs a lot when moving further offshore but the methods of comparison use prototype data as not a lot of far offshore wind parks are in use. For that reason, it is important to have a very detailed qualitative analysis until relevant data from the field could be gathered. Further research must be performed using considerations for preparedness and mitigation methods in case of hazardous incidents. They might have as a result that, the mitigation methods must suffer improvements but it is important to know in which extent. Nevertheless, The Far Offshore Sector presents an elevated relative risk factor which needs to be addressed with more attention than The Offshore Sector in order to keep it at a level which is considered as low as reasonable practicable.

Simulation

The simulations have been made under the assumption that the gathered data on failure rates and MTTR is relevant for the offshore, and far offshore location.

When moving further offshore, or far offshore, certain conditions change that can affect the risks in wind farm projects. Some of these stem from changes in location and weather changes, while other are not directly related to going further offshore, but rather the ever-growing size of the wind turbines.

When looking at some of the problem areas that have been identified over the years in the offshore wind industry, it could be assumed that some of these factors would have a larger effect on the failure rates of wind turbines, as the conditions become harsher when moving further offshore. Looking at the wind speeds, it can be expected that there is a 0,1 m/s increase in the mean wind speed, for every 10 km further from shore (See appendix 1). The increase in wind speed will also affect the other weather conditions, such as current and wave height[68]. While these harsher conditions affect the turbines themselves, they will also make it more difficult to access and repair the turbines, due to the limitations of some of the vessels used in industry. This problem is partially solved by using vessels that can handle the tougher conditions, reducing the number of weather days, such as the 2 SOVs Dong plans to use for Hornsea one and two, and other nearby projects.

Another effect of moving further offshore is the increasing water depth. The Hornsea projects will have a water depth in the range of 25 meters at lowest, to 40-67 m depending on which sources are used[42], [43]. The increased depth requires the use of bigger foundations. Though this primarily affects the installation phase, it does also bring some challenges to the O&M phase. All of Hornsea one is being constructed using monopiles for the foundation[42]. For Hornsea two the foundation type has not yet been determined, and monopiles, jacket or gravity foundations are being considered. One of the larger problems with monopile foundations is represented by the problem with grouting. According to [69] 4 out 5 north sea offshore turbines sustained failing grouting connections, with most of them being with monopiles foundations.

While there are factors that can affect failure rates in a negative way, there are also ones that can affect them in a positive way. Over the years the industry has gathered plenty of data on existing wind farms and gained experience on how to apply different maintenance strategies and which components are more likely to fail and cause downtime. While all of this information and data is not available to the public, as previously discussed, we can still speculate as to what they may have learned.

When looking at the development in offshore wind farms over the years, there has been an increase in the overall availability for projects as described in 7.6.3 Analyzing the results, if the availability goes up, it must mean that the downtime is being minimized through more effective O&M. This can be either through more preventive maintenance, more reliable components or a reduction in MTTR, or all of them combined.

Therefore, when trying to estimate values for failure rates there need to be considerations done based on the new conditions faced in far offshore, but also based on the supposed experience the industry has gained over the years. Neither of these approaches were implemented in the simulation, but would be interesting for future analysis, if the simulation was to be built upon.

The data used for determining the inputs for vessels in the simulations, has been made primarily by using vessels specific data input, based on the vessels used at London Array. Inputs such as speeds, significant wave height limitations etc. are based on what technical specification ware available for the vessels.

10 Conclusion

The current methods for handling legislation and standards in the Offshore Wind Industry, is based on individual legislative approaches based on the country the work is being done in, while the standards that are being used are internationally recognised. Most of the regulations regarding safety of workers is covered by standards such as GWO, which dictates what skills the workers should posess. The current development of GWO is based on the current methods and knowhow of the Wind Industry, and is developing alongside the industry. This can lead to situations where the industry develops faster, than the training programs. When it comes to design of vessels there is a dispartity between the sizes of the vessels, which determine whether or not they are subject to conventions such as SOLAS and IMO.

Currently, most of the operation procedures are done onshore, where the maintenance of offshore wind farms, are mostly performed by CTV's. As wind turbines are moving further out, new logistical solutions are needed. Weather conditions and the distance to shore are identified as key factors which can affect O&M procedures when moving further out. Therefore, this requires an adjustment on how previous strategies were handled. A solution could be placing a substation near the sites. This solution is already tested in the Oil and Gas Industry. A substation is also able to take advantage of short weather windows, and achieve a higher level of accessibility to the turbines. Another mitigation strategy for moving far offshore is to improve remote diagnostics, to better anticipate failures. As the majority of the O&M cost is caused by unscheduled corrective maintenance, much of it could be avoided if the preventative maintenance approach was improved.

Using CBS as a way of moddeling the O&M procedures in the Offshore Wind Industry requires accurate data and understanding of the industry. Two simulations were performed. One for London Array, which acted as a reference case for an allready operational Wind Farm, and one for Hornsea one and two, in order to simulate the effects of shared ressources.

