SOCIAL ACCEPTANCE OF DECOMMISSIONING OFFSHORE WIND FARMS

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TU Delft Delft University of Technology

VATTENFALL

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Social Acceptance of Decommissioning Offshore Wind Farms on the North Sea

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Preface

Dear reader,

It is with due pride that I present my master's thesis on Social Acceptance of Decommissioning Offshore Wind Farms on the North Sea. This paper is a testament to my competence as an engineer and concludes the MSc Management of Technology at the Faculty of Technology, Policy and Management at Delft University of Technology.

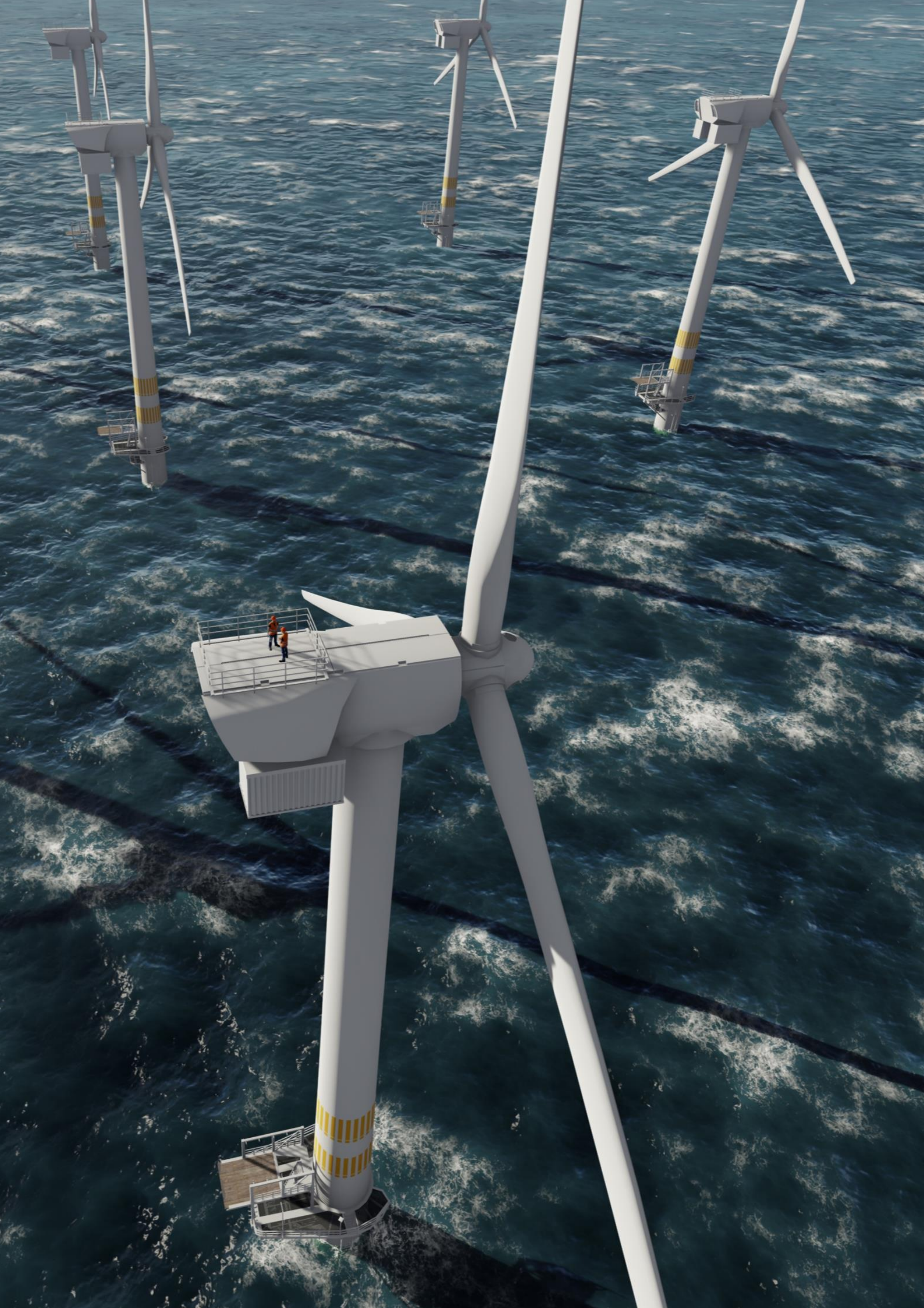
Over the course of seven months, I have immersed myself in the fascinating world of Offshore Wind Energy. For me, this subject speaks to my passion for engineering and technology, while working in this field matches my intrinsic motivation to contribute to the energy transition. Considering this, I could not have wished for a better fit for my graduation project. My thanks go to Vattenfall in general and to Jacob-Jan Lagerwerf and Ewoud Bloem in particular. Their continuous support and enthusiasm helped me to remain confident, even at times when I felt lost in the process. In addition, I would like to thank Aad Correljé and Rob Stikkelman for their academic supervision.

With the submission of this document, my student life (which some believe has endured long enough) officially comes to an end. When I look back on this time, I do so with great joy and gratitude. I owe a large part of my personal development to the many friendships I have gained over the years. I would like to thank my fellow VS95 residents, with whom I have lived for more than five years, making them feel like family. Next, I would like to thank the many friends that ensued from my time at DSRV Laga, with whom I share countless precious and hilarious memories. In addition, I am grateful to Jessica, who has tirelessly stood by me over the years and listened to my over-enthusiastic technical fascinations. My greatest gratitude, however, goes to my parents and family. For their unparalleled patience and support, but most of all for giving me the opportunity to follow my own path and develop into the person I am today.

Finally, I would like to address you, the reader. Thank you for taking the time to read my thesis. I hope it offers you some insights into how offshore wind development could be integrated into a more holistic approach to the use of our seas. Only then, offshore wind development will support the transition to truly sustainable societies in the future.

Kind regards,

Theo de Kruijf
The Hague, September 2021



Executive summary

Offshore Wind Farms (OWFs) have developed into an integral part of the European energy transition in the fight against climate change. The North Sea, with its excellent wind conditions and soil characteristics, as well as ports and industrial energy consumers nearby, has become the epicenter of offshore wind development. In 2002, the construction of Horns Rev 1 marked the beginning of OWF deployment on a commercial scale, after which the diffusion of the technology took off. Nearly 20 years later, the first OWFs approach end-of-life, considering their design life of 20-25 years. Due to constant innovation, turbines have become larger and farm layouts have changed significantly over the years, often making repowering technically infeasible. As a result, this forces the owner of the OWF to consider decommissioning, which includes all measures performed to return a site close to its original state, as is reasonably practicable.

While removal of the superstructure (all components above the waterline) is relatively straightforward, removal of the substructure (all components below the waterline) is inherently more complex, both from a technical and managerial perspective. Although international and national regulations dictate complete decommissioning, i.e., the complete removal of all components and infrastructure from the marine environment, the industry has been reluctant in adopting this approach. There have been discussions about the potential environmental impact of removing all substructures, as it is known that substructures are colonized by benthic communities and can transform ecosystems over their lifetime. This trade-off needs to be made in the context of social concerns regarding the degradation of the ecological condition of the North Sea and the increasing spatial pressure from economic activities. This research constructs a multidisciplinary view of OWF decommissioning and explores the factors important for social acceptance of OWF decommissioning strategies on the North Sea. Ultimately, this thesis serves to answer the main research question: what factors are important for social acceptance of OWF decommissioning strategies on the North Sea?

Currently, there exists no academic consensus on an all-encompassing definition of social acceptance. Therefore, the concept has been specifically defined and conceptualized for this study as: the passive or active approval of decommissioning strategies, as reflected in the attitudes and behaviors of individual or complex social actors, which can be measured at a particular point in time. The conceptualization of social acceptance was built upon the framework proposed by Wüstenhagen et al. (2007), which introduces three interrelated dimensions of social acceptance for renewable energy innovations, namely *socio-political, community and market acceptance*. Through a general literature review and qualitative interviews with policy makers, Non-Governmental Organizations (NGOs), and industrial and academic experts, an attempt was made to capture a multidisciplinary view of the topic. The exploration on itself has been academically refreshing and provided the necessary input on the implications for social acceptance.

Socio-political acceptance describes the extent to which society as a whole supports the deployment of a technology. As government policy tends to reflect widespread public opinion over time, the regulatory framework has been mapped through interviews with policy makers and an academic expert. This has led to the understanding that the development of OWFs on the North Sea is firmly embedded in and supported by the regulatory framework in the Netherlands. The included mandatory approach to complete decommissioning of offshore structures stems from two international treaties. The strict national enforcement of this policy is primarily due to the increasing spatial pressure on the North Sea. Abandoned structures on the seabed can potentially pose a threat to other legitimate users of the sea and complicate the redevelopment of an area.

Community acceptance refers to the degree to which communities tolerate the local impacts of a technology. The difference with socio-political acceptance is illustrated by the Not In My Backyard (NIMBY) phenomenon, which conveys that people might support a concept in general, but only as long as they are not personally inconvenienced by it. However, in the case of OWFs, there are no local human communities to consider, so NGOs were used as proxies for community acceptance. NGOs represent social concerns and actively advocate for the inclusion of social values in decision making. This research focused on NGOs that actively participated in the North Sea Agreement consultation sessions, demonstrating their commitment to the North Sea. In order to identify the values that are important to them, mission statements and position papers were reviewed and an interview was conducted. Overall, NGOs support the development of OWFs on the North Sea, but emphasize the importance of ecological research in decommissioning decision-making. In some cases, substructures can facilitate ecological enrichment, but Environmental Impact Assessments (EIAs) and a case-by-case approach are critical to this assessment. Moreover, NGOs stress the importance of circular design of offshore wind turbines and the urgent need for responsible resource and waste management in offshore wind development.

Market acceptance reflects the extent to which the market will consider adopting a technology. In the case of OWF decommissioning, this research has shown that market acceptance is dependent on socio-political acceptance. A market party has entered into an agreement with the government that allows them to develop OWFs in the public space. By entering into this agreement, they agree to carry out decommissioning as the authorities see fit. Thus, the willingness of the market to engage is not optional. Interviews with industry experts highlight the need for operational validation of novel technologies to mitigate risk and improve the economics of complete decommissioning. In addition, the industry expects governments to be more specific about decommissioning requirements to promote innovation and create a level playing field for competitors in the market. Governments should be confident in enforcing their policies to reduce the risk of social backlash for the market.

This thesis concluded that OWF decommissioning strategies are generally socially accepted in the Netherlands, although it should be noted that operational experience is essential to further strengthen this finding. In order to actively promote social acceptance, this thesis introduces recommendations. These recommendations are based on the factors identified in the interviews with experts. First and foremost, the industry is advised to take a holistic approach in offshore wind development on the North Sea. The complex trade-offs associated with decommissioning should be placed in the broader context of the many commercial activities at sea and the deteriorating health of the North Sea due to overexploitation of natural resources, pollution and habitat destruction. Failing to do so could threaten the reputation of offshore wind as a sustainable, renewable energy source, which could harm the energy transition and ultimately even the fight against climate change. Secondly, a level European regulatory framework with clear decommissioning requirements would stimulate developers to design WTGs for decommissioning and recycling, while boosting innovation in the sector. This will increase the incentive for the industry to consider complete decommissioning and recycling, eventually enhancing the sustainability of offshore renewable energy generation. Thirdly, long-term ecological research is key to underpinning the impact of decommissioning on complex ecological processes. As more and more OWFs reach their end-of-life, EIAs should increasingly consider the cumulative impacts of decommissioning. The results of this research can be taken into account when developing decommissioning strategies or even when shaping government policy. Fourthly and finally, transparent communication and collaboration in this sector are key to social acceptance. The co-use of OWF plots should be encouraged to alleviate spatial pressure on the North Sea and create shared objectives and responsibilities with other stakeholders. By ensuring that society and stakeholders are aware of the scientific arguments behind a particular approach, social unrest can be prevented.

The most prominent limitation of this thesis was the applicability of the theory by (Wüstenhagen et al., 2007). Although this theory has been very influential in the academic world for the conceptualization of social acceptance for renewable energy innovations, its focus on siting and deployment caused difficulties in this research. The two main discrepancies are that in this case, market acceptance is embedded in socio-political acceptance and community acceptance is hardly measurable due to a lack of local human communities offshore. Therefore, this research altered the theory of Wüstenhagen, to be better suited for offshore wind decommissioning. Further limitations are that OWF development is characteristically long-term and social values are prone to change over time, so this study cannot guarantee social acceptance in the future. Furthermore, as this study focused specifically on the Netherlands, it does not guarantee the applicability of its results on a wider scale.

Future researchers are recommended to quantitatively investigate social acceptance once more operational experience with decommissioning is available. From an engineering perspective, it would be highly relevant to investigate the impact on the design and business case if decommissioning is considered from the outset. Ecological research can fill knowledge gaps regarding the individual and cumulative ecological impacts of decommissioning.

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Acronyms

AWC	Abrasive Wire Cutting
AWJ	Abrasive Water Jetting
BAT	Best Available Technology
BEIS	British Department of Energy, Business and Industrial Strategy
BPEO	Best Practicable Environmental Option
BSH	Federal Maritime and Hydrographic Agency of Germany
CAPEX	Capital Expenditures
CS	Continental Shelf
DEA	Danish Energy Agency
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EKZ	Ministry of Economic Affairs and Climate
GDP	Gentle Driving of Piles
GROW	Growth through Research, development and demonstration in Offshore Wind
GW	Giga Watt
HyPE	Hydraulic Pile Extraction
IAC	Inter-Array Cables
IMO	International Maritime Organization
LCOE	Levelized Cost Of Energy
MOT	Management Of Technology
MP	Monopile
MW	Mega Watt
NGO	Non-Governmental Organization
NIMBY	Not In My Backyard
NIOZ	Dutch Institute for Sea Research
NSR	North Sea Region
NWEA	Dutch Wind Energy Association
O&G	Oil & Gas
OSPAR	Oslo and Paris Convention
OSS	Offshore Substation
OWEZ	Offshore Windfarm Egmond aan Zee
OWF	Offshore Wind Farm
PAWP	Princess Amalia Wind Farm
ROV	Remotely Operated Vehicle
RVO	Netherlands Enterprise Agency
RWS	Rijkswaterstaat
T&I	Transport and Installation
TPM	Technology, Policy and Management
TRL	Technology Readiness Level
UNCLOS	United Nations Convention on the Law of the Sea
VLT	Vibratory Lifting Tool
WTG	Wind Turbine Generator

Glossary

Benthic flora and fauna	The various plants and organisms found on (epifauna) and in (infauna) the seabed
Community acceptance	Reflects the acceptance of specific siting decisions and energy projects, particularly by residents and local authorities
Decommissioning	All measures performed to return a site close to its original state as is reasonably practicable
Functional jurisdiction	A limited form of jurisdiction, which only exists where it has a function
Hydro-morphology	Considers the physical character and water content of water bodies
Market acceptance	Relating to market adoption of a technology or innovation, including a willingness of financial institutions to invest or lend against the technology, large scale manufacturing of the technology and for consumers to engage in the markets created by the technology
Primary data	Data collected by researchers directly from sources, using methods like surveys, interviews and experiments
Scour protection	The protection of soil or other submerged material against scour by covering them with other materials
Secondary data	Data collected by someone other than the primary user
Social acceptance	A positive attitude towards a matter at a particular point in time, which is stated in a specific idea or in a particular behavior including encouragement, confirmation and approbation
Socio-political acceptance	Reflecting the broader issue of acceptance, such as state policies and institutional frameworks that allow or promote the deployment of specific technologies and wider public opinion conducive to the development of the technology
Substructure	All parts of an offshore wind turbine generator and its energy infrastructure, located underneath the sea level
Superstructure	All parts of an offshore wind turbine generator and its energy infrastructure, located above the sea level


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1. Research introduction

This chapter introduces background information on the development of offshore wind and emphasizes the growing amount of offshore wind farms (OWFs) that reach the end of their operating lives. Moreover, key experiences from the past and challenges in the near future are introduced. In section 1.2, the problem statement is provided, which contains the research objective and research question. In addition, the social and academic relevance of the subject is substantiated. Subsequently, the link with the Management of Technology (MoT) program is given in section 1.3 and finally the outline of the thesis is described in section 1.4.

1.1 Background

"As yet, the wind is an untamed force, and unharnessed force; and quite possibly one of the greatest discoveries hereafter to be made, will be the taming and harnessing of it". These were the words of Abraham Lincoln in a lecture on *Discoveries and Inventions* in 1860. Even though wind energy was already being utilized in sailing and early-stage windmills, there was little known about how to harness the full potential of this undeniable force of nature. It would take more than thirty years, until 1891, before the first wind turbine generator (WTG) for electrical power was developed by Danish scientist Paul La Cour. Mostly Danish, but also American and German inventors designed different variations, aspiring to achieve the highest efficiency without compromising on safety and durability (Ackermann & Söder, 2000). This innovation process ultimately led to the massive wind turbines the world relies on for renewable energy today.

