DECOMMISIONING INDUSTRY IN NORWAY: MOVING FROM OIL & GAS TO DECOMISSIONING OF OFFSHORE WINDPARKS.

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ABSTRACT

Since the discovery of oil in the southern North Sea field Ekofisk in 1969, the city of Stavanger in the region of Rogaland has been known as the oil capital of Norway. The Norwegian supply industry includes more than 1 250 companies supplying goods and services for all stages of the value chain, including seismic and engineering services, drilling rig equipment, advanced offshore supply of service vessels and subsea technology. Some of these companies have specialized in decommissioning activities developing technology and infrastructure for the oil & gas industry. A systematic work was carry out to identify Norwegian companies that have the technical capability to participate in decommissioning of offshore wind parks at the North Sea. Companies with relevant project experience were contacted for an interview and visit was carry out to their facilities. Some companies were invited to participate in technical workshops to introduce them to the idea of moving from oil & gas to decommissioning of large scale offshore wind farms. This work presents the results from these interviews and workshops. Technical information regarding relevant infrastructure and technology that can be used for decommissioning of large scale offshore windfarms is presented, including a summary of the Norwegian companies that are interested to enter this business area in the future. This work was carried out as part of the Decom Tools project financed by Interreg North Sea Region.

NOMENCLATURE

O&G: Oil and Gas
NGL: Natural Gas Liquid
R&D: Research and Development
EU: European Union
OWP: Offshore Wind Parks
HVL: Western Norway University of Applied Sciences.
NOK: Norwegian kroner
Decom Tools: Interreg project for decommissioning of offshore wind turbines.

1. NORWEGIAN O&G

The petroleum business in Norway has been around for more than 50 years. Since 1969, the region of Rogaland is known as a centre of O&G technological expertise with clusters of companies, R&D institutes and universities such us HVL. The O&G activities have been central to the growth of today's welfare society in Norway. It is Norway's largest industry in terms of value creation, government revenues, investments and export value [1]. Almost all oil and gas produced in Norway is exported, and the export value represents about half of total Norwegian goods exports as shown in Fig.1.

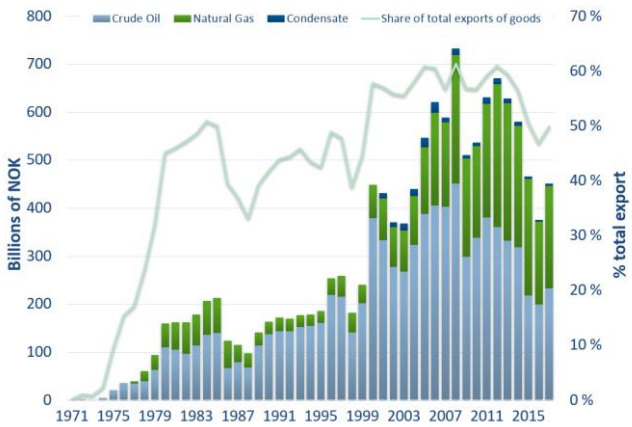

Figure 1. Norwegian O&G historical production in millions of Norwegian Kroner.

Norwegian crude oil production peaked in 2001 with a total liquid production of 3.4 million barrels of oil equivalents per day, NGL and condensate included. Between 2001 and 2011the fall in oil production was compensated by the development of the gas fields. Norwegians companies were developing a comprehensive gas pipeline system from an early stage. They were already operating the Norpipe gas pipeline since 1977, Europipe I in

1995 and Europipe II since 1999. This made it possible for the Norwegian industry to make the transition from oil to gas exports, bringing the Norwegian gas on land directly to Europe. Today Norway supplies about 25 per cent of the total gas consumption to the EU.

The decline of the Norwegian crude oil production and the transition to gas production during 2001-2011 also helped to promote a diversification strategy on the public agenda during these years. Between 2007 and 2009, the public attention to climate change opened an opportunity for the idea of offshore wind development in Norway. The Norwegian government signalled that it had big ambitions for offshore wind in Norway, hence leading to large public and industrial R&D initiatives [2]. However, during 2011-2014 the interest for this diversification strategy of the O&G was in decline. Until today, only 2.3 MW of offshore wind power capacity has been constructed in the Norwegian coast.