The results from the simulations indicate that the London Array simulation is within acceptable limits of the actual conditions reported for London Array, when comparing it to the availability for the project. The simulation of Hornsea project one and two yields less accurate results, which shows a buildup of unresolved work orders over time. The problem with the simulation stems from modelling the use of the HLVs correctly. The simulation at Hornsea project one and two, was used to test shared ressources. This was done by utilizing SOVs which stayed at sea for four weeks at a time, with the CTVs returning to the SOVs, rather than the harbor. This mimics the use of an offshore hub or substation. The CTVs did see a small reduction in downtime, due to no available vessels and weather conditions.

With the help of the risk analysis methods it is possible to identify the major hazards that have an influence on the relative risk factor for both the offshore and the far offshore wind projects. The likelihood and consequences of the hazards are assessed, allowing the option of evaluating the danger they represent for the O&M procedures offshore. With the help of a risk matrix the hazards are prioritized and examined to understand how they are affected by existing mitigation methods. It can be concluded that the Far Offshore Sector shares the same hazards as the Offshore Sector, the only difference being represented by the increased severity determined by factors such as weather conditions or the size of components. Because of this increased severity of the consequences the same hazards will present an elevated risk factor in the Far Offshore Sector. This leads to the statement that the relative risk factor of certain hazards like dropped objects, marine incidents or extreme weather incidents increases and the mitigation methods used for the regular offshore projects will have to suffer improvements. Of course, all these improvements need to keep the risk level at a value which is considered as low as reasonable practicable.

Regarding the Emergency Management Process, it can be concluded that the policy and objectives share the same ideas in both sectors. The difference comes when trying to determine a protocol applicable for the response procedures and actual interventions. There are some parameters that change in the Far Offshore Sector like distance to shore and weather conditions. These parameters are highly interactive with each other. The weather conditions become harsher when moving further away from the coastline. This aspect combined with the different distance to shore make the far offshore interventions more challenging and special care needs to be taken also when following predetermined protocols. Because the conditions change rapidly in the far offshore sector, even if the availability exists some missions can be aborted because of rapidly changing conditions like sea state or visibility.

To conclude, a change in risk picture related to severe weather conditions and the increased size of wind turbines can be seen when moving further offshore. The use of computer based simulations can help analyze far offshore O&M procedures, but the input of the data can determine the accrucy of the results.

Bibliography

[1] "Fossil fuel energy consumption (% of total) | Data." [Online]. Available: https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS. [Accessed: 01-Nov-2017].

[2] "Renewable energy - European Commission." [Online]. Available: https://ec.europa.eu/energy/en/topics/renewable-energy. [Accessed: 31-Oct-2017].

[3] "Wind energy is crucial for the EU's renewable energy targets - European Commission." [Online]. Available: https://ec.europa.eu/energy/en/news/wind-energy-crucial-eus-renewable-energy-targets. [Accessed: 31-Oct-2017].

[4] A. R. Henderson, "Offshore wind in Europe. Walking the tighttrope to success.," *Refocus*, vol. 3, no. 2, pp. 14–17, 2015.

[5] "Offshore : Danish Wind Industry Association." [Online]. Available: http://www.windpower.org/en/policy/offshore.html. [Accessed: 26-Oct-2017].

[6] "Boundary Pushers: The true impact of technology on the offshore industry | Windpower Monthly." [Online]. Available: http://www.windpowermonthly.com/article/1440416/boundary-pushers-true-impact-technology-offshore-industry. [Accessed: 08-Nov-2017].

[7] "ESVAGT bruger O&M simulationsprogram fra Shoreline til at optimere... - ESVAGT A/S." [Online]. Available: http://nyt.esvagt.com/pressreleases/esvagt-bruger-o-og-m-simulationsprogram-fra-shoreline-til-at-optimere-sov-loesninger-2002352. [Accessed: 10-Jan-2018].

[8] DEA, "Vindmøller i Danmark," 2009.

[9] "Distance to shore and water depth." [Online]. Available: http://windmonitor.iwes.fraunhofer.de/windmonitor_en/4_Offshore/2_technik/2_Kuestenentfernung_und_Wassertiefe/. [Accessed: 08-Nov-2017].

[10] Danish Energy Agency, "Danish Experiences from Offshore Wind Development," pp. 1–38, 2015.

[11] M. Ferrer *et al.*, "Weak relationship between risk assessment studies and recorded mortality in wind farms," *J. Appl. Ecol.*, vol. 49, no. 1, pp. 38–46, Feb. 2012.

[12] E. Bash, "Explaining NIMBY Opposition to Wind Power," *PhD Propos.*, vol. 1, no. 9, pp. 1689–1699, 2015.

[13] "Study area in the North Sea. (A) Water depth and distribution of..." [Online]. Available: https://www.researchgate.net/figure/Study-area-in-the-North-Sea-A-Water-depth-and-distribution-of-sandeel-grounds-B_303896472. [Accessed: 28-Dec-2017].

