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Western Norway
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MASTER'S THESIS

Methods for decommission of offshore wind parks on the basis of the knowledge from the oil- and gas industry.

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24th of May 2019.

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of the knowledge from the oil- and gas industry.



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Methods for decommissioning of offshore wind parks on the basis
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Master thesis in Maritime Operations

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Preface

This thesis has been the final work in a master's degree in Maritime Operations at the Western Norway University of Applied Sciences and is credited 30 ETC points.

The background for this thesis is the project namely labeled *DecomTools* which is funded by the EU in the programme "*Interreg VB North Sea Region programme*".

DecomTools is led by Marcus Bentin from Hochschule Emden/Leer of Applied Sciences in Germany. Jens Christian Lindaas and Andrés Olivares Lopez are the leading figures on the team from Western Norway University of Applied Sciences. The work on this thesis has been mostly literature review and reasoning, however, visiting and discussing with local companies that have knowledge of similar offshore decommission has also been a part of the process.

It has been exciting and enjoyable to be able to write a master's thesis regarding an area of the industry that is just starting to develop.

Acknowledgements

I own a great deal of thank-you's and appreciations to my internal supervisor, Jens Christian Lindaas. Heavy in experience from the subsea- and offshore industry, he led this project with a steady hand. He has survived two major projects supervising me the last year – thank you!

Also, I would like to thank fellow master student, lunch-mate and *DecomTools* team member Børre Mæland for his knowledge which I have extremely well benefitted from – thank you!

In addition, the team owes a lot of appreciation to the local companies for allowing us to visit and sharing their valuable experiences from offshore decommission – thank you DeepOcean, ReachSubsea, Kværner and AF Decom!

Summary

The decommission of offshore wind farms is a relatively new field in the renewable energy area and has yet to be fully industrialized. Through the EU-project Interreg VB North Sea Region programme and DecomTools, this thesis has had a goal of looking into the bigger picture of the decommission process of offshore wind turbines and addressing alternative approaches to methods of dismantling today.

The thesis has been conducted as both literature studies of how operators and owners of today are planning to do the future decommission on existing farms, though also discussing and participating at a workshop with local offshore, subsea and decommission companies.

The reverse installation has been the base case of how the operators of today's wind farms are planning to do it, though this will (even according to them) most likely change as we are able to produce more economical and sustainable methods of removal.

Alternative approaches found to the reverse installation, might be to cut of the blades by the root, plug and make the tower watertight to be able to float it thus making a towing possible. This can ease the decommission operation of several vessel days as the big heavy-lift vessels will be relieved of travelling to and from the shore dismantling-facilities several times throughout the entire operation.

Additionally, findings show that we do not have any sufficient methods of recycling the composite wind turbine blades used, and that this is one of the biggest issues on how to ensure the wind turbines stay green and sustainable. Consequently, at the end of the thesis there is a selection of subjects for future research.

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Abbreviations

Abbreviation	Description
OWT	Offshore Wind Turbine
HVL	Høgskulen på Vestlandet
EU	The European Union
DECC (UK)	The Department of Energy & Climate Change – UK
IMO	International Maritime Organization
UNCLOS	United Nations Convention on the Law of the Sea
EEZ	Exclusive Economic Zone
mbsf.	Meters below the seafloor
MW	Mega Watts
TP	Transition Piece
UXO	Unexploded Ordnance
PTV	Personnel Transport Vessel
WOW	Waiting on Weather
PSV	Platform Supply Vessel
HLV	Heavy-lift vessel

1 Introduction

The aim of this chapter is to introduce the research question and the author's interpretation of it. Stating which methods have been used to solve these questions and give the reader background knowledge on the DecomTools-project, European wind-industry regulations and offshore wind turbines.

1.1 Research Question

The ambition of this thesis is to explore and review the methods for decommission of offshore wind parks, on the basis of the knowledge that can be found in the oil- and gas industry.

Thus, the author's interpretation of this is to look at the installation process of *offshore wind turbines* (OWT) – where a preliminary decommission process of a wind farm planned for decommission in approximately 2035 will be described to enhance the understanding of how to remove it most efficiently.

This thesis will further challenge what is the current practices of decommission in the industry, hence formulate, describe and discuss alternative methods of removal. A conclusion will be drawn on the premise of what is discussed, and which recommendations are made, in reference to today's planned methods.

1.2 Research Methods

The approach that has been taken to solve the research question:

- Literature studies.
- Visiting and discussing with local companies that have experience from subsea and/or offshore decommission.
- Debating within the *DecomTools* team and workshop.

1.3 Background

Offshore wind park decommissions (as well the use of wind as an efficient energy source) is a nascent sector of the energy industry, that in the next few decades is assumed to have an outburst in the technological development and methodology of installation and dismantling.

Both on the basis of how the commission/decommission will be done and the costs related to it, the technology-led opportunities are substantial. Also, the reduction of CO₂ emissions is an important goal of the project. The European Union want to be a leading part of this and is coordinating research through the scope of the *DecomTools* project¹ and the *Interreg VB North Sea Region programme*.

Detailed overall project objectives are; optimization for dismantling offshore wind energy structures, develop new logistical concepts for dismantling, develop new recycling concepts for dismantling and foster the market uptake of the newly developed solutions.

However, here in Haugesund, the team will focus on this defined statement:

Use the methods and experiences from decommissioning of offshore installations and apply this in connection with decommission of offshore wind farms, as well as we will be looking at new methods and vessels.

Most wind turbines have a designed and certified service life of 20-25 years [1]. Illustrated below (figure 1) by DNV GL, we can observe that at the end of service life, they either have to be decommissioned or life-time has to be extended (usually through repowering).

¹ Appendix 8.1 - Programme of DecomTools.

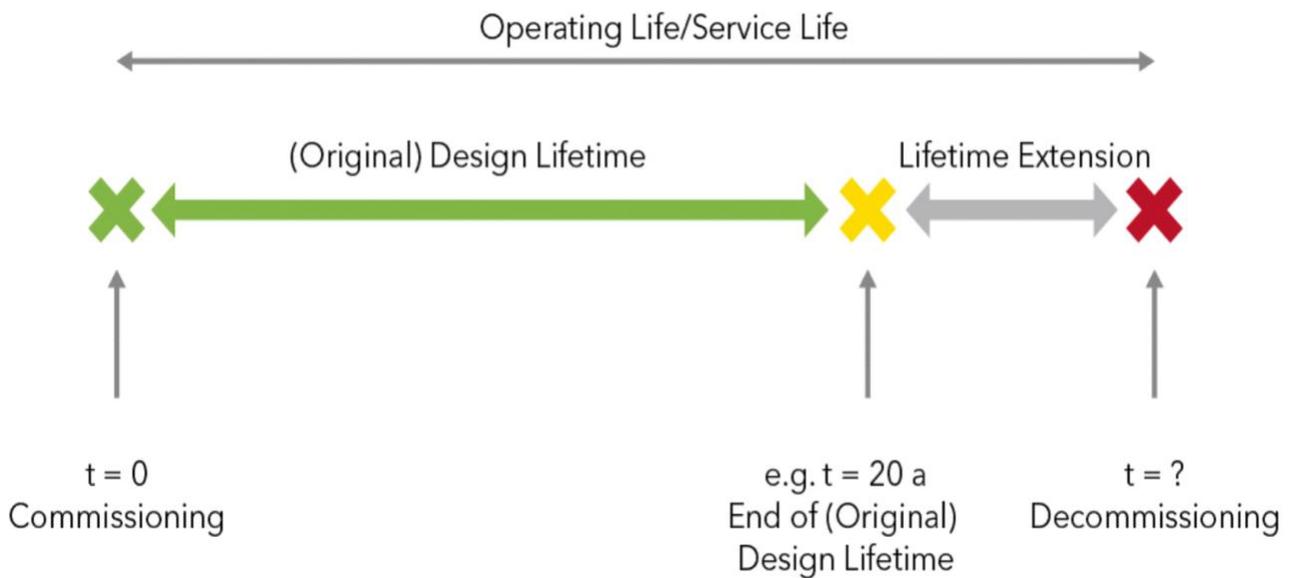


Figure 1: Lifetime extension of OWT [24]. Downloaded from page 10 in DNVGL-report 20th of January.

The *repowering*, or *updating*, of the turbines, can either be completed through replacing a number of old turbines with fewer, yet higher capacity turbines. Another possibility is to swap original parts with new, more efficient solutions. The repowering might be a suitable option if the area's wind regime is proven favorable. The area a wind park is based on will often be contracted/leased for 50 years. Though, the repowering cannot progress endlessly.

The wear, tear and corrosion of the components and supporting structures over a long period of time will become considerable. Fatigue develops both from the external factors like wind and waves, but also internally from moment created by the blades, and height and weight of the structure. The safety margin placed on the OWT's are quickly surpassed if updates on every component are accumulated.

Figuratively speaking the increase of wind energy from OWT's around Europe, with the progress the last years, is escalating. However, the growth will not continue to develop exponentially into eternity. Today there are very beneficial financial support schemes for those who venture into

the renewable energy-region. It can be assumed that (*if and when*) these schemes are removed, only a handful of the big energy companies can afford to handle the risk.

Therefore, economical and reasonable methods/technologies are required for installation and decommission. Below is an assumption of amount and year of wind farms to be decommissioned in Europe over the next 20 years.

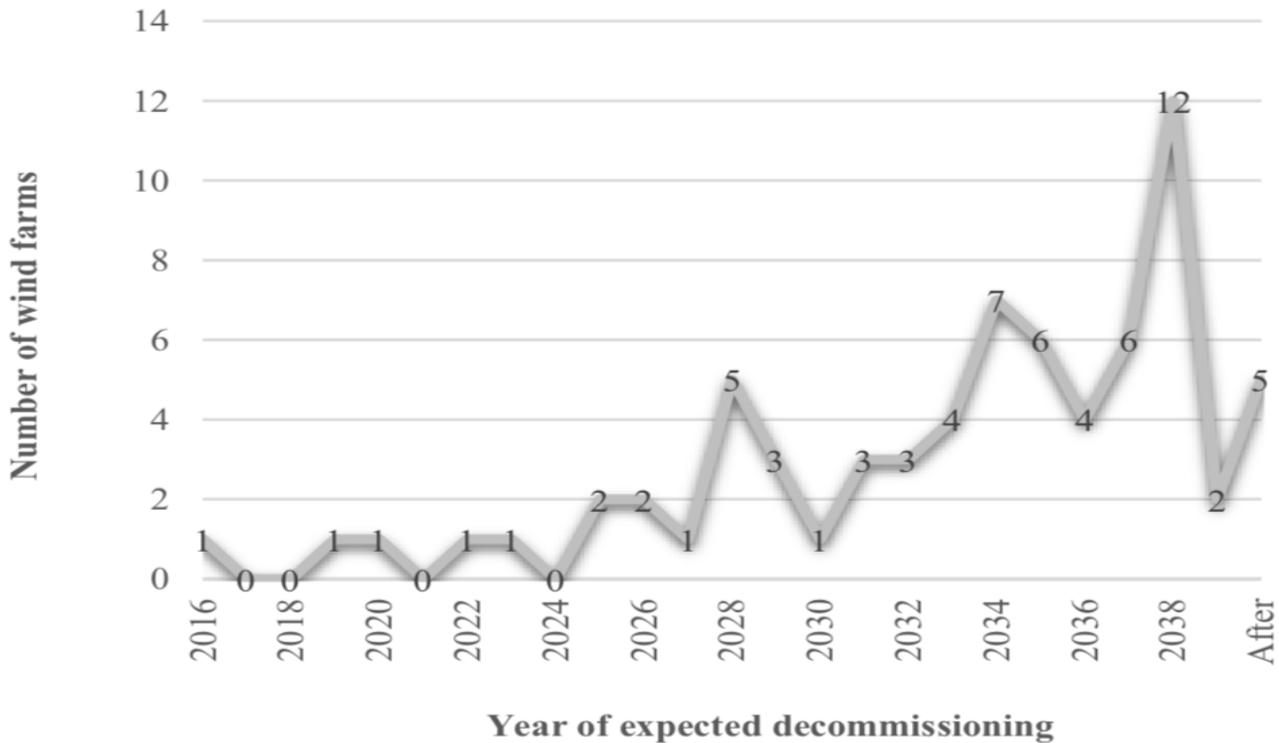


Figure 2: Expected year of Decom on existing farms in Europe [28].

As the United Kingdom is the leading OWT nation in Europe with 1753 active turbines at the end of 2017 and a total capacity of 6.835 megawatts [2], it is fit to use one of the wind parks located in UK waters for the attainment of document-information, and use it to create a base case. In addition, the UK wind farm rules, regulations, and legislations will also serve in the base case.

The Sheringham Shoal Offshore Wind Park [3] consisting of 88 Siemens 3.6 MW turbines, equaling 316 MW. This park is based on the east coast of the United Kingdom, operated by Norwegian

energy company Equinor (Scira), will serve both as a core principle for how rules and regulations of decommission requirements are arranged, but also describing how a decommission process is planned today. Equinor, previously Statoil, is an oil (energy company) thus the link between the OWT decommission and oil- and gas industry is appropriate for this thesis.

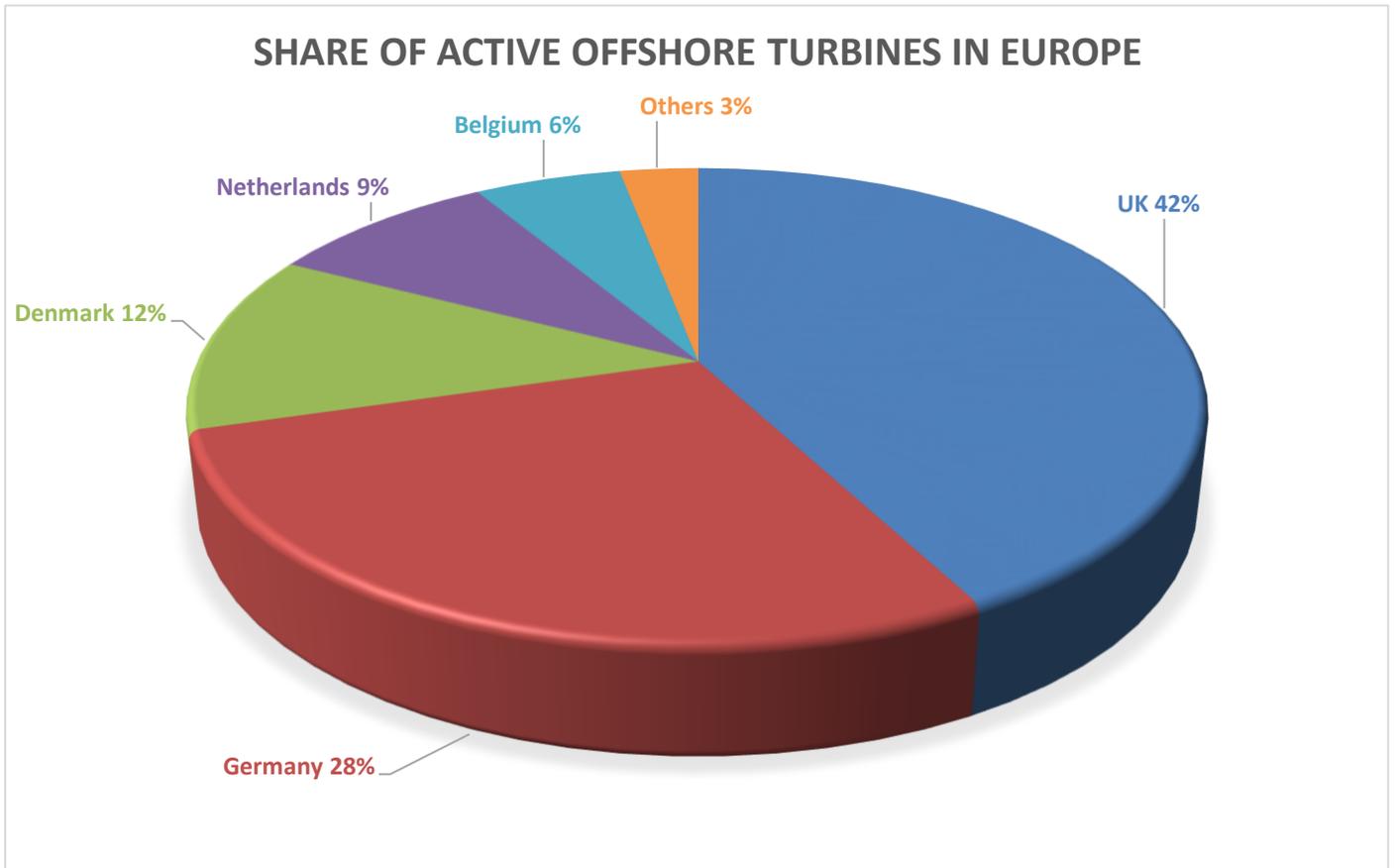


Figure 3: Installed capacity in Europe (figure created by author) on the basis of sources from Wind Europe [2].