Renewable energy has seen enormous growth and development in the twenty-first century. The main driver for this phenomenon is the global ambition to mitigate CO_2 emissions in our energy supply, which mainly originate from the combustion of fossil fuels. Moreover, the increasing energy demand, the search for national energy security and roadblocks in nuclear power development accelerates the adoption of renewable energy (Esteban et al., 2011). The attractiveness of wind energy specifically among renewables, can be explained by the high resource availability of wind and the high technology maturity level of wind energy technologies. Although most of this development came from the construction of onshore WTGs, most European countries have grown hesitant with their placement onshore and increasingly move to offshore installation. Explanations vary from lack of space in the fierce local opposition. Offshore wind advocates also highlight the superior wind conditions and minimal environmental impact related to offshore installation. The North Sea has ideal characteristics for offshore installations, as water depths are moderate and installation is relatively easy due to the soil type. Due to recent developments, offshore wind is now able to expand to the Baltic, Mediterranean and Black Sea as well. Hence, Southern-European and Baltic countries have now committed themselves to develop OWFs.

The majority of coastal European countries are betting on offshore wind to be one of the key energy sources in their energy transition. The European Green Deal endorses this, as it describes ambitious targets for offshore wind installation. Whereas countries in the European Union had 12 GW installed in 2020, the aim is to increase that to 60 GW in 2030 and 300 GW in 2050 (European Commission, 2020). In order to get there, Europe invested a record amount of €26.3 billion in 2020, which will initiate the development of 7,1 GW of new offshore wind capacity in the following years (WindEurope, 2021a). More and more supportive national regulatory frameworks come in to place and the birth of the first subsidy-free OWF, Hollandse Kust Zuid, was a major milestone in offshore wind development and offers great promise for the future.

Besides the installation of new capacity, coming years will also mark a novel trend in the sector, since a growing amount of commercial OWFs will reach the end of their design life. According to Ortegon, Nies, and Sutherland (2013) a wind turbine reaches its designated life expectancy (20-30 years) when it cannot function efficiently due to failure or fatigue, or no longer satisfies the expectations or needs of its user. Generally, OWF owners have three options when an OWF reaches its design life; lifetime extension, repowering or decommissioning. Lifetime extension involves the engineering assessment of generating assets, which might lead to the replacement of worn-out components, whereby the lifetime of the OWF can be extended by generally five to ten years. Repowering is the process of replacing the old generating assets with the latest technology which operates at lower cost and/or higher output. Both options depend on the permit in place or the authority's willingness to extent it. The last option is decommissioning, which is defined as "*all measures performed to return a site close to its original state as is reasonably practicable*" by Topham and McMillan (2017). Whereas the first two options will only be considered when a project fits all technical, economic, regulatory and environmental requirements, decommissioning will ultimately always have to be carried out. In addition, due to the rapid pace at which wind turbine technology has evolved, which led to a significant drop in costs and increased capacity and size, repowering is often not considered technically feasible. Therefore, the decommissioning process will lie at the heart of this research study.

Since the first substantial OWFs in the EU have been commissioned in the mid-2000s, coming years will mark the end of lifetime of a growing amount of OWFs. Hence, the annual potential volume of decommissioning work will rapidly ramp up from 22 WTGs in 2020, to almost 800 WTGs in 2035 (DecomTools, 2021), as is depicted in Figure 1.1. In addition to the growing frequency of decommissioning, the growing size and capacity of WTGs increases the complexity of dismantling.

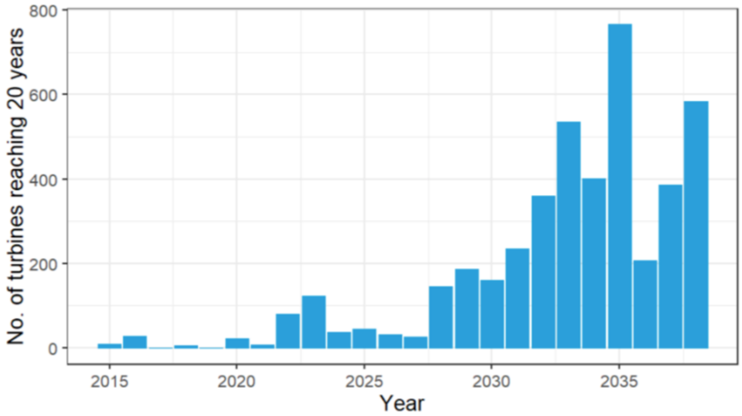

Figure 1.1: Annual number of turbines reaching the 20-year lifetime in Europe (Topham et al., 2019)

Although some lessons can be learned from offshore oil & gas (O&G) decommissioning projects, the industry's current offshore wind decommissioning experience is limited to the removal of relatively small offshore wind projects, as presented in Table 1.1. Only OWFs which were significant in size, i.e., which contain more than two WTGs, were included. All projects were located in Northern-Europe and mostly relied on monopile foundations.

OWF name	Location	Capacity [MW] & no. of WTGs	Foundation type	Decommission year	Owner
Yttre Stengrund	Sweden	10 (5 x 2 MW)	Monopile	2015	Vattenfall
Lely	Netherlands	2 (4 x 0,5 MW)	Monopile	2016	Vattenfall
Vindeby	Denmark	4,95 (11 x 0,45 MW)	Gravity Based	2017	Dong Energy (Ørsted)
Utgrunden I	Sweden	10,5 (7 x 1,5 MW)	Monopile	2018	Vattenfall

Table 1.1: Overview of decommissioned OWFs until 2019 (Topham et al., 2019)

The experiences which can be drawn from these decommissioning projects, have been studied by Topham and McMillan (2017) and Jensen (2018) among others. The key take-aways are that duration and costs are often not adequately captured in the planning activities and should be included from the initial development stage of an offshore wind project. If not, complications in decommissioning can cause radical changes to the levelized cost of energy and the owner's business case. Moreover, the number of uncertainties surrounding the process is significant, as every OWF varies in turbines size, location, foundation type, water depth and distance to shore, thereby complicating the establishment of best practices.

In 2002, Vattenfall commissioned the first large-scale OWF in the world, Horns Rev I, on the coast of Denmark. With a capacity of 160 MW, it quadrupled the previous largest OWF and marked the beginning of a new era in offshore wind installation and development. 19 years later, Horns Rev I is approaching its end of lifetime, and is expected to be one of the first significant commercial sites to be decommissioned. As Vattenfall has the third largest market share (7%) of cumulative offshore wind capacity in Europe in 2019 (Statista, 2021a), decommissioning will play a major role in Vattenfall's Marine Logistics and Operations department in the coming years. A list of OWFs that approach their end-of-lifetime, owned by Vattenfall, is given in Table 1.2.

OWF name	Location	Capacity [MW] & no. of WTGs	Foundation type	Commissioning year (age)	Owner(s)
Horns Rev I	Denmark	160 (80 x 2 MW)	Monopile	2002 (19 years)	Vattenfall (60%), Ørsted (40%)
Kentish Flats	UK	90 (30 x 3 MW)	Monopile	2005 (16 years)	Vattenfall
Egmond aan Zee	Netherlands	108 (36 x 3 MW)	Monopile	2006 (15 years)	Vattenfall (50%), Shell (50%)
Lillgrund	Sweden	110 (48 x 2,3 MW)	Gravity Based	2007 (14 years)	Vattenfall

Table 1.2: OWFs owned by Vattenfall that approach their end-of-lifetime (Vattenfall, 2021)

As can be seen, future decommissioning work is significantly different than what already has been done. When comparing the first substantial decommission project, Vindeby, to Horns Rev 1, the number of turbines has almost increased eight-fold, the capacity per turbine quadrupled and the hub height doubled. Therefore, the complexity of decommissioning OWFs has risen and complications during the process will have an increasing impact.

1.2 Problem statement

The previous sections introduced the broad topic area and indicated the scale of the challenge that lies ahead. To be able to conduct good research, it is essential that a specific and purposiveness problem statement is formulated. To operationalize the problem statement, research objectives and research questions have been drawn up. Subsequently, the social and academic relevance of the subject will be established.

Vattenfall is a Swedish power company which operates in Sweden, Germany, the Netherlands, Denmark and the UK. Whereas 51% of Vattenfall's power plants were fossil-fuelled until 2011, it managed to decrease this to 23% in 2019 by increasing their share of hydropower, nuclear power and renewables, fully in line with its mission: "*fossil free within one generation*". The search for fossil-free generation capacity also explains Vattenfall's significant expansion in the offshore wind market. Vattenfall was the first to invest in offshore wind power and developed into a major player in the European offshore wind sector.

Since Vattenfall was one of the first movers in offshore wind, they currently own some relatively old OWFs, which are approaching their end of life. The scale of these wind farms is not comparable to the "pilot" OWFs that have been decommissioned so far and therefore brings new challenges and higher risk. It is therefore imperative to be aware of the potential impact a certain decommissioning strategy can have. WTGs can be decommissioned in different formats with corresponding consequences on economic, environmental and social levels.

Most governmental policies dictate the developers to completely remove the OWF, however, this is not what has been seen in the decommissioning projects so far. Authorities allow deviations from this default decommissioning strategy only when the developer can substantiate why their alternative strategy will lead to a more desirable outcome, this will be further explained in section 5.1. Due to the limited experience with decommissioning OWFs, the regulatory uncertainty and insufficient knowledge of the economic, environmental and social impacts of decommissioning strategies, the industry is not able to provide comprehensive argumentation for different decommissioning strategies, let alone guarantee social acceptance for them.

1.2.1 Research objective

Vattenfall aims to make well-informed decisions in decommissioning its wind farms, a subject that has long been ignored by the entire industry. Since it has not been given much academic or social attention over the years, not much is known about the public opinion towards offshore wind decommissioning or how it is influenced. Whereas there is some experience with decommissioning onshore projects, the characteristics are inherently different and are therefore hardly applicable on offshore projects. In order to aid Vattenfall in this process, this thesis aims to map the framework in which decommissioning decisions for OWFs are taken. It does that by constructing a comprehensive multidisciplinary overview of the positions on decommissioning strategies of various social actors and exploring which factors might be influential in reaching socially accepted decommissioning strategies. So, the research objective is to obtain a multidisciplinary view on OWF decommissioning and explore what values are important for social acceptance of OWF decommissioning strategies on the Dutch North Sea.

1.2.2 Research questions

Following from the research objective of the research as described above, research questions have been formulated. The complex issue is divided into several sub-questions. These sub-questions ultimately lead to the answering of the main research question, as formulated below:

What factors are important for social acceptance of Offshore Wind Farm decommissioning strategies on the North Sea?

The sub-questions are as follows:

1. *How can social acceptance be conceptualized?*
2. *What strategies are there for decommissioning Offshore Wind Farms?*
3. *What values are important for different stakeholders in the process of decommissioning Offshore Wind Farms?*

1.2.3 Social relevance

As this thesis is the end result of publicly funded education, it is only fair that it addresses a topic which is socially relevant. This section will argue why social acceptance for decommissioning OWFs is relevant for society. The decommissioning process affects many different stakeholders, each with their own values. Developers seek to keep costs down, environmental organizations strive for minimal environmental impact and other users of the sea pursue their own ideals. Because these values often conflict, it is up to the government to reach a satisfactory compromise for as many parties as possible. However, although developers and authorities work together on the optimal decommissioning strategy for each specific OWF, taking into account technical, economic, environmental and social elements, this may not always work out as expected. Lessons can be learned from one of the biggest controversies in O&G decommissioning, Shell's Brent Spar.

Brent Spar

The floating oil storage platform, which was located on the Brent oil field in the northern North Sea, ceased operation in 1991 after fifteen years of service. Detailed decommissioning studies were carried out by Shell and independent external organizations to assess the options. Two of these were compared in detail, horizontal onshore dismantling and deep-sea disposal. Ultimately, deep-sea disposal showed six times lower safety risks, four times lower costs and minimal environmental impact. The UK government announced its agreement with this approach and notified 12 other nations and the European Commission, all signatories of the Oslo Convention for the protection of the marine environment, none of whom objected within the usual time limit. In 1995, however, Greenpeace activists occupied Spar and made false claims about its toxicity and Shell's plans to dump it in the North Sea. Public opinion changes dramatically and in Germany protesters damage 50 Shell service stations in response. Although independent British scientists support Shell's environmental decision-making, based on reason and sound science, Shell decides to halt its disposal plan. Further independent research confirms that the environmental effects of deep-sea disposal would have been very small and localized but Shell was forced to consider other disposal options. In the end, Spar served a final use as the base of a Norwegian ferry quay (Shell, 2008).

This unique case illustrates that sound science and regulatory approval, while important, are not sufficient. The complexity of offshore decommissioning requires more interaction with society, to understand and respond adequately to people's concerns and expectations. In the event of a social disapproval, not only would the developer and the relevant nation be blamed, but the entire industry could sustain damage. Following the public outcry in June 1995, European environment ministers quickly proposed an update of the Oslo and Paris (OSPAR) Convention, to reflect current public opinion, which was clearly against deep-sea dumping. This shows that today's public opinion can be tomorrow's law, even without any scientific basis. This phenomenon has been demonstrated by work by Page and Shapiro (1983) and more recently by Burstein (2003).

The case of Brent Spar serves as an example how rational, scientific decision-making in offshore decommissioning can fall short. The need for socially supported decommissioning strategies in the offshore wind sector is apparent, as favourable regulations are dependent on social support and essential in further development of offshore wind. When this is not accounted for, the industry's ability or incentive to achieve the goals set out in the European Green Deal are at risk. This highlights the need for social support for offshore decommissioning.

1.2.4 Academic relevance

In the previous section, the social relevance of decommissioning OWF substructures was presented. This section describes the existing scientific knowledge on the subject. This will be identified through a systematic literature review as described by Jesson, Matheson, and Lacey (2011), focusing on the following search question: *What is known with regards to social acceptance for offshore decommissioning activities related to energy infrastructures?*

Systematic literature review

The search for relevant articles took place in two major scientific databases; Scopus and ISI Web of Knowledge. Beginning with the use of *natural language* search terms to find relevant articles, which in turn helped to identify appropriate *controlled vocabulary keywords* assigned to the article. These keywords identify central themes of the article, which were used to find other relevant articles. In order to include as much relevant literature as possible, it was decided to include everything published after 2010. In addition, all material relating to specific superstructure decommissioning or focusing only on technical aspects was excluded. All inclusion and exclusion criteria used can be found in Table 1.3.

Criterion	Inclusion	Exclusion
Age	2010 - 2021	Before 2010
Study length	-	-
Language	English, Dutch	Languages other than English and Dutch
Research type	Grey literature, scientific articles, books, professional reports, peer-reviewed scientific articles	Other
Relevance	- Related to offshore oil and gas / offshore wind - Related to social acceptance for decommissioning - Related to partial/ complete decommissioning strategies - Related to environmental/ economic and social values	- Related to only superstructure decommissioning - Related to only technical aspects

Table 1.3: Inclusion and exclusion criteria during literature search

By combining keywords such as "offshore wind farm", "oil & gas", "decommissioning" and "social acceptance", a wide variety of literature was found. After careful assessment of the title, keywords, abstract and in some cases conclusion, a selection of relevant literature was identified. An overview of the search terms used, the results and the relevant output can be found in Appendix A. Ultimately, all search attempts resulted in only a limited number of unique relevant articles that could contribute to answering the search question as previously mentioned. The number of results is presented and ordered in Table 1.4.

Category	Number of relevant articles
Offshore Wind Farm decommissioning	15
Social acceptance for offshore wind development	8
Social acceptance for offshore wind decommissioning processes	0
Social acceptance for oil & gas decommissioning	0
Environmental impact of offshore wind farm decommissioning	11
Social impact of offshore wind farm decommissioning	2
Economic impact of offshore wind farm decommissioning	7

Table 1.4: Overview of number of relevant articles categorized by their topic

It is noteworthy that the amount of literature associated with OWF decommissioning was very limited until 2015, after which it became increasingly popular. This highlights the lack of academic interest in this topic, despite the fact that the installed capacity of offshore wind turbines was already significant at that time. The need for research into the approach to OWF decommissioning has only increased since. Topham and McMillan (2017) caught it early and did work identifying the numerous features that make decommissioning a challenge. They mention technical limitations of vessels, the lack of specific regulations but also stress that the unique characteristics of OWF sites ask for case-by-case analyses with regards to environmental impact. Topham et al. (2019) categorizes these features into four main categories, being the regulatory framework, the overall planning of the process, the logistics and vessels' availability and the environmental impacts of the process. They emphasize the presence of great uncertainties in the process, which complicates a straightforward approach to decommissioning OWFs. Smith and Lamont (2017) recognized the need to transfer experiences and lessons learned from Oil & Gas decommissioning to offshore wind. They highlight the importance of design for decommissioning and keeping meticulous records of the site throughout its life.

The presence of several decommissioning techniques, numerous stakeholders with opposing values and general uncertainty, urged some scholars to research applicable decision-making methods. Most decision-making methods considered are based on multi-criteria decision analysis (MCDA), which defines the criteria central to offshore decommissioning. However, due to limited industry experience, empirical data is not available and scholars used highly uncertain assumptions (Kerkvliet, 2015) or expert opinions (Fowler et al., 2014). Although MCDA methods are powerful tools to address complex decision-making problems, the validity of incorporating qualitative values into a quantitative process still proves uncertain. In addition, according to Fowler et al. (2014), stakeholders are rarely involved in weighting the importance of factors, raising concerns about the equitability of the process. Moreover, when the depth of analysis is increased, it affects the comprehensibility for non-technical stakeholders, which often leads to more conflicts.