[14] European Environment Agency, *Europe's onshore and offshore wind energy potential*, vol. 6, no. 6. 2009.

[15] "Wind costs heading in the right direction | Windpower Monthly." [Online]. Available: https://www.windpowermonthly.com/article/1421836/wind-costs-heading-right-direction. [Accessed: 02-Jan-2018].

[16] "Maintenance Strategies for Large Offshore Wind Farms," *Energy Procedia*, vol. 24, pp. 281–288, Jan. 2012.

[17] A. R. Henderson, C. Morgan, B. Smith, H. C. Sørensen, R. J. Barthelmie, and B. Boesmans, "Offshore Wind Energy in Europe- A Review of the State-of-the-Art," *Wind Energy*, vol. 6, no. 1, pp. 35–52, Jan. 2003.

[18] "Joint Venture (JV)." [Online]. Available: https://www.investopedia.com/terms/j/jointventure.asp. [Accessed: 02-Jan-2018].

[19] "Is this the future? Dutch plan vast windfarm island in North Sea | Environment | The Guardian." [Online]. Available: https://www.theguardian.com/environment/2017/dec/29/is-this-the-future-dutch-plan-vast-windfarm-island-in-north-sea. [Accessed: 02-Jan-2018].

[20] "Safety, Reliability and Risk Analysis: Beyond the Horizon - Google Bøger." [Online]. Available: https://books.google.dk/books?id=u1DvBQAAQBAJ&pg=PA1177&lpg=PA1177&dq=as+offshore+wind+farms+grow+build+further+from+shore&source=bl&ots=nAFR8AChU3&sig=YrzKF6lmbPoK9Bgx-CENfesMctQ&hl=da&sa=X&ved=0ahUKEwiWi5WnzsvYAhXidpoKHTZGD-IQ6AEITjAI#v=onepage&q=as o. [Accessed: 09-Jan-2018].

[21] “The future of offshore risk management - Offshore.” [Online]. Available: http://www.offshore-mag.com/articles/print/volume-76/issue-5/departments/beyond-the-horizon/the-future-of-offshore-risk-management.html. [Accessed: 09-Jan-2018].

[22] European Agency for Safety and Health at Work, *Occupational safety and health in the wind energy sector*. 2013.

[23] “Esvagt indgår aftale med Dong Energy.” [Online]. Available: http://shippingwatch.dk/Offshore/article9987298.ece. [Accessed: 03-Jan-2018].

[24] Danish Maritime Authority and DNV-GL, “Summery report on North Sea regulations and standards,” no. December, 2015.

[25] “Basic Safety Training (BST) (Onshore / Offshore) Version 10,” no. May, 2017.

[26] “Interview at AMU 21.12.17.m4a - Google Drive.” [Online]. Available: https://drive.google.com/file/d/1oe5k8p6DOUqLPjzT9TUZkZ8CiGF14ylE/view. [Accessed: 21-Dec-2017].

[27] “Global Wind Organisation.” [Online]. Available: http://www.globalwindsafety.org/. [Accessed: 09-Jan-2018].

[28] L. W. Smith, P. Manager, and S. Technology, “Stakeholder Analysis : A Pivotal Practice of Successful Projects,” 2000.

[29] J. De Vivero, “An exercise in Stakeholder Analysis for a hypothetical offshore wind farm in the Gulf of Cadix,” *Spicosa-Inline.Databases.Eucc-D.De*, pp. 1–32, 2007.

[30] “The end of the line for today’s wind turbines - Renewable Energy Focus.” [Online]. Available: http://www.renewableenergyfocus.com/view/43817/the-end-of-the-line-for-today-s-wind-turbines/. [Accessed: 09-Jan-2018].

[31] GL Garrad Hassan, “A guide to UK offshore wind operations and maintenance,” *Scottish Enterp. Crown Estate*, p. 42, 2013.

[32] M. Windows *et al.*, *Wind Energy Explained Theory, Design and Application*, vol. XXXIII, no. 2. 2002.

[33] A. Williams, “Improving wind farm availability Better performance and increased ROI through accurate availability measurement Improving wind farm availability.”

[34] “Windea La Cour - Ulstein.” [Online]. Available: https://ulstein.com/references/windea-la-cour. [Accessed: 28-Nov-2017].

[35] “Offshore O&M takes the higher road | Windpower Monthly.” [Online]. Available: https://www.windpowermonthly.com/article/1076487/offshore-o-m-takes-higher-road. [Accessed: 28-Nov-2017].

[36] “Fatal Injuries in Offshore Oil and Gas Operations — United States, 2003–2010.” [Online]. Available: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6216a2.htm. [Accessed: 28-Nov-2017].

[37] H. Level and R. Helideck, “Helideck and accommodation facilities on offshore platforms for wind farms,” no. June, 2015.

[38] “Accommodation Module for Horns Rev II | Solution | Semco Maritime | State of Green.” [Online]. Available: https://stateofgreen.com/en/profiles/semco/solutions/accommodation-module-for-horns-rev-ii. [Accessed: 29-Nov-2017].

