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FRAMEWORK FOR EFFECTIVE SPARE PARTS MANAGEMENT IN LATE-LIFE/END-LIFE FROM PLANNING TO DECOMMISSIONING & REMOVAL

Preface

This master's thesis has been written in cooperation with APPLY AS during the spring semester of 2021 at the Department of Mechanical and Structural Engineering and Materials Science at the University of Stavanger.

I would like to express my gratitude towards Jawad Raza at APPLY AS and Jayantha P. Liyanage at the University of Stavanger for guidance throughout the thesis. Writing the thesis in cooperation with APPLY AS has been a good experience, and it has given me excellent insight into the industry.

Abstract

The Norwegian oil and gas industry is at an earlier stage of maturity. As the end of the lifecycle for an offshore asset is approaching, decommissioning activities must be initiated. The decommissioning process is the final step in the lifecycle of an asset, and it represents some very considerable business opportunities for oil and gas companies. The activity requires detailed planning and careful considerations to maintain high operational and financial performances. In this thesis, new technologies and trends have been explored in order to develop a framework for effective spare parts management in the late-life/end-life of offshore installations.

The framework has been created by assessing various techniques, looking at their benefits, and what happens when they are applied together. The technologies and techniques that have been studied include additive manufacturing, blockchain, cloud technology, the Internet of Things and the circular economy. The result of the study is a spare parts management policy that mitigates costs and environmental impacts while simultaneously improving the asset's operational performance.

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List of Abbreviations

ALARP	As Low As Reasonably Practicable
AM	Additive Manufacturing
BSEE	Bureau of Safety and Environmental Enforcement
CMR	Critical Material Requirement
EAM	Enterprise Asset Management
ERP	Enterprise Resource Planning
IoT	Internet of Things
JIP	Joint Industry Project
MC	Material Coordinator
NCS	Norwegian Continental Shelf
NOROG	Norsk Olje og Gass
NPD	Norwegian Petroleum Directorate
NPF	Norwegian Petroleum Society (Norsk Petroleumsforening)
OPEX	Operating Expense
OSPAR	Oslo/Paris Convention
RAS	Required at Site
SPM	Spare Parts Management

1 Introduction

1.1 Background

According to a report issued by Oil and Gas UK (2016), the Norwegian industry is at an earlier stage of maturity. There are 90 fields on the Norwegian Continental Shelf currently producing oil and gas, split between the North Sea, the Norwegian Sea and the Barents Sea (Norwegian Petroleum 2021a) (See Appendix 1-4 for more information). However, the older fields have been producing since the 1970s, and the decommissioning phase has not been the focus when implementing them. Therefore, it is a challenge to perform the decommissioning on the older installations. The NPD expects 20-30 of the currently producing fields to end their productions and decommission their assets over the next decade (Norwegian Petroleum Directorate 2019). Figure 1 shows an overview of selected fields on the Norwegian Continental Shelf, highlighting their lifetime and how their lifetimes can be extended past the expectations.

In their most recent yearly report, The Norwegian Petroleum Directorate has estimated that oil production will continue to rise in the coming years leading up to 2025 (Norwegian Petroleum Directorate 2021).

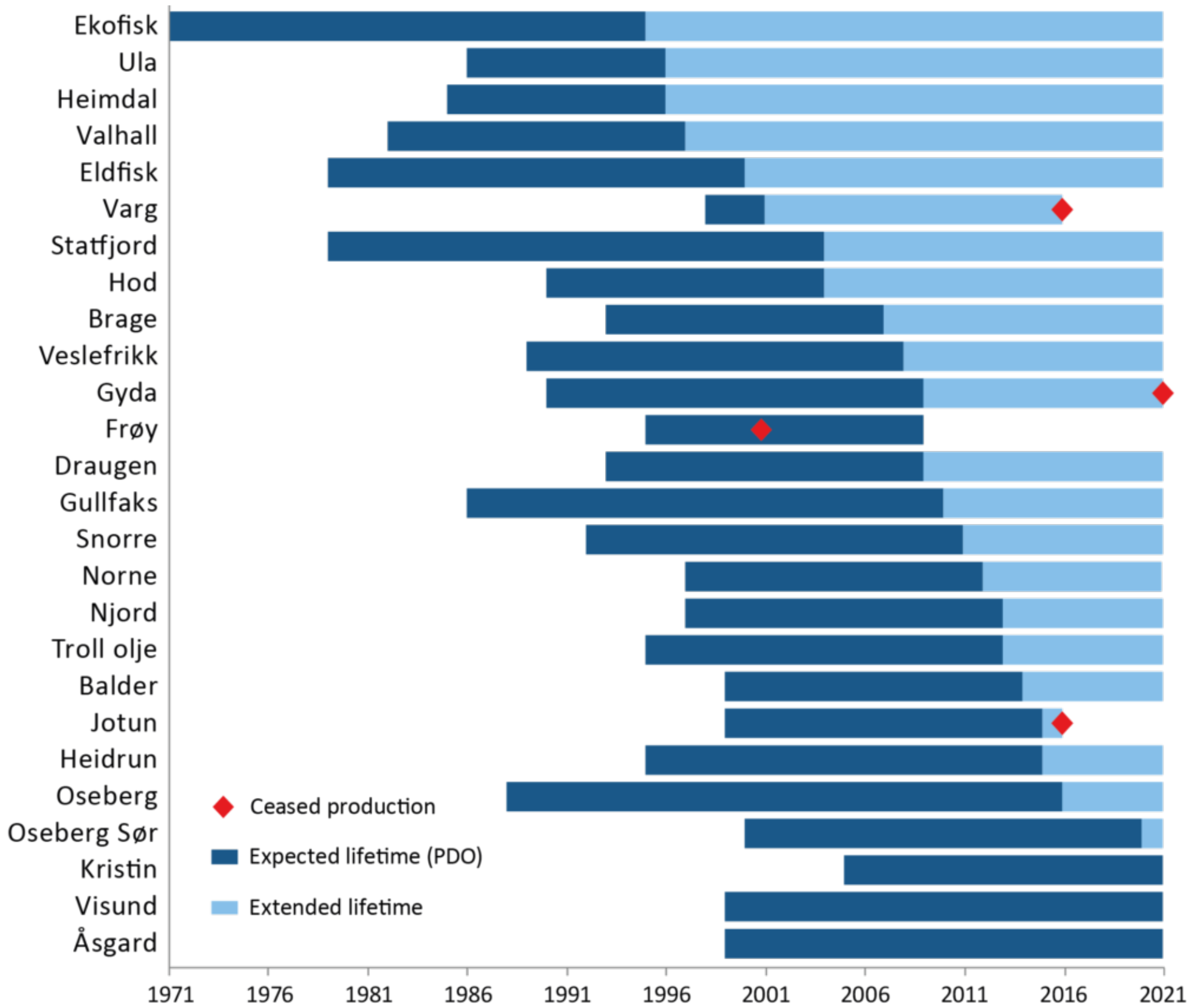

Figure 1: An Overview of the Lifetime of Selected Fields on the NCS. (Norwegian Petroleum 2021c)

Decommissioning is the final stage of the entire lifecycle of the asset. This is a complex process that needs planning and utilization of available resources to close an asset without any environmental risks and simultaneously keeping all costs to a minimum. Depending upon the level of automation, digital processes, experiences, databases, etc., there is a more significant potential for using available data to provide insights for effective planning and managing the late-life/end-life towards safe and effective planning and removal of the asset from the North Sea. Due considerations must also be made regarding the regulatory framework, such as relevant standards. Environmental impacts should be considered and kept to a minimal level.

1.2 Problem Definition

The central problem of this thesis is to determine ways of improving and preparing for the decommissioning process both regarding cost and environmental impacts. The main focus will be on developing an ideal spare parts management policy for the late-life/end-life of the asset.

1.3 Scope of the study

The study will explore the current methods of managing spare parts in the late-life/end-life of offshore assets and suggesting and assessing various new and exciting policies. In addition, considerations will be made as to how or if digitalization and new and modern data-driven technologies can help to improve the process. Finally, there will be some conclusions.