Recently, work has been done by scholars to construct an economic assessment framework for OWF decommissioning, using a cost breakdown structure (CBS) (Adedipe & Shafiee, 2021). By identifying cost drivers, critical elements in the decommissioning process are identified and can be adequately managed. Unfortunately, the is a lack of further literature on the economic effects of offshore decommissioning strategies. In contrast, there is a wealth of literature available on the environmental impact of offshore decommissioning. The majority focuses on the positive effects offshore man-made structures can have on marine ecosystems (Fortune & Paterson, 2020; Fowler et al., 2018; Smyth et al., 2015). Other scholars have examined the importance of circularity in offshore decommissioning (Jensen, Purnell, & Velenturf, 2020) and the mitigation of impact on wildlife (Gartman et al., 2016).In contrast, the social impact of offshore wind decommissioning decision-making has received surprisingly little academic attention.

The aspect of social acceptance has received surprisingly little academic attention and is solely focused on siting, installation and operation of offshore wind farms, often in comparison to its onshore counterpart. Kaldellis et al. (2016) does touch upon the social aspects of decommissioning offshore wind farms, but does so only superficially.

Academic knowledge gap

This systematic literature review has clearly demonstrated that there is a knowledge gap in the subject of social acceptance for OWF decommissioning. The state of literature on the subject of OWF decommissioning has increased throughout recent years and many limiting factors have been identified. However, whereas studies into the environmental impact of offshore wind farms often include the decommissioning phase, the social aspects of decommissioning are seldom studied. Moreover, due to the rapid innovation in the industry, conditions used in literature may have changed and require updating, which this thesis can also facilitate.

In summary, social acceptance for offshore decommissioning processes, whether in the O&G or offshore wind industry, are rarely investigated. Considering the social relevance of the topic, as explained in section 1.2.3, this indicates a unique opportunity for this thesis.

1.3 Link with Management of Technology program

The MSc program of Management of Technology (MOT), offered by the Faculty of Technology, Policy and Management (TPM) at Delft University of Technology, focuses on technology management in a societal context. MOT graduates have knowledge of the various aspects of technology and innovation and how to manage people, risk and corporate responsibility. This thesis focuses on the social implications of removing offshore energy infrastructures. It looks at technology and innovation as a corporate resource with wide social implications. This fits particularly well with a MOT thesis, which should involve scientific research in a technological context. It is expected that the skills and knowledge acquired during the MOT curriculum will be very valuable in this research. In light of the above, it is concluded that this work fits well within the MOT program and allows the author to demonstrate its competency in the field as a technology manager.

1.4 Thesis outline

Chapter 1 has introduced the background of this research and subsequently described the problem statement and the interface of the research with the MoT program. In Chapter 2, the research approach is presented, in which the research strategy, the scope and data collection protocol are given. Chapter 3 introduces the theoretical framework which gives the research a strong scientific basis. In this chapter, relevant theories, definitions and concepts are given, which the rest of the thesis builds upon. Subsequently, chapter 4 gives an extensive overview on the specifics of offshore wind farms, the development of decommissioning technologies and associated possible decommissioning strategies. This chapter is essential for readers who have no further knowledge on offshore wind development and decommissioning. Chapter 5 looks at the state of socio-political acceptance of OWF decommissioning, starting with the regulatory framework, both international as national. It further elaborates on the Dutch policy landscape for both offshore wind development as decommissioning. Chapter 6 addresses the state of community acceptance by identifying stakeholders and values central to OWF decommissioning. Chapter 7 discusses the state of market acceptance through interviews with several market players. The conclusion is presented in Chapter 8 after which the discussion takes place in Chapter 9. This order of conclusion and discussion is deliberately chosen to ensure total objectivity in the conclusion, whilst giving room to personal viewpoints in the discussion.

2. Research approach

This chapter introduces the research approach taken in this thesis study. It argues why the research strategy proposed is appropriate for the subject in question and suggests the steps to be taken to collect sufficient data to answer the main research question. Furthermore, it delineates the study based on social, spatial and technical characteristics to ensure applicability and generalizability.

2.1 Research strategy

The research strategy addresses the overall plan for conducting this research. It aids in finding an answer to the main research question and arriving at the research objective. Research into the social acceptance of decommissioning OWFs is still at a preliminary stage and lacks a clear and specific problem definition. This indicates the need for a better understanding of the topic and its environment. This justifies the use of a qualitative, exploratory research methodology. The aim of this study is to explore the topic, identify issues and opportunities and indicate the state of social acceptance. The overall research strategy is shown in Figure 2.1.

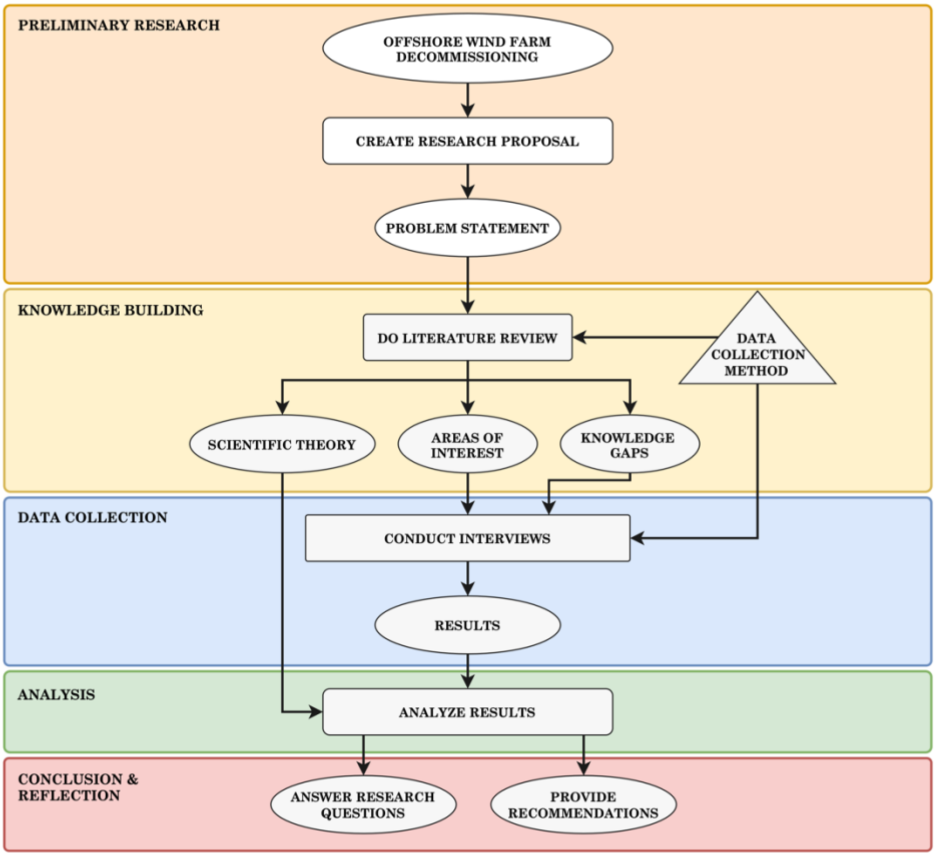

Figure 2.1: Visualization of research strategy

After the formulation of the problem statement, in which the research objective and research questions are embedded, the research scope is delineated. Next, a literature review will be carried out. Initially, the desk research will explore topics central to the process to gain in-depth knowledge of the offshore wind market, technical characteristics of wind turbines and decommissioning strategies. Then, the study will focus on three objectives: finding a scientific theory to conceptualize social acceptance, identifying areas of interest for research and establishing where scientific knowledge is lacking.

Scientific theories are used to provide a theoretical framework in which social acceptance is defined and conceptualized. This provides a scientific foundation and gives structure to the research. Further literature review will provide a deeper understanding of the decommissioning process of offshore wind farms and indicate what stakeholders need to be considered.

Once the areas of interest are determined and relevant stakeholders are identified, a plan for the collection of qualitative data will be developed. This will involve interviews with experts with different perspectives to obtain a comprehensive view of the multi-level impact of decommissioning. The qualitative data will then be analyzed in order to answer the research questions.

2.2 Scope

In order to focus the research down to what is practically possible within the given timeframe for this master thesis, a research scope is provided here. The scope identifies the boundaries within the research performed and indicates what will be covered and, more importantly, what will not be covered. This is especially important in an exploratory study, as such a process is inherently more dynamic and flexible. Without the definition of the scope, it is complicated to reach completion of the study, as no limits have been defined.

The research scope will be divided into three main parts; the spatial scope, the technical scope and the social scope.

2.2.1 Spatial scope

Vattenfall's offshore wind operations are located exclusively in European waters and in the jurisdiction of Norway, Germany, Denmark, the Netherlands and the United Kingdom. Most of these are deployed in the North Sea, but the Baltic Sea and the Atlantic Ocean also host some OWFs. For practical reasons, it has been decided to limit the spatial scope to OWFs located in the North Sea.

The shallow and sandy environment of the North Sea is the reason offshore installation was reasonably practicable and achievements in O&G enabled positive business cases for initial offshore wind development. This is why the first offshore wind farms were installed in the North Sea and are therefore also the first to be decommissioned. In addition, the optimal specifications of the area have made the sea the focal point of offshore wind development in Europe. A socially accepted strategy in decommissioning should therefore be integrated with the larger ambitions of offshore wind development.

The North Sea has another unique characteristic that makes it exceptionally suitable for this research. It is a rich natural resource for economic activities and other forms of human use. Apart from the development of offshore wind energy, the North Sea is also home to other essential functions, such as Natura 2000 areas, busy shipping routes, oil and gas extraction, mineral extraction, CO2 storage and commercial fishing. Space is limited and allocation and use of this space is strictly regulated. Therefore, social acceptance for decommissioning of offshore structures is even more relevant on the North Sea.

The jurisdiction of the North Sea has been divided between the surrounding coastal states, which have the exclusive right to manage and regulate exploitation within their maritime borders. Therefore, regulation and markets can be significantly different from state to state. Although the difference in regulation and markets is certainly relevant for this research, it is not reasonably practicable in the given timeframe to construct a comprehensive overview of the offshore wind industry in each coastal state. Therefore, it has been decided to include all coastal states in the basic research, but apply specific focus on the situation in the Netherlands. The Netherlands has invested significantly in long-term research on the multi-level impact of OWFs. Hence, it is expected that Dutch institutions and businesses have in-depth knowledge on the subject and are generally open to contributing to scientific research.

2.2.2 Technical scope

In order to delineate the technical scope of decommissioning OWFs, it is wise to first establish the definition of decommissioning. Topham and McMillan (2017) define decommissioning as the last phase in a project's lifecycle and can be considered as the opposite of the installation phase, in which the principle "the polluter pays" applies and ensures that the site if left in a similar condition as it was before the deployment of the project. So, decommissioning covers an entire phase within a wind farm's lifecycle and consists of all measures taken to bring a site back to its former state. This includes consenting, planning, offshore operations and waste management. The entire process of decommissioning could be a research topic on its own, therefore it would be overly extensive to cover every aspect of the decommissioning phase in this thesis. This research will focus solely on the offshore operations and the impact these operations potentially have.

Through preliminary research and experiences from experts within Vattenfall it became clear that decommissioning OWFs essentially consists of two main procedures. Removal of components above sea level, such as the turbine itself and the rotor blades, and removal of the components below sea level. The latter essentially consists of the foundation, the electricity cables and the scour protection. More technical elaboration will be given in section 4.1. What is important for defining the scope is that the challenge of offshore decommissioning mainly lies with the underwater components of the OWF. The major impactful challenge of decommissioning OWFs is associated with the removal of the subsea structures, so the technical scope delineates the research to this point. This means that the technical focal area of this research is limited to the removal of the foundation, array cables and the scour protection. Since 81% of the wind farms currently in operation on the North Sea are grounded on a monopile structures (Statista, 2021b), these are considered as the standard foundation in this study.

2.2.3 Social scope

During initial exploration of the subject, it became clear that only a limited number of the actors affected by decommissioning, have a standpoint on the issue. It was therefore fitting to delineate the social actors to those well-informed. Governmental agencies are responsible for policy and regulation regarding decommissioning and are therefore highly influential. NGOs are advocacy groups for supposed social interest without governmental involvement. They have grown quite influential and are known to advise governments on topics such as ecological conservation and environmental policies. Knowledge institutes such as universities and research institutes are considered because they provide the technology and innovation needed for decommissioning. With that, they determine to what extent decommissioning can be performed and what the impact will be. Lastly, we consider the businesses responsible for decommissioning and in pursuit of social acceptance for their strategies.

Through general conversations it became clear that the general community is not aware of the importance and urgence of decommissioning OWFs. As the first substantial offshore wind decommissioning projects are yet to be executed, it has not attained the widespread attention that its onshore counterpart has had. In addition, people tend to focus on the 'visible' components of the wind turbines and are not aware of the complexity of removing the subsea parts. Therefore, the author worries that including the general public in the analysis would be premature and only introduces incorrect data into the analysis. Instead, it is argued that NGOs can be used as proxy for societal concerns, as NGOs are often founded by concerned citizens and are known to have a high degree of public trust (IISD, n.d.).

2.3 Data collection protocol

After establishing the research strategy and delineating the scope of the research, the set-up for data collection is formulated. Since this thesis aims to explore and develop in-depth insights of a relatively unknown subject, the focus during data collection is on qualitative data. Qualitative data helps to understand how different parties interpret their environment in various ways and therefor offers unique insights. Where possible, this study uses *secondary data* available through relevant literature. However, since the topic of this thesis has not been studied very often, part of the data needed will come from people. For this reason, this research also makes use of qualitative interviews to acquire its *primary data.* This chapter will elaborate on the objectives and methods of the data collection protocol.

2.3.1 Scientific literature

Literature studies are a reliable method of collecting scientifically supported data. However, as mentioned before and substantiated in section 1.2.4, the amount of scientific research on the subject of this thesis is very limited. Nonetheless, the research available can be very helpful in initial exploration of the subject and in establishing a theoretical framework for this research. Therefore, this section will elaborate on the objectives of the literature study and describes the method taken.

Literature search objectives

The literature review as carried out in this thesis has three main objectives which will be described below. The first is the initial exploration of offshore wind turbines, offshore wind farms and the process of decommissioning. What is involved, who is involved, what knowledge is available, what is perhaps already outdated? This can be summed up to the concrete objective of gaining in-depth knowledge of offshore wind decommissioning processes.

The second objective of this literature research is to indicate where gaps in knowledge are. Since the subject has rarely been studied, the literature research will mainly indicate what is not known yet. However, this information is very valuable as it is used to develop the objectives of the qualitative interviews, as described in 2.3.2.

The third objective is to find a suitable scientific theory which can be used in the theoretical framework of this research. This theory gives structure to the research process and adds rigor to the research through a strong scientific basis.

Literature search method

In order to arrive at the aforementioned objectives, a structured and systematic literature review is vital. The approach to and conditions of a systematic literature review in this thesis have already been described in section 1.2.4 and will therefore not be described again. However, the selection of sources and analysis of results is different for each objective.

Since there is much uncertainty surrounding the subject and current developments are not yet laid down in studies or reports, it is essential to identify preliminary issues and opportunities, so that the author can determine which can be studied in-depth. In achieving that, a more open approach to sources is required. Whereas scientific journals mainly provide in-depth knowledge of very specific topics, newspaper or magazine articles often display qualitative data from experts or stakeholders in the field. It should however be borne in mind that these sources are less reliable and should therefore be double-checked on validity. Conference and lecture transcripts and presentations can also give a unique contemporary view on a certain subject. The qualitative data obtained will be used to shape Chapter 4 and 1 and helps the author in becoming familiar with the subject.

The second objective is expected to naturally stem from the aforementioned literature review. Current gaps in knowledge will be identified, which can serve as input for the qualitative expert interviews that are discussed in 2.3.2.

The third objective however, asks for a thorough literature review. The assessment of social acceptance for energy infrastructures is a subject that has received significantly more academic attention and therefore requires more time to assess. Several theories will have to be assessed on their applicability in this thesis.

2.3.2 Qualitative interviews

Interviews are a widely used method of primary data collection in business research. It can be defined as a guided, purposeful conversation between two or more people and allows the researcher to collect a wide variety of data from human respondents (Sekeran & Bougie, 2010). The sections below will address the interview goals, the method used and the identification and justification of participants.

Interview objectives

This research relies on interviews to meet the following three objectives. First of all, as this is an exploratory study, the interviews are used to shed light on gaps in knowledge and possibly indicate additional areas of interest. This will help shape the research and construct a comprehensive view on the subject. Secondly, the interviews are used to validate relevant scientific literature, as far as available. Since the topic is rarely studied by scholars and the market develops quickly, validation is key to this research. Thirdly, the interviews will provide the input for analysis with the aim of answering the research questions.