1.3.1 Rules and regulations

The focus will be on the rules of wind parks within the exclusive economic zone (EEZ), as this is the area most frequently being used for wind energy. The EEZ stretches 200 nautical miles out from the baseline of the designated countries coast.

UK Department of Energy & Climate Change (DECC) has under the Energy Act of '04 enacted that:

“Sections 105 to 114 of the Energy Act 2004 introduced a decommissioning scheme for offshore wind and marine energy installations. Under the terms of the Act, the Secretary of State may require a person who is responsible for one of these installations or lines to submit (and eventually carry out) a decommissioning programme for them²” [4].

This requires the owners of the offshore wind park to prepare a decommission programme while initiating the installation work. Additionally, the International Maritime Organization (IMO) and the United Nations Convention on the Law of the Sea (UNCLOS) has a set of rules and guidelines that must be followed.

They go hand-in-hand and *article 60 part 3* of the UNCLOS namely termed “*Artificial islands, installations and structures in the exclusive economic zone*” advocate that:

Due notice must be given of the construction of such artificial islands, installations or structures Any installations or structures which are abandoned or disused shall be removed to ensure safety Appropriate publicity shall be given to the depth, position and dimensions of any installations or structures not entirely removed³ [5].

² Direct quotation from page 4 of the document. Can be accessed from www.gov.uk/publications/decommissioning-offshore-renewable-energy-installations.

³ Some sentences have been omitted. From article 60 in the UNCLOS, which can be accessed from http://www.un.org/Depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm.

The IMO resolution A.627(16) entitled “*guidelines and standards for the removal of offshore installations and structure on the continental shelf and in the exclusive economic zone*” describes in *chapter 1.1* that:

Abandoned or disused offshore installations or structures on any continental shelf or in any exclusive economic zone are required to be removed, except where non-removal or partial removal is consistent with the following guidelines and standards⁴
[6].

Nevertheless, *chapter 2.1* advice that:

The decision to allow an offshore installation, structure, or parts thereof, to remain on the sea-bed should be based, in particular, on a case-by-case evaluation, by the coastal State with jurisdiction over the installation or structure [6].

The general approach is to demand a full decommission of both structures and pipes/cables on a case-to-case basis, according to the individual circumstances. The removal of buried pipelines/cables may cause disturbance to the marine environment, seabed and induce additional stress on the shipping density in and around the area. However, socioeconomic and wildlife impact is thoroughly investigated prior to demanding a complete decommission.

Alas, the benchmark when removing fixed-bottom OWT is to keep the cables in-situ and cut the monopile approximately 2 meters below the seafloor (mbsf.). This is what is planned for the decommission of Sheringham Shoal and is the norm when removing other subsea constructions anchored well below the seafloor. The tubular steel monopiles used at Sheringham Shoal are driven 23-37 meters into the seabed and will expectedly sit there for a *very long* time.

⁴ Direct quotation from resolution A.627(16). Full document can be downloaded from <https://vp.imo.org/Login.aspx?ReturnUrl=%2f> (possible to create a 2-day free trial).

Yet, on the basis of the legislations mentioned above and the development of technology, the decommission plan for Sheringham Shoal park could be subject to major changes in the next 20 years.

On page seven of the official decommission-programme, it is stated that:

It will be both appropriate and necessary to review the decommissioning programme throughout the lifetime of the wind farm as legislation, regulatory requirements and current approaches change over time. Such reviews will also need to reflect advances in knowledge and understanding of the marine environment, changes in working practices and technological advances.

1.4 Structure of the thesis

Chapter 1 – Introduction

Setting the foundation for the thesis and giving the reader a widened perspective of things.

Chapter 2 – Theoretical background

Relevant information on the theory of what an offshore wind turbine consists of and a base case wind-farm used in the continual of the thesis. Both the installation process and the planned decommission processes are summarized.

Chapter 3 – Methodology

The different scientific methods used for conducting the research and writing the thesis will be explained in this chapter.

Chapter 4 – Alternative decommission approaches

This chapter aims to ascertain a new set of perspectives on how the decommission process can be improved. A series of new approaches will be outlined. Including the choice of lifting/decommission vessel.

Chapter 5 – Discussion

A general discussion of errors and uncertainties, and an assessment of the validity of the presented new alternative approaches

Chapter 6 – Conclusion

Chapter 6, the concluding remarks regarding what is written in the thesis, summarizing the findings of this thesis.

Chapter 7 – Further work

This chapter will house the recommendations for further work found in the thesis.

2 Theoretical background

This chapter aims to illuminate the theory of how an offshore wind turbine is constructed, where the major parts will be highlighted. Furthermore, a base case describing the installation process and the decommission plan will be depicted. All of this will increase the understating of how best to dismantle and recycle/-use the old OWT.

2.1 Components of an offshore wind turbine

When dissecting the fixed-bottom OWT, it seems fit to start by looking at the foundation it is based upon and moving upwards to the more complicated parts. Identifying different categories of components and their main objectives will be done, be familiar with how best dismantle them. The most used, thus relevant, category of the components will be given the most attention.

2.1.1 Supporting Structure

The fixed-bottom OWT is mounted on a supporting structure which is designed to cope with different factors e.g. water depth, geology, and soil of seabed, forces on the structure, construction- and installation-requirements.

Monopiles (figure 4 on the following page) are the governing substructure with 87% of the market share [2] in Europe. Favorable use at depths ranging between 20 and 30 meters. This structure is of a rather simple design. The monopile supports the tower either directly, or by the use of a transition piece. It is formed as a cylindrical steel tube, making it relatively easy to drive it into the seabed.

The depth of which it is driven depends on the diameter of the tube, forces exerted, soil and height/length and weight of the pile, tower and blades. Additionally, there will be vibration forces, bending moments and axial loads due to the transition piece and heavy rotating blades (concentric and eccentric loading).

For the Sheringham Shoal the monopiles vary from 44 to 61 meters long, weighing from 375 to 530 tons. They are driven 23 to 37 mbsf. [3]. An assumed thickness in the vicinity of 60 mm for the monopile steel-walls.

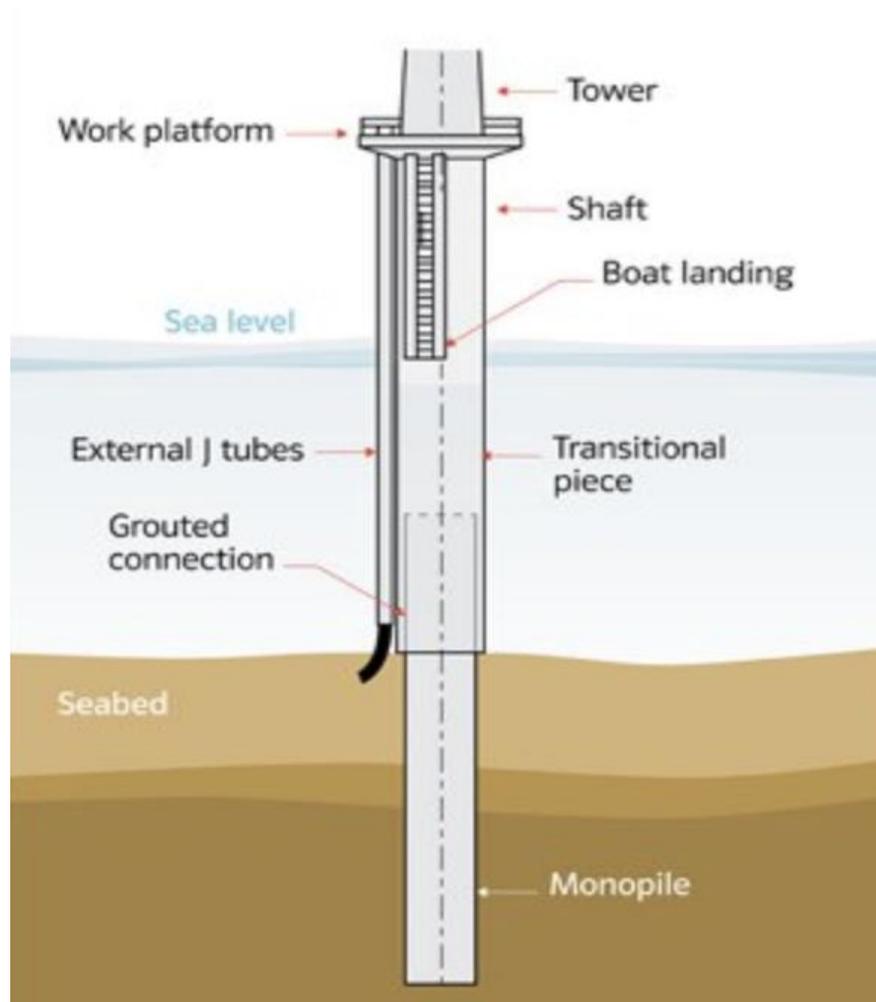


Figure 4: Monopile foundation [25]. Downloaded from 4C Offshore 16th of February.

Other supporting structures are used in a *low magnitude* compared to the monopile (figures of the alternative methods can be found in appendix [B – figures of supporting structures](#)).

- Tripod. Three-legged, lightweight steel jacket. The three corner-piles are driven 10-20 meter into the seafloor. Good stability, but not used for depths less than 6-7 meters. The piles are met at the middle and a steel central column goes up to the surface. Used for 20-30 meters water depth.

- Tripile. Three-legged, heavy-weight steel jacket structure. This foundation has three solid, long legs that are connected at the surface. It is enormous and its weight is tremendous. The usage varies between 25-40 meters.
- Jacket or Lattice. A large tower with either three or four legs connected with piles driven into the seabed. Typically used for water depths up to 50 meters.
- Gravity-based. Normally a concrete based structure with steel skirts. Using sand, iron ore or rock to fill the base of the structure. Up to 60 meters water depth.
- Suction anchor/bucket or Caisson. A bucket up-side-down lowered onto the seabed where the water inside is pumped out, thus creating a lower pressure. This pressure and weight of the bucket cause the foundation to sink into the seabed. Up to water depths of 55 meters.

2.1.2 Transition Piece

The transition piece (TP) used on fixed-bottom OWT is a fortified component of the supporting structure that is connected between the monopile and the tower of the turbine. The main objective for the transition piece is to withstand bending moments, shear forces and axial loads caused by the heavy tower, rotating blades and periodical stresses from waves and winds. However, it also functions as an entering point for the technicians arriving the OWT.

Grouting is used to seal the connection between the monopile and the transition piece. The grouting's intention is to seal, but also increase the reliability in the structure. If some of the grout is broken down, a downward movement will be induced (due to the heavy weight). Increased contact stress provides further settlement. Up to 100 tons of grout is used, of concrete-type. The transition piece also acts as a lid for the monopile, preventing air into the pile thus avoid the corrosion inside the pile.

A conical connection design (figure 5) has been developed which increases the effect of the settlement onto the grout mentioned above. In the Sheringham Shoal park, these transition pieces are 22 meters long, and weight 200 tons.

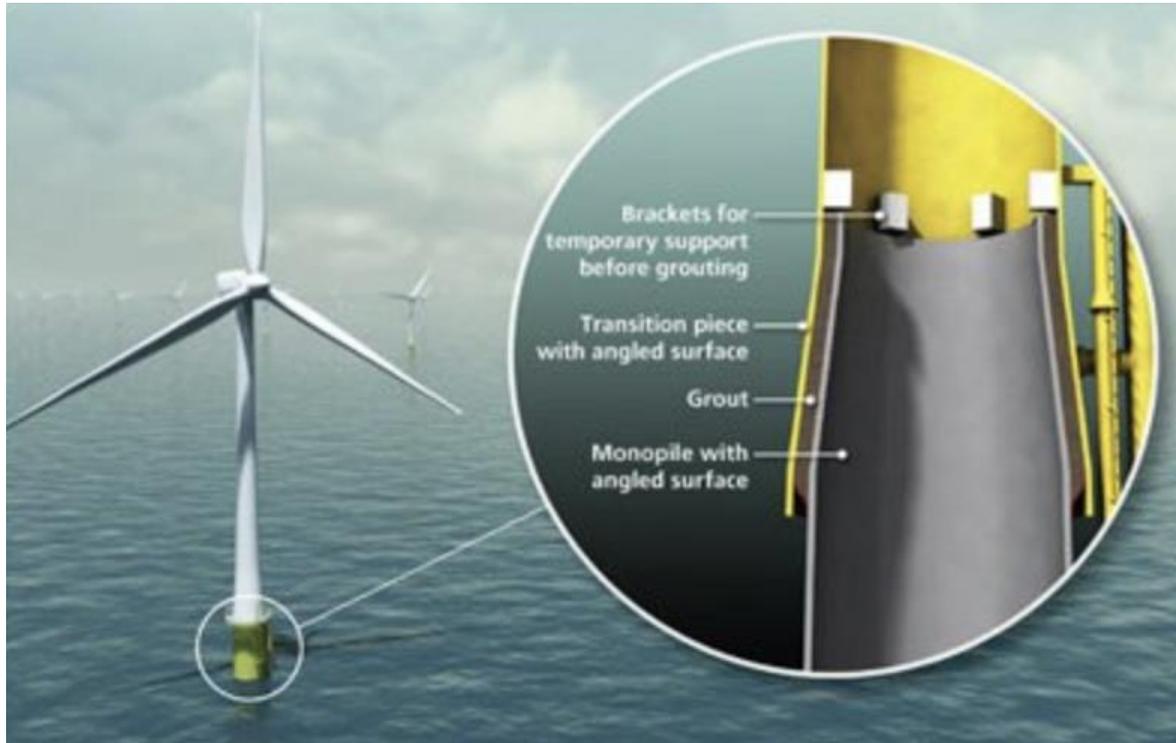


Figure 5: Transition piece, tower, nacelle and blades [25]. Downloaded from 4C Offshore 18th of February.

2.1.3 Tower

The tower extends from just above the water level (where the yellow-colored transition piece ends – figure 5) and up to the nacelle of the turbine. The goal of the tower is to support the turbine assembly and get the nacelle and blades elevated above the surface. The towers used at the Sheringham Shoal are 80 meters tall, with a weight up to 300 tons. It looks like a tubular steel pipe, which narrows from bottom to top. For the Sheringham Shoal, a diameter around 5 meters near the bottom of the tower can be assumed. With a 30-40% decrease in breadth, the diameter gradually culminates in a 3 – 3.5 meters diameter at the top of the 80 meters [7].

The thickness of the steel can be assumed to be in the proximity of 25 – 30 mm at the bottom of the tower. Thickness at the top can be assumed in a case like that, to be in the vicinity of 17 – 23 mm.

2.1.4 Nacelle

The nacelle is a housing enclosing the gearboxes, generators and blade hub at the top of the turbine. This will automatically turn to face the wind, thus maximizing the energy collection of the blades. Additionally, there is a shaft inside the nacelle which is rotating due to the resulting blade movement. The nacelle can be termed the “brain” of the wind turbine. The nacelle has an oil volume of approximately 750 liters. The nacelle is a compact, though a relatively heavy, component of the OWT. Typical nacelle-length for a 3-4 MW turbine is 10-15 meters, width of 4-6 meters and a height of 2-5 meters. The weight of the nacelle for the 3.6 MW turbines at Sheringham Shoal wind park is 140 tons [8].

2.1.5 Blade

The most common use for offshore wind turbines are three-blade turbines, where the blades are made up of some form of composites e.g. fiber-glass reinforced epoxy (GRE), and having a horizontal axis manufactured direction [8]. Attached to the Siemens 3.6 MW turbines at the Sheringham Shoal, are three blades, where the length of each blade is 52 meters and each blade weighs approximately 20 tons. They are crafted and shaped to enhance the lift force created by the wind. Figure 12 shows the cross-section of a blade and can be seen in chapter 4.4 – recycling of blades.