1.4 Objectives

- Perform a state-of-the-art analysis on the management of spare parts and look into how this can be utilized in the late-life/end-life of an offshore asset.
- Figure out how to handle supply chain (parts and equipment) for a circular economy, i.e., reusing, re-selling or recycling.
- Identify how digitalization & data-driven technologies support these processes.

2 Literature Study

The first part of the literature study will contain a definition of offshore decommissioning, the regulatory framework for the decommissioning processes carried out on the NCS, and what considerations need to be made. Following this, some of the challenges connected to the decommissioning of offshore assets will be discussed. Finally, an industry study will give insight into how Apply works with their clients to provide a realistic picture of the relevant processes.

2.1 Offshore Decommissioning on the Norwegian Continental Shelf

Fam et al. (2018) defined decommissioning as "the final stage of the life cycle of an industrial facility, and is the process of closing down an industrial facility via methods, which balances the sensitive boundaries of minimizing financial costs, costs to human life and well-being and to the environment." According to the Bureau of Safety and Environmental Enforcement (BSEE n.d.), offshore decommissioning can be defined as "the process of ending offshore oil and gas operations at an offshore platform and returning the ocean and seafloor to its pre-lease condition."

When the industrial asset is no longer profitable, or when it is no longer of use, the decommissioning phase will be initiated. A lot of planning goes into the process before the actual work can be carried out. One of the major challenges is to follow the regulatory framework, such as rules and regulations that must be followed. On the Norwegian Continental Shelf, a specific set of rules must be considered in the decommissioning process, and these will be described closer in the following section.

2.1.1 Regulatory Framework for Decommissioning Processes on the Norwegian Continental Shelf

Decommissioning operations are regulated both by national and international laws, rules and regulations. The Petroleum Act of 29 November 1996 No. 72 relating to petroleum activities is the primary set of federal rules and regulations for all petroleum activities on the NCS. Chapter 5 of the act is related to the cessation of petroleum activities. The key takeaway in this chapter is that a decommissioning plan containing "proposals for continued production or shutdown of production and disposal of facilities" should be submitted to the Ministry. This action must be done between five and two years before their license expires or is surrendered or before the facility is no longer of use. Also, it states that the licensee must notify the Ministry if the facility is to be permanently terminated before the license expires (Act 29 November 1996 No. 72 relating to petroleum activities). Figure 2 gives an overview of the Norwegian Continental Shelf and the current status of the licensed areas as of September 2020.

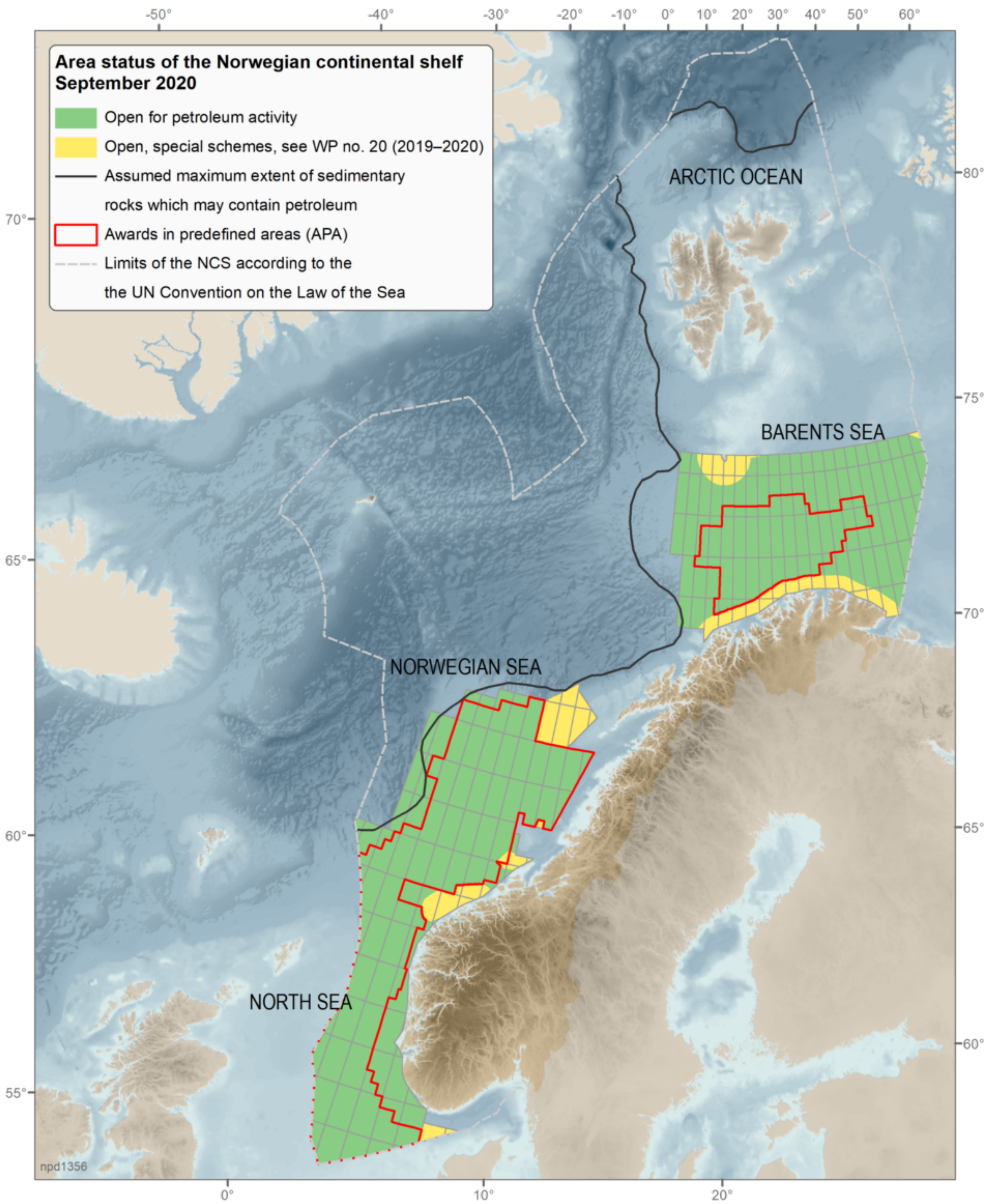

Figure 2: The Status of the Norwegian Continental Shelf. (Norwegian Petroleum 2021d)

In addition to this, there is the OSPAR convention where Norway is one of the participating countries. The OSPAR Convention is concerned with protecting the marine life and environment in the North-eastern parts of the Atlantic Ocean and is regulating international cooperation in the area. The OSPAR decision 98/3 on the Disposal of Disused Offshore Installations is a framework developed to control the decommissioning of offshore installations. It is relevant for the entirety of the NCS. The main points from the OSPAR decision 98/3, according to Gibson (2002), are as follows:

- The topsides of all installations must be returned to shore.
- All steel installations with a jacket weight of less than 10,000 tonnes must be removed entirely for reuse, recycling or final disposal on land.
- For steel structures with a jacket weight greater than 10,000 tonnes, it is possible to consider whether the footings of the installation may remain in place.
- For concrete installations, it is possible to consider whether they should be left wholly or partially in place.
- All installations emplaced after 9 February 1999 (when OSPAR 98/3 came into force) must be removed entirely.
- Exceptions can be considered for other structures when exceptional and unforeseen circumstances resulting from structural damage or deterioration or other reasons which would prevent the removal of a structure.

2.2 Challenges Related to the Decommissioning of Offshore Assets

Several challenges must be considered upon the decommissioning of offshore assets. One of the pressing challenges raised at the 21st NPF North Sea Decommissioning Conference was what happens to the physical parts and components after being removed from the site. Decom North Sea reported that around 98% of the structures such as oil field platforms, subsea systems, pipelines, and wind turbines are being recycled. This is a very high rate compared to other industries of scale; however, roughly half of the recycled material is exported to Asia. With a different policy and perhaps an implementation of new technology, a significant amount of the said parts can be reused and sold on instead.