[39] “About - Shoreline.” [Online]. Available: http://www.shoreline.no/about. [Accessed: 09-Jan-2018].

[40] I. Dinwoodie, O.-E. V. Endrerud, M. Hofmann, R. Martin, and I. B. Sperstad, “Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms,” *Wind Eng.*, vol. 39, no. 1, pp. 1–14, 2015.

[41] 4C Offshore Ldt, “London Array - 4C Offshore.” [Online]. Available: http://www.4coffshore.com/windfarms/london-array-phase-1-united-kingdom-uk14.html. [Accessed: 09-Jan-2018].

[42] 4C Offshore Ldt, “Hornsea Project One - 4C Offshore.” [Online]. Available: http://www.4coffshore.com/windfarms/hornsea-project-one-united-kingdom-uk81.html. [Accessed: 09-Jan-2018].

[43] 4C Offshore Ldt, “Hornsea Project Two - 4C Offshore.” [Online]. Available: http://www.4coffshore.com/windfarms/hornsea-project-two-gb-uk1u.html. [Accessed: 09-Jan-2018].

[44] “UPDATE - Dong’s reconfigured Hornsea wind zone off UK may host up to 6 GW.” [Online]. Available: https://renewablesnow.com/news/update-dongs-reconfigured-hornsea-wind-zone-off-uk-may-host-up-to-6-gw-

516032/. [Accessed: 09-Jan-2018].

[45] "Dong Energy plans world's largest windfarm repair hub at Grimsby | Business | The Guardian." [Online]. Available: https://www.theguardian.com/business/2016/sep/22/dong-energy-windfarm-maintenance-hub-grimsby. [Accessed: 09-Jan-2018].

[46] "An Introduction to Crew Transfer Vessels - 4C Offshore." [Online]. Available: http://www.4coffshore.com/windfarms/an-introduction-to-crew-transfer-vessels-aid2.html. [Accessed: 09-Jan-2018].

[47] "ESVAGTS VINDMØLLESKIB HAR SWIMMING POOL?! | WorldCareersTV - Det Blå Danmark - YouTube." [Online]. Available: https://www.youtube.com/watch?v=GF6f1IFTToc. [Accessed: 09-Jan-2018].

[48] I. Dinwoodie, "Modelling the operation and maintenance of offshore wind farms," 2017. [Online]. Available: https://energyhub.theiet.org/users/56821-iain-dinwoodie/posts/18580-operation-and-maintenance-of-offshore-wind-farms.

[49] R. Martin, I. Lazakis, S. Barbouchi, and L. Johanning, "Sensitivity analysis of offshore wind farm operation and maintenance cost and availability," *Renew. Energy*, vol. 85, pp. 1226–1236, 2016.

[50] L. Array, "London Array: the world's largest operational offshore wind farm," *Eng. Technol. Ref.*, no. January, pp. 1–5, 2015.

[51] "Is seafarer fatigue understood in the offshore wind industry?" [Online]. Available: http://www.owjonline.com/news/view,is-seafarer-fatigue-understood-in-the-offshore-wind-industry_42682.htm. [Accessed: 09-Jan-2018].

[52] 4C Offshore, "4C Offshore," 2016. [Online]. Available: http://www.4coffshore.com/. [Accessed: 09-Jan-2018].

[53] B. Hagen, I. Simonsen, M. Hofmann, and M. Muskulus, "A multivariate Markov weather model for OandM simulation of Offshore wind parks," *Energy Procedia*, vol. 35, no. 1876, pp. 137–147, 2013.

[54] "London Array Simulation - YouTube." [Online]. Available: https://www.youtube.com/watch?v=XdDYg_3A1Cs&feature=youtu.be. [Accessed: 09-Jan-2018].

[55] "Hornsea one and two Simulation - YouTube." [Online]. Available: https://www.youtube.com/watch?v=vy2ssQYfyNE&feature=youtu.be. [Accessed: 09-Jan-2018].

[56] N. Emsholm, "Reliability in operations and maintenance – Experiences from the offshore wind sector," *Agenda*, no. October, 2009.

[57] "London Array | Renewable Energy Record Achieved at London Array." [Online]. Available: http://www.londonarray.com/project/renewable-energy-record-achieved-at-london-array/. [Accessed: 09-Jan-2018].

[58] 4C Offshore Ldt, "London Array - 4C Offshore." [Online]. Available: http://www.4coffshore.com/windfarms/london-array-united-kingdom-uk14.html.

[59] S. M. Certificate, "Revised ISM Code Effective as from 1 January 2015 INTERNATIONAL MANAGEMENT CODE FOR THE SAFE OPERATION OF SHIPS (INTERNATIONAL SAFETY MANAGEMENT (ISM) CODE)," no. January, 2015.

[60] "Embracing Web 2.0 to Manage Emergencies - Veoci." [Online]. Available: https://blog.veoci.com/embracing-web-2-0-to-manage-emergencies/. [Accessed: 09-Jan-2018].