The diversification strategy for OWP in Norway promoted a rapid engagement in the private sector during 2009 and 2010. Several O&G companies entered to competition for contracts in the European OWP market, often citing expectations for future market opportunities as a motivation [3]. Norwegian companies such as AF group and Dr. techn. Olav Olsen invested in an OWP start-up called ViciVentus. Draka invested in a new cable production facility to power OWP parks. Fred. Olsen, a pioneer firm in OWP since early 2000s, received concessions for OWP farms in Scotland and Ireland. Norwegian companies were looking forward to the opening of new markets in the OWP based on the idea that their expertise from offshore operations will give them a valuable advantage for installation services of OWP in the North Sea region.

The diversification strategy from the Norwegian government was stopped in part by a strong growth in revenues from O&G in the period 2011–2014 when oil prices averaged well above US$100 per barrel. The discovery of the Johan Sverdrup oil field in 2010, (the third largest in the North Sea) influenced the direction of political agenda by altering the expectations for offshore wind and the legitimacy for public policy [2]. A third important factor to stop the development of OWP industry in Norway was the lack of a domestic demand for electric power. Because hydropower provides 96% of the domestic electricity consumption in Norway, the R&D initiatives from the industry lacked a domestic market that could provide a learning arena for the offshore wind industrial initiatives. The revenues from O&G was later impacted by a downturn cycle. From June 2014 to January 2015 the price of oil dropped 60 percent reversing the growth in revenues and taking the current values back to 2007 levels [4]. The prolonged weak market conditions have resulted in repercussions in all segments of the industry: Exploration, drilling, operation, fabrication, installation, operation and decommissioning.

As a result of the downturn after 2014, Norwegian companies have established large restructuring programs making the overall cost levels come down and regained competitiveness in the capital allocation [4]. A new interest in a diversification strategy for the Norwegian O&G industry is present in the public agenda as ‘det grønne skiftet’ (the green change). Since 2016 the Norwegian government established an expert committee on green competitiveness challenging the business community to develop strategies for transition to the low-emission society in various industries. Hence, it is likely that the diversification strategy for the Norwegian O&G industry is going to continue in the future and that the industry will attempt to use their offshore expertise as an advantage for future developments in installation of OWP. However, because until today few OWP have been decommissioned in the North Sea region, the Norwegian O&G industry may be not aware of the potential market opportunities for innovation in decommissioning of OWP.

2. O&G DECOMMISIONING

The decommissioning O&G industry includes segments specialized in different operations. Some decommissioning companies primarily offer services related to the decommissioning of offshore installations, such as plugging and abandonment of oil wells, while others specialize in services related to infrastructure removal or recycling of large structures. Some Norwegian companies, which have operational focus primarily in other segments of the O&G industry, also place decommissioning as an integral part of their services. Companies such as Kværner are involved in the whole value chain of the oil & gas

industry from executing engineering, procurement, construction (EPC) and decommissioning.
The projections for the market shares of the future decommissioning market is shown in Fig.2. It is expected that the Norwegian decommissioning market has the potential to be the second largest in the North Sea after the UK [5]. Several of the fields that were in operation in the early phase of the O&G development in Norway are still producing today and they will soon reach the end of their expected service life. The Norwegian Petroleum Directorate estimates that decommissioning could cost around NOK 160 billion making this a significant emerging area of business in the Norwegian sector.

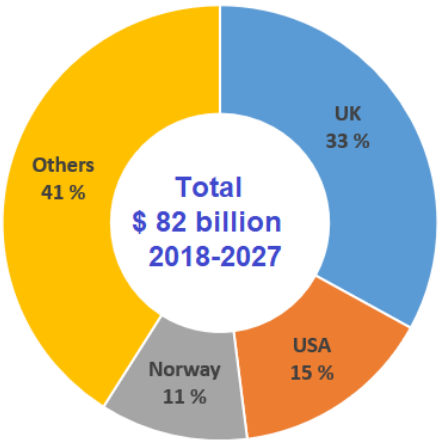

Figure 2 Top three markets for decomissioning of O&G for global dcommissioning expenditure 2018-2027, total $ 82 billion.