Reusing or selling the structures and components will have economic advantages for the operators as, on the one hand, they can sell the equipment for a higher price. On the other hand, it is cheaper for the operators to purchase already existing structures instead of having new ones made for the purpose. In addition, there are also some significant environmental advantages to this. The difference between a recycling and a circular economy is demonstrated in Figure 3. In a recycling economy, the material will continue to be recycled repeatedly until it can no longer be used, in which it must be disposed of. In a circular economy, however, the parts will be repaired and reused if possible, and in theory, it can be reused many times before it needs to be recycled.

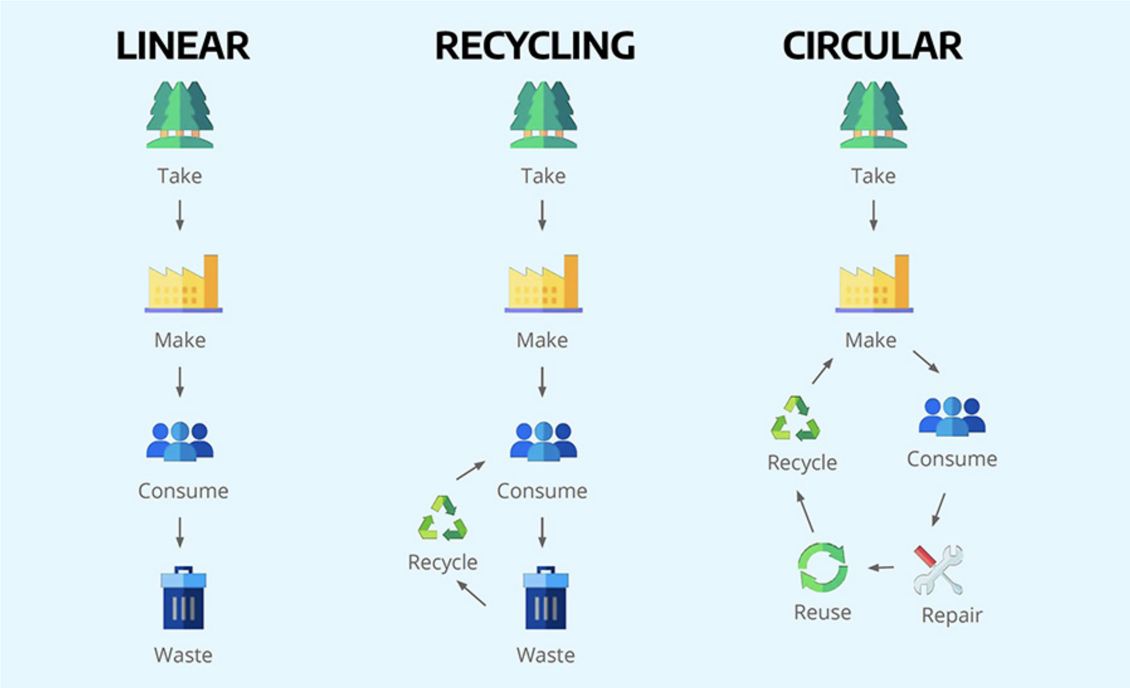

Figure 3:The Idea of Linear vs Recycling vs Circular Economy (Packaging Strategies 2021)

Deciding whether or not a part is reliable and can be reused is a challenge that must be visited. The costs of certifying and clearing decommissioned parts for reuse can often be high, and therefore, it is cheaper to buy brand new parts in many cases. With the implementation of new technology, certifying the items for reuse can be much more straightforward. Akinyemi (2018) developed a data integration framework that makes the process of assessing decommissioned parts fast and easy. The framework uses data from the lifecycle of the engineering asset to determine its reuse potential. It can quickly assess the reliability of the item. It can process data of varying forms, and it overcomes the challenge of different stakeholders wanting the information represented in different ways.

2.3 An Industry Study of the Processes at Apply

To get a realistic view of the real-life processes, there will now be a brief industry study highlighting some of the procedures at Apply. Apply is a leading Norwegian engineering company specializing in contracts in all phases of a project, from concept development and studies to decommissioning. The company has different policies for their operations, such as their procurement policy, where the general idea is to select the optimal subcontract template for the procured item in question. Then the terms and conditions can be decided, and these will be used during the execution of the project. Apply also has a policy for managing the materials in a project. Here, the general idea is to have a material coordinator responsible for executing the material management in the project and supervising interfacing disciplines. In essence, the material coordinator makes sure the required parts are in stock and present at the RAS date for the project.

3 Methodology

The aim of this thesis was to explore ways to improve the decommissioning process of offshore installations, with the main focus being on spare parts management in the late-life/end-life of an asset. First, a comprehensive study will be performed on the current policies of spare parts management in the late-life/end-life of offshore assets. Following this, relevant digitalization & data-driven technologies will be explored, and an assessment of how new technologies can improve the current practices will be performed. The study will primarily be based on published work, such as papers, publications and press articles. Still, there will also be some inputs from conferences such as the NPF 21st North Sea Decommissioning Conference. Finally, the experts at Apply have shared plenty of their knowledge, and along with the author's knowledge and efforts, the thesis has been formed.

4 Trends Impacting Spare Parts Management

In this chapter, there will be an examination of methods that can improve the decommissioning process, including using new technologies that can contribute to a state-of-the-art solution for spare parts management in the late-life/end-life of an asset. A state-of-the-art spare parts management solution will impact its operational and financial performance. According to Blumberg (2021), three trends significantly impact the Spare Parts Management of today. Those are the rise of new technology, the emergence of the circular economy, and the servitization of products. These trends will continue to drive spare parts management forward and evolve state-of-the-art spare parts management.

4.1 Digitalization & Data-Driven Technologies

The rise of new technology has been driving the industry forward for many years already. With the implementation of some of the most exciting technologies, spare parts management in the late-life/end-life of an asset can significantly improve the entire decommissioning process.

4.1.1 Additive Manufacturing

Additive manufacturing can be defined as "the process of joining materials to make objects from 3D model data, usually layer upon layer" (Wohlers Associates 2010). AM is a technology that has been used for a few years already in different industries, such as the aerospace sector. However, the technology has not been utilized much in offshore areas such as oil and gas. There are various AM processes, which means that it has many different applications. Today's operators keep a high number of spare parts in their inventory to ensure a maximum amount of uptime. As a result, many of the spare parts will never be used, and they end up just storing away tremendous values. There is also the aspect of paying significant fees to keep their warehouses maintained and up to standards to store the items correctly. Additive manufacturing can shorten the lead time for the spare parts as the printing of the item itself is a pretty fast and straightforward process. There is not a lot of work that has to be done by the operating personnel in acquiring the part, and in many cases, the manufacturing process itself can be done on-site without any issues.

DNV and other companies, such as ConocoPhillips and Vallourec, have formed a joint industry project called 'Digital Warehouse', which utilizes AM technology. The project is recognized by companies representing all levels of the value chain, which indicates its massive potential. The project is based on having digital files stored in a cloud and making the files available for the operators to receive the blueprint of the required parts on demand. This will contribute to a reduced dependency on warehouses, shorter lead times and lower costs. The ultimate goal of the JIP is "that the user gets the right part, with the right properties within the right time" (DNV n.d.).