[61] International Maritime Organization, "ISPS Code," pp. 1–131, 2003.

[62] A. Sanderson and R. Elvin, "Risk Management and Health & Safety The Hazards and Risks from Wind Energy."

[63] OPITO, "OPITO APPROVED STANDARD Offshore Emergency Response Team Member Training and Competence Assessment," pp. 1–46, 2014.

[64] EWEA, "Working the Wind Safely. Guidelines on Emergency Arrangements Including First Aid," no. December, 2013.

[65] RenewableUK, "Offshore Wind and Marine Energy Health and Safety Guidelines," no. 2, 2014.

[66] "5 Types of Risk Treatment - Simplicable." [Online]. Available: https://simplicable.com/new/risk-treatment. [Accessed: 09-Jan-2018].

[67] "5 Types of Risk Treatment - Simplicable." .

[68] "Currents, Waves, and Tides: The Ocean in Motion | Smithsonian Ocean Portal." [Online]. Available: http://ocean.si.edu/ocean-news/currents-waves-and-tides-ocean-motion. [Accessed: 09-Jan-2018].

[69] N. Resources and E. Weather, "About NR & E Extreme Weather Impacts on Offshore Wind Turbines : Lessons Learned," pp. 1–10, 2017.

[70] "denmark.png (2551×1453)." [Online]. Available: http://www.msp-platform.eu/sites/default/files/country/denmark.png. [Accessed: 29-Dec-2017].

[71] "Construction Begins On First Offshore Transfer Vessel For U.S." [Online]. Available: https://www.maritime-executive.com/article/construction-beings-on-first-offshore-transfer-vessel-for-us. [Accessed: 09-Jan-2018].

[72] "Ship Photos of the Day - World's First X-Stern 'Windea La Cour' Goes to Work at North Sea Wind Farm – gCaptain." [Online]. Available: http://gcaptain.com/worlds-first-x-stern-windea-la-cour-goes-to-work-at-north-sea-wind-farm/. [Accessed: 09-Jan-2018].

[73] "The world's largest offshore windfarm is in operation - Øglænd system." [Online]. Available: https://www.oglaend-system.com/news/latest-news/the-world-s-largest-offshore-windfarm-is-in-operation-article25711-832.html. [Accessed: 09-Jan-2018].

[74] "An Introduction to Crew Transfer Vessels - 4C Offshore." [Online]. Available: http://www.4coffshore.com/windfarms/an-introduction-to-crew-transfer-vessels-aid2.html.

[75] "Dong Energy plans world's largest windfarm repair hub at Grimsby | Business | The Guardian." .

[76] "Offshore Wind | Heavy Lift Specialist." [Online]. Available: http://www.heavyliftspecialist.com/tag/offshore-wind/. [Accessed: 09-Jan-2018].