The costs related to decommissioning of O&G are mainly separated into two categories: Cessation cost regarding shutting down and plugging the wells, and disposal costs related to implementing the physical removal or abandonment of facilities. Shutdown and disposal costs in Norway had a total value of NOK 8.5 billion during 2016 [3]. Cessation cost is a large segment with an estimate of 49% of the total expenditure in decommissioning in the North sea from 2018 to 2027 [5].
An estimated 3 000 wells will need to be plugged and abandoned in the future. Norway expects to decommission an average of 22 wells each year through to 2024, after which a significant increase is forecasted. Between 2025 and 2027 some large O&G decommissioning projects are expected to get underway, with annual well decommissioning expected to increase to an average of 70 per year. [3]. At the same time some of the largest OWP installed in the North Sea region will be reaching their expected service life. The market analysis carried out by Kruse M. [6] in the context of the Decom Tools project shows that by the end of this decade a large volume of decommissioning activity is expected in the OWP at the North Sea.

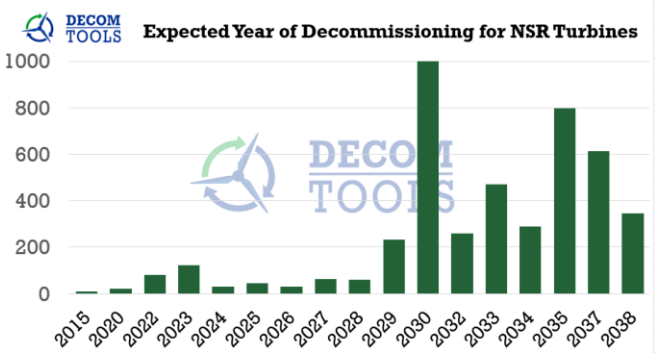

Figure 3. Expected number of offshore wind turbines to be decommissioned in the North Sea Region.

Disposal activities in O&G include removals of topside and substructures of oil platforms, subsea structures and pipelines, site remediation and post-decommissioning monitoring and the onshore recycling. Offshore structures are placed on deck of the crane vessel and transported to onshore deep-water quays. The onshore recycling of topsides and substructures from O&G require high technical standards for waste handling. The dismantling activities of large structures are carried out onshore in open areas close the sea as shown in Fig. 4. This create a risk for possible contamination of marine environment or ground water from the falling rain.

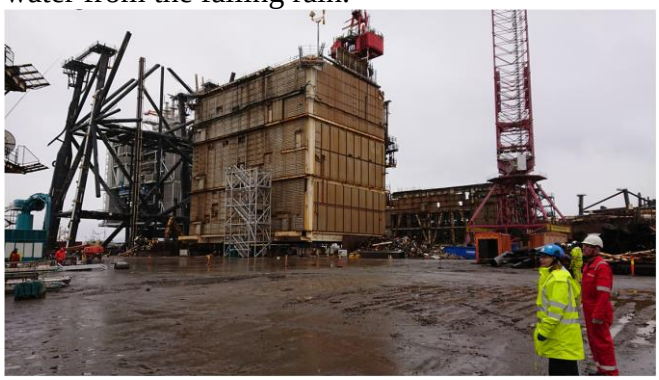

Figure 4. Deconstruction area at Kværner, Norway. The picture shows a topside structure and jacket from an oil platform in the process of dismantling.

Topside structures from O&G and the equipment inside may contain hazardous waste materials, including rest of hydrocarbons, radioactive

residuals and heavy metals. Hence, to minimize the risk of contamination of the surroundings the complete area for deconstruction activities must have a membrane below the top layer of concrete in combination with a drain system to collect the rainwater. All water collected must go through the water treatment plant at the same facility. As the volume of collected water is significant, the water treatment plant needs to be sized accordingly, making the water treatment plant an important piece of technology for the operation of dismantling sites. The Norwegian company AF Decom have been using a large cave in a mountain to collect large volumes of rainwater during the dismantling of the O&G structures. After collection, the water is then sent to the water treatment plant to assure decontamination (fig. 4).