Interview method

As there are several types of interviews, it should be determined which fits best with the research strategy. The first step is to determine how the interview is administered. Face-to-face interviews offer the advantage of longer conversations and enable the researcher to ask more questions based on verbal and non-verbal communication by the participant. Unfortunately, the covid-pandemic limits the author to work from home, so real face-to-face interviews are not possible. Therefore, conducting the interviews via MS Teams video calls was the best alternative.

An interview as a method of collecting data in research can also be categorized by the extent to which a researcher follows a pre-determined line of questioning. *Structured interviews* are mainly used in quantitative research and follow a pre-established interview schedule, to make sure every participant answers the same questions under the same conditions. This allows for convenient data analysis and high reliability of the research. *Unstructured interviews*, on the other hand, lack a predetermined interview plan and often work with themes instead of specific questions. This can help to bring preliminary issues to the surface and determine which need further investigation. It does require more alertness of the interviewer in order to avoid incomplete results. *Semi-structured interviews* work by means of a general interview schedule but with more generic questions, of which the interviewer is able to deviate. This often results in more and detailed information and allows the interviewer to adapt to what is being said (Sekeran & Bougie, 2010). In light of the interview objectives, the semi-structured interviews fit best to this research.

In order to conduct proper scientific interviews, relevant literature is consulted. Rowley (2012) states that semi-structured interviews come in various formats, but they generally include six to twelve questions. The interview should take no longer than 60 minutes. The interview design used in this research is based on these recommendations. Rowley also suggests the that the interviewer is creative in order to engage the interviewee in the interview. As OWF decommissioning is a debated topic in the work field of the interviewees, it is expected that they are eager to express their concerns and elaborate on opportunities or challenges expected. When this is not the case, the researcher will encourage the participant to talk about its own work and try to distil the implications for OWF decommissioning. This approach requires a flexible attitude during the interview.

To ensure meticulous transfer of the qualitative data, the interviewee will be asked whether he or she opposes the interview being recorded. When he or she does not, the recording will be used to create a transcript. When the interviewee is a Dutch native, the interview will be carried out in Dutch to prevent anything from getting lost in translation. Afterwards, the transcript is translated to English and summarized for practical reasons. To make sure errors in transcribing, translating or summarizing are identified, the interviewee is asked to validate the interview results afterwards. Any irregularities will be corrected as requested by the interviewee. A complete overview of each interview, consisting of the interviewee identification, interview setup, questions and the validated summarized response is included in the Appendix.

The interview results will be used to illustrate the landscape of viewpoints of the different actors considered. In using the insights derived from these interviews, there will be referred to the appendices.

Justification of participants

As the interviews are used to indicate potential areas of interest and offer practical insights that are not available in literature, it has been decided that the participants should be selected based on their expertise in some areas related to the topic. This sampling design is called *judgment sampling* and is sometimes the only meaningful way to investigate (Sekeran & Bougie, 2010). In order to obtain as diverse a view as possible and to protect the research from bias, it has been decided to include multiple experts from knowledge institutes, businesses, NGOs and governmental agencies as participants. This will ultimately provide four different perspectives in the results obtained, which will enable the use of data triangulation. Data triangulation is about using multiple perspectives to approach a research problem (Sekeran & Bougie, 2010).

The selected interviewees are listed in Table 2.1 and described based on the organization they work in and the position they have. The justification of why a participant is relevant to the research is given in the last column.

#	Organization	Type:	Position	Justification
A1	Rijksuniversiteit Groningen (RUG)	Knowledge institute	Postdoctoral researcher	Participant A1 is a postdoctoral researcher at the Groningen Centre for Energy Law and Sustainability at the University of Groningen. Her input will be essential to understand the applicable laws in offshore decommissioning.
A2	Growth through Research, development & demonstration in Offshore Wind (GROW)	Knowledge institutes & Businesses	CEO	Participant A2 has worked for Ecofys, the IEA and the IPCC on various renewable energy and policy issues. This, combined with his current position at GROW, allows him to share insights in policy and technology developments, and how these interact.
A3	Koninklijk Nederlands Instituut voor Onderzoek der Zee (NIOZ)	Knowledge institute	Head of department of Coastal Systems	Participant A3 is a professor in experimental biological oceanography. He is experienced in providing the EU with advice on fisheries, aquaculture and marine spatial use. Since 2020 he is the head of the department of Coastal Systems within NIOZ.
B1	Energy, Circularity and Human capital Transition management (ECHT)	Business	Product manager	Participant B1 is an expert on circular treatment of OWFs and nature reinforcement measures at OWFs. His insights will highlight potential innovations that have the potential to boost social support for OWF decommissioning.
B2	Business in Wind	Business	Director	B2 has a civil background and has extensive operational experience in the wind decommissioning sector. He was involved in the decommissioning of 1000+ turbines. Recently he switched to Business in Wind, which facilitates a second life for used wind turbines.
B3	Vattenfall	Business	Head of department of offshore wind installation	B3 has over 10 years of experience in the operational side of offshore installation, after which he became head of offshore installation at Vattenfall.
B4	Vattenfall	Business	Product manager decommissioning	B4 has over 10 years of experience in the operational side of offshore installation at multiple contractors. Since 2020 he became the product manager decommissioning for Vattenfall.
B5	Nederlandse Wind Energie Associatie (NWEA)	Business	Industry specialist offshore wind	B5 is sector specialist for offshore wind at the Dutch industry association for wind energy. His main task is to derive the main concerns of the industry and actively lobby at governments and NGOs.
C1	Stichting De Noordzee	NGO	Project manager	Participant C1 is project manager nature-friendly energy at foundation De Noordzee.
D1	Rijksdienst Voor Ondernemend Nederland (RVO)	Governmental	Advisor Offshore Wind	Participant D1 is a senior advisor on offshore wind at RVO. Since 2013 he is the tender coordinator for offshore wind tenders in the Netherlands.
D2	Rijkswaterstaat (RWS)	Governmental	Programme manager Offshore Wind	Participant D2 is the programme manager Offshore Wind at Rijkswaterstaat. He has extensive experience with offshore wind projects within Dutch ministries. He now is responsible for the roll out of the Offshore Wind programme in the Dutch energy transition.

Table 2.1: Overview of selected interview participants

As can be seen in Table 2.1, the interviewer unfortunately managed to interview only one NGO. Although the multiple NGOs were contacted that are committed to the North Sea, only one accepted the interview. Others declined or did not respond at all. Businesses, on the other hand, were eager to deliver input for this thesis. In order to arrive at an all-encompassing overview, businesses from different industry sectors were included.

3. Theoretical Framework

A theoretical framework is constructed using scientific theories and provides a scientific basis throughout the research. This framework provides the definition of social acceptance, such that it subsequently can be conceptualized. The conceptualization of social acceptance enables the research to build upon a scientific base and offers tools for assessment.

3.1 Definition of Social Acceptance

According to the Cambridge Dictionary, the generic definition of acceptance is the general agreement that something is satisfactory or right. Social or public acceptance, on the other hand, is defined as a positive attitude towards a matter at a particular point in time, which is stated in a specific idea or in a particular behavior including encouragement, confirmation and approbation (Cohen, Reich, & Schmidthaler, 2014).

Schumann (2015) refers to three methods of assessing social acceptance for new technologies. Social acceptance for products and everyday technologies can be expressed through the purchase of these products or technologies. For technologies intended for the workplace, social acceptance is reflected by the extent to which employees actively use the technology. For large-scale technologies, such as the decommissioning of offshore wind farms, social acceptance means that the respective impacts are tolerated by those affected.

As the affected are often not decision-makers in the use or deployment of technology, public acceptance also reflects the active or passive approval of decisions or actions by others (Schumann, 2015). The public acceptance of decommissioning offshore wind farms can therefore be defined as *the passive or active approval for decommissioning strategies, which is reflected in the attitudes and behavior of individual or complex social actors and can be measured at a certain point in time.* A complex social actor can be understood as a collection of individuals that share the intention to acquire a shared product, achieve a shared objective or realize a shared interest (Scharpf, 2000).

A distinction must be made between the concept of "acceptance" like defined above and the concept of "acceptability". Assessing the acceptability of a technology involves making a normative judgement as to whether and under what conditions the impact of the use of the technology are considered acceptable. The basis for this judgement is either rational criteria or democratically legitimated decisions (Grunwald, 2005). In the first case, we are talking about acceptability in the sense of rational theory; in the second, about acceptability in the sense of theory of democracy. In the sense of rational theory, the acceptability of decommissioning OWFs is the collection of risks that would be indicated as acceptable, based on normative criteria. The definition of those criteria is generally the result of scientific research and risk assessments. In the sense of democratic theory, on the other hand, the acceptability of decommissioning OWFs is defined as a democratically legitimate agreement on what can reasonably be expected while decommissioning OWFs (Schumann, 2015).

In light of the limited operational experience with decommissioning OWFs, the rational theory based on scientific research and risk assessments is not yet substantiated. Therefore, the democratic approach seems more fitting to this particular topic.

3.2 Conceptualizing Social Acceptance

Wüstenhagen et al. (2007) acknowledged that social acceptance as a part of renewable energy implementation has largely been neglected so far. Therefore, they aimed to clarify the concept of social acceptance of renewable energy innovation by distinguishing three dimensions of social acceptance, as shown in Figure 3.1. The first is *Socio-Political Acceptance* and relates to the general acceptance of the technology in question and whether it is supported in government policy and by the general public. The second is *Community Acceptance*, which is related to the acceptance of developments by host communities. The last dimension is *Market Acceptance* and reflects the market's willingness to adopt the technology. It is important to note that these dimensions are interrelated and that the degradation of one of them, hurts the others subsequently, resulting in declining social acceptance.

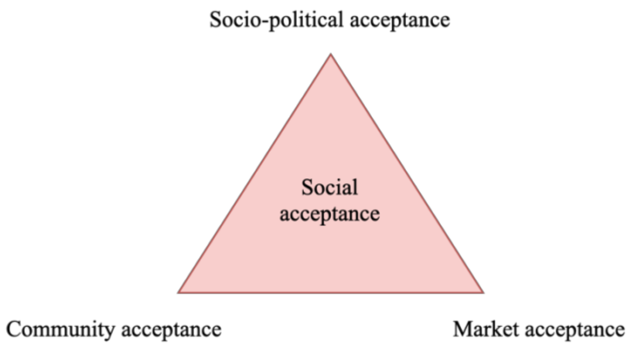

Figure 3.1: The triangle of social acceptance of renewable energy innovation, adapted from Wüstenhagen, Wolsink, and Bürer (2007)

3.2.1 Socio-Political Acceptance

The socio-political aspect of social acceptance is the broadest, most general form of social acceptance. It reflects the extent to which society as a whole supports the deployment of the technology and how this is regulated by governmental policies. Therefore, it focuses on the public, key stakeholders and policy makers. It not only focuses on the general acceptance for the deployment of the technology, but also concerns the acceptance of effective policies. These policies require the institutionalization of frameworks that effectively foster and enhance market and community acceptance (Wüstenhagen et al., 2007). In terms of decommissioning OWFs this could involve regulation that obligates developers to cooperate with knowledge institutes and NGOs during decommissioning to stimulate collaborative decision-making.

3.2.2 Community Acceptance

Community acceptance refers to the acceptance of local stakeholders, such as residents and local authorities. According to Gross (2007), procedural justice (equitable decision-making with all stakeholders), distributional justice (fair distribution of burdens and benefits) and trust in relation to the information provided is key in community acceptance.

The difference between socio-political acceptance and community acceptance is nicely portrayed by the NIMBY-phenomenon. Not-In-My-Backyard (NIMBY) is a term used in spatial planning, which conveys that people may support a concept in general, as long as they are not inconvenienced by it. Although the legitimacy of this phenomenon is still subject to discussions, it does explain how support can be comprehensive on a global scale, but small on a local scale.

3.2.3 Market Acceptance

Market acceptance is characterized by consumers, investors and intra-firm relations and their interdependent paths. It reflects how 'the market' views implementation of the technology and how willing stakeholders are to engage in the market. In terms of decommissioning OWFs, market acceptance describes the extent to which developers intent to carry out decommissioning, what technologies they use and what their motives are.

Since operational experience regarding decommissioning is limited, developers are possibly not sure about their approach and standpoint yet. It is expected that experiences from upcoming decommissioning projects will help shape company policy and dictate the extent of market acceptance.

3.3 Applicability

Although its validity is often questioned and doubts exist whether complex social phenomena can be simplified into a term such as 'social acceptance', it continues to be a widely recognized construct for which there is currently no alternative. Despite these conceptual weaknesses, social acceptance continues to have a strong resonance amongst researchers, regulators and developers and thus creates an important space in which social and political dimensions of wind energy can be confronted and debated (Geraint & Ferraro, 2016). The framework introduced by Wüstenhagen et al. (2007) has been specifically designed for the assessment of social acceptance for renewable energy innovation and has been widely adopted both in academic as policy environments. It takes a unique approach to differentiating between general attitudes towards wind energy and project specific issues.

Furthermore, some doubts may exist on the applicability of this social acceptance framework on decommissioning offshore wind, as it is focused on removal opposed to the understandably controversial placement of these invasive technologies. However, it cannot be emphasized enough that decommissioning is an inherent part of wind energy development and should therefore be assessed with the same standards. Although some views on social acceptance of offshore wind deployment might also apply to decommissioning, others might be significantly different. The framework assists in the exploration and identification of issues and opportunities in arriving at socially accepted decommissioning strategies for offshore wind farms on the North Sea.

So, as argued for in the beginning of this chapter, for large-scale technologies, such as the decommissioning of offshore wind farms, social acceptance means that the respective impacts are tolerated by those affected. The following chapters will try to identify those impacts and aim to map the levels of acceptance from stakeholders.

4. Offshore Wind Farm Decommissioning

As this thesis addresses a highly technical subject in a societal context, in which the technical specifics have a significant impact on the societal consequences, it is imperative to outline the relevant engineering and technologies. Therefore, this chapter introduces the technical characteristics of offshore wind turbines, the development of OWFs on the North Sea, the current state of development of decommissioning technologies and the decommissioning strategies associated with these technologies. In addition, the potential magnitude of the OWF decommissioning industry is outlined last.

4.1 Offshore Wind Turbines

This section discusses the technical characteristics of an individual offshore wind turbine and its position in an OWF. Since not all wind turbines are identical and their rapid development introduces new technologies on a regular basis, this section will focus only on the main components. A brief outline of these components will be given in order for them to referred to in this thesis. The complete composition of an offshore wind turbine with monopile foundation is shown in Figure 4.1.

A wind turbine converts the kinetic energy of wind into mechanical energy and subsequently into electrical energy. How this mechanism works is beyond the scope of this thesis and will therefore be omitted. Instead, the main building blocks of a wind turbine will be addressed and are divided into two categories; the superstructure and the substructure.

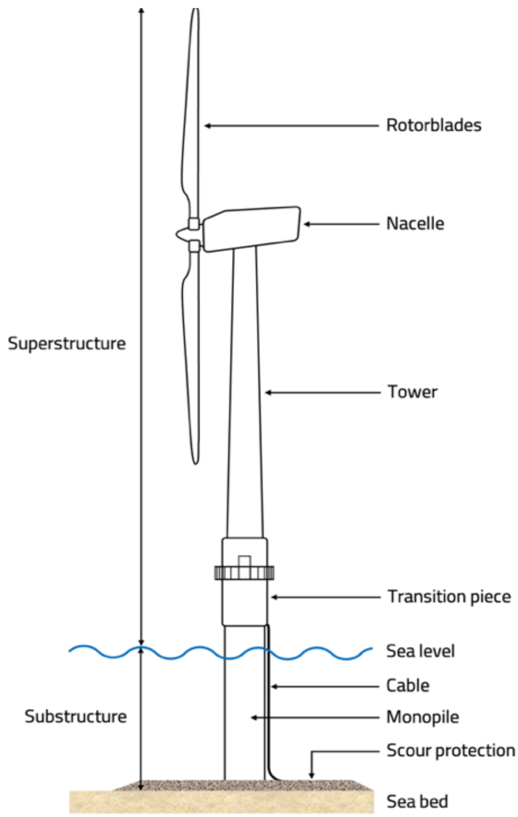

Figure 4.1: Composition of offshore WTG with monopile foundation

The first is the complete structure above sea level, hereafter referred to as the *superstructure*. It consists of the rotor blades, the hub, the nacelle, the tower and in most cases a transition piece. The rotor blades are connected to a hub, which in turn is connected to the nacelle, which houses the gearbox and generator. The nacelle is attached to the tower, often made of tubular steel, which in turn is fixed to the transition piece. The transition piece connects the tower to the foundation of the WTG and often houses several essential functions, such as maintenance access, cable connections and corrosion protection.

The *substructure* consists of all components below sea level, which in this study includes the monopile, inter-array cables (IAC) and scour protection. Monopiles are steel pipes that are driven deep into the seabed, thus serving as a solid base on which the rest of the WTG can be mounted. Inter-array cables enable the transmission of electricity from the WTGs to the offshore substation (OSS), where it is collected, converted and transported to shore. To prevent the cables from being damaged by displacement or collisions, they are typically buried 1 to 3 meters below the seabed. The scour protection usually consists of stones, rocks and gravel of different sizes positioned at the base of the foundation to prevent sediment displacement due to the hydrodynamic scour effect. This phenomenon, shown in Figure 4.2, occurs as a result of high velocity currents at the base of the foundation caused by the obstruction of the monopiles. If scour protection is not accounted for, the structural integrity of the foundation may be compromised, as shown in Figure 4.3. There is also the risk of cable unburial, which can lead to increased cable bending stress. Scour protection typically covers an area four to six times the monopile diameter around the monopile.