2.1.6 Offshore substation

The offshore substation, or Offshore Transformer Module, has its main objective where it gathers the total power from the wind turbines (through the buried in-field cables) and it increases the voltage before it is transported the distance from offshore to shore. This will help avoid losses over the long distance from farm to shore. Further, the power is converted from alternating current (AC) to direct current (DC). Weight and dimensions of these vary by type and manufacturer, but the two substations established at the Sheringham Shoal, both weighing nearly 1000 tons and is 30 meters long, 18 meters wide and 16 meters high. It is typically installed on top of pre-installed jacket/piles. There are two sub-stations on the Sheringham Shoal farm.



Figure 6: Offshore Substation, Siemens. Downloaded from [26].



Figure 7: Blade and nacelle of an older model of the Siemens 3.6 MW [27]. Attached to illustrate blades and nacelle.

2.2 Base Case

This sub-chapter will give an introductory explanation of the base case for the thesis – where both the installation and planned decommission process are provided in short. In order to be able to envision the decommission of an OWT, we must know the basics – both on the design of the turbine and how the installation process is completed. In the previous sub-chapters, we visited the main components of the OWT. The regular installation process of offshore turbines in the range of 3 – 5 MW turbine will be portrayed, followed by the planned decommission process.

2.2.1 Installation Process

The installation begins with the preparation of the site, with the scouring, unexploded ordnance (UXO) clearance and surveys of seabed and layers. The installation process starts at the port where the monopiles and transition pieces are loaded onto either barges or jack-up vessels and transported out to the farm area. The loading of the vessels requires experience and awareness, due to the extreme weight and height of the components.

The jack-up vessel moves into position, lowers its legs and stabilizes to begin the operation of lifting the monopiles offboard with the powerful crane and using a hydraulic hammer to drive the monopiles deep into the seabed. The transition piece is lifted and placed on top of the monopile, where it is grouted (cemented) compact and watertight. The transition piece act like the base for the turbine tower.

At this point, either the jack-up vessel goes back to the harbor to pick up the tower, nacelle and blades – or a barge is already in place with these components. Figure 8 shows the vessel in place and ready to lift the tower onto the TP. How this is done depends on the economic feasibility and availability of vessels, barges and day-rates (though, also the weather plays a factor for the use of barges and floating vessels). The towers are lifted using specialized equipment fixed on the crane hook. When the tower is placed on the base of the transition piece, a crew of technicians will start with the securing mechanisms on the flange to the arranged position, using tension-bolts.

When the tower is in place, the turbine housing is installed subsequently. The housing, or the nacelle and rotor hub, consists of all the electrical components and operate as the brain of the OWT. Normally, the nacelle and the rotor hub are installed as one piece, which again results in the operation of connecting one and one blade to the rotor hub. Nonetheless, it is possible to arrange the nacelle alone first, then fit the three blades on to the rotor hub and lift it collectively in place. However, this depends on the capacity of the crane, area available on deck and planning.

When the turbine is completely erected, it is connected with the infield cable and is ready to generate power. Additionally, inside the turbine, elevators are installed and other appliances for the future operation and maintenance are added.



Figure 8: Fred. Olsen Windcarrier installing monopile, fixed-bottom OWT [13].



Figure 9: Jack-up vessel "Seajacks Leviathan" loaded with tower and blades, next to a monopile fitted with the yellow transition piece [3].

2.2.2 Decommission Process

For this section, the official decommission program produced by operator Scira is relayed [9]. Decommission at Sheringham Shoal has been divided into three steps in the temporary decommission program; 1st campaign is the preparation of the OWT and foundation, 2nd campaign is removal of OWT and foundation whereas the 3rd campaign is rock dumping, completion and third-party inspection of the area.

1st phase: It is planned for some of the preparation work to be done with a specialized ROV. Additionally, Scira has planned for 8 decommission crews consisting of 5 men each, working 12-hour shifts. 2 personnel transport vessels (PTV) will transport the crew and equipment between the OWTs. Total work time for phase one was in 2014 estimated to 66 days (132 vessel days for two vessels) which include 20% waiting on weather⁵ (WOW).

When preparing the OWT in phase one, there will be a big amount of trash, junk and fluids that must be removed prior to the structural removal. This trash is planned to be stored inside the tower in containers and be lifted out by the jack-up crane. Additional tasks to be done in phase one is the installation of temporary lighting and ventilation systems, cutting of wires, preparation of bolts, applying penetrating oils and removal of elevator system.

2nd phase: Assumes the use of two large jack-up vessels (comparable to the Pacific Osprey [10]) working in parallel. The operation will start in April, and it is estimated 154 working days for each vessel – this includes WOW. Cutting tool used for the large diameter on the tower/monopile is assumed to be of no issue in 20 years, as the market will produce/discover and supply the need for tools.

It is planned with two teams of divers to remove the J-tubes (infield cables connecting the OWT to the field grid). Additionally, for the second phase, a DNV simulation tool has been used to estimate time necessary to remove the structures. This model was specifically made for Statoil at the time and comprises data on how many structures can be removed (time for each component

⁵ DNV weather model – appendix C

in different weather). In appendix [C - Operational sequence from DNV model](#) it is possible to see how the WOW changes drastically throughout the season.

The second phase is the most coherent phase of the removal. The two vessels should have deck space for loading approximately five complete OWT and foundations. They will be transported to a recycling center in Hartlepool, UK. The preliminary decom-report states that the OWT will be taken down as a *reversed installation*. Plasma cutters are used to remove rusted bolts. Synchronized with the tower removal, the preparation of the foundation is carried out. Cutting tools are arranged below the airtight lid of the TP. The crane is supporting the pieces being cut, and they are lifted immediately onto the vessel-deck. Scour deployed at the installation covering the monopile and the cables at the field is assumed to be left in-situ.

3rd phase: It is presumed that the rock dumping to even out the hole the cut monopiles leave will be carried out by specialized vessels, covering 4 OWT sites per day – totaling 22 days. Furthermore, final inspection to be carried out by ROV with a duration of 11 days, plus 2 days of sailing and mobilization. Succeeding the complete decommission, sea-bed clearance will be performed. This must be done in regard to the rules and regulations and will serve the purpose of identifying (and removing) any remains that can be associated with the Sheringham Shoal Wind Farm on the seabed.

Furthermore, throughout the planned life cycle of the wind farm, there will be held extraordinary reviews/inspections to assess the wear and tear of the OWT. The first will be held two years after initiating the operation, then the second 15 years into operation and the last will be held 2-5 years prior to planned decommission. These inspections make it possible to have high situational awareness on the possibilities of repowering. Scira says in its preliminary decom-report that a final decom-plan will be ready 2-5 years prior to certain decommission.

2.3 Other decommissioned wind constellations

There have been a few other wind parks decommissioned the last few years, both in the sea and in freshwater lake.

2015 – Yttre Stengrund offshore wind farm [11] [12]:

The five NEG Micon 2MW turbines were dismantled in late 2015. This small farm was constructed in 2001 and only operated for 14 years. The limited availability of spare parts, and the costly upgrade of the turbines, thus the expensive new export cables if newer turbines were to be installed – resulted in the decommission. This farm was taken down like a reverse installation, where blades, nacelle and tower were lifted down. The monopiles were cut down at the seabed and the site restored to its original condition. Even all the cables were later removed – which is not normal practice when dismantling offshore structures today.

2016 – Lely nearshore wind farm [13]:

Four turbines of 500 kW each were in 2016 dismantled from a freshwater lake in the Netherlands. The farm was built in 1992 and had operated for 22 years when the production stopped, shortly after one of the turbines lost its rotor head and blades due to metal fatigue in 2014. The turbines are approx. 60m tall and use the monopile foundation at 10m water depth. The dismantling was done by lifting the nacelle and blades onto a barge, then the tower in two separate units. The monopiles were *fully removed* by the use of vibratory hammers [14]. The monopiles weighed between 70 to 80 tons each and had a diameter of approx. 3.5m.

2017 - Vindeby offshore wind farm [15] [16]:

In March 2017, DONG Energy (today Ørsted) had the responsibility of performing the decommission of the offshore wind farm, *Vindeby*, in the south-east of Denmark. This park was

constructed in 1991 and consisted of eleven 450 kW OWT. The blades, nacelle and towers were taken down as a reverse installation by a jack-up vessel. The foundational structures at this farm were concrete gravity-based and were broken down on site by hydraulic demolition shears. The 40m tower and 30m blade length of this old farm are relatively small compared to the giants set up at the Sheringham Shoal farm.

3 Methodology

This chapter advice in what methods of scientific research has been done for this thesis to become a reality, and what is crucial to be aware of when using those specific methods. This is done to assure the transparency and legitimacy of the thesis. This thesis has been a variety of literature studies, team debates and considerations of how the industry today *is currently working*. Thus, plenty of input has been collected from the visits at local companies with first-hand experience from the decommission-branch. Their opinions and assumptions have been considerably weighted when designing this thesis. The above-mentioned ways of gathering knowledge make this a qualitative researched thesis. As this subject is relatively new, no information has been found in written books, as the “standard literature review” suggests.

3.1 Literature study

There have been two processes for carrying out the literature studies in this thesis:

1. Searching online for actual methods of offshore/subsea dismantling, tools of removal and planned decommission reports. This was done using google and search words similar to, and in different combinations of: *wind turbine, decommission, tools for cutting, offshore wind turbines, subsea cutting, installation of offshore wind turbines, supporting structures* and so forth. The common denominator has been to find tools, methods for installation/decom, components and dimensions – accurate and factual specifications.
2. Searching online for reports, articles and written scientific reports on the subject. I used the databases *SCOPUS* and *Web of Science*, as the University library recommended these. The main inclusion criterion for my searches was that the results had a relevant link to the decommission of offshore structures. Using the following search string:

TOPIC:(Decommission) AND TOPIC:(offshore)

This search granted 199 results in Web of Science and 55 results in SCOPUS⁶. Additionally, searching *within* the original results for TURBINE granted 21 results in Web of Science and 6 results in SCOPUS⁶. The first step was to scan the headlines of the articles and decide which could be interesting. Next step was to read the abstract if the content could be applicable for the research, resulting in the full read of the article. Further exclusion criteria were not considered as there were relatively few results, to begin with.

3.2 Project Workshops

Decom-Tools project team and our meetings have been an important part of being able to navigate the seas of information, and in regard to which companies would be worth visiting, what leads to follow and discussing different methods for decommission that has come up as the project has been in forward-motion.

Also, the DecomTools-team arranged a project workshop in Haugesund in April. Attending was several local companies, Saga Subsea, Scanmudring and Unitech. The Norwegian Maritime Directorate was also present. Additionally, a group of students from HVL campus Bergen writing their bachelor thesis, another master student writing her master thesis in collaboration with Unitech, the local Wind Cluster⁷ for offshore floating turbines and several lecturers linked to the DecomTools team. In general, the workshop was used to discuss different ideas, as the decommission plot and project is in its early existence.

This has been truly essential for the cooperation between the author of this thesis and Børre Mæland, fellow student writing his own thesis. His topic is also on the decommission of offshore wind farms, though his focus is more explicitly the areas of cutting tools and removal techniques.

⁶ Searches done 13th of March 2019.

⁷ <https://offshore-wind.no/> - accessed 26th of April.

Balancing on the thin red line of not doing the same work, yet creating two reports that complement each other, the project meetings have been a success.

3.3 Visiting and discussing with local companies

The visits to the local subsea/offshore companies have been an invaluable experience. All of them have substantial familiarity with the decommission of subsea and offshore structures. We had a pre-made list of questions for the company visits, and they can be found in the appendix, with summarized answers from the companies. Additionally, these questions are going to be by the team in Germany to understand the market and approach the companies carry there.

Below is a short summary of the main points the team acquired when visiting the local companies. In addition, at the end of the thesis are the minutes of meeting attached as appendixes. The following subchapters are compiled and paraphrased in the order of visiting the companies. The main takeaway's from each visit will be summarized, making it easy to compare what the different companies consider about the industry. Rundown of what the companies had in common, both on experience and thoughts:

1. Towing is possible and can be done in several different manners, using external objects to keep structure floating or its own buoyancy.
2. Dredging is an unpredictable and time-consuming task, if it is possible, they would all advise against this.
3. Recycling can done almost up to a grade of 100% of the used material, except for the turbine blades, these we still have challenges related to.

3.3.1 DeepOcean

DeepOcean⁸ is a leading subsea service provider and has been involved in a handful of offshore decommission operations. Ranging from wellhead removal to concrete mattress removal and a variety of cutting and lifting operations. They have been deeply involved in most of the projects, doing both the engineering, planning and execution which give them broad experience of all stages of the decom-process.

Takeaway's from the visit at DeepOcean:

- Dredging is an unpredictable operation subsea. DeepOcean estimates dredging/trenching to cut a pile 2m below the seafloor to 4-5 working days.
- Lifting subsea structures onboard can be done, though it depends on the size of system and vessel (heavy, medium or small). It is done on a cost-efficiency basis.
- Towing of whole structures has been performed.

3.3.2 Reach Subsea

Reach Subsea⁹ is subsea-operation provider with extensive knowledge of engineering and state-of-the-art ROV systems. They have been involved in decommission of monopiles, removal of trawl protection structures and removal of concrete subsea structures. Performing the engineering, project management and execution of the operations. In addition, they have several employees who have been involved with several other decommission projects.

Takeaway's from the visit at Reach Subsea:

⁸ www.deepoceangroup.com/about - accessed 24th of March 2019

⁹ <http://reachsubsea.no/company/about/> - accessed 25th of March 2019

- Dredging is always an uncertainty, and it is hard to estimate total time. It depends a lot on the seabed soils and its characteristics, but also on equipment used, sea current, structural specs.
- Says it is possible to reverse the installation in a decom-operation, however, the most cost-effective method is likely another approach.
- Used subsea baskets when lifting onto the deck, as these make it easier when sea fastening.

3.3.3 Kvaerner

Kvaerner¹⁰ has extensive experience from decommission in the offshore oil and gas industry. Kvaerner offers decom topside, subsea and onshore demolition, disposal and recycling at the base on Stord. They have been involved in a broad range of operations, both when structures have been delivered to them, but also doing the entire operation from removal offshore to the complete disposal of the materials. Engineering, project planning and execution have all been done by Kvaerner. Quay-facilities and water depth outside these are one of their main competitive advantages.

Takeaway's from the visit at Kvaerner:

- Towing of structures has been done by pencil buoys and buoyancy tanks, depending on the type of structure. Also, lifting has been done by heavy-lifting vessel and PSV's with capable cranes.
- In most of the cases they are able to recycle and/or reuse up to 99.5% of the total oil- and gas structures. Though, the fiber-glass reinforced epoxy blades are an issue in the industry.
- They would advise *against* the use of explosives due to the issue of either not completing the explosion or not completing the cut, and wreckages all over the seabed (thus picking it up) among some of the reasons.

¹⁰ <https://www.kvaerner.com/Products/Decommissioning/> - accessed 25th of March 2019

3.3.4 AF Decom

AF Decom¹¹ is one of Europe's leading decommission and recycling companies on offshore installations and structures. They have a widespread experience and competency and is recycling up to 98% of the steel. They have been a big stakeholder in the North Sea related to the decommission for the last 15 years. Removal and recycling of jackets and platforms is the main source of work. They have been both the main contractor and sub-contractor, doing planning and engineering. The water depth outside the quay-facilities in Vats is, as at Kvaerner, one of AF Decoms biggest competitive advantages.

Takeaway's from the visit at AF Decom:

- Recycling of steel is close to perfection. However, they understand the obstacles related to the recycling of the wind turbine blades made of composites that are hard to recycle and/or burn.
- The quay facilities in Vats are particularly suited for deep-water heavy lift vessels, and huge structures coming in all at once. If offshore turbines would be interesting, it would have to come into the facilities in large quantity and serial-dismantled.

¹¹ <https://afgruppen.no/offshore/> - accessed 25th of April 2019

4 Alternative Decommission Approaches

This chapter will describe unconventional and unique approaches compared to the decommission process of today. It will start with a summary of the new approaches and further evaluation will be done. These plans will be moreover discussed with reference to the practice of today, in the discussion chapter.

Below is a table recapitulating the alternative approaches, preceding a detailed description.