Figure 5. Water treatment facilities at AF Decom, Norway. A large cave in a mountain is used for collection of large volumes of water. The collected water is then sent to the water treatment plant on the left side of the picture.

There is a large cost for implementing the infrastructure required to carried out deconstruction activities for decommissioning of O&G structures. Hence, in Norway, there are only three companies that are operating this type of facilities (Fig. 6). Lutelandet offshore and AF Decom have constructed their port specifically for O&G decommissioning. Lutelandet decommissioning quay is still in development, but it is claiming to be developing an onshore area for decommissioning up to 1 400 000 m² including yard, harbour and Europe's largest dry dock. AF Decom has its decommissioning quay at Vats, Rogaland. It comprises 68 000 m^2 with concrete surface and membrane and drainage systems underneath. It is custom built to handle offshore installations and other marine structures. This site has deep water quays, calm weather conditions, and minimum tidal differences, which helps to make the facility suitable for advanced and heavy lifting marine operations.

Also Kværner has a quay specifically adapted to decommissioning of O&G structures. It comprises an area of 80 000 m^2 of which around 40 000 m^2 is padded. Kværner also operate a construction yard and it shares the area with other companies related to O&G business at Stord. As Fig. 6 shown, the three companies have chosen strategic locations of their decommissioning onshore sites in relation to the O&G industry in the North Sea region.

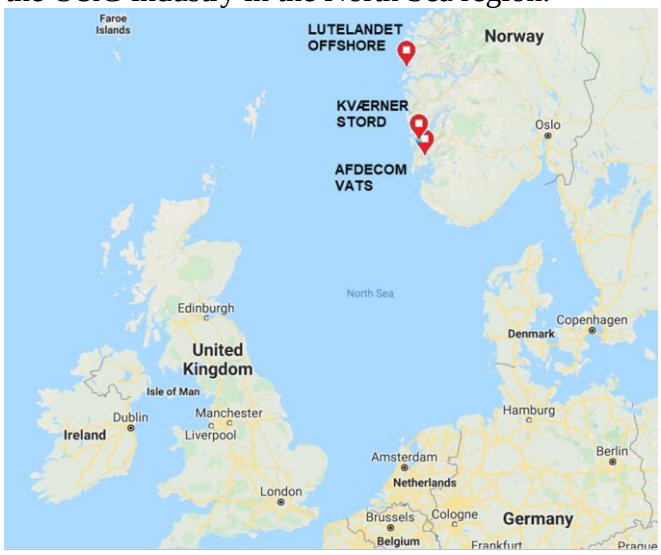

Figure 6. Location of Norwegian companies with dedicated infrastructure specific for O&G decommissioning.

3. TECHNOLOGICAL OVERLAP

The O&G sector have been attempting to influence the development of a Norwegian industry around OWP since the first decade of the diversification strategy impulse by the Norwegian government. At the end of 2009 the partially state-owned company Equinor installed ‘Hywind’, the first pilot floating wind turbine of industrial scale. This was the first offshore wind turbine installed in Norway, and the location selected was again at Rogaland, specifically in the Haugaland area. The Haugaland area in Norway is specialized in subsea operations, hence the services and knowhow required to carried out marine operations in the O&G industry was relevant for the success of the project. The pilot Hywind project was only one turbine of 2.3 MW and it was considered to be a demonstration project to show the technical feasibility of a floating wind concept. The project was considered as the first practical example to apply the Norwegian experience from O&G to

offshore wind developments. Pilot Hywind was originally planned to be in operation for only two years, but it is still in operation today. A later development scaled up the concept to the first commercial scale OWP at Scotland. Hywind Scotland was commissioned in 2017 with a total installed capacity of 30 MW and six floating turbines. The floating turbines were assembled at Kværner yards at Stord and towed to Scotland. The use of the Norwegian O&G expertise in the Rogaland area was key to accomplish the project successfully.

The required specialized skills and services related to offshore technologies and operations for design, construction, transportation, installation and decommissioning of offshore objects are fields where technology overlaps exist between OWP and O&G [6]. Norwegian firms such as Kværner draw on knowledge acquired in O&G and concentrate in supply chain segments such as foundations for turbine and substation, offshore operations, maintenance, ocean meteorology and monitoring services for survey and subsea [6].