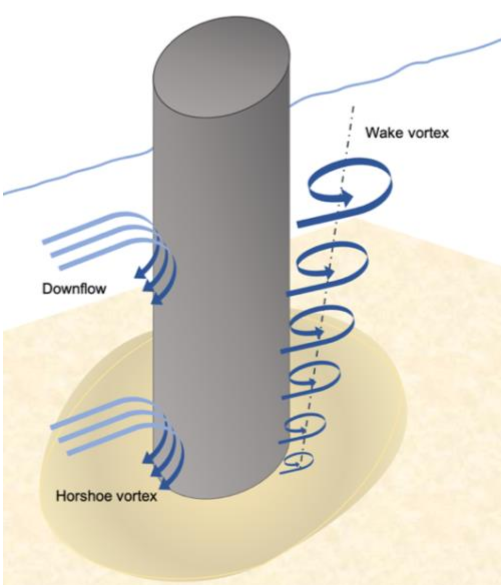

Figure 4.2: Hydrodynamic scour effect (own production)


Figure 4.3: Scour holes in a test setup (Amini & Solaimani, 2017)

4.2 Offshore Wind Farms on the North Sea

Since the commissioning of the first commercial offshore wind farm in 2002, Horns Rev 1, the development of offshore wind energy on the North Sea has gathered pace. In subsequent years, 58 more monopile-grounded wind farms have been installed, bringing the total capacity to 16.4 GW. Planned projects such as Hollandse Kust Zuid and Hornsea 2 are expected to add a further 2.8 GW in the coming years.

The UK is the undisputed leader in offshore wind power on the North Sea with a total installed capacity of 6.5 GW spread across 20 OWFs. Germany is second with 4.4 GW of installed capacity divided over 16 OWFs. The Netherlands hosts seven wind farms with a total capacity of 2.5 GW. Belgium and Denmark are responsible for the remainder of 3 GW. A map indicating all locations of OWFs on the North Sea is given below.

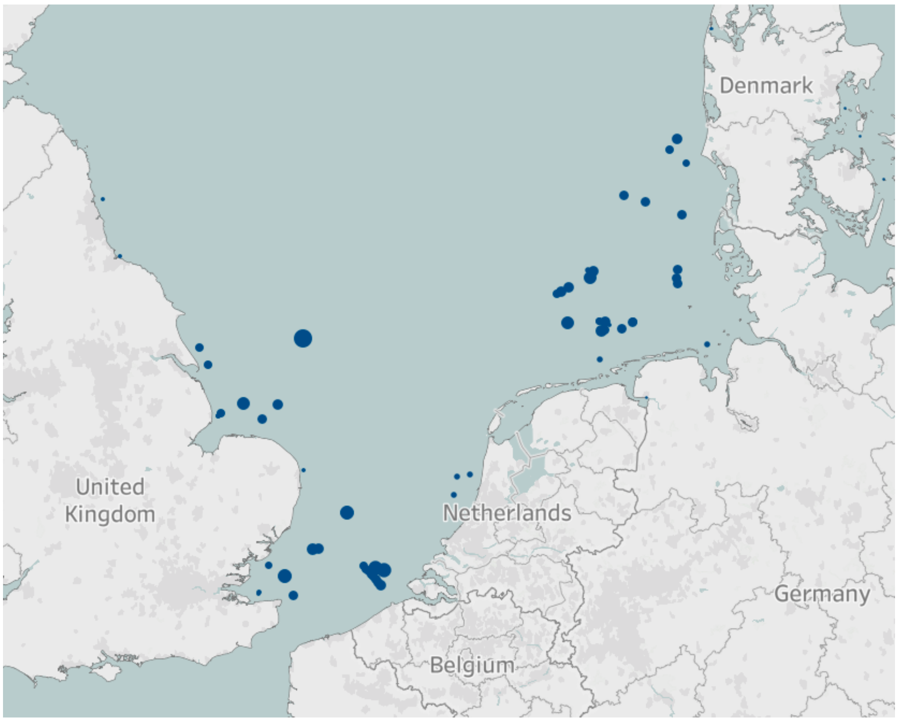

Figure 4.4: Visualization of all OWFs located on the North Sea (WindEurope, 2021b)

Looking at the data on monopile-based wind farms on the North Sea, certain trends can be identified. First of all, individual turbine capacity has seen enormous growth since 2002, gradually increasing from 2 MW to an impressive 11 MW in 2021. Understandably, this has also increased the capacity of entire wind farms over the years.

Secondly, it is evident that the diameter of monopiles has grown steadily over the years. While a monopile had a diameter of 4 meters in 2002, the increase in turbine power led to monopile diameters of 8 meters in 2020, and it is expected that diameters of 11 meters will be reached in the coming years. The growing monopile diameter, combined with the ability to install in deeper waters and thus increasing the monopile length, also has an impact on the monopile weight. A monopile weighed an average of 155 metric ton in 2002, while more recent projects have installed monopiles of 1250 metric ton each.

Third, improved installation techniques and cost reductions along the entire value chain have enabled the construction of wind farms located further from the coast. While this has some advantages in terms of turbine visibility from land, it also complicates offshore operations, increasing costs and emissions.

The substantial increase in capacity and size of monopiles is the main reason why repowering is often not feasible or reasonably practicable. Until the growth in capacity and size is halted, the industry will not be able to reuse existing foundations and electrical infrastructure. As a result, decommissioning is often the only options for developers.

4.3 State of Decommissioning Technology

In order to assess the industry's technological ability to carry out the decommissioning of OWFs, a comprehensive analysis of available technology is executed. Moreover, the development of new technologies, which might reach maturity over the coming years, will also be covered. The focal area of this analysis is on technology for the decommissioning of substructures, e.g., monopiles, IACs and scour protection. Insights of some interviewees were helpful in gathering a comprehensive overview of the (soon) available technologies. This section successively discusses the technology for removing monopiles, IACs and scour protection.

4.3.1 Monopile

The primary function of a monopile is to support the static and dynamic loads of the wind turbine through anchoring it firmly to the sea bed using the embedded part of the monopile. The steel monopile is by far the most commonly used type of foundation for OWFs in the North Sea, mainly because of its great price-quality ratio. The drawback however is that its applicability is limited to shallow waters and sandy, soft soil types. Usually, monopiles are driven tens of meters into the seabed in which they form a solid fixed base for the wind turbine. Years of subsidence of the surrounding sand complicates removal during the decommissioning phase. Although most regulations prescribe complete removal, which essentially includes the complete removal of monopiles, this is not what has been seen so far. Two of the three decommissioned monopile-based OWFs have been partially removed, which in this case means that part of the monopile remains in the seabed.

In recent years, new technologies have been developed to facilitate the complete removal of monopiles. Complete removal has several advantages, such as allowing full reuse or recycling of monopiles, rather than just partially. In addition, this approach to decommissioning fits better within the regulatory framework and can be expected to face less opposition from other users of the sea. The two most common methods of partial monopile removal and the three most promising technologies for complete monopile removal are presented below.

Partial removal

- *External cutting*, as the name implies, is a cutting technique that operates from the outside of the monopile. An example is Abrasive Wire Cutting (AWC), in which a cutting wire is passed over the monopile surface continuously. It was used in the decommissioning of OWF Yttre Stengrund, which took an average of 13 hours per monopile. The disadvantage of this technique is that a relatively large area must be excavated to make the cut below the seabed, with all the associated environmental impacts. If no excavation is carried out, the monopile is cut just above the seabed. This may present an obstacle to other users of the sea, such as fisheries. However, the choice of partial removal technique depends on several site-specific characteristics that sometimes do not allow for either option.

- *Internal cutting* is a technique that operates from the inside of the monopile. After the inside of the monopile has been excavated, the cutting device can be hoisted into the monopile, whereupon cutting begins. A widely used technique is Abrasive Water Jetting (AWJ), in which water and abrasive particles (usually sand) are fed under high pressure into the device, which releases it onto the steel surface. When the interior of the monopile is excavated, this technique allows the monopile to be cut below the seabed. After removing the cut section of the monopile, the soil is redistributed and the remainder of the monopile is no longer visible. This technique was used in 2018 during the decommissioning of OWF Utgrunden in Sweden and took approximately 3-6 hours per monopile (personal communication, March 4).

Complete removal

- A *Vibratory Lifting Tool (VLT)* uses vibrations to install and extract monopiles from the soil. The device uses a large centrifugal force that is able to overcome the large resistance that the compacted soil exerts on the monopile. During the decommissioning of the Lely OWF in 2016, a VLT was used, as shown in Figure 4.5, which removed the 26-meter monopiles in 45 minutes each (Dieseko, 2016). According to a developer, this technology is currently rated with a Technology Readiness Level (TRL) of 9 (CAPE Holland, 2021).

- *Gentle Driving of Piles (GDP)* is a technology that also uses vibratory equipment, but GDP uses low-frequency and high-frequency vibrators simultaneously in different directions. This makes the monopile slightly thinner, which makes the process of installation or extraction easier. Therefore, lower drive loads are required, thereby mitigating harmful noise emissions. Delft University of Technology started working on this technology in March 2018 and successfully demonstrated the concept in the appropriate environment in November 2019. Currently tests are carried out in different soil types. This technology is currently rated with a TRL of 3-5 and, assuming that the tests continue to confirm its effectiveness, could be deployed around 2025 (Appendix C).

- *Hydraulic Pile Extraction (HyPE)* is a nearly silent method of pile removal in which the pile is forced upward with water pressure. By eliminating moving or vibrating parts, this method causes very little disturbance to the environment. The development of this technology began in November 2018 and has so far established proof-of-concept at 1:20 and 1:30 scale with four different soil types. Test results showed that hydraulic extraction is more efficient with less slender piles, which is promising given the trend towards ever larger monopile diameters. However, the technique is currently rated at a TRL of 4 and has yet to be validated on a large scale (GROW, 2020). What makes this development unique is that it was initiated by the industry. Developer RWE held the view that partial monopile removal, and the associated residual flows of steel, did not fit in with its current business philosophy. In addition, they expect that governments will soon start making demands regarding decommissioning, which they would like to be ready for (Appendix C).

Figure 4.5: Vibratory Lifting Tool removing a monopile at OWF Lely, the Netherlands (Nuon, 2016)

4.3.2 Inter-array cables

IACs connect the individual WTGs within an OWF and are used to transmit power to an offshore substation, which transforms and transports the power to shore. Since the generally accepted spacing of offshore WTGs is at least seven times the rotor diameter (Meyers & Meneveau, 2012), the cable length can be hundreds to thousands of meters each. Typically, the cables are buried less than 3 meters in the seabed or have been stabilized with concrete mattresses to prevent the cables from shifting due to currents, which could cause damage.

Due to the high frequency of cable laying activities at sea, for internet and electricity purposes, the technology has matured. As far as the author and interviewees are aware, there are currently no innovation projects underway in this field. Cable removal activities make use of cable-laying vessels, crane vessels, remotely operated vehicles (ROVs) and basic hydraulic tools. The two renowned methods for cable removal are listed below.

- *De-burial* is the process of excavating the cable from the soil. This can be done using a detrenching ROV in combination with a vessel that pulls in the cable. On the vessel, the cable can be coiled or cut into pieces using hydraulic shears (personal communication, March 5, 2021).

- *Pull-out* is similar to de-burial, but without detrenching the cable first. If cable and water depth are acceptable, a cable-laying vessel can pull the cable directly from the seabed and wrap it around a carousel. This is also expected to have some consequences for the marine environment around the burial site (personal communication, March 5, 2021).

4.3.3 Scour protection

Most scour protection measures deployed consist of loose rock and gravel, however there are other types available. The options range from artificial vegetation to mattresses of used rubber tires. At present, much research is being done into the ecological enrichment that scour protection can provide. For example, there are experiments in which oyster beds are used as scour protection (Appendix D). When assessing the OWFs currently in operation, however, it becomes apparent that most developers have used the simplest form of scour protection; loose rock. Although this allows for a quick and cheap installation process, it does not account for easy removal.

Loose scour protection can be removed by means of dedicated excavation vessels but it is a time-consuming and cumbersome procedure. As far as the author and interviewees are aware, there are currently no innovation projects with regards to decommissioning underway.

4.4 Decommissioning Strategies

The aforementioned state of technology with regards to decommissioning helps to identify the options developers have in decommissioning their OWFs. These decommissioning strategies will be addressed in this section. Although international law (see section 5.1) prescribes developers to remove offshore substructures in entirety, they often argue that alternative approaches might have better outcomes. Several alternative decommissioning strategies are addressed in literature (Fowler et al., 2018; Smyth et al., 2015; Topham & McMillan, 2017). Combined with insights gained from expert interviews, the decommissioning strategies considered in this research are established. Table 4.1 lists the strategies and indicates removal with an 'X' and leaving in situ with an '-'.

Paragraph	Strategy	Monopile	IAC	Scour protection
4.4.1	Complete removal	X	X	X
4.4.2	Partial removal: full monopile	X	-	-
4.4.3	Partial removal: full monopile and IAC	X	X	-
4.4.4	Partial removal: partial monopile	Partial	-	-

Table 4.1: Overview of considered decommissioning strategies

4.4.1 Complete removal

In the complete decommissioning strategy, the complete substructure of a WTG is disconnected, dismantled and removed. The monopiles are withdrawn from or cutoff at the seabed, depending on the technology available. The scour protection is cleared and the IACs are retrieved from the seabed. Ideally, the site will be restored to its original condition and careful seabed surveys will show that no man-made structures or components remain. Eventually, other legitimate users of the sea will be allowed access to the site again. This strategy was used in the decommissioning of OWF Lely and OWF Vindeby, which were among the first decommissioning projects worldwide.

This strategy is in complete accordance with international and national regulations and is, when technically possible, considered as the default decommissioning strategy. However, developers have been known to argue that this approach ignores the environmental impact, high risk to personnel or extreme costs and therefore advocate partial decommissioning strategies instead (personal communication, March 2, 2021).

4.4.2 Partial removal: complete monopile

This strategy assumes the removal of the entire monopile, if the state of technology allows it, and suggest leaving the IAC and scour protection in situ. IAC removal is a tedious procedure and therefore involves extreme costs (Topham & McMillan, 2017). Developers argue that the considerable length of the cables increases the complexity of recovery as excavation would result in large scale disturbance to the marine environment and impose extreme costs (Greater Gabbard Offshore Wind Farm Ltd, 2007). Similar arguments are given for scour protection removal.

The environmental impact of leaving IACs in situ is a bit ambiguous, as leaving the cables buried also ignores the potential reusability and recyclability of valuable conductor materials such as copper and aluminum (personal communication, March 10, 2021). In addition, there is not much known about the degradation of the outer materials of the cable over time and the effect on the water quality, hence such an approach should include regular subsea monitoring, which can also be costly.

Scour protection generally consists of natural resources such as rock, which has little recycling value. Some developers argue that scour protection has had an ecological enrichment function during the OWF lifetime. Marine life is known to flourish around scour protection should therefore not be removed. An example is the 'Rigs to Reefs' approach, as explained by Smyth et al. (2015), in which disused oil platforms in the Gulf of Mexico are converted into artificial reefs. Avoidance of extreme costs and risk to personnel are also frequently used arguments in decommissioning discussions.

4.4.3 Partial removal: complete monopile and IAC

This strategy is comparable to the aforementioned, with the exception that this approach does account for complete IAC removal. This can be motivated by a variety of reasons, such as strict regulation, the conviction of developers to clean up after themselves, the scrap value of the conductor materials, the risk tied to continuous monitoring of cable unburial or a combination of them. In this case, it is assumed that permission is granted to leave scour protection in situ.

4.4.4 Partial removal: partial monopile

Partial removal refers to a decommissioning process in which the monopile is not completely removed. Monopiles can be cut both internally and externally, leaving the remainder of the pile in the soil. This approach could be justified when technological limitations would impose severe risk to personnel, significant environmental impact or expose developers to extreme costs. In case of external cutting, some scour protection must be removed in order to give access to the pile for cutting operations.

Thus, complete and partial removal strategies occur for a variety of reasons and therefore affect different substructure components. An overview of all decommissioning options, within and outside the scope of this research, is presented in Figure 4.6.