Alternative	Principle	Requirements	Outcome	Pros	Cons
Cut the three rotor blades	<p>Cut the blades near the nacelle to remove weight and make lifting of nacelle easier.</p> <p>Or ease a potential event of felling the OWT like a tree.</p>	<p>Crane with capacity of 30t at approx. 100 meters height. Cutting tool either mounted on crane or cut from the top of OWT.</p> <p>Satisfactory weather.</p>	<p>Three 20-30t blades with the length of approx. 50m must be placed on a vessel/barge and sea fastened.</p>	<p>Will ease the lifting of the nacelle, make the total OWT 60-90 tons lighter.</p> <p>Save deck space.</p>	<p>Three additional cuts at great height.</p> <p>Weather might be an issue.</p> <p>We do not have the tool to this as of this moment</p>
“Tree felling”	<p>Felling the OWT like a tree, to relieve lifting operation.</p> <p>Next operation is to either tow to land or lift onto barge/vessel. Bottom and top must be plugged.</p>	<p>Wires/airbag to restrain OWT from crushing down and being destroyed.</p> <p>Might have to remove blades and nacelle, too.</p>	<p>Alleviate one or two heavy lifts, which can take a lot of time.</p> <p>Additionally, free up deck space on the jack-up if tower is towed. Resulting in a more efficient operation.</p>	<p>Cut out lifting operations. Use cheap vessel for towing. Jack-up can work continuously.</p> <p>OWT can be left in water for a while.</p>	<p>Must be watertight to stay afloat.</p> <p>Can destroy the tower if it smashed into the ocean – lot of work to pick up wreckages.</p>

Alternative	Principle	Requirements	Outcome	Pros	Cons
<p>“Tree feeling” continued: Plugging the tower</p>	<p>Plugging the water-entrances.</p> <p>Can be done by external plug, or built-in from factory.</p>	<p>Ensure it is 100% watertight.</p> <p>Equipment to saw/cut the foundation. Big crane to lift tall enough.</p>	<p>Few heavy lifts, thus the less vessel days for the big vessels.</p> <p>However, tugs/vessels towing is needed.</p>	<p>Cheap way of transporting the tower, monopiles and nacelle to shore.</p>	<p>If not watertight, will sink fast.</p> <p>Can be hard to test prior to felling.</p>
<p>Towing the structure</p>	<p>Plugging, leaving the towers and monopiles in the water and towing in to shore.</p>	<p>100% watertight.</p> <p>Several vessels to tow. Cranes/arrangement at shore to lift the structures.</p>	<p>Several tower and monopiles can be towed at the same time and/or stay in the water.</p>	<p>Economical reasonable to tow compared to make heavy lift vessel carry.</p>	<p>Can sink, making loads of extra work.</p> <p>Need several vessels.</p>
<p>Continual use of foundation</p>	<p>Change out a few fatigued components and keep producing for a longer period.</p>	<p>Thorough assessment. Vessel/crew, weather.</p> <p>Spare parts.</p>	<p>Maximize the wind power, and lifetime of components.</p>	<p>Save money.</p> <p>Greener project.</p> <p>Produce for a longer time.</p>	<p>Fatigue of every piece of the OWT needs to be extensively monitored.</p>
<p>Recycling of the blades</p>	<p>Recycle the blades in the same manner as steel and other materials to a less environmental impact.</p>	<p>Knowledge of exactly what the blades consists of.</p> <p>Possibility to handle the large supply, at a low cost.</p>	<p>Recycle the composites as well as we do with steel today.</p> <p>Low-cost recycling of the material will in turn make it cheaper.</p>	<p>Increase the total level of recycling for the entire project, leaving a smaller environmental footprint.</p>	<p>Hard to know 100% what older blades are composed of.</p> <p>Today we do not have a sufficient process to recycle this material.</p>

Table 1: Summary of alternative approaches

4.1 Vessel requirements

Before the alternative approaches on how the decommission process can be enhanced is laid out, it is essential to establish a baseline of which vessels *can and cannot* be used for this type of operations. Obviously, this can be said to be a cost-based question, and as the day-rates for offshore supply- and construction vessels are remarkably volatile, it is impossible to predict the price a few years ahead, not to say fifteen-twenty years in the future.

Regardless of the day-rates in the industry, the price will follow the market and as always it keeps shifting, making the decommission process heavily influenced by it. Deciding to dismantle the farm a few years earlier due to a low day-rate or making predictions that the price will sink even lower can save (or lose) the company a great deal of money. On the other hand, the area of the wind farms is often leased for fifty years, hence leaving the entire farm in place for many years to come – could be a viable solution until the day-rates have decremented to a reasonable level.

A few vessel specifications that are needed for the decommission of offshore wind turbines today, that will be expanding in the future as the turbines are getting even taller and heavier:

- Lifting capacity of 4-500 tons at 100 meters above sea level approximately 5 meters out from vessel side. Typical vessels to obtain these capacities must have similarities like the Pacific Orca and Osprey [17] [18] mentioned earlier in chapter 2.2.
- Adequate cargo deck space for storage of multiple wind turbines for installation and decommission if they are too be handled on the jack-up. Pacific Orca and Pacific Osprey have approximately 4300 m² deck space each.
- Lifting in unstable weather conditions. The jack-up vessel is able to self-elevate up from the surface and will be affected less by the harsh environment. The four-six legs of the vessel provide additional stability compared to four legs. A double main-crane will also increase the work-around in windy conditions far better than compared to a floating vessel with one crane.

Looking at the specifications of one of the mighty offshore construction vessels from Norway, the Edda Freya¹² which was built in 2016 and is one of the largest of its kind. Crane capacity of this vessel is 400 tons at 20 meters height, with active heave compensation (AHC). Deck area is approximately 2250 m². It is impossible to use one of these construction vessels alone for the full decommission of offshore wind farms with the gigantic turbines we have today. On another note, it can be assumed that the future OWT will be even larger and heavier.

As mentioned, these prerequisites eliminate most of the construction- and supply vessels used in the oil and gas sector, where the heights are not as big a factor as offshore wind. It will not be viable to construct large enough floaters for this type of operations. Thus, it can be assumed that the jack-up vessel is a *necessity* for the decommission of offshore wind turbine farms consisting of 3+ MW OWT. A discussion on the future development and use of jack-up vessels will be done accordingly in the discussion chapter.

4.2 Cutting/removal of structures

As previously mentioned, the explicit cutting techniques of the infrastructure is in the scope of Børre Mæland and his thesis. However, as this thesis' intention is to look at the *bigger picture* of the decommission, it is relevant to have voiced a range of alternative practices that can possibly facilitate an eased decommission compared to the reverse installation. Thus, the proposed adjustments include the following approaches:

4.2.1 Cutting of turbine blades

Lifting and placing the OWT with both the nacelle and rotor blades attached, would take up a large amount of deck space on the jack-up vessel or barges used for transportation/loading. Though it has been regular practice to remove the blades when doing dismantling earlier, this has been done as a reverse installation. Thus, the blades could be reused for research purposes,

¹² <https://ostensjo.no/fleet/eddafreya/> - accessed 27th of March 2019

museums and as sound/vision barriers, or even at other wind turbines if the blades were fit. It must be deliberately considered if it is a suitable option to reuse the blades in smaller farms. However, it can be assumed that they have been heavily utilized in the 20-25-30 years of operation and that recycling is the only option (recycling of blades is discussed later). Looking at figure 10 below gives us an impression of some wear and tear the blades can be exposed to during its life cycle.

The new approach of cutting off the rotor blades gives the decommission process a few additional opportunities. As each of the rotor blades on a fixed-bottom turbine in the 3+ MW range weighs 20-30 tons and is 50 meters long, the total weight (and size) of the structure can be considerably reduced. Directly cutting the blade by the root, can save both time and make it safer by not having crew members at the top of the nacelle when the lift is performed. In the process of reverse installation, blades are loosened from inside the nacelle, whilst the crane is in retention and keeping a *slight* upward lifting force). The sketches in figure 10 and 11 show how it would be completed and a close up of an imaginary prototype of the gripping mechanism.

The practice when a saw is being used to cut the blade by the root would benefit from being incorporated into the tool that is gripping the blade (same as used for installation). This would reduce the time for removal since the gripping tool needs to clutch the blade regardless of cutting or unscrewing the bolts.

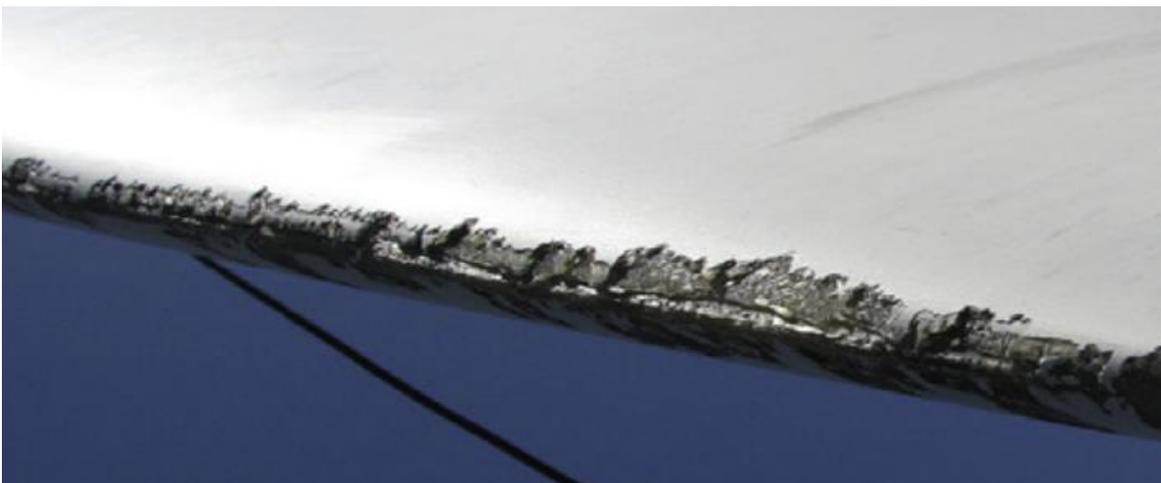


Figure 10: Leading edge erosion on turbine blade, occurring following small scratches in the surface [31].

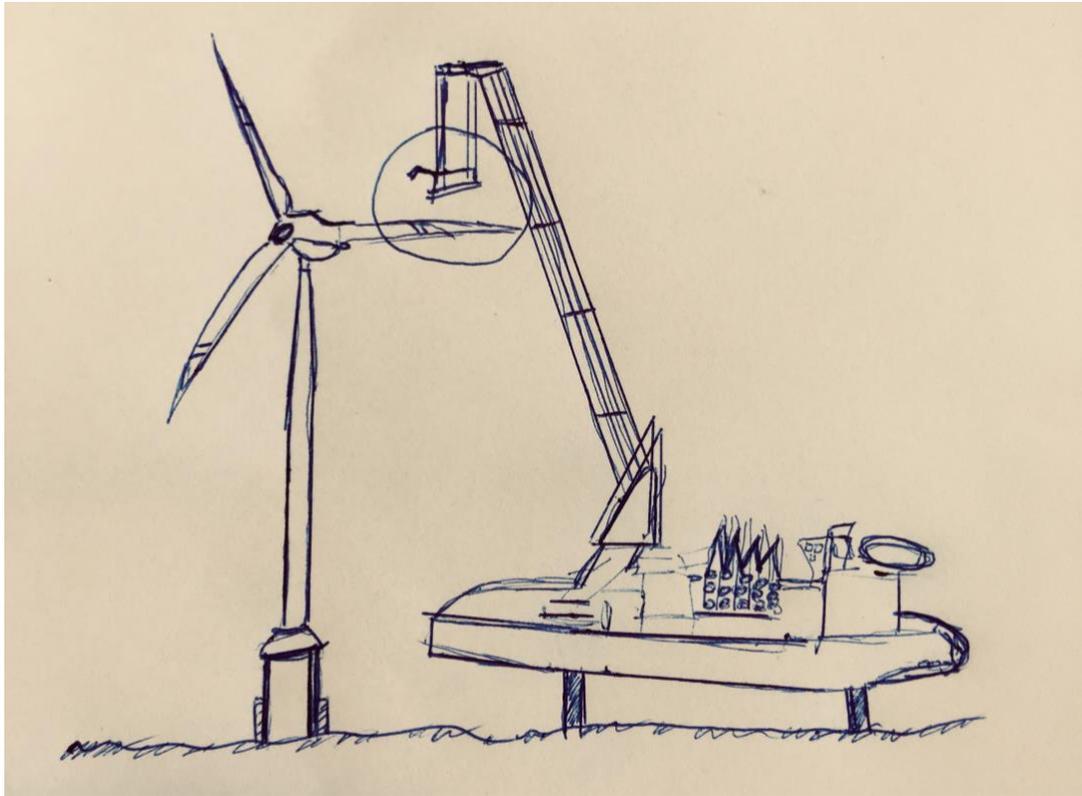


Figure 12: Sketch - Cutting of turbine blades. Circled area in the next figure.

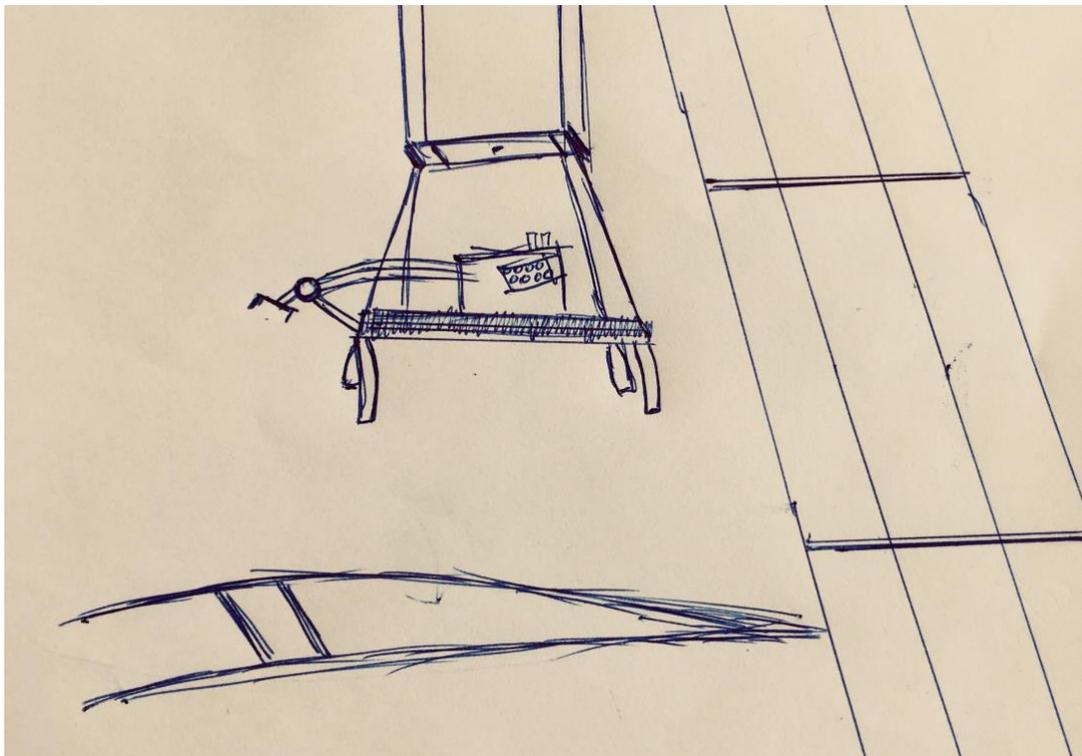


Figure 11: Sketch - Close-up of lifting jig and imaginary motor and cutter. Clutching the blade and at the same time cutting it off. Cutting-mechanism not defined, as this depends on future trends and economic viability.

4.2.2 “Tree felling” and plugging

When looking at the approach to fell the tower as a tree, which has been the author’s main idea from the beginning, but also briefly mentioned by all of the local companies visited and found in the literature [19], it would be imperative to divide this matter into multiple sub-concepts that would need attention.