The offshore competences acquired in O&G can form a knowledge base for dealing with similar conditions in OWP. Consequently, companies like Kværner are able to use the best practices of O&G regarding “what works” in designing and installing offshore constructions. These companies can redeploy their existing technologies and competences in OWP, which makes OWP an attractive industry to enter [7].

The diversification of Norwegian O&G companies is likely to continue in the future. In 2019 Kværner signed a contract for about 1.5 billion NOK with Equinor to deliver 11 floating concrete hulls for offshore wind power turbines and in addition execute marine operations services for the Hywind Tampen project. This will be the world’s largest floating offshore wind farm and is vital for industrialising solutions and reducing costs for future offshore wind power projects on deep waters.

Norwegian companies may enter the market for decommissioning of offshore wind park projects in the North Sea region when the large OWP enter into decommissioning phase. Hence as a part of the activities in the Decom Tools project a systematic identification of relevant market actors and technology from O&G was carried out in Norway. Additionally, a series of interviews with O&G companies and workshops were carried out during 2019. The results from these activities are presented in the next sections.

3.1 INTERVIEWS WITH DECOMISSIONING COMPANIES.

Beside workshop and conference, four relevant companies were visited and interviewed with a comprehensive list of questions regarding their actual decommissioning activities from O&G. Question regarding their interest in decommissioning of OWP were also included. All the interviewed Norwegian companies have considerable experience from decommissioning projects in O&G. The companies visited were:

- DeepOcean AS (Subsea operation and construction company, it is also involved in decommissioning projects).
- Reach Subsea AS (Subsea operation and construction company, it is also involved in decommissioning projects).
- Kvaerner AS (Decommissioning company with their own onshore decommissioning site/deep water quay).
- AF Decom AS (Decommissioning company with their own onshore decommissioning site/deep water quay).

Companies like Kvaerner and AF Decom claim that they already have the necessary facilities, personnel and competence to receive offshore wind turbines. These facilities include large deep-water quays in the deep and sheltered Norwegian fjords. These quays also have systems to take care of spills and pollution, and advanced cutting equipment.

They also can take care of the offshore dismantling and removal activities, but as per today they then utilize subcontractors like Heerema and DeepOcean. Generally, they then prefer as few cutting operations offshore as possible, as offshore vessel time is expensive. Large sections are then transported ashore for further dismantling and recycling.

If decommissioning of offshore wind turbines shall be of commercial interest to companies like Kvaerner and AF Decom, it will depend on the volume to be recycled. One or two turbines are not of any interest but decommissioning a large OWP will be very interesting.

Many tools and methods originally developed for the offshore oil- and gas industry are relevant for decommissioning of offshore wind farms. For example; a wide range of cutting tools have been developed for different applications, both for top-side- and subsea structures.
Cutting tools based on the diamond wire- and hydraulic shear /scissor principles are promising, as they are relatively simple and environmentally friendly in use, compare to other alternatives such as water jet with abrasives.
Regarding the use of explosives as an alternative to conventional cutting methods for offshore wind turbines. It is considered as an effective method, but there are also reasons for why this method has been utilized only to a minor degree in relation to oil & gas decommissioning projects. The material quality and wall thickness can be unpredictable; thus, it will cause a big problem if the cutting process does not penetrate 100%, or if the charges will not explode correctly. Environmental issues with marine life and debris on the seafloor to be picked up afterwards were also mentioned as challenges during the interviews.
Regarding the operations conducted in connection with decommissioning of O&G structures that also can be relevant for decommissioning of offshore wind farms, the next list presents the relevant operations:

- Pre-operation survey of the seafloor prior to the actual decommissioning activities
- Dredging of seafloor sediments (the time for this can be difficult to estimate). Must often be done before cutting.
- Top-side- and subsea lifting of structures (after cutting)
- Retrieval of piles
- Retrieval of concrete protection mats
- Retrieval of cables, often also submerged cables
- Retrieval of debris
- Post-operation survey