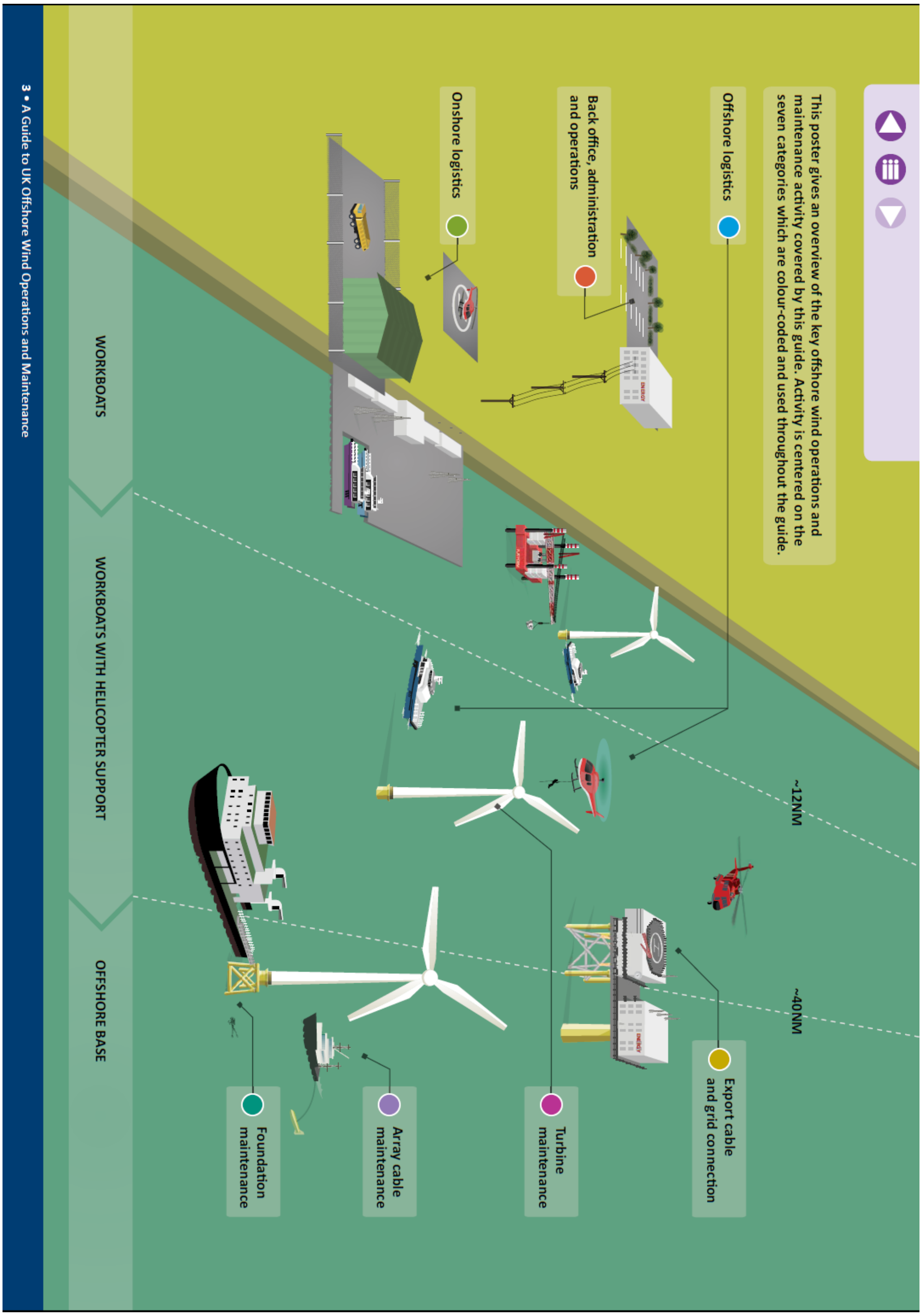
List of Figures

List of Tables

AALBORG UNIVERSITY
DENMARK

Appendix

Appendix 1



https://www.thecrownestate.co.uk/media/5419/ei-km-in-om-om-062013-guide-to-uk-offshore-wind-operations-and-maintenance.pdf

Appendix 2

Weather conditions for offshore wind in the North Sea

We are working on a project which investigates the analysis of two seperate wind parks situated in the north sea at 20 km and 100 km away from the danish coast line. For the analysis, we need to research on relevent weather conditions which influence the wind parks like fx. Wave height , wind speed etc.

At the moment we are working with a simulation software which allows us to use weather input based on historical weather measurements. We need to simulate weather conditions for a period of 10 years, and we are able to do this with the help of a randomizer. We would therefore like to know if you can help us with your expert knowledge in obtaining weather data for a period of ten years relevant for our wind park positioning in the North Sea. In addition to this we would like to ask you some questions regarding the transition from near shore to far offshore. **(Red text is the answers from Senior Wind Specialist Miriam Marchante from Dong)**

- How does the weather conditions change when moving further offshore from (20 km to 100 km). You can assume an increase of 0.1m/s every 10km
- Could you say there's more risk associated with far offshore projects than near shore projects for (personnel and vessels). Definitively, yes. Weather conditions will be rougher. This means the number of weather windows to do actual work will be limited.
- Do you see the climate change affecting far offshore projects in the future. Well, this is unclear. I can give you my personal impression. In my view, extreme events will be more frequent, so counting for high wind speeds and extreme waves may become more relevant for the extreme loads cases and foundations design. On the other hand, it happens that when wind speed is above 25m/s, turbines are shut down, so in theory, it is only the integrity of the foundation what may be affected. In Taiwan and Japan, turbines offshore have experienced earthquakes, typhoons and they withstood those extreme conditions.
- What benefits are there for moving further offshore (wind speed etc.) Higher wind speed and higher production. Remember power varies with WS^3, so minor changes in WS have a huge impact on production.
- Are there any disadvantages moving far offshore (weather related) as said before, you may have less weather windows, higher waves, and also longer time for the technicians to reach the wind turbines, so higher down time and a loss of production as a consequence.
- Do you have weather data from the north sea (like the table below). We have but those are confidential because they are part of our developments. I suggest you use FINO1 or FINO 3 met mast. They are publicly available. http://www.fino1.de/en/research/measurement/117-meteorological-measurements

http://www.fino3.de/en/

Day 1 is 30-04-2011. The reference date indicates how many days there are between day 1 and the day the action begins