The main idea with the felling is to use the experience from the oil and gas sector, where they have floated and towed a variety of oil and gas subsea and topside structures by the use of pencil buoys and buoyancy tanks. However, rather than using external objects to float the OWT, their own buoyancy will be enough to keep them afloat, as can be seen by the following equations 1 through 4. All the dimensions are approximations; however, the excessive float ratio shows that it stays afloat to a broad measure.

$$(1) \quad F_{\text{buoyancy}} = V_{\text{tower}} \cdot \rho_{\text{seawater}} \cdot g$$

$$\rho_{\text{seawater}} = 1\,025 \frac{\text{kg}}{\text{m}^3}$$

$$g \approx 10 \frac{\text{m}}{\text{s}^2}$$

$$L_{\text{tower}} = 80\text{m}$$

$$r = 3\text{m}$$

$$(2) \quad V_{\text{tower}} = \pi \cdot r^2 \cdot L_{\text{tower}}$$

$$V_{\text{tower}} = 3,14 \cdot 3\text{m}^2 \cdot 80\text{m} = 2\,300\text{m}^3$$

$$(1) F_{\text{buoyancy}} = 2\,300\text{m}^3 \cdot 1.025 \frac{\text{kg}}{\text{m}^3} \cdot 10 \frac{\text{m}}{\text{s}^2} \approx 23\,150 \text{ kN}$$

$$(3) \text{Weight}_{\text{tower}} = 300\,000 \text{ kg} * 10 \frac{\text{m}}{\text{s}^2} \approx 3\,000 \text{ kN}$$

$$(4) \text{Float ratio} = \frac{F_{\text{buoyancy}}}{\text{Weight}_{\text{tower}}} = \frac{23\,150 \text{ kN}}{3\,000 \text{ kN}} \approx 7.7$$

Prior to felling, it is said that it is necessary to remove all of the hydraulic oils/liquids¹³ in the nacelle and those which are used in the elevators. The reversed installation would entail the removal of the entire elevator, which with the felling of the tower can now be left in-situ. Depending on the installation of the elevator, and the force the tower would create by the fall, waves when towed etc. the elevator could be ruined before arriving land.

The elevator is most likely of industrial type, which is significantly cheaper than commercial ones used in i.e. hotels. Nevertheless, this is a small cost to pay if freeing the total operation of numerous vessel-days can be made possible. Additionally, the in-situ elevator would make it easier when handling the removal of the blades and optionally the nacelle. Besides, the crew performing the dismantling of the elevator and other tasks inside the OWT would be relieved a great load of work.

Felling of the tower would free the decommission of at least one, though most likely several heavy lifts at big heights. Leaving the blades and nacelle on will possibly make the entire operation possible without the use of a jack-up vessel. Though the further investigation of this matter will assume the blades are removed due to the force of crash, space on deck and weight of the structure. As a base for further arguments, the turbine tower and the nacelle are standing tall. There are a couple of major ways of felling and towing the turbine tower (and monopile) as the author can see it;

¹³ Sheringham Shoal decommission report on page 48, first sentence.

1. Using some form of explosives or a cutting-arrangement that will *not* jam under the weight of the tower. (This specific cutting-arrangement can consist of some extension-legs drilled into the structure to bear the weight, or steel wedges). Plugging the bottom of the tower can either be done by an inflatable plug, or some form of a flange that can be installed in the preparation of decommission. Newer towers can have this plug installed at the beginning and disabled until floating and decommission. The top of the tower with the nacelle needs to be watertight as well. This can be done either by ensuring the nacelle is made watertight from the time construction and installation or a plug/flange is set up. Alternatively, a watertight bag or seal can be threaded over the nacelle and top. Besides, this bag can operate as an airbag to mitigate the nacelle from being destroyed. Letting the structure fall directly into the water might impart damage to it, so it could be a method to fasten two wires, one on each side, at an angle to the vessel assisting with the cutting. This would mitigate to the damages of falls, though it can incur dangerous situations. I.e. if the structure won't stay afloat and is pulling the vessel down.
2. Lifting the tower up from the transition piece, onto the heavy-lift vessel and down onto a plug resulting in it being waterproof. This approach also would entail some sort of plugging/closing off the nacelle and top of the tower. The same principle of being watertight in both ends apply for this method. Figure 12 and 13 on the next page shows this principle in short for the bottom plug, lifting and putting it on deck.

Alas, if the nacelle would be removed the flange/plug/bag would be put directly on top of the turbine tower, likewise as done at the bottom. This can either be done by a specific tool mounted to the crane-jig or sort of like an installation where the crew is inside the top of the tower and fastening bolts to the flange.

3. Both the floating and towing would also be possible for the monopile. Cutting it off below the mudline, lifting it up and placing it for a short period of time on deck to fit both the top- and bottom plug, then letting it back into the water for towing. Likewise, could the

installation of both top and bottom plug/flange/inflatable under water and then drain the water out resulting it to eventually float. This can either be done by an ROV, externally mounted system or installed at the construction of the OWT.

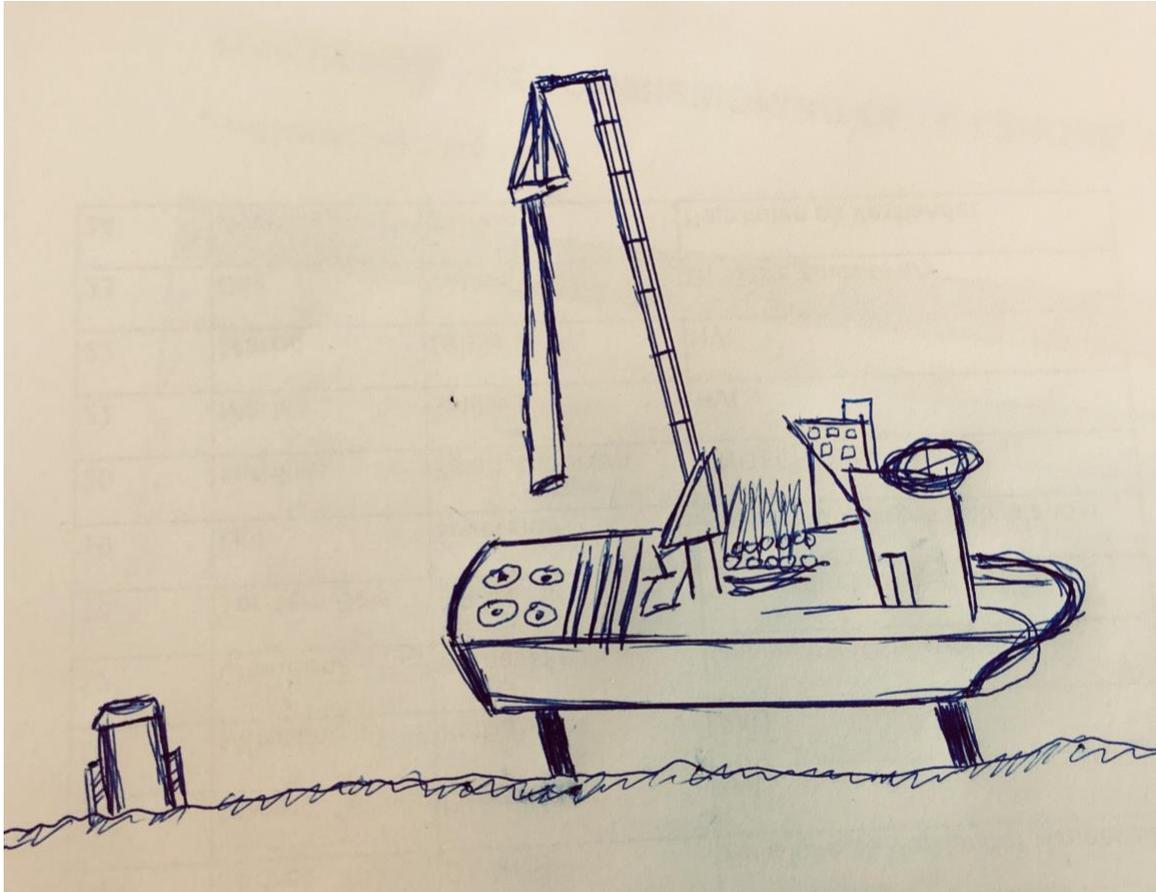


Figure 13: Sketch - Plugging method by lifting.

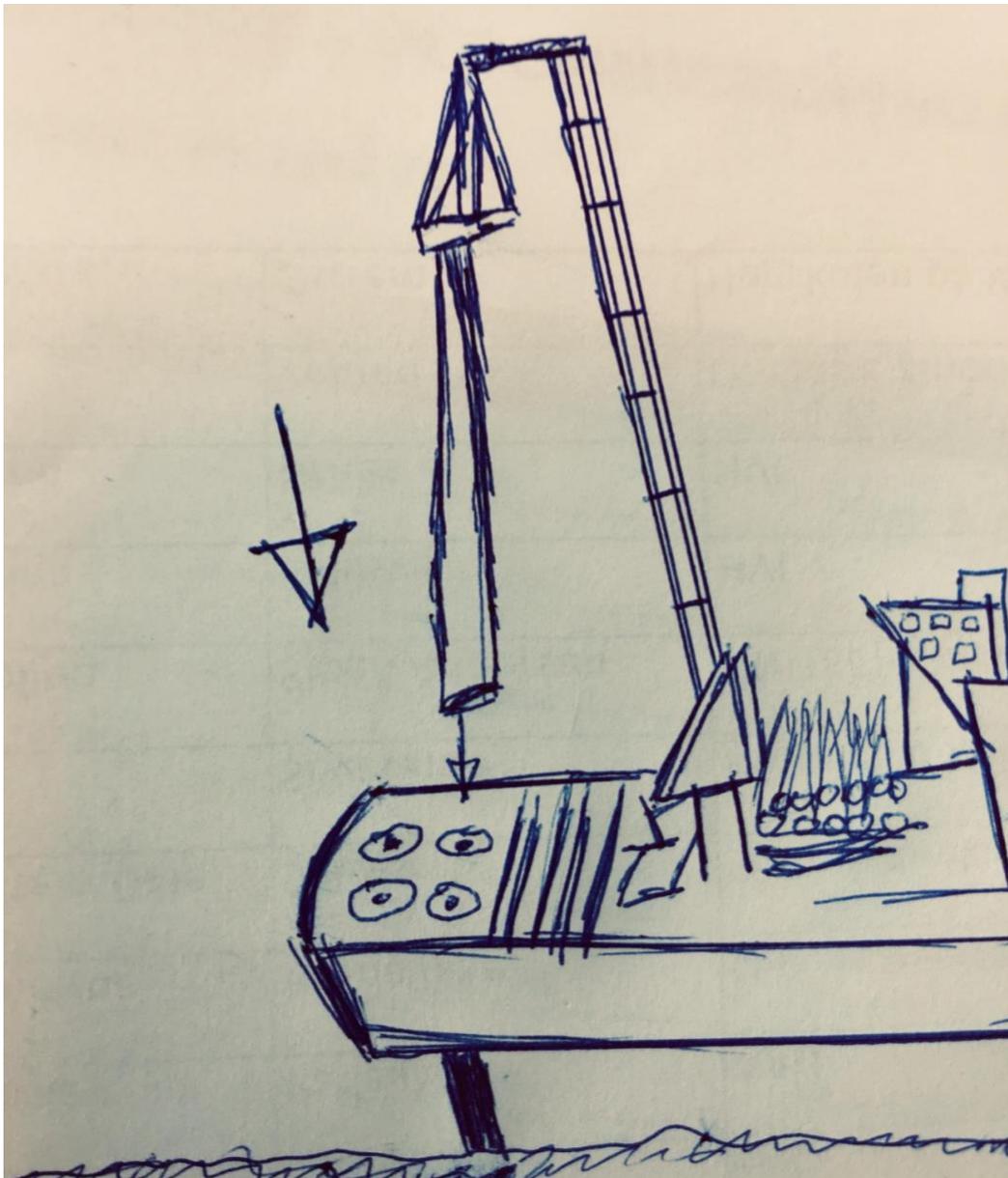


Figure 14: Sketch - Close-up of putting the tower onto the plug at the aft deck of the lifting vessel.

4.2.3 Towing

Regardless of whether the tower is felled like a tree or lifted off the transition piece, the towing would be a very valuable substitute method for loading the entire OWT structure onto the heavy lifting vessel. What is proposed in the Sheringham Shoal documents and done in the previous cases of the dismantling the smaller wind farms is to fully cargo-load the heavy-lift vessel, send it to the decom-facilities, unload it and send it back out to continue operation. Alternative approaches to this practice would be to either;

1. Load components onto a barge and shuttle-transport it to the decom-facilities. This might be a reasonable approach if there are cranes at the onshore facilities to unload the barges, the weather/sea state is feasible, and a cost-effective solution is found. Nevertheless, the heavy-lift vessel will *most likely* be the biggest cost-driver, and if it can work around the clock with lifting – money and time possibly can be saved.
2. Plug it, put it back into the water and tow it. Assuming the tower and nacelle (monopile, too) easily, and in a cheap manner can be made entirely watertight, the most viable option of transport would be to tow several of them to the onshore facilities by a cheap tug/towing boat. This approach would, as the barge-option, also entail that the heavy-lift vessel continuously can stay on-site and do the lifting while the towing is done as a separate enterprise of the operation. The floating towers/monopiles can also be left floating if fastened, waiting for the towing vessel.

For the onshore facilities, winches can be installed and a ramp to pull the OWT-structure out of the water, eliminate the need of a heavy-lifting crane at the quay-facilities. However, this would be simple to arrange if towing of hundreds of OWT were to happen in a decommission-operation. Additionally, the distance of towing to demolition facilities is one of the factors if towing would be viable. Though, there are several other and vastly more economical and technical issues; i.e. the plugging and lifting to be considered before towing can be considered and realized.

4.3 Alternative architecture to optimize decommission

Even though this next alternative approach is not a new way of altering the construction of the entire OWT, it would give us an alternative use of the foundational structures. Repowering or updating the turbines are often linked with updates of both the power grid, substations and connection between the OWT's in the farm. However, down-grading of the turbines would mean using the same foundation, though smaller and lighter towers, nacelles and/or blades. Resulting in the repowering related issues to not be the same problems in that manner.

Foundations are in most cases vastly over-dimensioned [20] and as these areas are found to be well-suited for wind farm development, it could be a clever way of squeezing out a few extra megawatts of the field before full decommission, ensuring an increased yield per foundation. Obviously, the fatigue of every component needs to be carefully calculated and tested if the following ideas *could* apply.

Two different approaches to this would be either construct the transition piece differently, so it can be simple and easy to replace the existing tower, nacelle and blades, with new ones. Or, just changing out the nacelle and blades at the top with lighter/smaller ones. Today, the transition piece is connected, progressively in almost all new OWT, with mechanical couplings and fastenings, instead of grout. The mechanical coupling has two main improvements compared to the grouting, the environmental impact of the approximately 100 tons of grouting used and the difficulty to remove the transition piece when it is cemented in place.

The idea of changing out both tower and top of the OWT will be a costly one, though it can be affordable with low day-rates on the lifting vessels, and high electricity prices. However, when about the whole OWT is changed, it would presumably be able to stay in action for a long period still without being dismantled due to fatigue, harnessing the wind for many years to come. The second method would only change/modify the nacelle and blades, which would require a less complex modifying operation. There is a whole new level of dynamics to consider if one should apply any of these ideas. The state of wear and tear would need to be elaborately detailed.

4.4 Recycling and handling of blades

From the visit at the decommission facilities at Kvaerner and deriving from their input, it can be stated that in most cases 98-99% of the total material from oil/gas installations and structures will be possible to recycle and/or reuse in another manner. Any material (metals, electronics, naturally-occurring nuclear material NORM, toxic compounds etc.) will be safely handled. For the offshore wind turbines, there are sustainable processes for the foundation, tower, gearbox and housing. However, as the Decom Tools-team, both Kvaerner and AF decom, recognize an issue of recycling the wind turbine blades, which is made up of glass and carbon fiber reinforced composites. As of today, we do not have any sufficient and sustainable methods for recycling of this material due to its high resistance to high temperatures and harsh chemical conditions [21]. As this resistance is a result of its high mechanical performance, which is needed for the large turbine blades, we cannot reduce the quality of the blades, to make it less complicated to recycle.

From figure 14 on the next page, a cross-section of a wind turbine blade is shown. The geometries and logic of the what's and why's of this design and architecture will not be discussed. However, three approaches to the reuse and/or recycling found in the literature, discussed when visiting the local companies and at the workshop is as follows;

1. **Using a different material** (e.g. wood, metal, aluminum) rather than the fiber/epoxy/carbon composite. This is mostly a dream-scenario to solely use materials similar to wood. Reference to figure 9 and the erosion of the ends. Furthermore, creating smaller blades (up to 5-6-7 meters) long blades in wood will still result in varying stiffness, weight and strength characteristics from piece to piece. The even longer blades would have to contain some form of composite that still uses the carbon/glass fiber reinforced materials [22] trying to remedy the exponential increase in volatile structural characteristics. It is crucial to have totally identical parts for this type of mass-production and mass-handling, as it is decisive to have the wear and tear. The use of a blade like this would definitely have an increased cost, though the environmental impact could be severely improved.