Special challenges and possibilities for decommissioning of OWP were also identified during these interviews. OWP in the North Sea region have been installed in relatively shallow waters (10 – 40 m), this can represent a challenge for offshore- and heavy lift vessels, the ROV and diving operations.
It was also mentioned in the interviews that decommissioning a large OWP consisting of 80 or more identical turbines offers an opportunity for automation and optimization of the process, both offshore and on land. This has so far not been done in any extent for O&G structures, as the structures have been “One of a kind” and they are not standardized in size and configuration.
The possibility of towing the turbine towers structures ashore was also mentioned during interviews. This should be looked closer into, because then cheaper vessels can be utilized. Either the structures themselves can be made buoyant, or buoyancy tanks can be added.
Most of the same receiving recycling facilities and decommissioning quays for O&G can be used for decommissioning of OWP. However, there is one important exception with the blades for the turbine. These are usually made of a composite material not easily recycled.

3.2 CUTTING OPERATIONS

Companies in O&G decommissioning have used different cutting methods, depending on the scope of work. For cutting methods in offshore decommissioning, the main target is to cut the materials as fast and reliable as possible. During the interviews, companies mentioned that for subsea operations they rely mainly on diamond wire cutting as a standard method for its cutting operations offshore because it is a reliable and simple method, both subsea and top side. Diamond wire is a relatively slow method, but easy to set up when doing the mobilization of the vessel. It does not need a third-party technical operator.
Alternatively, diamond saw is faster, more durable with an easy setup and mobilization and do not need extra personnel to operate it. Compared to these alternatives, high-pressure water jet with abrasive particles is fast, but requires mobilization/installation of bigger team and more equipment topside. Additionally, it is uncertain if the cut is successful and has cut through the material.
Cutting methods in onshore decommissioning relies mainly in hydraulic cutters as a more environmentally friendly method compare to high pressure water jet with abrasive or oxygen cutting torch. Hydraulic cutters can be mounted in standard excavators to reach different parts in the

structure and reducing the metal components to smaller pieces for further processing, as it is shown in fig. 7.

Figure 7. Hydraulic cutting tool in operation during visit to Kværner facilities.

Large jacket structures as the one shown in Fig. 4 are usually cut into smaller segments by hand operation with the help of oxygen cutting torches. Then the smaller segments can be further reduced in size with the use of specialized hydraulic guillotines as the one shown in fig. 8. These types of hydraulic guillotines are complex and expensive hydraulic equipment, which give a competitive advantage when large quantities of metal parts need to be reduced in size for further processing. Once the metal parts are small enough, they can be loaded into a scrap metal vessels to be sold in in the regional or global market.

Figure 8. Hydraulic guillotine at AF Decom facilities. Metal segments shown in the picture are around 50 mm in thickness.

Kværner is also working with the development of more automated cutting processes for O&G decomissioning, the main reason for this is safety and working environment. Working with handheld equipment on big structures takes time and the operator doesn't see the end of the job, this is a situation where the operator gets bored. This can lead to dangerous situations and incidents. To reduce the amount of manual operations, Kværner has mounted a guillotine cutter for large pieces of steel. This guillotine can cut pieces with a thickness of up to 150 mm into small pieces ready to ship to customers.

4. DECOM TOOLS, NORWEGIAN RESULTS

Decom Tools is an Interreg project financed by the European Regional Development Fund of the European Union. The project partners are collaborating in the North Sea Region with the main goal to have an overall sustainable approach to end of the lifecycle for OWP. This project shall close this gap by devising and developing eco-innovative concepts that will reduce the decommissioning costs by 20% and environmental footprint by 25% (measured in CO_2 equivalents). Decom Tools activities increase the know-how and expertise of the involved stakeholders.
For the specific case of HVL as the only Norwegian partner participating in Decom Tools, the goal is to take the decommissioning knowhow from the Norwegian O&G to improve the future activities for decommissioning of OWP at the North Sea region.
Beside the interviews, visits and workshops carried out in Norway in the context of the Decom Tools project, three master's thesis regarding transfer of knowhow from O&G to Decom Tools goals have been published [9-12]. The main point of these works have been to contribute with concrete proposals to improve the decommissioning operations for decommissioning of OWP based on the experiences learned from O&G.
The list of relevant operations from O&G presented in section 4.1 as well as the identification of relevant cutting tools have been based in part on two of these master thesis [9],[10]. The work of Hechler J. [11] focused mainly on the optimization of the dismantling process of wind turbine blades from offshore wind farms during decommissioning. Vessel days was identified as a relevant cost driver for offshore operations, thus by reducing vessel days both cost and environmental footprint can be reduced. To achieve this, one of the proposed solutions is to