A question that has to be raised on the topic of using additive manufacturing in oil and gas and other offshore industries is if the manufactured parts are reliable. Offshore assets are exposed to some of the most demanding conditions imaginable, and their components must therefore be both durable and reliable. Vendra and Achanta (2018) performed a study where the benefits of AM, such as a reduction of both the lead time and the cost, were confirmed. The study also claimed that "AM facilitates creating parts that are lighter, stronger and more efficient that are designed for functionality; enables creation of high complexity parts for function integration". Furthermore, comparing an original part and one created with AM concluded with the additive design being more reliable. This indicates that AM technology is close to being ready for adoption in the oil and gas industry. There are, however, some other challenges and constraints that must be overcome. Those are discussed in the study and includes:

- **Build Speed**. The AM machines must be upgraded to enable faster build speeds, large builds and consequently rapid AM.
- **Process Modelling**. There is a need for enhanced modeling and simulation tools to predict and validate the build process outcome and material properties.
- **Process Control**. There must be some process monitoring system on-site where deviations can be detected and corrected to ensure quality control and technology improvements.
- **Material Development**. There should be a continuous development of the material used in AM to improve the quality and offer unique properties. The understanding of the properties should also be good to predict its performance and lifetime.
- **Qualification and Certification**. There is already a strict policy on which parts are qualified for being used on offshore installations. Currently, the variability of the AM parts makes the qualification and standardization of the process quite comprehensive. For AM to be accepted, standards for the AM parts must be developed by the certification agencies. This is currently the most significant barrier for AM implementation, but the industry is continuously making progress on developing the standards.

- **Workforce Training**. The workers must be adequately trained and develop a sufficient understanding of the AM technology and processes.

4.1.2 Blockchain

Blockchain is another example of a new and upcoming technology that, upon implementation, can help to improve and streamline spare parts management. The technology is continuously evolving, and therefore, the opportunities that can be brought by blockchain is almost endless. One of the benefits this technology can offer includes more transparent supply chain activities, as it makes the relevant information visible to all stakeholders. The data can be accessed by everyone, all the way from the suppliers and manufacturers. However, the technology is immutable, which means that the data are protected, and even though everyone can see it, they cannot alter it. In other words, the technology also has a very high degree of safety. As the name suggests, the blockchain is a chain of “blocks” that are connected in chronological order. The blocks contain relevant data such as certifications, dates, locations and so on, which allows the supply chain to be more effectively managed. When new information is added to the blockchain, it is not overwriting the old data, but instead, it is saved next to the old data, hence why it is considered transparent. According to Deloitte (n.d.), the key benefits to implementing blockchain in the supply chain are:

- The traceability of the material in the supply chain improves and ensures the expected standards are met.
- The losses from trading with nonauthorized distribution channels that are not related to the manufacturer decreases.
- Outsourced manufacturing contracts become more visible with a higher level of compliance.
- The amount of paperwork decreases due to everything now being online, which also impacts and lowers the administrative costs.

Other benefits include a stronger reputation, credibility and public trust for the company, and that the stakeholders are more involved in the proceedings.

In 2018, Quisitive combined cloud technology, the internet of things, and blockchain in a project called “Blockchain Oil Pipeline.” They created a platform that stored the data and its source safely and reliably for all stakeholders. It works as a pipeline monitoring and data collection tool that helps the oil producers and operators maintain the standards of crude oil cleanliness (Musienko 2019).

In the oil and gas industry, blockchains can, together with distribution registry, smart contacts and the IoT, open up for real-time tracking of raw materials and equipment in a just single pool of reliable data. According to Musienko (2019), the advantages of this technology includes:

- Increased legitimacy of the market, as the source of the raw materials at any stage of the product life cycle can be tracked.

- The blockchain has all the relevant data on any specific piece of equipment stored, making it easier to backtrack when, where and by whom a part was made if it was to break and need a replacement.
- It will be more straightforward to monitor if the recommended maintenances have been performed.
- Big data can be analyzed to verify the effectiveness of the supply chain and if there is room for improvement.
- The randomness of the market will decrease, which can lead to more accurate predictions on the processes.

4.1.3 Enterprise Asset Management and Enterprise Resource Planning

According to IBM (n.d.) Enterprise Asset Management "is a combination of software, systems and services used to maintain and control operational assets and equipment. The aim is to optimize the quality and utilization of assets throughout their lifecycle, increase productive uptime and reduce operational costs."
Enterprise Resource Planning refers to "software and systems used to plan and manage all the core supply chain, manufacturing, services, financial and other processes of an organization. Enterprise Resource Planning software can be used to automate and simplify individual activities across a business or organization, such as accounting and procurement, project management, customer relationship management, risk management, compliance and supply chain operations." (QAD n.d.)
The two software systems can be integrated together due to the development of other new technologies such as IoT, machine learning and AI. The combination allows the company to see a bigger picture of all asset management activities. This will allow all information on the asset and costs, availability, and spare parts activities to be kept in one place. As a consequence, better decisions can be made in a shorter amount of time.

4.2 Circular Economy

As mentioned in the previous chapter, the circular economy model is more fixed on the equipment being repaired and reused before it is eventually being recycled. Therefore, it often involves selling and buying used parts as opposed to disposing of them or manufacturing brand new parts. In this section, various potential methods of implementing a circular economy policy will be explored.

4.2.1 Surplus Marketplace

When trying to implement a circular economy, the first important question that surfaces is how can the parts that no longer are of use be moved on sustainably and simultaneously profitably. Norwegian Oil and Gas (Norsk Olje og Gass) is a company that has created a service called "Surplus Marketplace" that helps answer this question. The service is available for operators on the NCS that are members of NOROG. The idea of the service is that the company can outsource the marketing and sales process of the parts to a professional third-party sales organization that has an extensive network of potential buyers. The surplus marketplace aims to maximize the material turnover by increasing its value and simultaneously reducing the operator's OPEX by eliminating storage costs. In addition to this, the service ensures a positive environmental impact by making sure the components are reused instead of being recycled or disposed of. Even though the sales process is entirely in the hands of a third-party company, the operator can still follow the process as they are communicating throughout the process.

The sales process is quite extensive. When the third-party company receives the mission, they gather all the required information on the object before creating a tactic for performing the process, from marketing to it being sold, in the best possible way. They make sure all the required documentation is there and the part being acceptable according to standards. When all of this is in place, they will perform the sale, including administration of customs clearance, invoicing and payments.

4.2.2 Critical Material Requirement

Critical Material Requirement is another service provided by NOROG. It serves as a tool that allows operators on the NCS to exchange critical material when facing a risk of production loss. The service has two functionalities. The first one being the online form for submitting requests, i.e., where the operator that urgently needs a part can send a request for it. The second one being an online portal where personnel from each operator can communicate and handle the case. In addition, the personnel can verify that the request is matching the in-stock material. Similar to the Surplus Marketplace, this service is available for all operators on the NCS that is a member of NOROG.

CMR can be a helpful tool when unanticipated failures occur. It fits under the circular economy theme, as parts that are excessive for one operator can be used immediately by a different operator. The benefits of CMR includes a shorter lead time for the critical material, lower OPEX for both parties, as one frees up their inventory space while the other receives the part at a lower price. In addition, the downtime for the receiving operator becomes much smaller as a consequence of the shorter lead time.

5 Spare Parts Management in the Late-Life/End-Life of an Asset

In this chapter, there will be an assessment of how a state-of-the-art solution for spare parts management can improve the performance of an asset in the decommissioning phase.

5.1 Establishing the KPIs

There are multiple ways of assessing how the decommissioning process' performance is affected by the changes in spare part management. Financial, operational, health & safety and environmental key performance indicators are excellent measurements of tracking how the implementations affect the performance. OPEX is one of the interesting financial KPIs. The operators will want to keep the OPEX as low as reasonably practicable, and technology can help them achieve this. Uptime and lead-time are operational KPIs that the operators want to be in control of and keep low to maximize the performance of the asset. Keeping health & safety KPIs, such as the number of accidents and incidents, low, are also of the operator's interest. Finally, there are strict regulations on the environmental aspects of the operations, and KPIs such as greenhouse gas emissions have to be kept low according to these regulations. An ideal spare parts management strategy should see all or most of these KPIs being lowered.

5.2 Assessing the Influence of New Technology on Spare Parts Management

Having established a way to assess the influence of the new technology on the SPM in the late-life/end-life of an offshore asset, each of the trends discussed in the previous chapter can be evaluated.