2. Cut the composite blades in **big sections** to work as some form of shielding/cover/barriers in housing projects, walls, etc. [23]. This is one of the concepts set to life by a team of researchers from City College of New York. The focus is on large-size reuse in affordable houses, though this approach can be applied in many different and alternative arrangements. However, as the materials are *still* non-biodegradable, the composite materials are yet being produced – and that is one of the matters we should consider terminating. Alas, the same goes for the next approach.

3. **Cut into smaller pieces** and use in concrete. There are two practices of cutting the blades for use in concrete – coarse aggregate and discrete reinforcement. Though, the coarse abrasives have shown to reduce the strength of both the compressive and tensile strength in concrete. Discrete reinforcement (also called needles) on the other hand, has shown significant improvement in tensile strength and energy absorption [21]. Additionally, the break-down into needles compared to the coarse aggregate is a less energy- and time-consuming method.

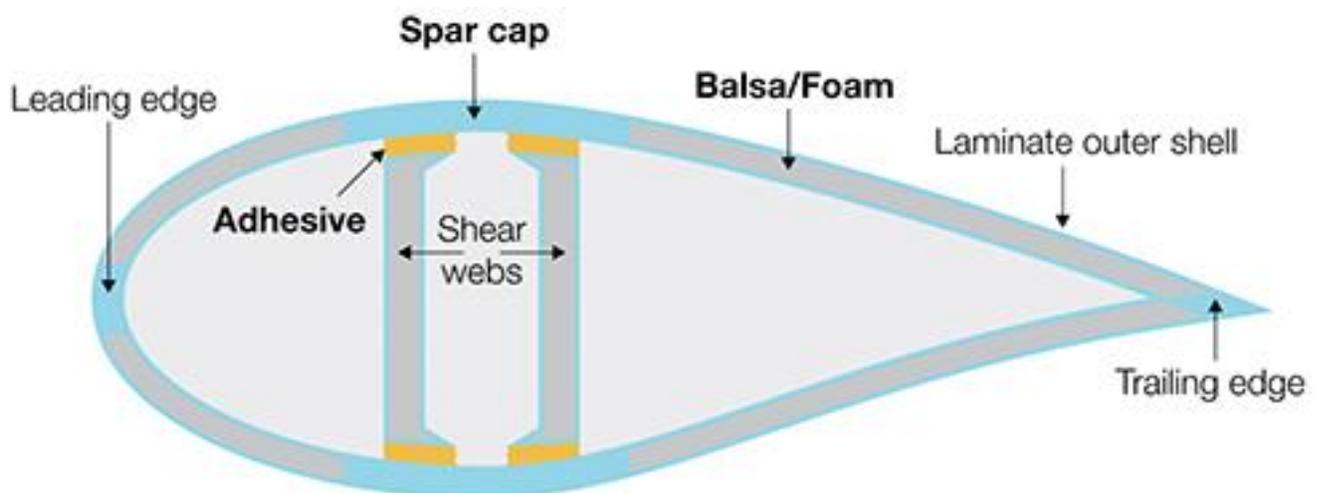


Figure 15: Cross-section of turbine blade [32].

5 Discussion

The overarching goal is to improve the efficiency of the offshore wind farm decommission. EU's goal is to reduce the environmental footprint by 25%. To be able to reach this goal, the stakeholders need to save time (reduce total vessel days) which will reduce both costs (goal is to cut costs by 20%) and the emission related to the dismantling. The high installation volume today suggests that a similar decommission volume can be expected in the future.

Save time

Reduce
costs

Reduce CO₂

Figure 16: EU goals to achieve through the DecomTools project for the decommission process.

Saving time will not consequently result in reduced costs and vice versa. Thus, the same manner as reducing time will not automatically reduce the environmental impact. However, they are all intertwined – if the companies and operators are willing, initially, to take the complicated and arduous route of finding a more feasible method of constructing, installing, maintaining and dismantling the future of renewable energy. This chapter will systematically and chronologically, discuss the previous approaches in the thesis to assess future sustainable and economical sound solutions. In consideration of making the readers experience effortless, the subjects are designed in sub-chapters and resulting numbering bulletins.

5.1 Vessel requirements

One of the key elements to the decommission process is the use of offshore vessels being able to lift and/or handle the offshore wind turbines in a fast, secure and economical manner. There are a few considerations that must be discussed on this term;

1. **Weather sensitivity** related to vessels being utilized. As most of the turbines are located in the (*shallow part of the southern part of the*) North Sea, we know the weather can *regularly* turn rapidly and represent a massive role in any operation, thus be a momentous factor in the planning. The shallow water-depths is also creating more instability in the waves. If it becomes possible (due to sizes of the turbines or combination of floating and jack-ups) floating vessels like offshore construction- and supply vessels, with the smaller cranes (compared to the jack-ups), can be a risk of play. Even though these vessels *might* have a lower day-rate (adjusted by seasonal variations) in comparison to the more expensive, though greater weather-resistant jack-ups or heavy-lifting vessels. When planning the decommission, a trade-off based on the cost, risks, availability, time and requirements will be done by the main contractor.
2. This leads us to the next point of interest, the **installation vessels**. Today, this is typically a specialized heavy-lifting vessel similar to the Pacific Osprey/Orca mentioned earlier and those in the fleet of Fred. Olsen Windcarrier¹⁴. These are designed particularly for the installation/decommission of today's wind turbines and farm. Yet, what is most likely to happen, is that the turbines are getting bigger and bigger (up to a point), maybe as big as 150m tall and doubled the weight, or conversely a paradigm shift into a floating turbine domination. Floating structures are being tested now, possibly changing the established fixed-bottom industry we have today in Europe. Additionally, the floating turbines make up a more dynamic solution for countries with large depths outside their coasts – i.e. Norway. Either the shift to floating, or the enlargement of the fixed turbines, today's installation jack-

¹⁴ <https://windcarrier.com/fleet/#jack-ups> – accessed 2nd of May 2019.

ups will be outdated and too small for installation of bigger turbines, hence they will be perfectly suited for the decommission of the same turbines they installed 15-20 years ago.

The wind industry is not like the oil business where money has been of less issue. For the entire process, until very recently, a big amount of financing has come through governmental subsidizing when manufacturing a wind farm. In recent years, the operators have been able to increase the efficiencies to earn money, though this business will never be as lucrative as the oil- and gas industry, resulting in the decommission to be an extremely low earner and, unfortunately, deprioritized. However, this might change if we are able to find a smoother approach on how to decommission the parks making it more profitable, but also finding better solutions to the issue of the composite blade recycling.

5.2 Cutting of turbine blades

The removal of the turbine blades in the dismantling process may seem to be a wise move, as the blades are not extremely heavy, although they take up plenty of deck space if they aren't disassembled. As mentioned in the alternative approaches, cutting the blades by the root of the nacelle in comparison to unscrewing can save substantial time. Which cutting method being used, depends on the market and how it is possible to fit different mechanisms on the lifting jig. Alas, there are possibilities to have compressors, hydraulics and other auxiliary needed for the cutting mounted on top of the jig. The lifting capacity in tonnage is not the limiting factor when using the heavy-lift jack-up vessels, neither is the height requirement.

Depending on how the blades are cut, a few objectives are worth noticing;

1. The sawing/torching/cutting needs have either a *vacuum-cleaner tool* or bag in the proximity of the cutting area to avoid any debris slip away and into the ocean.
2. Guillotine cutting mechanism could break of bigger "straws" or pieces.
3. Weather sensitivity of the chosen method.

4. Reliability of the cutting equipment is of paramount importance. E.g. if the cutting operation is done around 70% and stops, the blade will possibly fracture and fall of if lifting jig and clutching system is removed.

Point number four listed above makes the entire operation as to the cutting of the blades more uncertain. If we cannot be sure if the cut can be complete for i.e. 300 turbine blades without any inconvenience, it could justify the reverse installation and removal of the blades as originally intended. Nevertheless, this method is also risky as there will be heavy lifts at great height, crew inside the tower and several actors involved. If the cutting system breaks and/or get stuck in top position at the beginning of the cut, it would be simple to bring the jig down, however, this will not be possible if the cut is almost successful, without a big probability of the blade falling down when the jig is released. Resulting in the removing of blades to be safer and proficient when done as a reverse installation. It is the same with the weather sensitivity, a method for removing the blades, but also the entire structure needs to be solid in relation to the rough sea state and windy conditions encountered.

On a separate note, when discussing with Scanmudring what cutting methods are available, dimensions they are able to cut and what future possibilities there are, it does not depend on them as a cutting sub-contractor to be able to design/create a tool for the operations – but on the operator/main-contractor that is going to pay for the operation. It was expected consensus in Scanmudring that the companies hiring them *not always* wants to apply and hire the tools providing the swiftest and quickest method for cutting. This is most likely due to keeping the vessels and crew occupied for a longer duration. It might seem strange, however, it makes sense as this is a factor in relation to both 1) pushing the day-rates and vessel days up, as the biggest IMR-companies operate their own fleets, and 2) keep the vessels and crew away from lay-off in the tough times we have had the last few years.

To elucidate and clarify the above issue, there are two ways we can get about; 1) the owner of the wind farm is dictating how and with what methods the removal must be done, or 2) governmental legislations are made to ensure compliance and most sustainable practice is

executed. If point one could be enough, the operators would have a big responsibility to the environment and not just only to their shareholders to make the most dollar.

5.3 “Tree felling”, plugging and towing.

This sub-chapter consists of a broad spectrum of approaches, including both the “felling” of the turbine, plugging to ensure it is watertight and towing from wind farm to shore. Originally, as discussed above, the removal of the turbine blades will be done as a reversed installation process. Prior to removing the turbine and nacelle, the elevators and other mechanical structures inside the turbine will need a check. It is mentioned in the decommission plans of Scira at the Sheringham Shoal that the hydraulic oils and lubricants need to be removed. However, this might not be necessary, if air-vents are closed and plugged, and an overall assessment of the locked hoses, vents, etc. is performed prior to the felling/removal, leaving the lubricant in-situ will not only save time, though the possibility of spilling oils inside the tower when removing is eliminated. Additionally, the transport of the containers from towers and onto crew vessels will be dismissed and can save both time and potential severe personnel-injuries if multiple big barrels of oil is being lifted in an uneven sea state, onto a smaller vessel stuffed with crew.

1. Plugging, and establishing a base of being certain that the tower is absolutely watertight, is the inaugural assignment that is needed before towing/felling. The plugging with a flange or with inflatable bags is both viable options. Mechanical flanges inserted into the tower/monopile can propose a more extensive job with the fitting of them compared to using mobile, inflatable and shapeable rubber/composite bags. An extra benefit with these, are the capability to reuse them at a later stage. They will additionally have a low weight compared to the steel plugs/flanges. The flanges would most likely need to be installed prior to commissioning offshore. This might be a solution to implement in newer turbines, though the thousands of older turbines don't have this kind system in place – favoring the inflatable bags. As long as these are adequately tested and have high durability and resistance to puncturing this is a viable option. If this method is to be used on the monopiles, they would

have first had to be plugged, then all the water would need to be drained out of the pile resulting in the pile eventually floating to the surface. Additionally, one of the pros with the inflatable bags is the possibility to add several to increase the redundancy.

2. When the tower/monopile is satisfactory watertight, the felling/lifting can commence. As previously mentioned, this can be done either by cutting/explosives and felling directly into the water, or by the means of lifting onto the deck of the heavy-lift vessel and onto a plug/flange/inflatable bags. The felling was initially preferred, though several arguments on why this might be a poor solution have appeared. Firstly, if explosives are going to be used and there is a faulty detonation, it will be a huge case to clarify this. Explosive teams would need to come in, and dangerous conditions can occur. Also, if explosives are planned used for the remaining, there will definitely be a stop in operation to figure out where the issue lies. On the other hand, if the felling is done with cutting and a partly cut is made before the tool break, we have another potentially dangerous situation. For both scenarios, it could be possible to add a redundancy layer of tools used to cut. Alas, there will be a heavy-lift vessel around taking down the blades, and this can rapidly be used for the lifting of the tower onto the deck, fitting of watertight plugs, then lifting and releasing the structure into the water ready for towing.
3. Towing of the structures to shore decommission base is a modest task if the two tasks above are done appropriately and according to plan. The vessels used for towing operation depends on what is most economical viable for the sub-contractor, distance from farm to onshore facilities, weather at time of towing, vessels available. The onshore facilities would need to have winches/cranes to be able to get the structures on land, and as mentioned by AF Decom, a plan for serial decommission of the hundreds of similar pieces that will be incoming regularly.

5.4 Alternative architecture

The alternative ways of designing the structures are in forward motion and evolving by those who manufacture and sell the wind turbines, where they are trying to lower the cost for themselves, thus which will result in lower costs eventually for all who buys them. Though, it is important that the choices related to materials used and solutions are taken into thorough consideration. This is in the hands of those who order the OWT. As we know, the turbines need to be removed sooner or later, and that will also be a cost for the operator. One paradigm shift in that area, is the change from grouting used to connect the TP and the monopile to mechanical connections. Not only is this better for the environment, but it will also (hopefully) make the dismantling more painless. It can be possible to reuse the monopile or transition piece, conversely will the recycling of them be smoother with less particles.

It should also be possible to design with a higher focus on the decommission. If the shift to floating turbines will stop the advances of the fixed-bottom is still left to see, though by increasing the attention to include the decommission in the bigger picture, will aid in making the industry even greener. This can be done by e.g. pre-installing pipes for injecting explosives when designing the structure, so when that time comes it is easy to plant explosives into either monopile, tower (or both). It can additionally be to install cutting mechanism-mounts making the fitting smoother at the end of life, air-tight fillings at appropriate points throughout monopile and towers. These can be manufactured with entrances/covers for crew movement inside, that can conveniently close and satisfactory stay air-tight (in an event of future towing).

The possible downgrading or repowering can only happen after a comprehensive analysis by the operator. It is hard to say at this the beginning of the life-cycle of a wind farm what will be the most economical solution in 10-15-20 years. It is also worth noting that the decommission possibly can ruin the area and sea life – though only for a short period of time. Nevertheless, will this be accepted by the government is not known. Removing all the cables, monopiles and making a big mess might take decades to get back into its original state – or in the worst case, it never recovers. If the monopiles should be left as artificial reefs is a case that need comprehensive

investigation before removing the huge farms. These new issues arise when fresh industries are born, in Germany they have already had some similar cases to subsea structure decommission. When filling the holes and smoothening the seabed, only the exact same sediments that had been there previous could be used.

5.5 Recycling and handling of blades

The recycling of the turbines is already taken care of, e.g. through the extensive and detailed recycling programs at for example Kvaerner and AF Decom. They are able to reuse and/or recycle up to 99% of offshore and subsea installations – thus dealing with offshore wind turbines will be easy, as they are mostly pure steel and the components inside the nacelle are simple to recycle. Also, the huge sub-stations weighing 1000 tons will be recycled in a similar manner. Getting these on land and ready for recycling is not an issue. AF Decom said this would be done in a manner comparable to how big platforms are removed today – either cut into appropriate sizes (the larger the better), lifted onto the heavy-lift vessel and sailed to the decom-base for further dismantling.

However, it is the composite-blades that is the issue. The composites are non-biodegradable, and in the United States the majority of this type of waste is used as landfilled. If the blades are not handled in a sustainable manner, the concept of *green wind power* cannot be considered clean.

Today, it is a realization that most of the industry initiatives addresses the end-of-life aspect of the technology we currently have. However, a more sustainable approach would be to address the design methods and aspects whereas considering substituting the composites, thus resulting in a closed-loop recycling of the blades. Alas, this would require partnership and teamwork within the suppliers, wind industry giants and end-of-life sections. This can constitute the wind turbines as renewable both in terms of energy generation *and* material use. An approach like this will be perfect to the *circular economy*, where the resources stay in the circle for a prolonged time. This system tries to minimize the waste and make the most out of the resources. There are companies in Europe now, that is trying to break the code to achieve an environmental process of recycling these blades.

One example is the Norwegian company Ecofiber¹⁵. Although, this company only accepts pure glass-fiber and composites, a small company like this will most likely not be able to receive the number of blades a wind farm consists of, it is a beginning. Additionally, what is also a case in the offshore industry, is the “*as built*”-concept. This means that the blueprints and drafts on the original structure (as built) can deviate to a large extent on how the structure appear today. This might have been a bigger concern a few decades ago, on larger platforms and rigs. Nevertheless, for the industry to be able to find an acceptable solution, it is important to know with 100% accuracy what the blades consist of. In the coming years, the amount of glass-fiber composites waste to be recycled is exploding. Finding sustainable approaches to this, is the biggest challenge in the process around green decommission of wind turbines at the moment.