Vessel	Start date	End Date	Contractor	Service days	Reference date
CTV	30-04-2011	03-12-2015	Gardline Enviornmental Ltd	1679	1
CTV	01-05-2011	13-11-2012	MPI Workboats	563	2
CTV	01-06-2011	21-08-2011	Turbine Transfers Limited	82	33
CTV	01-07-2011	26-09-2014	Turbine Transfers Limited	1184	63
CTV	03-07-2011	31-12-2012	Danish Offshore Transport	548	65
CTV	06-07-2011	30-08-2011	Maritime Craft Services Ltd	56	68
CTV	01-08-2011	05-11-2011	P&O Martime Services	97	94
CTV	01-10-2011	01-11-2014	Turbine Transfers Limited	1128	155
CTV	01-11-2011	30-11-2012	Gardline Enviornmental Ltd	396	186
CTV	01-11-2011	12-02-2013	Gardline Enviornmental Ltd	470	186
CTV	06-11-2011	30-06-2012	P&O Martime Services	238	191
CTV	11-12-2011	27-06-2016	Gardline Enviornmental Ltd	1661	226
CTV	01-02-2012	31-03-2013	Fred. Olsen Windcarrier AS	425	278
CTV	01-02-2012	12-10-2012	Windcat Workboats Ltd	255	278
CTV	01-02-2012	30-03-2012	Windcat Workboats Ltd	59	278
CTV	11-03-2012	29-04-2013	Fred. Olsen Windcarrier AS	415	317
CTV	01-04-2012	17-01-2013	Windcat Workboats Ltd	292	338
CTV	01-04-2012	30-10-2012	Dalby Offshore Service Ltd	213	338
CTV	01-04-2012	16-09-2012	Windcat Workboats Ltd	169	338
CTV	02-04-2012	30-10-2012	Dalby Offshore Service Ltd	212	339
CTV	15-04-2012	12-02-2013	Fred. Olsen Windcarrier AS	304	352
CTV	15-04-2012	28-08-2013	Fred. Olsen Windcarrier AS	501	352
CTV	20-04-2012	27-09-2013	Northern Offshore Services A/S	526	357
CTV	23-04-2012	30-09-2012	Dalby Offshore Service Ltd	161	360
CTV	29-04-2012	02-06-2013	Cwind Ltd	400	366
CTV	02-05-2012	01-07-2012	Turbine Transfers Limited	61	369
CTV	13-05-2012	14-04-2013	Cwind Ltd	337	380
CTV	01-06-2012	23-11-2015	Gardline Enviornmental Ltd	1271	399
CTV	14-06-2012	21-11-2013	ASP Workboats Ltd	526	412
CTV	17-06-2012	24-10-2013	Northern Offshore Services A/S	495	415
CTV	08-07-2012	19-07-2013	Turbine Transfers Limited	377	436
CTV	14-07-2012	23-08-2012	Turbine Transfers Limited	41	442
CTV	01-09-2012	23-04-2013	Northern Offshore Services A/S	235	491
CTV	01-09-2012	31-07-2013	Offshore Turbine Services	334	491
CTV	11-09-2012	10-06-2013	ASP Workboats Ltd	273	501
CTV	16-09-2012	24-05-2013	Cwind Ltd	251	506
CTV	01-10-2012	20-03-2013	Northern Offshore Services A/S	171	521
CTV	14-10-2012	24-10-2013	Enviroserve	376	534
CTV	30-10-2012	16-01-2013	Gardline Enviornmental Ltd	79	550
CTV	30-10-2012	21-10-2013	Enviroserve	357	550
CTV	01-11-2012	30-03-2013	Northern Offshore Services A/S	150	552
CTV	12-11-2012	23-04-2013	Offshore Wind Power Marine Services Ltd	163	563
CTV	09-12-2012	16-12-2012	Turbine Transfers Limited	8	590
CTV	09-12-2012	23-04-2013	Northern Offshore Services A/S	136	590