5.2.1 Evaluating the Additive Manufacturing Technology

Starting with the AM technology, the benefits included a decreasing need for storage space, shorter lead times, and a lower cost related to acquiring the parts. In terms of the KPIs, a decrease can be expected in the OPEX and lead-time, and at the same time, it facilitates more uptime. In addition, the technology has its advantage on the environmental aspect. The parts can now be manufactured closer to the site, meaning that emissions related to transport are reduced. In terms of the health & safety KPIs, there should not be much of a change with the AM technology. If anything, AM is seen as a safe way of manufacturing the parts, assuming that the operating personnel have received appropriate training.

5.2.2 Evaluating the Blockchain Technology

One of the benefits surrounding blockchain technology was that it offers an outstanding level of transparency within all the supply chain activities of the process. The technology is also very safe. A blockchain's resistance to cyber-attacks, such as hacking, is exceptionally high. When paired with cloud technology and the IoT, there is room for developing an automated process of storing data, predicting failures and ordering spare parts. To create a comparative assessment for the various technologies, the same KPIs will be evaluated for them. The uptime will increase for the automated system as there will ultimately be very few unexpected failures. There can never be a guarantee for eliminating all kinds of unexpected failures, and therefore there is still a need to keep spares of the most critical parts stored just in case. Combined with knowing where the material comes from and its lead time, the ordered parts can arrive close to the RAS time, thereby lessening the need for a big storage area. Safety is one of the technology's biggest strength, and it, therefore, raises the overall safety of the system. There are also some advantages regarding the environment as blockchain technology is fully digitalized. As a result, there is no need for papers and paperwork.

5.3 Assessing the Influence of Circular Economy on Spare Parts Management

A circular economy includes some great environmental benefits, as described in Chapter 4. For example, instead of recycling the parts that have been removed, there will be an evaluation on whether it can be repaired or restored in an economically sustainable way, back to a shape that corresponds with the standards. In addition, buying and selling used parts are beneficial for the operator's finances. Selling the equipment, either to a different operator or someone else who can use it, brings in extra money. Buying used parts is also cheaper than ordering brand new material that has to be manufactured and maybe even transported across borders, adding customs fees.

5.4 Assessing the Possibility of Combining Different Technologies and Policies

Having looked at how different technologies and policies influence spare parts management in the late-life/end-life separately, it is apparent that the ideal solution can be a combination of them. By combining blockchain, cloud technology and IoT with AM, a concept solution with an entirely automated process based on a massive selection of data is developed. Similar to the method described earlier, accurate predictions are made, but now, most spare parts can be manufactured locally with AM technology. Blueprints are stored in the cloud similarly to the Digital Warehouse JIP, and they can easily be retrieved when needed. For parts that are too complicated for AM technology, the knowledge on the original part is still stored, meaning it can be ordered in the traditional way. The solution is still very safe and reliable, and it still offers the same excellent transparency.

Further, when introducing a circular economy policy to the mix, old parts will be sold instead of being recycled. Acquiring new equipment when a replacement is needed can also be affected by this. However, it is reasonable to think that the process will be overly complicated with that addition. Anyway, assuming that it is achievable, the surplus marketplace will also be connected to the process. Now, there are three ways of acquiring new parts when a replacement is needed. First, a request will be sent to the surplus marketplace database with immediate feedback when a piece is required. If there is no instant match, the part is manufactured with AM technology or an order is placed, depending on the part's complexity. This is a cost-effective, efficient, safe, and environmentally pleasing process where many of the KPIs defined earlier will be within their ideal boundaries.

When the asset reaches the end of its lifecycle, and the installation is decommissioned, all parts are evaluated and prepared for being sold. Again, the surplus marketplace service comes into the picture. The sales process is outsourced to professionals, who make sure everything is okay, and this ensures that the circular economy is overheld.

As mentioned in Chapter 4, the AM technology is not quite ready to implement into the oil and gas industry just yet. The challenges discussed there must be overcome, and the technology must be widely recognized in the industry before it can be implemented. However, great minds are already working on it, so it is only a matter of time before progress can be seen and the solution is a real possibility.

6 Conclusions and Further Work

As the study is coming to a close, there will be some conclusions and pointers to what has to be done in the future.

6.1 Conclusions

This thesis aimed to develop a state-of-the-art spare parts management policy in the late-life/end-life of an offshore asset that improves the decommissioning process. One of the objectives was to discover trends and modern technologies and how they could affect the process. A strategy involving digitalization and the latest modern technologies such as additive manufacturing, blockchain, cloud technology and IoT was suggested, along with the potential benefits of the solution.

Along the way, there was a focus on trends that are currently shaping spare parts management. For example, new technologies and circular economy are two of the most significant drivers for improvements in spare parts management. Extensive studies were performed on various technologies, such as additive manufacturing and blockchain. Their benefits on the supply chain were discussed, and assessments were made on how they would impact spare parts management.

In order to evaluate the impact the various concepts would have on the performance of the decommissioning process, the KPIs of the process had to be formed. Financial, operational, health & safety and environmental KPIs were determined to be excellent measurements of tracking how the implementations affect the performance. Further, OPEX, uptime and lead-time, number of accidents or incidents, and emissions were suggested as more specific KPIs to indicate the better option.

6.2 Further Work

The continuous development of new technology should be monitored to keep the solution up to date and working as intended.

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Appendix

1. North Sea Oil and Gas Fields

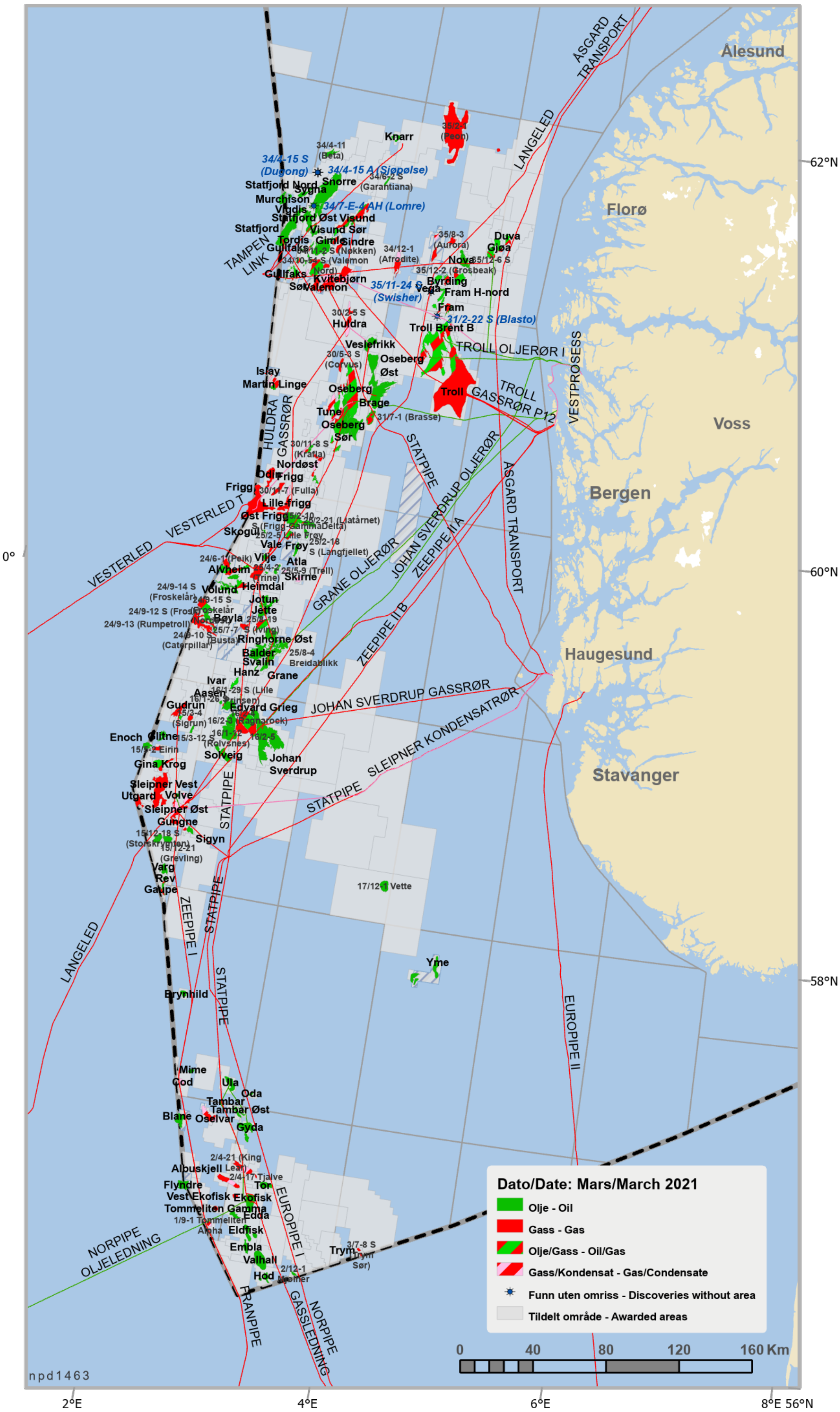

Figure 4: Oil and Gas Fields on NCS in the North Sea (Norwegian Petroleum 2021b)