¹⁵ <https://ecofiber.no/> - accessed 6th of May 2019.

6 Conclusion

A wind farm and offshore turbines are exposed of two types of aging; a performance loss as a direct result of wear and tear caused by time. Though also a relative aging resulting in an indirect performance loss, when it is compared to the newest technology on the market. When it is time for decommission, we need sustainable processes to be able to ensure and totally maximize what is the environmental profit of wind power.

The mission for this thesis was to look at the new methods and approaches to the decommission process in relation to the oil- and gas industry. Visiting local companies with a broad experience in this business and getting their thoughts on what could be viable options on how to decom offshore wind farms.

The major case is not the vessel days or the cost of the vessels, this will be handled accordingly by the market and the company winning the contract to perform the decommission. Day-rates for vessels will be variable at all times. Same goes for the tools used for cutting, the market will take care of it when the big farms are going to be removed in 10-15-20 years. Both these assumptions are based of the experience of the local companies and should be given great recognition.

Minor challenges and approaches that this thesis have concluded with is that it should be possible to tow the structures to shore instead of loading them onto the deck of the heavy-lift vessel or barge. This can save time, vessel days, resulting in a reduce of cost and consequently reduction of CO₂.

Though what is the biggest challenge, is the blades and the recycling of these. We do not have enough knowledge on this matter yet, alas many companies have seen the possibilities here and are exploring how they are able to take advantage here.

7 Further Work

Some future work derived from this thesis is can be summed up into the following;

1. Recycling of the blades is the biggest challenge. Finding methods that can sufficiently and sustainably recycle and/or reuse the composites used. Or, as an alternative, change the contents/substances being used in the creation of the blades. If we can stop using those materials proving to be hardest to recycle, though finding a more suitable fabric-composition.
2. Plugging with the inflatable bags. Designing this type of equipment/tools and testing them to be able to withstand the weather, towing, lifting and then being able to be reused at a later stage.
3. Solutions for towing. This might be a subject for the company doing the decommission if the towing is chosen. How will the towers roll and behave in the water? What is the best practice of towing in relation to how many structures are towed at once after each vessel, and several other questions arising when conducting the towing operation.

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Appendix

The appendix-part of the thesis will help to set light to a few matters have not been found important *enough* to be in the thesis, however it is information that can serve a broader purpose. Additionally, the documents made after meeting with the local companies, *the minutes of meetings*, are added at the end.

The appendix content consists of the following;

Appendix A – DecomTools programme and what the project is about.

Appendix B – Figures of the supporting structures used instead of monopiles.

Appendix C – DNV-model calculating the weather at the Sheringham Shoal installation phase.

Appendix D – Minutes of meeting from DeepOcean

Appendix E – Minutes of meeting from Reach Subsea

Appendix F – Minutes of meeting from Kvaerner

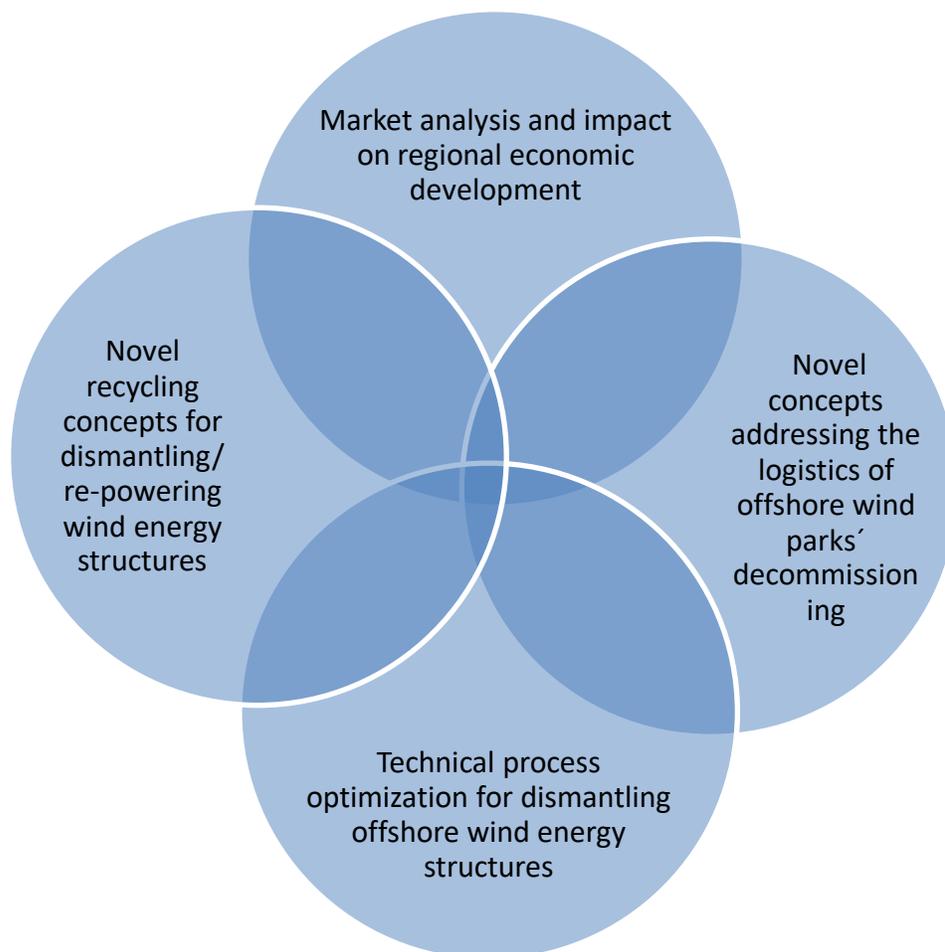
Appendix G – Minutes of meeting from AF Decom

A - DecomTools programme – Summary

INTERREG VB NORTH SEA REGION Programme (EU-Project) Decommission of offshore wind parks (DecomTools)

Detailed project objectives:

- ✓ Process optimization for dismantling offshore wind energy structures
- ✓ Developing new logistical concepts for dismantling offshore wind structures
- ✓ Develop new recycling concept for dismantling / re-powering offshore wind energy structures
- ✓ Foster the market uptake of the newly developed decommissioning solutions



Our «Scope»:

Use the methods and experiences of decommissioning of offshore installations and apply this in connection with offshore wind farms, as well as we will be looking at new methods and vessels.

Partnership:

13 Partners from 6 North Sea Region-countries (DE, DK, BE, NL, UK and NOR) are involved: public authorities, business development agencies, businesses, scientific institutions and public infrastructure providers. Associated partners will support the project.

Partners:

1. University of Applied Sciences Emden/Leer (Lead) (DE)
2. Hamburg Institute of International Economics - HWWI (DE)
3. Maritime Cluster Fyn (DK)
4. Offshoreenergy.dk (DK)
5. Port of Grenaa (DK)
6. Samsø Kommune (DK)
7. Port of Oostende (BE)
8. Regional Development Organisation West-Flanders, POM (BE)
9. De Lauwershorst Groep (NL)
10. Energy Valley (NL)
11. Virol (NL)
12. University of Aberdeen (UK)
13. Western Norway University of Applied Science (NOR)

Budget:

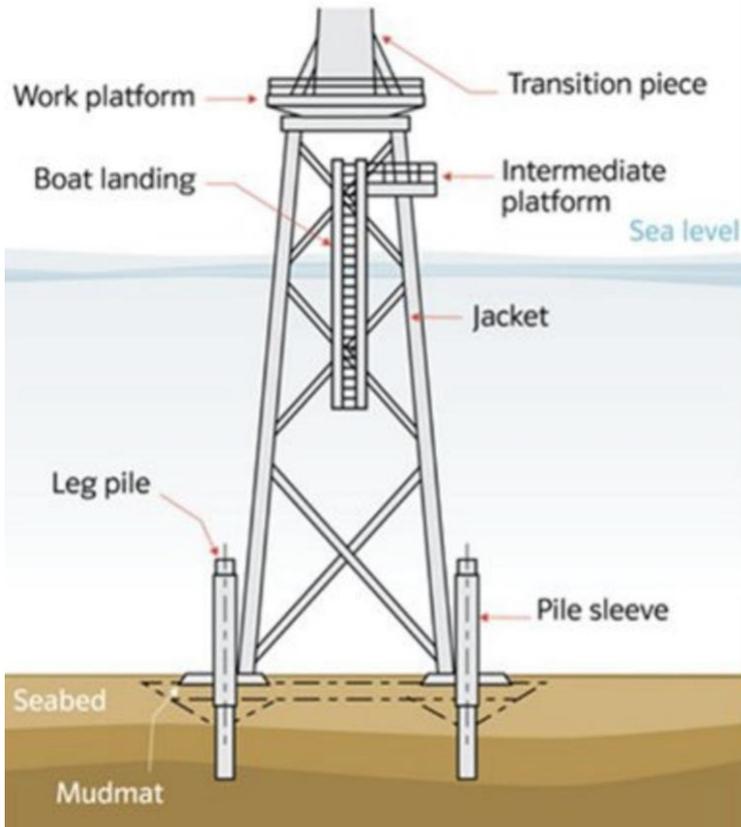
Total: 4,7 mill. Euro

HVL's cut: 178.000 Euro

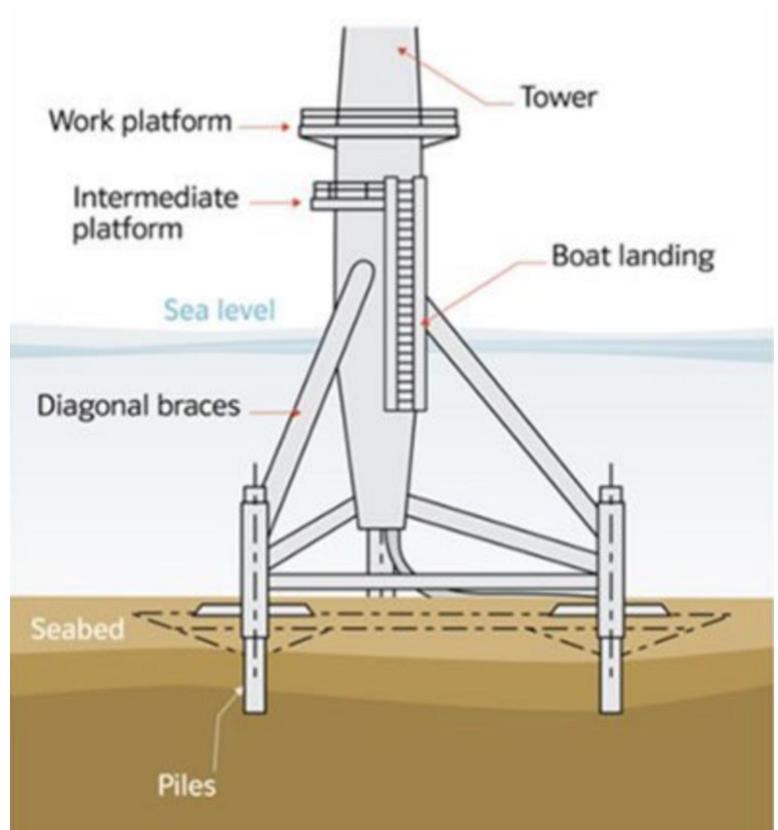
Timeline:

Project will last 4 years.

B – Supporting Structures



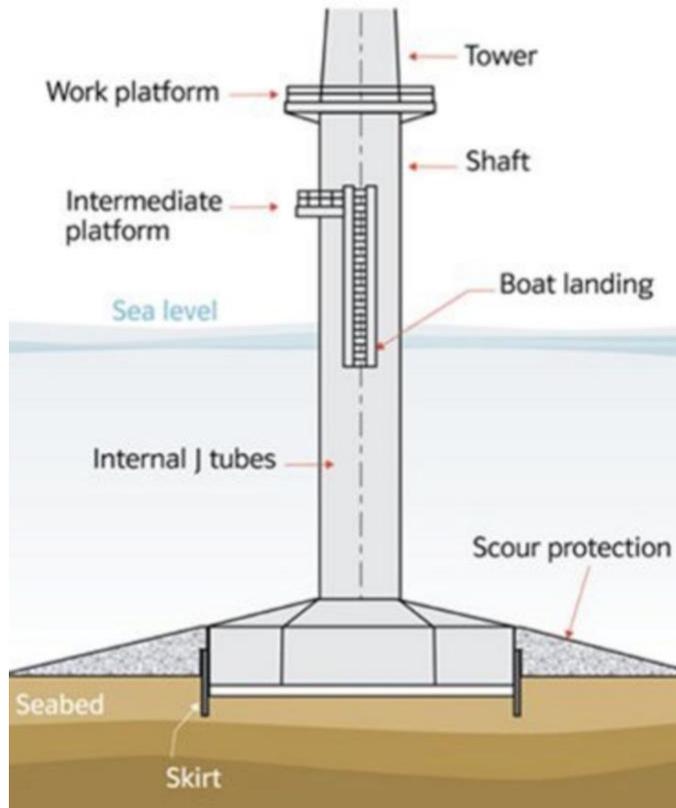
Appendix Figure 1: Jacket/Lattice



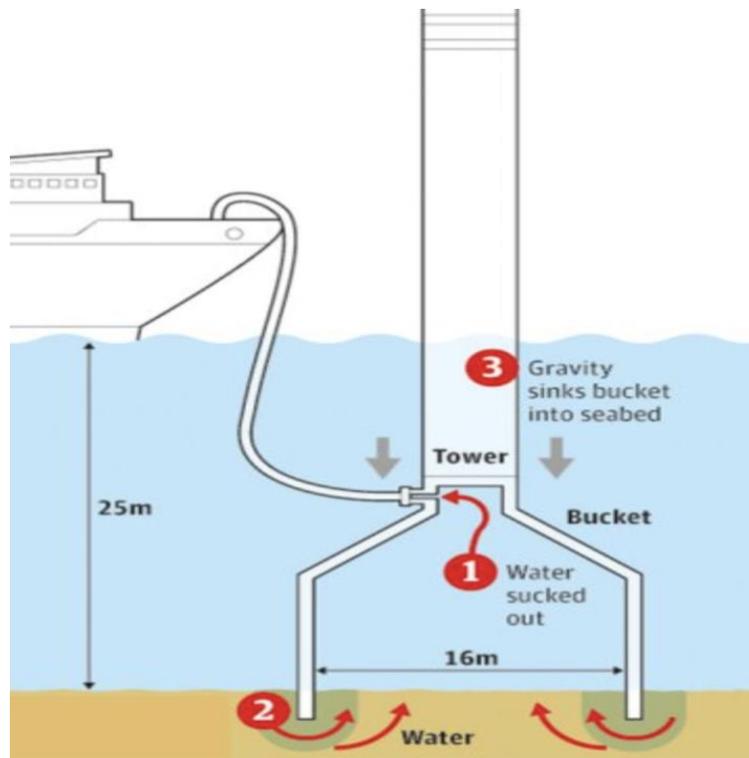
Appendix Figure 2: Tripod



Appendix Figure 3: Tripile



Appendix Figure 5: Suction based

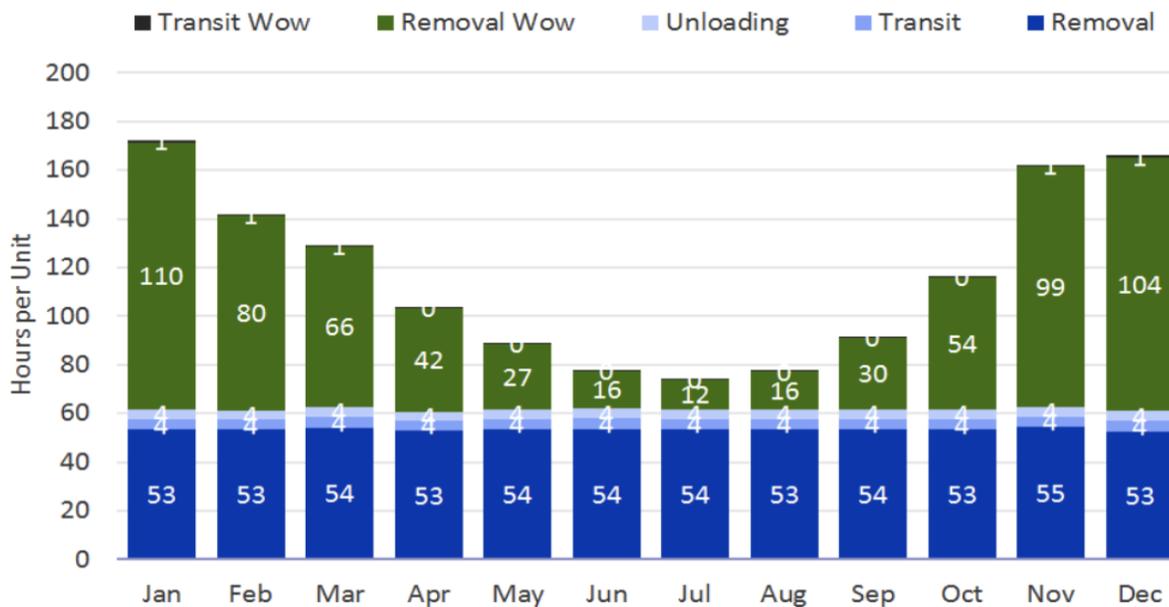


Appendix Figure 4: Gravity based

C – Operational sequence from DNV model

	Duration [H]			Hs limit [m]	Max WindSpeed [m/s]	Comments
	P10 [h]	P50 [h]	P90 [h]			
Tower						
Positioning	3	6	8	1.8	14	
Jack-up and pre-loading	6	8	10	1.8	14	
Removal of Blades	6	8	10	4	10	Reverse of Installation
Removal of Nacelle	2.5	4	6	4	14	Reverse of Installation
Removal of upper tower section	2.5	4	6	4	14	Reverse of Installation
Removal of lower tower section	2.5	4	6	4	14	Reverse of Installation
Removal of TP above grouted connection	4	5	7	4	14	
Removal of MP and grouted connection	8	11	15	1.8	14	
Jack-down	1	2	4	1.8	14	
Total	35.5	52	72			

Appendix Figure 6: Operational times created from DNV model



Appendix Figure 7: Distribution of time used for removal, seasonal changes

D – Minutes of Meeting, DeepOcean 25th of January 2019

DECOM Tools Project

This document is a summary of minutes of meeting at DeepOcean on the 25th of January 2019.