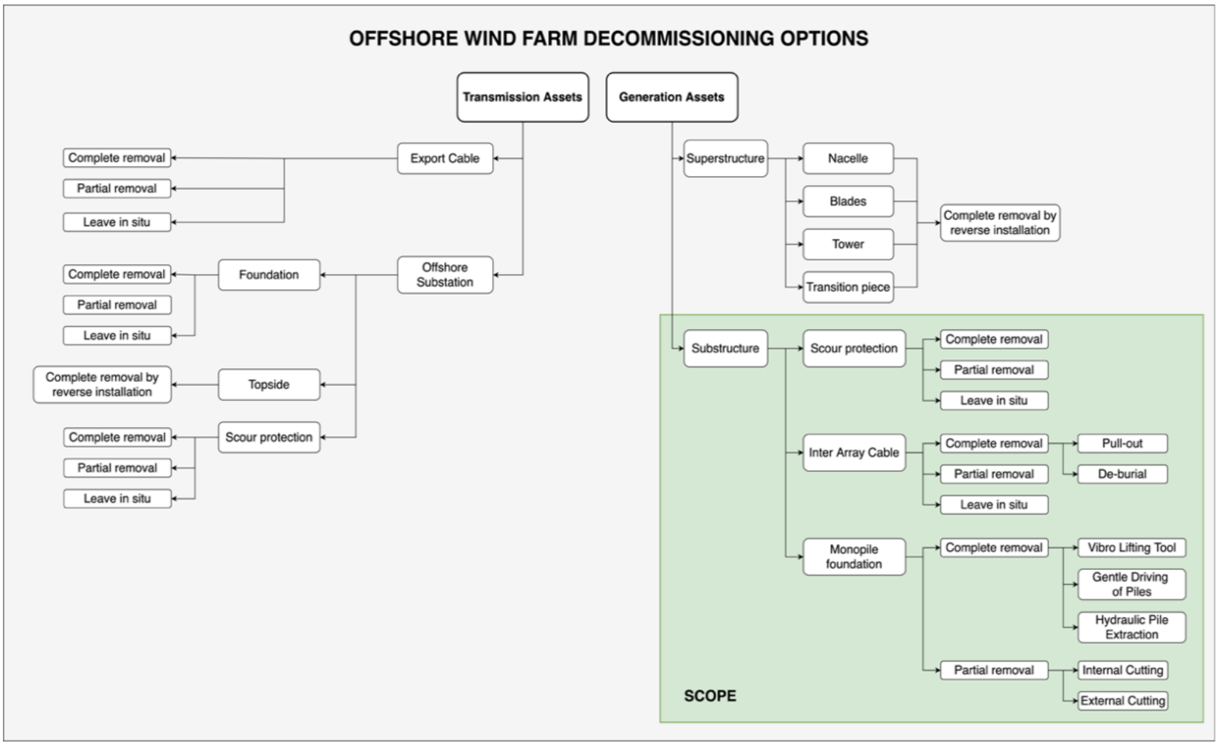

Figure 4.6: Overview of decommissioning options inside and outside the scope of this research

5. Socio-political Acceptance

Successful implementation of new technologies requires socio-political acceptance. Decommissioning offshore wind farms is a form of innovation, as it implies the implementation of novel technologies. By definition, innovation is the successful application of new ideas, transferred into products, processes or organizations (Wolsink, 2013). However, integration of decommissioning technologies into society is not purely about applying science. The socio-technical system around this technology consists of social, economic, technological and environmental factors.

Seen that regulations usually reflect a widespread public opinion over time, this chapter starts with mapping the policy currently in place to regulate offshore wind decommissioning on the North Sea. This chapter successively addresses international treaties and conventions, national law of NSR states and the functioning of Dutch policy specifically. Data is collected through researching legal documents and interviewing an expert in energy infrastructure law on the North Sea and multiple governmental and industry stakeholders.

To ensure the safety of navigation and the protection of the marine environment, developers of offshore installations must comply with a wide range of national and international regulations and agreements. These apply to the construction and operation of the wind farm, as well as to the decommissioning phase. This section elaborates on the overarching international law, standards and guidelines developed to guide national policymakers, agreements between Northern-European nations and national policies. On national policy it has been decided to focus on the countries part of the North Sea Region (NSR). This historically cooperative group of nations consists of Belgium, Denmark, Germany, Norway, Sweden, the Netherlands and the United Kingdom (UK). Subsequently, focus will be given to the Dutch policy environment, specifically.

5.1 International Law

OWF developers must adhere to several international and national laws when developing, operating and decommissioning an OWF. The overarching international law in this area is the United Nations Convention on the Law of the Sea (UNCLOS), drawn up in 1982 and in action in 1994. Since all states in the NSR have ratified UNCLOS, this international law provides the foundation for most national regulatory frameworks.

Within UNCLOS, a distinction is made between two maritime zones, each with different rights and duties of coastal states. The first, the territorial zone, stretches up to 12 nautical miles (22.2 km) from the coast and is basically an extension of the land territory. Thus, all national laws apply to this area and the state has full *territorial sovereignty*. The second zone is called Exclusive Economic Zone (EEZ) and can reach up to 200 nautical miles from the coastline. Within this zone, coastal states have the exclusive right to explore and exploit the natural resources found in the waters, seabed and subsoil of the area. Coastal states that proclaim an EEZ are responsible for nature conservation in the area, which is also lied down in UNCLOS. Figure 5.1 illustrates the composition of EEZs in the North Sea.

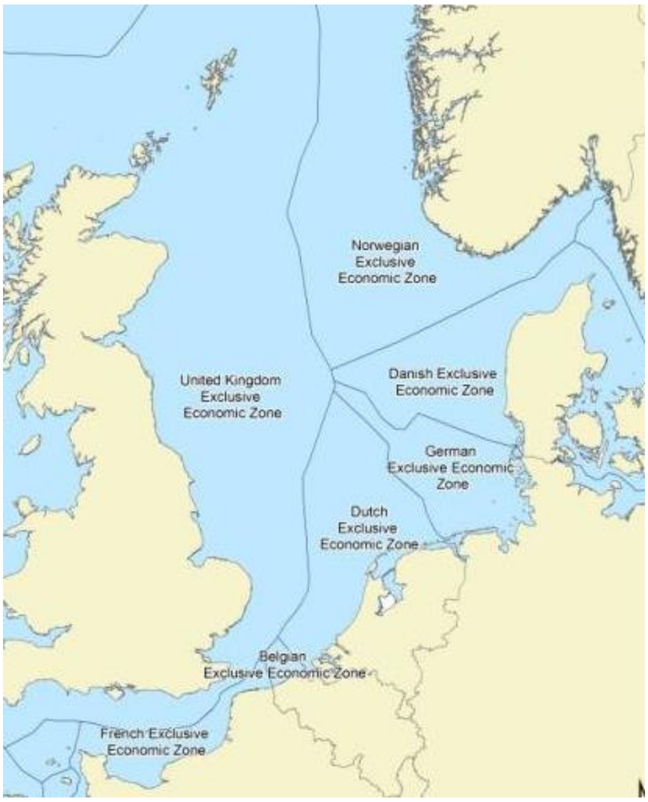

Figure 5.1: Illustration of the EEZs within the North Sea (Bolman et al., 2018)

The state has *functional jurisdiction* in the EEZ, meaning that it is limited to regulating the economic exploration and exploitation of natural resources and does not extend further. UNCLOS has included the extraction of energy from wind, waves and currents and the construction of artificial islands, installations and structures under economic exploration and exploitation. Therefore, coastal states have full jurisdiction over OWFs in the territorial zone and functional jurisdiction over OWFs in their EEZ (Nieuwenhout, 2017). Another term that is common is describing rights and duties at sea is the Continental Shelf (CS). A CS is the part of a continent that is under water. It can extent further than 200 nautical miles but includes only the seabed and subsoil, whereas the EEZ also includes the water column.
With the right to place installations and structures in the EEZ, also comes a duty. This is described in article 60(3) of the UNCLOS convention and states that;

"Any installations or structures which are abandoned or disused shall be removed to ensure safety of navigation, taking into account any generally accepted international standards established in this regard by the competent international organization. Such removal shall also have due regard to fishing, the protection of the marine environment and the rights and duties of other States" (UNCLOS, 1982).

Surprisingly, UNCLOS does not explicitly mention subsea cables or scour protection, as those are not necessarily structures or installations. On the other hand, a policy expert states that everything that is essential for the operation of an installation, is an inherent part of the installation and should and will be considered as such (Appendix L).

The competent international organization, as mentioned in article 60(3) of UNCLOS, is the International Maritime Organization (IMO), which has established international guidelines and standards in the 1989 Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone (IMO, 1989). It requires that all abandoned or disused offshore installations or structures on the ES or in the EEZ be removed. An exception may be made when non-removal or partial removal complies with the following guidelines and standards and has the consent of the coastal state with jurisdiction.

Guidelines

- Any potential effect on the safety of surface or subsurface navigation, or on other uses of the sea
- The rate of deterioration of the material and its present and possible future effect on the marine environment
- The potential effect on the marine environment, including living resources
- The risk the material will shift from its position at some future time
- The costs, technical feasibility and risks of injury to personnel associated with removal of the installation or structure
- The determination of a new use or other reasonable justification for allowing the installation or structure or parts to remain on the sea-bed.

Standards

- All abandoned installations or structures standing in less than 75m of water and weighing less than 4000 tons, excluding superstructure, should be entirely removed.
- The means of (partial) removal should not cause a significant adverse effect on navigation or the living resources of the marine environment.
- The coastal state may determine that the installation or structure may be left wholly or partially in place when;
    - An existing installation or structure will serve a new use if permitted
    - An existing installation or structure can be left there without causing unjustifiable interference with other users of the sea

In addition to the IMO guidelines, nations bordering the North Sea must take into account the Oslo and Paris (OSPAR) Convention for the Protection of the Marine Environment of the North-East Atlantic, signed in 1992. OSPAR recognizes the jurisdictional right of States over the seas and, within this framework, the application of the main principles of international environmental policy to prevent and eliminate marine pollution and to achieve sustainable management of the maritime area (Appendix B). The OSPAR Decision on the Disposal of Disused Offshore Installations states that it is prohibited to dump disused offshore installations or leave them wholly or partially in place within the maritime area (OSPAR, 1998). This is legally binding for all signatories, i.e., all coastal states bordering the NSR, and the European Union (EU).

5.2 National Law

Both IMO and OSPAR indicate that exceptions may be made, by the relevant coastal states after careful case-by-case consideration of the proposed decommissioning plan. Ultimately, the extent to which decommissioning is considered by coastal states is laid down in national law. A detailed legal framework constructed by Nieuwenhout (2017) on offshore electricity grids was very helpful in finding the relevant sources for the legal aspects of OWF decommissioning. Also, a summary of national policy of coastal states of the North Sea given by DecomTools (2019) aided the process. This has led to the following summary of the prevailing policies of leading countries in the NSR.

Belgium

In Belgium, an initial financial and technical decommissioning plan must be submitted, before a permit is granted for the construction of OWFs. The financial part includes a reserve levied on the exploitation results in order to finance decommissioning, while the technical part prescribes the removal of the installation, securing of the area and the conservation and protection of the marine environment. However, the extent to which these activities should be carried out remains unclear (Belgisch Staatsblad, 2000). However, the Belgian government assumes the best practicable environmental option (BPEO) and best available technology (BAT) have advanced since the permit was granted and expects the developers to submit updates to the original decommissioning plan as the end of the OWF's life approaches.

Denmark

In Denmark too, basic decommissioning requirements are stipulated in the energy production permit, issued by the Danish Energy Agency (DEA). It states the following: *"The Concessionaire must, at its own cost, restore the area to its former condition, including carry out clean-up and tidying as necessary in the area, as well as decommission and entirely remove the electric electricity generating facility according to a decommissioning plan approved by the DEA."* (Appendix H). At least two years before the expected end-of-life of the OWF, the developer must hand in a detailed decommissioning plan which will be assessed by the DEA. When the decommissioning activities have a significant impact on the environment, the developer needs to submit an environmental impact assessment (EIA) as well. Danish law does not include specific requirements regarding decommissioning. It states that environmental requirements and the BAT will have to be determined at the time of decommissioning and that the lack of proven practical experience legitimizes a case-by-case approach. The authorities do require a financial security of at least €80 million which should be provided within 12 years after the first turbine was commissioned. If the developer can prove that decommissioning costs are less, and is able to put forth third party verification, the DEA can decide to lower the amount of the required financial security (DecomTools, 2019).

Germany

The focus in Germany is strongly on achieving power targets and therefore specific regulations for decommissioning and the end-of-life phase have not yet been defined. A dismantling plan shall be drawn up in good time before the end of the operating phase, based on the dismantling concept examined in the course of the design assessment. Insofar as the state of the art has been further developed between the design phase and the end of the operating phase, the dismantling plan shall be adapted to the current state of the art. The implementation of the plan is monitored by the inspector and dismantling is carefully documented with a certificate of conformity which summarizes the individual inspection reports and is to be submitted to the Bundesamt für Seeschiffahrt und Hydrographie (BSH) for approval (BSH, 2015). When the BSH decides to approve a OWF planning permit, it can already demand a financial security, however nothing is prescribed in terms of the amount.

Norway

Norway has not yet developed OWFs, although some initiatives have been launched by the Ministry of Petroleum and Energy in the last year. Therefore, the specific regulations for decommissioning OWFs do not go beyond the notion that the developer should consider removal in his permit application (Royal Decree Offshore Energy Regulation, 2020).

Sweden

Although Sweden's main offshore wind potential lies in the Baltic Sea, it is still considered here as they border a bay called Kattegat, essentially part of the North Sea. While most nations considered have not yet faced decommissioning of OWFs, Sweden was the first country in the world when it decommissioned OWF Yttre Stengrund, as can be seen in Table 1.1. This of course required the development of decommissioning regulations, putting Sweden ahead of the other countries in the NSR. Permits in Sweden come with requirements and conditions with regard to decommissioning. According to the Environmental Act, financial securities should be in place to recover the damage to the environment after removal (Nieuwenhout, 2017).

The Netherlands

Compared to the aforementioned, the Netherlands have drawn up more detailed decommissioning regulations. These are defined in the Water Act and the so-called site decision. In short, it reads that all materials and components utilized in construction, exploitation and decommissioning of an OWF must be removed within two years after terminating exploitation and within the permit period. Under specific circumstances, the responsible minister may decide that this plan may be deviated from, when, for instance, the environmental impact is too large. Only four weeks before decommissioning begins, the decommissioning plan should be submitted (Waterbesluit Artikel 6.16, 2009). This allows the developers to consider BAT and BPEO in their decommissioning plan (Appendix L).

Moreover, a financial guarantee of €120.000 per MW must be issued at commissioning and will be re-evaluated after 12 years of operation. The fee will be under the control of the Netherlands Enterprise Agency for the duration of the permit (Kavelbesluit V Artikel 4.5, 2021)

The United Kingdom & Scotland

From all nations in the NSR, the United Kingdom has the most complete decommissioning program in place. In the UK, developers are obliged to hand in a decommissioning programme which should include a base case of complete removal, alongside any alternatives that the operator proposes, backed up by evidence and reasoning for the preferred option. The British Department of Business, Energy & Industrial Strategy (BEIS) will consider exceptions of full removal only on presentation of compelling evidence that removal would create unacceptable risks to personnel or to the marine environment, be technically unfeasible or involve extreme costs. In addition, a financial security for decommissioning should be in place, in order to protect taxpayers from liability when a developer/ owner defaults on their obligations (BEIS, 2019).

5.3 Dutch policy

Interviews with Dutch policy experts provided additional insight into how Dutch policy on OWF decommissioning works (Appendix K, Appendix L).

5.3.1 Policy landscape

Policy making for offshore wind development in the Dutch EEZ is in hands of the Ministry of Economic Affairs and Climate (EZK). However, the implementation of this policy is the responsibility of the Netherlands Enterprise Agency (RVO), which issues permits and tenders. The enforcement of and supervision over permits and tenders is in hands of Rijkswaterstaat, the executive office for government activities on the North Sea.

In 2013, EZK, industry parties, NGOs and other organizations signed the Energy Agreement for Sustainable Growth. In this agreement, the state ensured that a robust legal framework would be put in place to enable the upscaling of offshore wind energy (Wet windenergie op zee: Memorie van toelichting, 2014). In addition, substantial subsidies were arranged for 5 750MW OWFs, on condition that the industry would work towards a 40% cost reduction between 2014 and 2024 (Appendix K).

The Water Act is the Dutch law that contains regulations on the management and use of water systems. Prior to the Energy Agreement, Article 6.16 of the Water Act described the regulations for the development of offshore wind energy in Dutch territorial waters and EEZ (Waterbesluit Artikel 6.16, 2009). The renewed regulatory framework, known as the Offshore Wind Energy Act, entered into force in 2014 and was intended to provide the industry with better tools and conditions to achieve the agreed price reductions.

Both laws have been integrated into so-called site decisions, which determine where and under what conditions an OWF may be installed, operated and decommissioned. Other laws, such as the Nature Conservation Law, also provide input for site decisions. The site decisions ultimately define the boundaries in which developers prepare their tender submission. The tender system is managed by the RVO, which provides developers with comprehensive data about the site, from water depth to soil conditions. The RVO receives several offers, from which it selects one on the basis of various criteria.