CTV	01-02-2013	14-07-2013	Excel Marine Services	164	644
CTV	06-03-2013	30-03-2013	Ocean Wind Marine Ltd	25	677
CTV	13-03-2013	16-07-2013	MPI Workboats	126	684
CTV	01-05-2013	19-06-2013	TP Offshore	50	733
CTV	29-05-2013	17-06-2013	Cwind Ltd	20	761
CTV	01-07-2013	23-08-2013	East Coast Charters Ltd	54	794
CTV	01-07-2013	17-08-2013	Dalby Offshore Service Ltd	48	794
CTV	06-07-2013	30-10-2013	East Coast Charters Ltd	117	799
CTV	15-07-2013	02-09-2013	East Coast Charters Ltd	50	808
CTV	30-07-2013	10-08-2013	Turbine Transfers Limited	12	823
CTV	18-08-2013	24-06-2014	Gardline Enviornmental Ltd	311	842
CTV	18-09-2013	21-05-2014	Turbine Transfers Limited	246	873
CTV	05-01-2014	27-01-2014	Maritime Craft Services Ltd	23	982
CTV	16-01-2014	14-04-2014	Gardline Enviornmental Ltd	89	993
CTV	02-04-2014	09-11-2014	Gardline Enviornmental Ltd	222	1069
CTV	01-05-2014	30-12-2014	Cwind Ltd	244	1098
CTV	06-05-2014	31-10-2014	Cwind Ltd	179	1103
CTV	15-05-2014	27-08-2014	Enviroserve	105	1112
CTV	04-08-2014	21-08-2014	Windpower Support Limited	18	1193
CTV	30-08-2014	04-09-2014	Turbine Transfers Limited	6	1219
CTV	11-09-2014	30-10-2014	Enviroserve	50	1231
CTV	29-09-2014	27-05-2015	Turbine Transfers Limited	241	1249
CTV	15-10-2014	06-11-2014	Cwind Ltd	23	1265
CTV	29-10-2014	29-11-2014	Gardline Enviornmental Ltd	32	1279
CTV	07-11-2014	30-06-2015	Turbine Transfers Limited	236	1288
CTV	03-12-2014	11-01-2015	Cwind Ltd	40	1314
CTV	05-12-2014	16-06-2015	Dalby Offshore Service Ltd	194	1316
CTV	06-01-2015	25-01-2015	Cwind Ltd	20	1348
CTV	21-01-2015	30-06-2015	Turbine Transfers Limited	161	1363
CTV	06-03-2015	04-10-2015	Spectrum Offshore Limited	213	1407
CTV	12-04-2015	30-04-2015	Gardline Enviornmental Ltd	19	1444
CTV	27-04-2015	08-06-2015	Windwave Workboats	43	1459
CTV	18-06-2015	19-06-2015	Gardline Enviornmental Ltd	2	1511
CTV	19-06-2015	30-07-2016	Cwind Ltd	408	1512
CTV	29-06-2015	20-04-2016	Cwind Ltd	297	1522
CTV	11-07-2015	18-08-2015	Gardline Enviornmental Ltd	39	1534
CTV	30-07-2015	31-01-2016	Gardline Enviornmental Ltd	186	1553
CTV	04-09-2015	12-09-2015	Cwind Ltd	9	1589
CTV	23-11-2015	24-11-2015	Dalby Offshore Service Ltd	2	1669
CTV	25-11-2015	23-01-2016	Windcat Workboats Ltd	60	1671
CTV	09-02-2016	30-07-2016	Gardline Enviornmental Ltd	173	1747
CTV	20-02-2016	26-02-2016	Windcat Workboats Ltd	7	1758
CTV	03-04-2016	30-07-2016	Cwind Ltd	119	1801
CTV	06-04-2016	28-05-2016	Windcat Workboats Ltd	53	1804
CTV	01-06-2016	09-09-2016	Windcat Workboats Ltd	101	1860
CTV	04-06-2016	13-09-2016	Spectrum Offshore Limited	102	1863
CTV	17-06-2016	21-06-2016	Gardline Enviornmental Ltd	5	1876

CTV	27-06-2016	30-09-2016	Windcat Workboats Ltd	96	1886
CTV	29-06-2016	15-10-2016	Sima Charters	109	1888
CTV	19-07-2016	16-11-2016	Ocean Wind Marine Ltd	121	1908
CTV	20-07-2016	28-07-2016	Excel Marine Services	9	1909
CTV	10-08-2016	30-09-2016	Windcat Workboats Ltd	52	1930
CTV	26-08-2016	31-01-2017	Windcat Workboats Ltd	159	1946
CTV	16-09-2016	21-09-2016	Windcrew Workboats	6	1967
CTV	19-12-2016	19-02-2017	Spectrum Offshore Limited	63	2061
CTV	01-02-2017	18-09-2017	Windcat Workboats Ltd	230	2105
CTV	14-03-2017	05-04-2017	Windcat Workboats Ltd	23	2146
CTV	30-03-2017	30-09-2017	Trinity Marine Services	185	2162
CTV	04-04-2017	06-11-2017	Cwind Ltd	217	2167
CTV	07-04-2017	22-07-2017	Windcat Workboats Ltd	107	2170
CTV	17-04-2017	26-05-2017	MPI Workboats	40	2180
CTV	06-05-2017	26-05-2017	Cwind Ltd	21	2199
CTV	09-05-2017	10-06-2017	Cwind Ltd	33	2202
CTV	23-05-2017	20-06-2017	Cwind Ltd	29	2216
CTV	29-06-2017	06-08-2017	Cwind Ltd	39	2253
CTV	20-07-2017	28-07-2017	Excel Marine Services	9	2274
CTV	01-09-2017	31-10-2017	Sima Charters	61	2317
CTV	18-09-2017	30-11-2017	Windcat Workboats Ltd	74	2334

Heavy Lift V	**Start date**	**End Date**	**Contractor**	**Service days**	**Reference date**
HLV	01-02-2011	30-04-2011	Red7Marine Ltd	89	1
HLV	16-06-2013	19-06-2013	ZITION A/S	4	867
HLV	04-07-2013	12-11-2013	Hyperbaric Consult ApS	132	885
HLV	07-05-2014	22-09-2014	Menas UK	139	1192
HLV	06-10-2014	07-10-2014	A2SEA A/S	2	1344
HLV	27-04-2015	11-05-2015	A2SEA A/S	15	1547
HLV	06-06-2015	08-06-2015	A2SEA A/S	3	1587
HLV	02-12-2015	02-12-2015	Iceni Marine Services	1	1766
HLV	16-05-2016	18-05-2016	ZITION A/S	3	1932
HLV	15-09-2016	21-09-2016	ZITION A/S	7	2054
HLV	28-01-2017	30-06-2017	A2SEA A/S	154	2189