use or develop efficient cutting tool methods in order to reduce the total working days for vessels involved in the operations.
A large part of the decommissioning time offshore is related to the high-tension bolts which have to be loosened to take the turbine blade from the turbine hub. Hence, a cutting tool designed specifically to cut the wind turbine blades instead of loosening the bolts will have a large impact in reducing the time, the cost and the CO_2 footprint of the decommissioning process for large OWP. As an example, the installation of the Sheringham Shoal offshore wind park in the UK, comprises 88 wind turbines with a total of 21 000 bolts for the blade-to-hub connection. Hence, the future decommissioning of such a large OWP will largely benefit from the specifically designed cutting tool to reduce the offshore decommissioning time.
The idea behind the blade cutting approach is to cut the blade as close as possible at its root. Operation of this tool will be carried out at high altitude, hence a specially designed clamp-frame for the blade can act as a lifting frame as well as a clamping device to secure the cutting operation of the wind turbine blade as it root, this is conceptually shown on fig. 9.

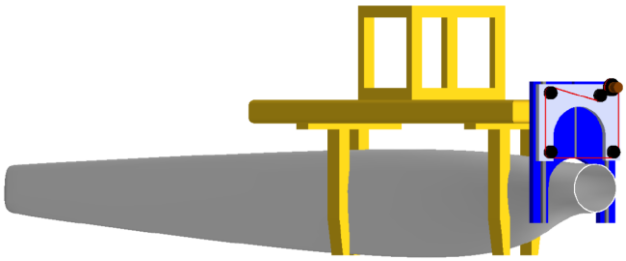

Figure 9. Conceptual design of the cutting tool for the wind turbine blade, source: Hetchler J. [11].

Wind turbine blades are complex components made of composite materials in combination with structural metal parts. Hence, the development of such a cutting tool will require to consider the type of blades used in OWP. Based on the experience from subsea cutting activities for complex structural components such as composite pipes with concrete and metal combinations, a wired diamond saw in combination with the lifting frame can be a practical solution for this cutting operation. Norwegian companies have long experience designing such tools for subsea cutting operations, hence they are likely to benefit from previous experience in the development of such cutting tools. Preliminary calculations and design details were estimated by the work of Hechler [11], showing that parameters such as cutting speed and coolant supply are reasonably achievable with the current technology available.

5. CONCLUSIONS

Moving from oil & gas to decommissioning of OWP will not be difficult for the Norwegian O&G decommissioning companies. The responses from the interviews to decommissioning companies in Norway show that they do not see big technical challenges regarding decommissioning of OWP and the visits to their infrastructure confirm that they are technically well prepared. They also claim that they have the necessary competence and personnel available. However, companies with onshore decommissioning infrastructure will require a large bulk volume of wind turbines. Companies such as Kværner and AF Decom will compete with UK similar infrastructure from O&G decommissioning. Hence, they will need to be prepared for this competition when the large volume of offshore wind turbines comes in the market for decommissioning.
Several decommissioning operations from O&G have been identified as relevant for decommissioning of offshore wind farms. This point to new market opportunities relevant for the Norwegian O&G decommissioning companies, especially regarding all the subsea operations mentioned in section 3.1.
Cutting tools technology from O&G is relevant for decommissioning of offshore wind turbines. A new cutting tool conceptual design was proposed as part of the Decom Tools project activities carried out during 2019. Preliminary results show that this tool is technically feasible, it will have a large impact in reducing the time of offshore decommissioning, the costs and the CO_2 footprint during the offshore operations.
Future works should focus in developing the detail engineering for the proposed cutting tool, identifying relevant Norwegian companies interested in the development of such a tool, as well as conceptual development for vessels that can reduce the cost and CO_2 foot print during the decommissioning of OWP. The interregional cooperation developed in the context of Decom

Tools is likely to benefit these developments in the future.

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