5.3.2 Decommissioning

As the interviewed representatives of RVO and Rijkswaterstaat explained, the Water Act and the Offshore Wind Energy Act are based on UNCLOS and OSPAR and essentially state that everything that is installed and no longer in use must be removed. So, complete removal of OWF installations is the starting point. That the industry is aware of this obligation has been reaffirmed with the signing of the North Sea Agreement in June 2020. The North Sea Agreement was the result of North Sea Consultation sessions, where all stakeholders on the North Sea were considered. It was based on the idea that North Sea policy should have the broadest possible support in order to avoid conflicts, enable the growth of the number of OWFs and ensure a healthy North Sea, in line with its ecological carrying capacity. Regarding decommissioning, it states: *Decommissioning of installations must be carried out in accordance with national and international regulations (including the OSPAR Convention)* (Het Akkoord voor de Noordzee, 2020).

Although regulation is clear about the obligation to remove offshore installations and structures, it does not go into detail about the scope of decommissioning. The interviewee argues that everything an offshore installation cannot function without, is inherently part of the installation. Following that reasoning, this would imply that IACs and scour protection are part of the installation and should therefore be considered as such during decommissioning (Appendix L). Regulation also states that only the Minister of Economic Affairs and Climate can grant an exemption from the default approach to decommissioning, but does not specify what exceptional circumstances would justify such a request (Waterbesluit Artikel 6.3, 2009).

The interviewee argues that detailed decommissioning plans cannot be part of the site decision because the state of the art is not known until decommissioning is in sight. Therefore, the government allows developers to wait up to four weeks before decommissioning before submitting their plan. In addition, the interviewee stresses the importance of incorporating lessons learned into new site decisions. It is expected that in a few years, when the first decommissioning projects have been executed, more detailed requirements related to decommissioning will be included in the site decisions (Appendix K).

In the past, the O&G sector was allowed to leave pipelines on the seabed during the decommissioning of oil rigs, because their removal was considered an environmental hazard.

Large quantities of disused communication cables also remain on the seabed as developers were not required to remove them at the time (Appendix L). These pipelines and cables can form physical obstacles in the redevelopment of an area, imposing technical challenges that have economic implications. The more structures and installations that remain, the more this hinders future offshore developments, such as further deployment of offshore wind farms. Although it is not directly visible, the North Sea is under great spatial pressure originating from busy seaways, mining, Natura 2000 sites and OWFs (Appendix L). Therefore, there is a high likelihood that areas where OWFs are decommissioned, will subsequently be redeveloped as OWFs. In this respect, abandoned substructures left in place may threaten the profitability of a site and thus jeopardize the effective roll-out of offshore wind farms in the Netherlands. Interviewee D2 urges developers to assess their impacts at a meso level rather than the current micro level. This means looking at the impact of decommissioning on the future of offshore wind and other functions of the North Sea, rather than just focusing on convenience and economic reasoning. This will ultimately ensure the most sustainable growth of the offshore wind sector (Appendix L).

The interviewee also assumes that most wind farm owners strive for partial decommissioning based on economic reasoning, which makes sense in light of the cost reductions. They probably derive the perceived legitimacy of their position for partial decommissioning from the O&G history, when partial decommissioning was more common. Assuming this will continue to be possible is simply opportunistic (Appendix L). The ecological impact on the other hand, will be carefully assessed at time of decommissioning. Should it be the case that the OWF site has developed in a rich ecological environment, in line with the desired carrying capacity development of the North and the KRM objectives for the conservation of certain species, then it would make no sense to destroy that during decommissioning. This characterizes the “no, unless” policy currently in force (Appendix L).

5.4 Implications for socio-political acceptance

The development of offshore wind farms on the North Sea is firmly embedded in and supported by the regulatory framework in the Netherlands. The government has set ambitious targets for offshore wind development on the North Sea and developers are aided in the design, financing and installation through institutional frameworks at the national level. The Dutch mandatory approach to complete decommissioning of offshore installations and structures is embedded in international treaties such as UNCLOS and OSPAR in order to protect the marine environment. There is however another driver for this national policy, which is in part why the North Sea Agreement came into existence. The increasingly spatial pressure on the North Sea asks for a holistic view on offshore wind development, in which there is no place for abandoned installations and structures on the seabed.

However, the continuous push for cost reductions has diverted attention from decommissioning and postponed its consideration. Now that the first OWFs approach their end-of-life, developers start to explore their options and increasingly plead for partial decommissioning. Although the policy framework does leave room for exceptions, these are primarily intended for OWFs sites with unique ecological developments. As such developments must be in line with the desired carrying capacity development of the North Sea, this asks for detailed EIAs and a case-by-case approach to consider them.

So, ultimately there is widespread socio-political acceptance for complete decommissioning of OWFs at the North Sea. Also, partial decommissioning can in some occasions count on socio-political acceptance but only after a detailed assessment of the circumstances.

6. Community Acceptance

Historically, the focus of social acceptance for renewable energy innovation has been on local communities and their acceptance of local siting decisions of projects (Wolsink, 2013). This concept originates from times in which developers approached public opinion as 'nontechnical factors', without investing time or resources into its investigation. When opposition from local communities started to emerge, it was first dismissed as NIMBYism. However, when the high potential of social acceptance in case of community level initiatives came to light, it became clear that there was more to it. Since, companies dedicate resources to increase public awareness, collaborative decision-making and incorporation of civil initiatives in order to gain public acceptance and encounter less resistance.

Wolsink (2013) describes two main conflicts of interest in the consideration of wind power development in local communities. First, the application of wind power as a public interest versus wind power as a private investment of the owner of the wind farm. Secondly, wind power in conflict with various private interests versus wind power in conflict with public interests of the community. Although this offers an interesting insight into the motives of local communities, this is not directly applicable to the topic of this thesis. This thesis addresses offshore wind farms, where the physical impact on local communities is much smaller than for onshore wind projects. Common community complaints such as drop shadow and noise do not apply to offshore projects. Other concerns local communities might have to offshore wind, such as visual pollution of coast lines, apply in particular to siting decisions. The removal of these wind farms is therefore expected to take away those concerns, instead of fueling them.

Wolsink's interpretation of community acceptance is more fitting to onshore wind than to offshore wind and to siting and installation processes than decommissioning. Since it is not directly applicable on decommissioning offshore wind farms, it is decided to approach the concept differently. A well-known definition of a community is given by MacQueen et al. (2001) and reads as follows: *A group of people with diverse characteristics who are linked by social ties, share common perspectives and engage in joint action in geographical locations or settings*. So, instead of delineating a community based on their shared place of living, we can also delineate it based on their shared perspectives and joint action for the benefit of a particular location. Applied to offshore wind farms, this can indicate groups of people who are committed to the North Sea and the functions it facilitates. Therefore, this chapter tries to identify complex social actors that are engaged in the representation of social values tied to the North Sea and actively pursue the incorporation of these values in decision-making.

6.1 Non-Governmental Organizations

The United Nations defines a Non-Governmental Organization (NGO) as "a not-for profit, voluntary citizens group organized at the local, national or international level to address issues in support of the public good. It further states that NGOs are made up of people with a common interest and perform a variety of services and humanitarian functions, bring citizen's concerns to the attention of governments, monitor the implementation of policies and programs, and encourage participation of civil society stakeholders at the community level" (Leverty, 2008). According to this definition, NGOs are well suited to be considered as social actors in community acceptance of OWF decommissioning.

NGOs actively participate in decision-making and policy-making related to offshore wind farm development and decommissioning at the Dutch North Sea. Interviews were conducted to find out what drives them and how they feel about the current approach to decommissioning. The focus was on three NGOs that took part in the North Sea Agreement consultation meetings, which demonstrated their active involvement in the interest of the North Sea. The aim was to arrange interviews with all three NGOs, but unfortunately only 'Stichting De Noordzee' agreed. The findings from this interview are used in this section and can be found in Appendix J. An attempt was made to identify Greenpeace's and WWF's positions on OWF decommissioning through their mission statements and position paper. Also, the North Sea Agreement proved to be crucial in creating a comprehensive picture of the NGO's values.

Stichting De Noordzee is a Dutch NGO that focuses specifically on the North Sea. It acts on the basis of four main pillars, of which nature-friendly energy is the most relevant for this research. This pillar describes the pursuit of minimal environmental damage from offshore energy production and optimal use of environmental opportunities. Fundamentally, the foundation is in favor of the development of offshore wind energy on the North Sea, as it is necessary to achieve climate goals and offers a perspective for the future. Its main objective is to make governments aware of the importance of ecological research in and near wind farms on the North Sea. Regarding the decommissioning of these wind farms, the interviewee states that the foundation has no general position. She argues that it is important to look at projects on a case-by-case basis and to value energy, money, biodiversity and nature equally. In addition, the lack of specificity in decommissioning requirements should be urgently addressed, as the industry's willingness to develop individual strategies for each wind farm is likely to shape the public's perception (Appendix J).

Greenpeace is one of the best-known environmental NGOs in the world. It advocates for a greener and more sustainable world in general and bases its mission on five pillars. Of these pillars, a clean climate and safe oceans are the most relevant. Greenpeace acknowledges the importance of the deployment of wind farms on the North Sea and affirmed this during North Sea Agreement consultation sessions. Since Greenpeace was founded in the Netherlands, the NGO has been fighting against overfishing and pollution of the North Sea. Their peaceful and original protests often lead to policy changes in governments and companies (Greenpeace Nederland, 2021). Their campaign against deep-sea disposal of Shell's Brent Spar was probably the most memorable. Unfortunately, apart from their aim to deploy more offshore wind farms on the North Sea, nothing about their stand on decommissioning emerges from the organization's mission statement. Nevertheless, it is safe to assume that Greenpeace will not oppose decommissioning strategies that account for ecological development in the North Sea.

The World Wide Fund for Nature (WWF), one of the largest nature conservation organizations in the world, also acknowledges that offshore wind constitutes an essential part of the energy transition and is therefore indispensable in a climate neutral world. On the other hand, WWF underlines that the development of offshore wind farms also leads to additional pressure on marine ecosystems that are already under severe strain. WWF has published a position paper on nature protection and offshore renewable energy in the European Union. This paper is primarily concerned with the environmental impacts of installation and operation, but the final chapter explains the importance of circular design. It argues that it is critical throughout the full project cycle to design, develop and deploy renewable energy in a circular and renewable way. Infrastructure should be designed to disassemble and to refurbish/recycle, while all parts should be repairable, replaceable and completely reusable in one way or another. Also, emphasis is placed on repowering to reduce the environmental impact of new projects. It goes on to highlight the importance of using the BAT during installation and decommissioning and actively support initiatives and research on sustainable, circular infrastructure treatment. Failing to address the circular design issues could prejudice the reputation of cleantech companies, or even the overall energy transition, which would not only be counterproductive to the energy sector but detrimental to the fight against climate change (WWF European Policy Office, 2021).

In summary, the NGOs argue that in addition to climate change, biodiversity collapse is another major threat to the world. These crises are intertwined and should therefore be addressed simultaneously. So, offshore renewable energy development must be considered within the broader context of the deteriorating health of the North Sea. Installation and decommissioning processes must therefore align with the restoration of marine biodiversity recovery and ocean resilience. The use of detailed EIAs to evaluate environmental impacts during decommissioning is essential. Furthermore, the application of best practices and the circular design of wind farms and waste treatment processes are crucial for truly sustainable development of offshore wind energy on the North Sea.

Since environmental impact seems to be the core value that NGOs pursue in offshore wind development, the next section addresses factors critical for the assessment the environmental impact of decommissioning OWFs. The majority of this information has been drawn from EIAs, executed by renowned consultancy firms and approved by governments.

6.1.1 Environmental Impact Assessment

In order to assess what is important in determining the environmental impact of OWF decommissioning processes, several EIAs of offshore installations have been consulted. In addition, other literature was used to form a comprehensive understanding of the current state of knowledge regarding decommissioning of offshore structures and installations. In order to validate this information and gain new insights, an interview with a program leader from the Dutch National Institute for Sea Research (NIOZ) was conducted. The proceedings of this interview can be found in Appendix D.

Due to the difference in water depth, nutrient richness, salinity, currents and composition of the bottom, the North Sea is rich in benthic fauna and fish. Unfortunately, the last century, the health of the ecosystems has deteriorated, resulting in a decline in biodiversity. The Dutch North Sea policy aims to ensure that the North Sea is a clean, healthy and productive sea in the future. To achieve this, the policy focuses on habitat protection, species protection and implementation of the Marine Strategy Framework Directive (Noordzeeloket, n.d.)

OWF decommissioning has a significant impact on the marine environment. The chosen strategy may have a direct effect on the present species and their habitat or a cumulative effect on the current, stratification and species productivity. As there is a paucity of scientific work on the ecological impacts of offshore wind farm substructure decommissioning, this section is based on current knowledge of the effects during the construction phase. EIAs generally assume that the expected disturbances during decommissioning, such as noise and vibration levels, will not exceed those experienced during construction of the wind farm and will be temporary and localized.

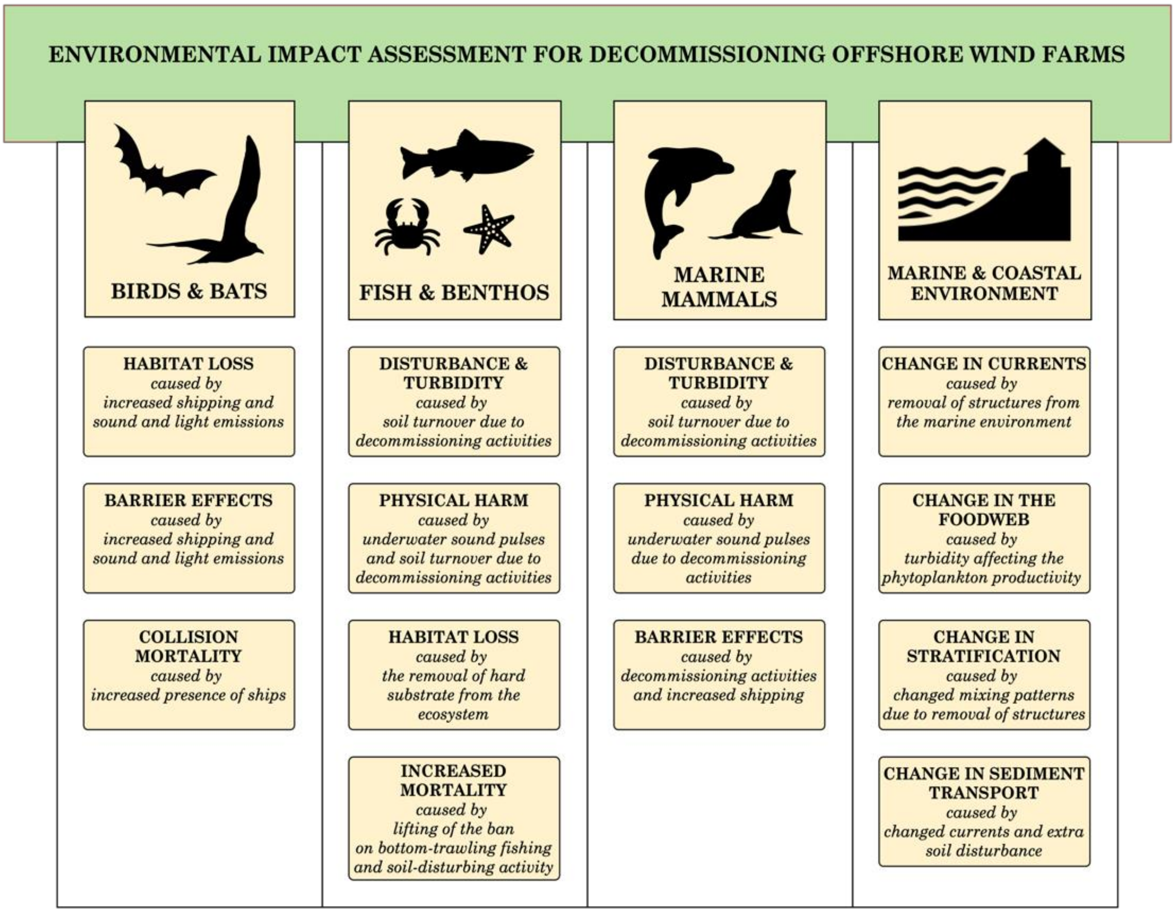

Figure 6.1: Environmental impacts to be considered during decommissioning OWFs (own production)

Therefore, the information presented here is derived from the current state of scientific knowledge on the impact of installation processes of OWFs, since it is similar in some ways to decommissioning and has been studied frequently. As this research is exploratory, the impacts are merely discussed and not evaluated.

Not only does the decommissioning process itself cause ecological changes, e.g., through disturbance and pollution, but the permanent removal of substructure components can lead to the loss of certain ecological functions. This section addresses the permanent and temporary ecological impacts affecting birds and bats, aquatic species and the general marine and coastal environment. The entirety of impacts to be considered when decommissioning OWFs, based on the current state of scientific knowledge, is shown in Figure 6.1.

Impact on birds and bats

For some species of shore- and seabirds, the North Sea is a permanent habitat. Seabirds live primarily at sea and come ashore only to breed. Shorebirds roost and breed on land, but hunt for prey at sea. In addition to these birds, the North Sea is used by millions of migratory birds that either arrive at British Islands from mainland Europe via the North Sea or leave Scandinavia to winter at Southern-Europe (Noordzeeloket, 2020).