2. Norwegian Sea Oil and Gas Fields

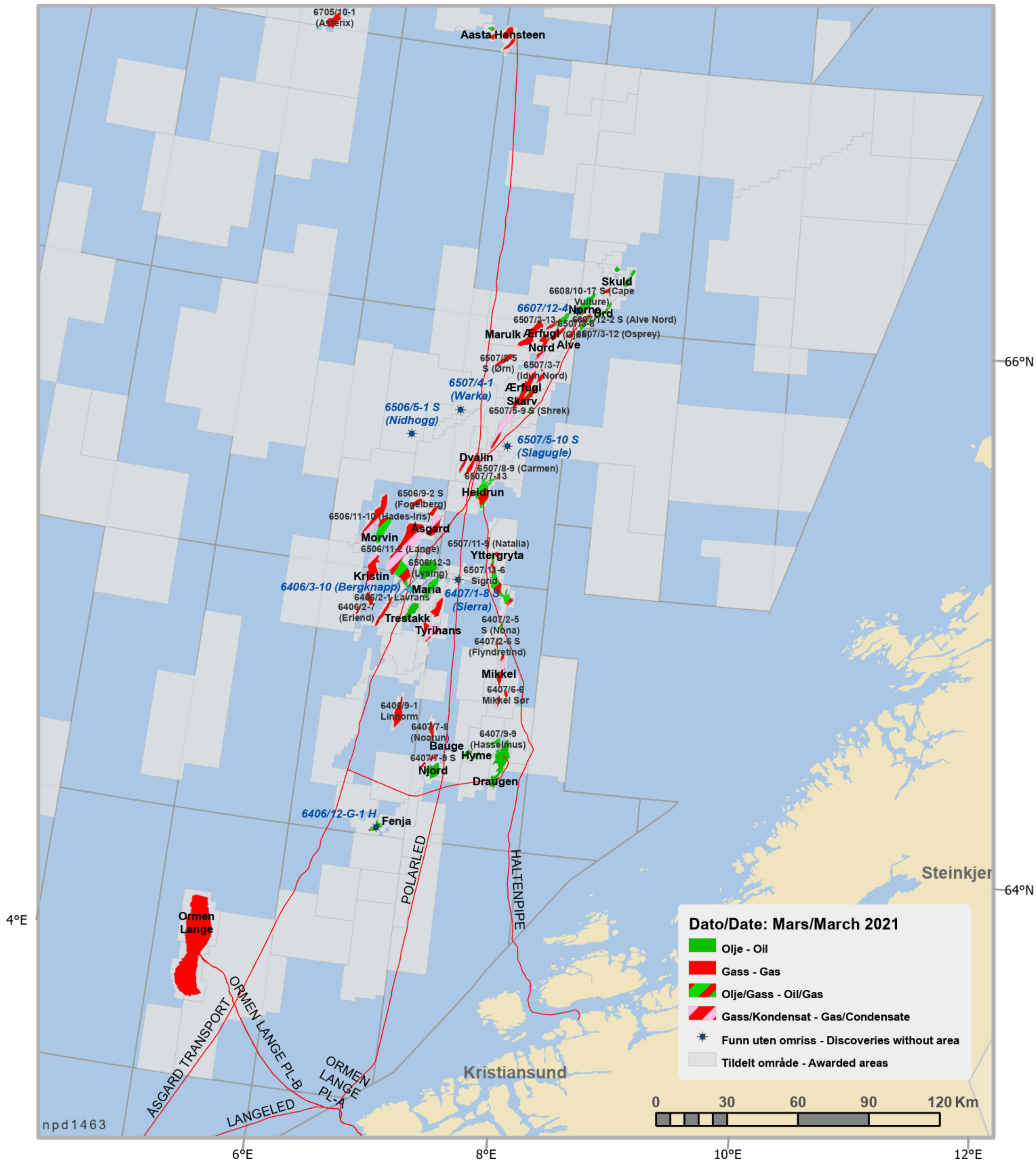

Figure 5: Oil and Gas Fields in the Norwegian Sea (Norwegian Petroleum 2021b)

3. Barents Sea Oil and Gas Fields

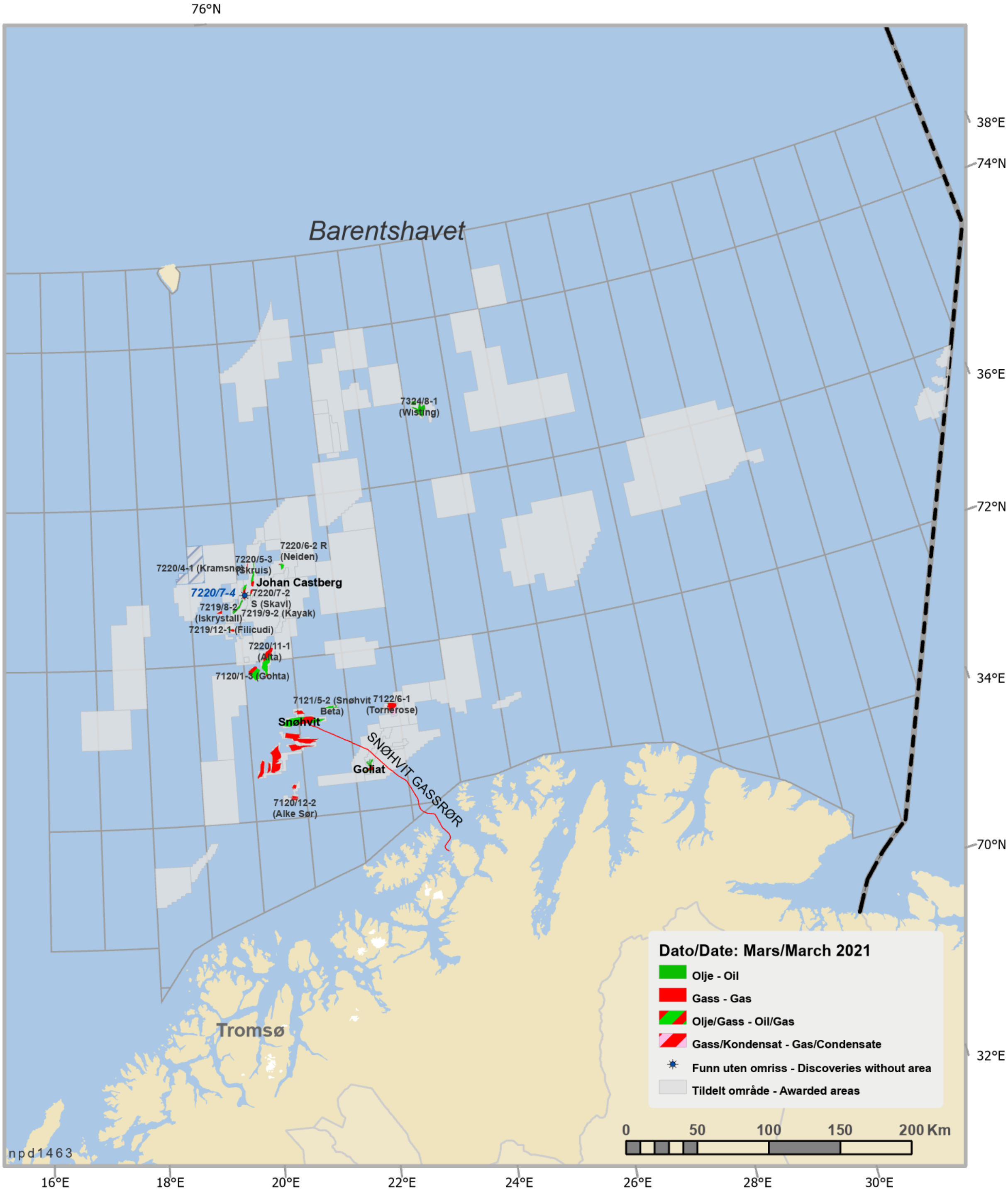

Figure 6: Oil and Gas Fields on NCS in the Barents Sea (Norwegian Petroleum 2021b)