Present:

Person 1, DeepOcean

Person 2, DeepOcean

Jens Christian Lindaas, HVL

Andres Olivares Lopez, HVL

Børre Mæland, HVL

Martin Urnes, HVL

Questions related to company visits (subsea operation- /construction companies):

- **Which decommissioning projects (oil and gas) have your company been involved in?**
DeepOcean have been involved in many projects subsea and offshore; steel removal, two different loading buoy removals, debris removal, drill string recovery, two times wellhead decom, mattress recovery, structural removal, drill cutting, pipeline decom.
- **What has been your Scope of Work in these projects?**
DeepOcean has done engineering, project management for the subsea operation. Operations include all types of dredging, a variety of lifting operations, cutting horizontal and vertical, cutting internal and external, pre-operation survey and post-operation survey, recovery of items into baskets and directly onto deck.
- **What methods and tools have been used for cutting/dismantling the structures (subsea and topside)?**
Company 1 ONLY subsea. Mostly diamond saw/diamond blade cutting. However, HP water jetting grit/abrasives also used. Guillotine cutting has also been used. Whatever method, it is ALWAYS depending on the cost, SoW and material being cut.
- **What is your experience using these methods/tools?**
Diamond wire – relatively slow, but reliable. Easy transport/mobilization.
Diamond saw blade – Fast, more durable.
HP water jet – Fast, but advanced mobilization/installation due to bigger team topside. Possibly problems with mixing grit. Additionally, uncertain if cut is successful (achieve full penetration).

This company hires sub-contractors for cutting operations. Mostly same methods as 10 years ago. Challenges related to shallow water, both for vessel and ROV.

DeepOcean estimates digging/trenching for cutting 2m below mudline outside-in to 4-5 day's work.

- **How have the parts been lifted onboard the vessel(s) and transported to the onshore base?**

Depending on the size of the pieces;

Heavy – entire structure/platform.

Medium – Structure cut into a few pieces.

Small – structure cut into several smaller pieces.

- **Which types of vessels have you been using?**

Construction vessels (max 600 tons crane weight) and jack-up rigs.

- **Has towing of structure elements been used?**

Yes, but mostly for whole structures (e.g. loading buoy). For this, usually towing vessel is acquired, as this is often cheaper.

- **Which onshore bases or quay facilities have you been using for the further dismantling and recirculation process?**

It is typical procedure to keep the elements in the country where the wind park/subsea structure is based. Alas, for floating structures the UK/German coast is not always suitable.

- **Which cutting methods and tools have they been using?**

This is not within the scope/knowledge of the subsea/decom company.

- **Where has the material been sent for further processing/recirculation?**

Same as previous.

- **Have you been involved in installation of offshore windmills? Which windmills/parks?**

No, only for cable grid and export cable for a few projects. For Ørsted and Dong.

- **What has been your Scope of Work in these projects?**

Cable laying trenching, dredging and connection. Mattress installation.

- **Can the installation process be easily reversed for decommissioning of the windmills?**

Yes, but what is most cost effective is usually a different method.

- **Will decommissioning projects related to oil and gas be a growing part of your business for the next five years?**

Yes, they would like to be part of the “decom-wave” hopefully hitting Norway in 5-10 years. In today’s market, the price is too low due to underestimation of cost when planning decom. Companies involved need to lose money before it is possible to earn.

- **Are you planning to expand your international operations related to decommissioning projects or will your main focus be in the Norwegian sector for the next five years?**

They are involved in decom in UK. UK is already in the “decom-wave”

- **Are you interested in entering the business regarding decommissioning of wind parks? Have you already been involved in such projects? If so, what has been the Scope of Work?**

Yes, if this can increase revenue.

E – Minutes of Meeting, Reach Subsea 22nd of February 2019

This document is a summary of minutes of meeting at Reach Subsea on the 22nd of February 2019.

Person 1, Reach Subsea
Person 2, Reach Subsea
Person 3, Reach Subsea
Jens Christian Lindaas, HVL
Jan Hechler, HVL
Børre Mæland, HVL
Martin Urnes, HVL

Questions related to company visits (subsea operation- /construction companies):

- **Which decommissioning projects (oil and gas) have your company been involved in?**
Brent, removal of debris on the decom of two of the Brent field fixed platforms.
Pile removal of Wikingen wind farm (40m depth).
Removal of trawl protection structure and recovering of concrete subsea structures.
- **What has been your Scope of Work in these projects?**
Brent SOW – engineering, project management and execution of the scope.
Wikingen wind farm SOW - Removed 9 piles in the Baltic sea. Mobilized soil plug removal, dredging equipment, abrasive HP water jet.
Trawl protection removal SOW – engineering, project management, execution and disposal of recovered items.
- **What methods and tools have been used for cutting/dismantling the structures (subsea and topside)?**
This company has been involved with many methods, depending on the scope of work.
Diamond wire, scissor cutting, guillotine and abrasive water jet have all been used.
- **What is your experience using these methods/tools?**
This company rely on diamond wire cutting, as a standard method. This is always the go-to method if possible. Reliable and simple method, both subsea and top-side. Diamond wire is easy to set up and when doing the mobilization of vessel. Does not need third party/technical operator! HILTI is expanding and entering the subsea cutting market – with a diamond wire cutting technique that is double the speed as today. Dredging is always a cost driver and is an uncertainty in the plan, it is difficult to estimate time used.

- **How have the parts been lifted onboard the vessel(s) and transported to the onshore base?**

This company has used subsea basket, due to simple and safe sea fastening of the gathered material.

- **Which types of vessels have you been using?**

offshore construction vessels, IMR-vessels, PSV.

- **Has towing of structure elements been used?**

No.

- **Which onshore bases or quay facilities have you been using for the further dismantling and recirculation process?**

N/A.

- **Which cutting methods and tools have they been using?**

This is not within the scope/knowledge of the subsea/decom company.

- **Where has the material been sent for further processing/recirculation?**

Same as previous.

- **Have you been involved in installation of offshore windmills? Which windmills/parks?**

Not for wind turbines, but for the concrete stabilization mats. And also, the packs of rock, used to lay on cables for protection. Scour protection has also been laid.

- **What has been your Scope of Work in these projects?**

Mattress installation

- **Can the installation process be easily reversed for decommissioning of the windmills?**

Yes, but what is most cost effective is usually a different method.

- **Will decommissioning projects related to oil and gas be a growing part of your business for the next five years?**

Yes, they would like to be part of the “decom-wave” hopefully hitting Norway in 5-10 years.

- **Are you planning to expand your international operations related to decommissioning projects or will your main focus be in the Norwegian sector for the next five years?**

As long as they can make money, they do anything.

- **Are you interested in entering the business regarding decommissioning of wind parks?
Have you already been involved in such projects? If so, what has been the Scope of
Work?**

Yes, if this can increase revenue.

F – Minutes of Meeting, Kvaerner 15th of March 2019

This document is a summary of minutes of meeting at Kvaerner on the 15th of March 2019.

Person 1, Kvaerner

Person 2, Kvaerner

Jens Christian Lindaas, HVL

Andres Olivares, HVL

Børre Mæland, HVL

Martin Urnes, HVL

Questions related to company visits (subsea operation- /construction companies):

- **Which decommissioning projects (oil and gas) have your company been involved in?**

Kvaerner have been involved in decom projects from 1995 and onwards. Reference is made to Attachment 1 Experience List.

- **What has been your Scope of Work in these projects?**

The projects have been related to engineering and preparation for decommissioning, some projects include removal operation and most include the onshore deconstruction and disposal operations. Reference is made to Attachment 1 Experience List.

- **What methods and tools have been used for cutting /dismantling the structures (subsea and topside)?**

Main methods used onshore are mechanical cutting by shears (mobile and stationary) and gas cutting. Some automatic cutting and semi-automatic cutting techniques and tools are used. Cold cutting like eg. diamond wire is used for certain operations.

For offshore and inshore works the techniques for onshore are utilised above waters.

Subsea water and water grit cutting technology are used as well as diamond wire, special shears etc. There are various specialised suppliers for subsea cutting tools.

There was a discussion on the use of explosives, but Kvaerner would rather use other methods if possible. This due to steel quality and uncertain method. Also, it will cause a big problem if it won't explode correctly.

- **What is your experience using these methods /tools?**

The most efficient tools as per today are mechanical cutting by shears and gas cutting.

Other tools are used tactically for specific tasks. The experience from using the different

tools depend on the application and the correct tools and cutting techniques must be selected based on the structure to be cut and working conditions.

They are working towards more automatically cutting tools.

- **How have the parts been lifted onboard the vessel(s) and transported to the onshore base?**

Modules and structures have been lifted onboard the vessel/HLV using the vessel crane.

- **Which types of vessels have you been using?**

Modules and structures have been lifted onboard the vessel/HLV using the vessel crane.

- **Has towing of structure elements been used?**

Yes, eg. towing of subsea structures using pencil buoy and removing of jacket structure using buoyancy tanks.

- **Which onshore bases or quay facilities have you been using for the further dismantling and recirculation process?**

Mainly Kvaerner's Disposal site at Eldøyane, Stord and for part of Frigg the Greenhead Base at Lerwick, Shetland.

- **Which cutting methods and tools have they been using?**

Reference is made to question 3 above.

- **Where has the material been sent for further processing /recirculation?**

The steel materials are cut in chargeable sizes and shipped to meltery in Europe. Stainless steel, copper, zink etc. is transported to more specialised recycling facilities. Wastes are treated, incinerated or disposed off through approved waste handling contractors.

- **Have you been involved in installation of offshore windmills? Which windmills /parks?**

No

- **What has been your Scope of Work in these projects?**

N/A

- **Can the installation process be easily reversed for decommissioning of the windmills?**

Yes, it can

- **Will decommissioning projects related to oil and gas be a growing part of your business for the next five years?**

The decom business segment is expected to grow; however the new build and modification activity is still expected to form the major part of our business the next years.

- **Are you planning to expand your international operations related to decommissioning projects or will your main focus be in the Norwegian sector for the next five years?**

The decom business segment is expected to grow with engagements also outside the Norwegian sector.

- **Are you interested in entering the business regarding decommissioning of wind parks? Have you already been involved in such projects? If so, what has been the Scope of Work?**

Yes and no. Yes, Offshore Wind will be part of our decommissioning. No, we have not been involved yet

G – Minutes of Meeting, AF Decom 24th of April 2019

This document is a summary of minutes of meeting at AF Decom on the 24th of April 2019.

Person 1, AF Decom
Person 2, AF Decom
Jens Christian Lindaas, HVL
Børre Mæland, HVL
Martin Urnes, HVL

Questions related to company visits.

Introduction

- **Which decommissioning projects (oil and gas) have your company been involved in?**
AF Decom has been involved in many projects concerning removal, dismantling and recycling; Ekofisk-tank, Ekofisk Cession 1 and 2, Murchison, Janice, B11 and H7, Inde Field.
- **What has been your Scope of Work in these projects?**
Typical SoW for these projects and AF Decom in general is the removal and/or dismantling/recycling. AF Decom has both been main contractor, but also sub-contractor with Heerema.

Cutting offshore

- **What methods and tools have been used for cutting/dismantling the structures (subsea and topside)?**
Heerema and subcontractors have mainly been responsible for this part.
- **What is your experience using these methods/tools?**
N/A

Logistics

- **How have the parts been lifted onboard the vessel(s) and transported to the onshore base?**
Main principle is reverse-installation, where a heavy lift vessel lifts it onto deck and transport it to Vats. The deep quay facilities are the main advantage for AF Decom. Old

platforms are built module based, and new ones are also built to be removed as a few big pieces/modules.

- **Which types of vessels have you been using?**

Heavy lift vessels like Heerema's Thialf and similar deepwater construction vessels. These can lift entire jackets and platform decks. Jack-up vessels have also been used, similar to Pacific Osprey.

- **Has towing of structure elements been used?**

Yes, only for floating loading buoys. Other than that – no.

Cleaning

- **Do you consider cleaning the parts of the rig/structure before and during decommissioning?**

Yes, cleaning is an important part of the decommissioning process. This relates both to removal of marine growth and removal of hydrocarbons and other deposits inside pipes. High pressure water jet is being used for this purpose.

Onshore dismantling /recycling /waste disposal

- **Which onshore bases or quay facilities have you been using for the further dismantling and recirculation process?**

They have been using their own facilities at Vats in Rogaland, Norway. This is a facility specially designed for this purpose with large quay areas, deepwater quays that can accommodate heavy lift vessels, and purpose made cleaning/filtering system to handle water spills and chemicals.

- **Which cutting methods and tools have they been using?**

Oxy-propane due to its fast nature of cutting and low cost. Shear cutter hanging from a crane, but also shear cutter mounted on excavators.

AF Decom has a stationary shear cutter for 2500 tons – the worlds biggest!

They were looking into the possibilities of wire-cutting onshore. Automation is something they want to get into. They will additionally look into the use of explosives in one of the future dismantling projects.

- **Where has the material been sent for further processing/recirculation?**

Stena Recycling, Eco-fiber, HIM, SIM, Celsa (for pure steel). They have an extensive NORM-check on everything leaving the site. (NORM –naturally occurring radioactive material.)

Wind farms

- **Have you been involved in installation of offshore windmills? Which windmills/parks?**
Not involved in wind turbines so far.
- **What has been your Scope of Work in these projects?**
N/A
- **Can the installation process be easily reversed for decommissioning of the windmills?**
Yes, but what is most cost effective is most likely a different method.

Business /marketing

- **Will decommissioning projects related to oil and gas be a growing part of your business for the next five years?**
If they can earn money.
- **Are you planning to expand your international operations related to decommissioning projects or will your main focus be in the Norwegian sector for the next five years?**
Reference is made to a later question.
- **Are you interested in entering the business regarding decommissioning of wind parks? Have you already been involved in such projects? If so, what has been the Scope of Work?**
Yes, if this can be done as serial decommission of many wind turbines. For AF Decom it is about getting big volume into the facilities in a short amount of time.
- **What needs do you identify in terms of labor market and infrastructure today and if entering this new business?**
No special needs compared to what they have already in relation to facilities and personnel.
- **How important is international cooperation in general and for you particularly?**
International cooperation and customers are already very important for them so this will not be something new.
- **Do you consider this “DECOM Tools”-project to be relevant and helpful? What do you expect from the project?**
Yes, it will be interesting to join the “Expert Committee” to follow the project.