4. *Overview of the Fields on the Norwegian Continental Shelf*

Field name	Area	Status	Disc. year	Orig. res.	Rem. res.	Prod. start	Operator
TROLL BRENT B ›	North Sea	Shut down	2005				Equinor Energy A
ÆRFUGL ›	Norwegian Sea	Producing	2000			18.04.2020	Aker BP ASA ›
ALBUSKJELL ›	North Sea	Shut down	1972	24.76	0.00	26.05.1979	ConocoPhillips Sk
ATLA ›	North Sea	Producing	2010	1.80	0.00	07.10.2012	Total E&P Norge A
BRYNHILD ›	North Sea	Shut down	1992	0.49	0.00	24.12.2014	Lundin Energy N
COD ›	North Sea	Shut down	1968	11.15	0.00	26.12.1977	ConocoPhillips Sk
EDDA ›	North Sea	Shut down	1972	7.20	0.00	02.12.1979	ConocoPhillips Sk
FRIGG ›	North Sea	Shut down	1971	116.66	0.00	13.09.1977	Equinor Energy A
FRØY ›	North Sea	Shut down	1987	7.27	0.00	15.05.1995	Aker BP ASA ›
GAUPE ›	North Sea	Shut down	1985	0.77	0.00	31.03.2012	A/S Norske Shell
GIMLE ›	North Sea	Producing	2004	4.19	0.00	19.05.2006	Equinor Energy A
GLITNE ›	North Sea	Shut down	1995	8.88	0.00	29.08.2001	
GYDA ›	North Sea	Shut down	1980	46.10	0.00	21.06.1990	Repsol Norge AS
HEIMDAL ›	North Sea	Producing	1972	52.92	0.00	13.12.1985	Equinor Energy A
HULDRA ›	North Sea	Shut down	1982	22.76	0.00	21.11.2001	Equinor Energy A
ISLAY ›	North Sea	Producing		0.10	0.00	10.04.2012	
JETTE ›	North Sea	Shut down	2009	0.44	0.00	20.05.2013	
JOTUN ›	North Sea	Shut down	1994	24.02	0.00	25.10.1999	Vår Energi AS ›
LILLE-FRIGG ›	North Sea	Shut down	1975	3.54	0.00	13.05.1994	Aker BP ASA ›
MIME ›	North Sea	Shut down	1982	0.47	0.00	01.01.1993	Aker BP ASA ›
MURCHISON ›	North Sea	Shut down		14.82	0.00	28.09.1980	
NORDØST FRIGG ›	North Sea	Shut down	1974	11.68	0.00	01.12.1983	Equinor Energy A
ODIN ›	North Sea	Shut down	1974	27.52	0.00	01.04.1984	Equinor Energy A
OSELVAR ›	North Sea	Shut down	1991	1.12	0.00	14.04.2012	DNO Norge AS ›
TOMMELITEN GAMMA ›	North Sea	Shut down	1978	14.64	0.00	03.10.1988	ConocoPhillips Sk
VARG ›	North Sea	Shut down	1984	16.69	0.00	22.12.1998	Chrysaor Norge A
VEST EKOFISK ›	North Sea	Shut down	1970	40.84	0.00	31.05.1977	ConocoPhillips Sk
VISUND SØR ›	North Sea	Producing	2008	9.36	0.00	22.11.2012	Equinor Energy A
VOLVE ›	North Sea	Shut down	1993	11.50	0.00	12.02.2008	Lundin Energy N
YTTERGRYTA ›	Norwegian Sea	Shut down	2007	3.29	0.00	05.01.2009	Equinor Energy A
ØST FRIGG ›	North Sea	Shut down	1973	9.29	0.00	01.10.1988	Aker BP ASA ›
REV ›	North Sea	Producing	2001	3.62	0.02	24.01.2009	Repsol Norge AS
ENOCH ›	North Sea	Producing		0.38	0.03	31.05.2007	
FLYNDRE ›	North Sea	Producing	1974	0.10	0.04	26.03.2017	
SINDRE ›	North Sea	Producing	2017	0.07	0.05	26.05.2017	Equinor Energy A

Table 1: Oil and Gas Fields on the Norwegian Continental Shelf Sorted by the Remaining Reservoir Contents (1/4) (Norwegian Petroleum 2021a)

BLANE ›	North Sea	Producing	1989	0.90	0.07	12.09.2007	Repsol Norge AS
TAMBAR ØST ›	North Sea	Producing	2007	0.43	0.07	02.10.2007	Aker BP ASA ›
FRAM H-NORD ›	North Sea	Producing	2007	0.69	0.08	06.09.2014	Equinor Energy A
SKIRNE ›	North Sea	Producing	1990	12.99	0.13	03.03.2004	Total E&P Norge
TUNE ›	North Sea	Producing	1995	22.52	0.20	28.11.2002	Equinor Energy A
VESLEFRIKK ›	North Sea	Producing	1981	64.18	0.24	26.12.1989	Equinor Energy A
BØYLA ›	North Sea	Producing	2009	2.80	0.52	19.01.2015	Aker BP ASA ›
GUNGNE ›	North Sea	Producing	1982	25.16	0.55	21.04.1996	Equinor Energy A
VALE ›	North Sea	Producing	1991	5.37	0.56	31.05.2002	Spirit Energy Nor
KNARR ›	North Sea	Producing	2008	11.02	0.62	16.03.2015	A/S Norske Shell
SIGYN ›	North Sea	Producing	1982	20.04	0.71	22.12.2002	Equinor Energy A
SYGNA ›	North Sea	Producing	1996	11.61	0.75	01.08.2000	Equinor Energy A
BYRDING ›	North Sea	Producing	2005	2.01	0.81	12.07.2017	Equinor Energy A
TRYM ›	North Sea	Producing	1990	6.26	0.83	12.02.2011	DNO Norge AS ›
SKOGUL ›	North Sea	Producing	2010	1.56	0.89	11.03.2020	Aker BP ASA ›
MORVIN ›	Norwegian Sea	Producing	2001	15.47	0.91	01.08.2010	Equinor Energy A
EMBLA ›	North Sea	Producing	1988	19.11	1.16	12.05.1993	ConocoPhillips Sk
SLEIPNER ØST ›	North Sea	Producing	1981	122.62	1.22	24.08.1993	Equinor Energy A
URD ›	Norwegian Sea	Producing	2000	8.93	1.26	08.11.2005	Equinor Energy A
MARULK ›	Norwegian Sea	Producing	1992	9.82	1.38	02.04.2012	Vår Energi AS ›
VOLUND ›	North Sea	Producing	1994	14.05	1.38	10.09.2009	Aker BP ASA ›
SKULD ›	Norwegian Sea	Producing	2008	6.41	1.48	19.03.2013	Equinor Energy A
RINGHORNE ØST ›	North Sea	Producing	2003	14.55	1.57	19.03.2006	Vår Energi AS ›
UTGARD ›	North Sea	Producing	1982	3.42	1.99	16.09.2019	Equinor Energy A
OSEBERG ØST ›	North Sea	Producing	1981	25.14	2.02	03.05.1999	Equinor Energy A
TAMBAR ›	North Sea	Producing	1983	16.15	2.02	15.07.2001	Aker BP ASA ›
HYME ›	Norwegian Sea	Producing	2009	4.58	2.23	02.03.2013	Equinor Energy A
VILJE ›	North Sea	Producing	2003	15.40	2.26	01.08.2008	Aker BP ASA ›
HANZ ›	North Sea	Approved for production	1997	2.91	2.91		Aker BP ASA ›
SVALIN ›	North Sea	Producing	1992	9.71	2.94	24.03.2014	Equinor Energy A
ALVE ›	Norwegian Sea	Producing	1990	14.98	3.15	19.03.2009	Equinor Energy A
BRAGE ›	North Sea	Producing	1980	69.83	3.42	23.09.1993	Wintershall Dea
ODA ›	North Sea	Producing	2011	5.91	3.80	16.03.2019	Spirit Energy Nor
ÆRFUGL NORD ›	Norwegian Sea	Approved for production	2012	4.52	4.52		Aker BP ASA ›
STATFJORD ØST ›	North Sea	Producing	1976	50.25	4.54	24.09.1994	Equinor Energy A
VALEMON ›	North Sea	Producing	1985	18.56	4.89	03.01.2015	Equinor Energy A

Table 2: Oil and Gas Fields on the Norwegian Continental Shelf Sorted by the Remaining Reservoir Contents (2/4) (Norwegian Petroleum 2021a)

STATFJORD NORD ›	North Sea	Producing	1977	47.96	4.91	23.01.1995	Equinor Energy A
KRISTIN ›	Norwegian Sea	Producing	1997	66.66	5.12	03.11.2005	Equinor Energy A
TORDIS ›	North Sea	Producing	1987	75.73	5.30	03.06.1994	Equinor Energy A
ULA ›	North Sea	Producing	1976	91.15	5.55	06.10.1986	Aker BP ASA ›
TRESTAKK ›	Norwegian Sea	Producing	1986	7.64	6.13	16.07.2019	Equinor Energy A
HOD ›	North Sea	Producing	1974	19.14	6.85	30.09.1990	Aker BP ASA ›
NORNE ›	Norwegian Sea	Producing	1992	110.50	8.04	06.11.1997	Equinor Energy A
DRAUGEN ›	Norwegian Sea	Producing	1984	157.62	8.19	19.10.1993	OKEA ASA ›
MARIA ›	Norwegian Sea	Producing	2010	11.53	8.76	16.12.2017	Wintershall Dea I
MIKKEL ›	Norwegian Sea	Producing	1987	55.95	9.07	01.08.2003	Equinor Energy A
SOLVEIG ›	North Sea	Approved for production	2013	9.22	9.22		Lundin Energy N
TOR ›	North Sea	Producing	1970	47.19	9.61	03.12.2020	ConocoPhillips Sk
YME ›	North Sea	Approved for production	1987	17.91	10.00	27.02.1996	Repsol Norge AS
VIGDIS ›	North Sea	Producing	1986	79.52	10.67	28.01.1997	Equinor Energy A
GJØA ›	North Sea	Producing	1989	73.37	11.13	07.11.2010	Neptune Energy I
DUVA ›	North Sea	Approved for production	2016	11.44	11.44		Neptune Energy I
SLEIPNER VEST ›	North Sea	Producing	1974	207.78	11.48	29.08.1996	Equinor Energy A
BAUGE ›	Norwegian Sea	Approved for production	2013	11.51	11.51		Equinor Energy A
FENJA ›	Norwegian Sea	Approved for production	2014	11.57	11.57		Neptune Energy I
NOVA ›	North Sea	Approved for production	2012	12.63	12.63		Wintershall Dea I
ALVHEIM ›	North Sea	Producing	1998	64.20	12.73	08.06.2008	Aker BP ASA ›
GULLFAKS ›	North Sea	Producing	1978	415.85	14.54	22.12.1986	Equinor Energy A
FRAM ›	North Sea	Producing	1990	62.93	15.78	02.10.2003	Equinor Energy A
IVAR AASEN ›	North Sea	Producing	2008	30.11	16.29	24.12.2016	Aker BP ASA ›
GUDRUN ›	North Sea	Producing	1975	46.88	17.30	07.04.2014	Equinor Energy A
STATFJORD ›	North Sea	Producing	1974	714.17	17.34	24.11.1979	Equinor Energy A
GOLIAT ›	Barents Sea	Producing	2000	31.36	17.49	12.03.2016	Vår Energi AS ›
DVALIN ›	Norwegian Sea	Producing	2010	18.81	18.80	23.11.2020	Wintershall Dea I
VEGA ›	North Sea	Producing	1981	48.44	19.11	02.12.2010	Wintershall Dea I
GINA KROG ›	North Sea	Producing	1978	29.49	20.34	30.06.2017	Equinor Energy A
GRANE ›	North Sea	Producing	1991	150.90	22.85	23.09.2003	Equinor Energy A
OSEBERG SØR ›	North Sea	Producing	1984	97.91	25.43	05.02.2000	Equinor Energy A
ELDFISK ›	North Sea	Producing	1970	195.05	25.46	08.08.1979	ConocoPhillips Sk
NJORD ›	Norwegian Sea	Producing	1986	67.24	26.00	30.09.1997	Equinor Energy A
KVITEBJØRN ›	North Sea	Producing	1994	154.42	27.26	26.09.2004	Equinor Energy A
EDVARD GRIEG ›	North Sea	Producing	2007	56.31	28.29	28.11.2015	Lundin Energy N

Table 3: Oil and Gas Fields on the Norwegian Continental Shelf Sorted by the Remaining Reservoir Contents (3/4) (Norwegian Petroleum 2021a)

AASTA HANSTEEN ›	Norwegian Sea	Producing	1997	51.05	35.58	16.12.2018	Equinor Energy A
TYRIHANS ›	Norwegian Sea	Producing	1983	91.93	35.86	08.07.2009	Equinor Energy A
BALDER ›	North Sea	Producing	1967	109.67	36.11	02.10.1999	Vår Energi AS ›
ÅSGARD ›	Norwegian Sea	Producing	1981	422.02	37.90	19.05.1999	Equinor Energy A
GULLFAKS SØR ›	North Sea	Producing	1978	180.99	39.90	10.10.1998	Equinor Energy A
VALHALL ›	North Sea	Producing	1975	194.08	41.22	02.10.1982	Aker BP ASA ›
MARTIN LINGE ›	North Sea	Approved for production	1978	41.60	41.60		Equinor Energy A
VISUND ›	North Sea	Producing	1986	117.08	45.63	21.04.1999	Equinor Energy A
HEIDRUN ›	Norwegian Sea	Producing	1985	248.95	57.19	18.10.1995	Equinor Energy A
SKARV ›	Norwegian Sea	Producing	1998	111.01	59.53	01.01.2013	Aker BP ASA ›
EKOFISK ›	North Sea	Producing	1969	729.74	64.42	15.06.1971	ConocoPhillips Sk
ORMEN LANGE ›	Norwegian Sea	Producing	1997	320.74	73.79	13.09.2007	A/S Norske Shell
OSEBERG ›	North Sea	Producing	1979	547.17	79.26	01.12.1988	Equinor Energy A
SNORRE ›	North Sea	Producing	1979	326.35	85.37	03.08.1992	Equinor Energy A
JOHAN CASTBERG ›	Barents Sea	Approved for production	2011	88.90	88.90		Equinor Energy A
SNØHVIT ›	Barents Sea	Producing	1984	248.61	170.02	21.08.2007	Equinor Energy A
JOHAN SVERDRUP ›	North Sea	Producing	2010	428.27	398.55	05.10.2019	Equinor Energy A
TROLL ›	North Sea	Producing	1979	1765.78	744.44	19.09.1995	Equinor Energy A

Table 4: Oil and Gas Fields on the Norwegian Continental Shelf Sorted by the Remaining Reservoir Contents (4/4) (Norwegian Petroleum 2021a)