Bats are also migratory animals and research has established these nocturnal mammals' presence at the North Sea (Kahlert et al., 2003). They are therefore also considered to be affected by decommissioning activities on their migration route. Literature has identified three main potential impacts of decommissioning activities on birds and bats, namely habitat loss, barrier effects and collision mortality.

Due to increased shipping and sound emissions from vessels and equipment during the deconstruction phase, birds and bats are expected to avoid the wind farm areas, thereby limiting their habitat (Teunis et al., 2021). The cumulative effects of this habitat loss may result in reduced prey availability and ultimately reduced species diversity. The second effect on birds and bats is the barrier effect. This effect occurs when species cannot cross the OWF area due to the presence of ships and are therefore forced to extend their flight paths. This requires additional energy and time during an already strenuous and challenging migration journey. (Jaspers Faijer, Sosef, & Perk, 2020). The last major effect that decommissioning OWFs may have on birds and bats is mortality from collisions with ships and equipment on board. Scientific studies have shown that the artificial lighting on board attracts birds under certain conditions, increasing the chances of collision (Rebke et al., 2019).

Research has also shown that the impacts are larger during periods of increased flight activity and under weather conditions that are optimal for migration (Kahlert et al., 2003; Lagerveld et al., 2017). Interviewee A3 reaffirms this and adds to this that the location of the wind farm might be equally decisive. The presence of important flyways in the area will have major consequences. Therefore, the timing of the decommissioning process is one of the most important impact mitigation measures. In addition, reducing noise, light, and shipping activity will also reduce the ecological impacts of OWF substructure decommissioning on birds and bats (Appendix D).

To put matters into perspective it must be noted that these effects are temporary and localized in nature and the associated long-term impact is expected to be negligible. Nonetheless, taking these impacts into account can be very important in achieving community acceptance.

Impact on benthic fauna and fish

The impact of decommissioning OWF substructures is significant for aquatic species and occurs on two levels. The first is the direct effect of temporary offshore activities and the second is the cumulative effects of permanent changes in the marine environment. Literature mentions temporary effects and two permanent effects.

During the decommissioning phase, offshore activities with emissions of powerful underwater sound pulses or vibrations can take place. These sound pulses can have adverse effects on fish ranging from temporary to permanent hearing loss, internal bleeding, and organ damage (Andersson et al., 2016; Hawkins & Popper, 2017). Research indicated that the impact of underwater sound emissions showed no major changes in the benthos community before and after wind farm construction that would indicate major damage and as a result of the sound or vibratory pulses (Bergman et al., 2012). Furthermore, no significant differences between the benthic community within and outside the PAWP have been demonstrated (Leewis, Klink, & Verduin, 2018).

The removal of substructures is a comprehensive operation and requires some soil disturbing activities. These activities cause disturbance of the top sediment layer and in the process could displace, damage, or destroy benthic species. Moreover, the shifting of sediments can cause high turbidity levels that limit the visibility of fish and benthos. This temporarily impedes the foraging and navigational abilities of these species (Jaspers Faijer et al., 2020). More permanently, increased turbidity limits the amount of light available in water, which impedes the productivity of phytoplankton, especially during blooming periods. In turn, this affects the productivity of zooplankton, fish, marine mammals, birds and essentially the entire food web. To provide some nuance it should be noted that the North Sea is a dynamic shelf sea on its own, where some sediment displacement and turbidity is natural (Appendix D).

During the construction of the wind farm, hard substrates were introduced into the seabed of North Sea, which is otherwise dominated by soft sediments. Research has shown that these hard substrates are generally rapidly colonized by benthic epifauna communities. As a result, the biodiversity and biomass of native and non-native species increase (Bouma & Lengkeek, 2009; Coates et al., 2014; Coolen et al., 2015; Vanagt, van de Moortel, & Faasse, 2013). Fish use the colonized monopiles and scour protection for hiding, foraging and spawning purposes (Couperus et al., 2010). The downside of hard substrate in the area is that it can also serve as a "stepping stone" for invasive species to spread out and colonize other areas of the North Sea. Complete decommissioning would remove the colonized hard substrates from the ecosystem and eliminate the facilitating function of the structures. This will certainly reduce the biodiversity and species richness, however the magnitude of impact depends on what baseline is chosen. Compared to the ecological situation during the operational phase of the wind farm, the impact would be severe, but compared to the ecological situation before the construction of the wind farm, the impact would be small. Partial decommissioning would allow for some conservation of the ecological developments. However, the question is whether the increase in species richness and biodiversity is in line with the desired carrying capacity development of the North Sea. If not, leaving substructures in place is counterproductive to the protection of native endangered species (Appendix L). Determining that is evidently very complex and should therefore always be assessed on a case-by-case basis.

Due to safety issues, bottom-trawling fishery and other soil-disturbing activities are prohibited in and near wind farms. A side-effect of this policy is that the seabed is undisturbed and benthos are allowed the opportunity to develop. Direct effects that have been established trough scientific work are; reduced mortality, change in food availability and change of habitat conditions. Although theoretically this could lead to increased biodiversity and biomass of the benthic community on the seabed, several studies were not able to prove this hypothesis (Bergman et al., 2012; Leewis et al., 2018). Interviewee A3 also confirms that long-term studies have not shown a change in benthic communities as a result of the elimination of soil disturbing activities (Appendix D). Surprisingly, fish monitoring after the construction of several wind farms also showed no significant differences between areas within and outside the wind farms. In a period of five year, no demonstrable positive effect of the fishing ban on the development of fish stocks could be proven (De Backer & Hostens, 2018; van Hal et al., 2012).

Whereas the impact on birds and bats was very temporary in nature, the impact on fish and benthos is far more permanent. Lasting changes in the characteristics of habitats can have far-reaching consequences for the desired development of certain species. Also, the cumulative effect on the marine food web as a result of soil-disturbance can be quite significant. In order to mitigate the impact on fish and benthos, it is important to develop less-invasive installation and decommissioning technologies. Moreover, the blooming period of phytoplankton should be accounted for in planning. Long-term research projects should quantify the impact of removing hard substrate and lifting of bans on soil disturbing activities. Investing in these measures potentially increases the chances for community acceptance.

Impact on marine mammals

The North Sea houses different species of marine mammals, however, the populations of porpoises and grey and harbor seals are by far the largest. These species are qualified as protected species under the European Habitat Directive and therefore deserve extra attention in their treatment. The presence of other species of seals, dolphins and whales visiting the North Sea is too incidental to include in this study. The North Sea and its coastal areas are used to forage, rest and breed. The ecological impact on marine mammals in the North Sea are categorized by barrier effects, disturbance and physical harm (Jaspers Faijer et al., 2020).

Due to increased shipping and underwater sound and vibration emissions from vessels and equipment during the deconstruction phase, marine mammals are expected to be deterred from the wind farm areas. The barrier effect limits the mammal's presence in the area. Soil turnover as a result of decommissioning activities and the associated turbidity can affect the foraging potential of marine mammals. Powerful underwater sound emissions can also physically affect marine mammals. These effects may manifest themselves in the form of a behavioral response, such as fleeing, or in the form of temporal or permanent hearing loss (Heinis et al., 2019). It cannot be dismissed that this could have a direct effect on their foraging as harbor porpoises are largely dependent on their hearing to locate prey.

Marine mammals are expected to be most inconvenienced by underwater sound emissions, as most of them have excellent hearing. Therefore, sound mitigation measures are expected to be vital in reducing the impact of decommissioning activities for marine mammals.

Impact on the marine and coastal environment

The marine environment entails the water and soil quality, characteristics, and dynamics in a given offshore area. The coastal environment includes the same characteristics, but for coastal areas. They could be temporarily affected by decommissioning activities or permanently by the removal of structures that have had a permanent impact on the environment. This section discusses the impacts to be considered.

Due to the presence of offshore decommissioning vessels and barges, currents and wave patterns could be affected to a very minor degree. Given the relatively small area affected and the fact that the North Sea is surrounded by busy shipping lanes, these impacts are considered insignificant. During complete decommissioning, the soil will temporarily be disturbed by removal of the monopiles, bringing up of scour protection, and excavation of IACs. Soil turn-over leads to the relocation and resuspension of sediments. This also affects the coastal environment as it is dependent on currents for sediment transport and deposition.

According to interviewee A3, the removal of monopiles could have a significant impact on stratification, currents and sediment transport. The obstruction of monopiles alters the mixing patterns and affects the stratification in the North Sea. This is especially important in areas of seasonal stratification, which drive the spring-bloom of phytoplankton. The productivity of phytoplankton essentially affects the entire marine food web. Impacts on hydrodynamic processes, which are essential to the marine and coastal environment, are generally not considered in EIAs for decommissioning OWFs. However, interviewee A3 stated that the growing number of offshore structures at the North Sea is increasingly impacting hydrodynamic processes. Unfortunately, further investigation is required before these impacts can be quantified (Appendix D).

6.2 Implications for community acceptance

In order to make community acceptance practicable for this research, it was decided to approach the concept of a community differently. The legitimacy of considering NGOs to represent community concerns and values was established. Conducting interviews and the assessment of literature helped to establish the core values that the NGOs represent and their stance on decommissioning.

The NGOs considered have a positive stance towards offshore wind energy on the North Sea and acknowledge its essential role in the energy transition. At the same time, they stress that the North Sea is already congested with economic activities and suffers from degrading health. Therefore, the lifecycle of offshore renewable energy projects should be considered within the broader context of environmental conservation and restoration targets of the North Sea. Some NGOs advise governments of the importance of ecological research, some take action and force policy change and some do their own research, but ultimately, they all strive for the inclusion of environmental values in offshore wind development.

The results lead to argue that the state of community acceptance is positive at the general level for decommissioning. However, the way governments and industry engage with ecological research and the way they include it in their policies will be decisive for sustainable and lasting community acceptance.

7. Market Acceptance

Social acceptance can also be interpreted as market acceptance, which essentially describes the process of market adoption of an innovation. The theory of diffusion of innovations (Rogers, 2003) explains consumer adoption of innovative products through a communication process between individual adopters and their environment. However, this study focuses on the market adoption of an energy infrastructure innovation, which is inherently more complex. Market acceptance is largely intertwined with socio-political acceptance, as the policy framework dictates the extent of decommissioning. However, the market itself has the opportunity to develop its own approach to the prescribed decommissioning process. It is also interesting to see how different companies in the market adapt to the upcoming decommissioning projects.

This chapter looks at different players in the 'market'. Interviews are conducted to gain a comprehensive understanding of how companies are adapting to future OWF decommissioning requirements. Participants ranged from research and development consortia to wind farm recycling experts and OWF developers. Publicly available OWF decommissioning plans provided additional insight into how different developers plan to execute decommissioning once in sight.

This chapter begins with an elaboration on how developers approach decommissioning and is supported by a case study of the decommissioning of a hypothetical OWF. It then discusses the motivation for technological development in the market. Finally, the emergence of a promising new market for the recycling and reuse of offshore wind turbine components is addressed.

7.1 Developer's perspective

To understand the developers' views on decommissioning, interviews were conducted with two representatives of Vattenfall (see Appendix G and Appendix H). In addition, seven publicly available decommissioning plans for OWFs were reviewed. The plans are from different developers but all relate to offshore wind farms in the UK. Section 5.2 explained that the UK requires developers to submit a baseline decommissioning plan at the consent stage and make it available to the public. In examining these plans, particular attention has been paid to the proposed strategy for the removal of monopiles, scour protection and IACs. The results are presented below in Table 7.1.

Unfortunately, no plans are available for OWFs in the Dutch North Sea. However, the regulatory framework in the UK is similar to that in the Netherlands, in that it also requires complete decommissioning. Therefore, the plans can be used to gain a deeper understanding of developer considerations.

OWF name:	Developer:	Monopile:	Scour protection:	IAC:	Source:
Dudgeon (UK)	Equinor	Cut 1-2 meters below seabed	Strategy unknown, awaiting BPEO and BAT	Left in situ	(Statoil, 2015)
Triton Knoll (UK)	RWE	Cut below seabed (depth not specified)	Left in situ	Left in situ	(Knoll, 2018)
Hornsea 2 (UK)	Ørsted	Cut below seabed (depth not specified)	Recovered and reused/ recycled	Left in situ,	(Ørsted, n.d.)
Doggerbank (UK)	SSE, Equinor	Cut below seabed (depth not specified)	Unknown	Left in situ	(RWE & SSE, 2020)
Sofia WF (UK)	RWE	Cut below seabed (depth not specified)	Left in situ	Left in situ	(RWE, 2020)
Sheringham Shoal (UK)	Equinor	Cut 1-2 meters below seabed	Left in situ	Left in situ	(Scira Offshore Energy, 2010)
Lincs (UK)	Various	Cut 1-2 meters below seabed	Left in situ	Left in situ	(Lincs Wind Farm Limited, 2010)

Table 7.1: Decommissioning strategies for substructures from publicly available decommissioning plans of existing OWFs

It is striking that not a single developer assumes that complete removal will be required at the time of decommissioning. Their strategy is to opt for partial removal, usually for reasons involving extreme cost or risk to personnel or the environment. The corresponding argumentation is often minimal or lacks any scientific basis. Most often, no attention is paid to the added value of recycling or reusing whole substructure components or the avoided carbon emissions associated with circular treatment of components and materials.

Interviewee B3 confirms that most decommissioning plans opt for partial decommissioning, although in his opinion the regulatory framework is very clear. He argues that developers probably derive the legitimacy of this approach from the O&G sector, where partial decommissioning was the norm for many years. Technical similarities aside, the implications of decommissioning these structures are actually inherently different when the energy output per m^2 is accounted for. An O&G facility uses relatively little space for its activities, while the impact of OWFs is much more profound. The focus on lowest cost of energy (LCOE) in recent years may have led to opportunism and/or conservatism in decommissioning considerations in early stages of OWF projects (Appendix G). This view was also expressed by the representative of the Dutch Wind Energy Association (Appendix I).

B3 recommends that developers consider decommissioning and disposal of substructures at the design stage to fully understand the impact on the design. This provides an opportunity to influence the design to avoid additional cost or complexity at end-of-life. Furthermore, the government should clearly articulate its long-term vision for the North Sea and maintain an open dialogue with stakeholders to ensure that offshore wind development remains feasible. According to B3, transparency and stakeholder management will ultimately determine widespread social acceptance. In general, most developers seem to believe that decommissioning is not yet part of their scope and are waiting for the experience of the first projects to learn and set the base (Appendix G).

Interviewee B4 confirms the impression that developers are not yet fully considering decommissioning. Most of them consider decommissioning as a reversed installation process, although decommissioning is much more complex. In order to carry out complete decommissioning in a cost-effective manner, it should be considered at the development stage of the project. B4 highlights the importance of the challenge of getting all stakeholders to adopt a holistic approach to offshore wind development on the North Sea.

7.1.1 Economic incentive

To investigate the extent to which developers have an economic incentive to propose partial decommissioning, a comparative case study was carried out (Appendix M). The cost of decommissioning a hypothetical wind farm was calculated based on different scenarios.

The hypothetical offshore wind farm was commissioned in the early 2000s and consists of 80 WTGs. The 2 MW turbines were erected on 30-meter high monopiles weighing 230 tons each. To prevent scouring, 473 m^3 of rock was placed at each site. The IACs have a total length of 60 km and consist of 3 copper conductors.

The decommissioning strategies described in 4.4 are used as scenarios for this case study. The partial decommissioning strategy includes internal cutting as the technology of choice and the VLT was selected for complete decommissioning due to its high TRL level and past performance. In addition, common vessels, barges and equipment were selected. Based on the usual day rates of the equipment and the cycle times estimated by experts, the decommissioning costs were calculated according to the four selected scenarios. Any scrap value for material recycling was also included in this calculation.

The cost for the base case of complete decommissioning including the removal of the monopile, IAC and scour protection is estimated at €60 million. These costs consist for 60 – 75% out of offshore marine spread, meaning the total cost of operating the marine vessels for decommissioning. If the scour protection is left in place, the expected costs decrease by 17%. If the scour protection and the IAC are left in place, the cost will only decrease by 12% as there is no revenue from recycling the IAC. If we assume that the scour protection and IAC are left in place and the monopile is partially removed, the costs drop with 22%.

It is important to note that the potential application of novel monopile removal technologies, such as GDP and HyPE, depends on the TRL level at the time of consideration. The applicability of the technology also depends on site-specific characteristics such as the type the soil and the structural integrity of the foundation. The availability of and demand for the required vessels have a strong impact on the volatility of day rates, increasing the uncertainty of the analysis.

The case study proves that developers currently have an economic incentive to propose partial decommissioning. Moreover, uncertainty about the applicability of novel technologies for the complete removal of monopiles introduces additional risk to the business case. However, once the proof of concept is established on full scale, complete removal of monopiles can lead to shorter cycle times, which significantly reduces costs. The steel monopile can subsequently be fully recycled, which increases revenue. Removing and recycling IACs is currently still slightly profitable, but the current trend toward aluminum conductors in IACs will greatly reduce their scrap value in the future. Removal of scour protection is a tedious and expensive process with little prospect of improvement.

7.2 Technology development

In order to demonstrate the extent to which the market is preparing for the technical challenges that complete decommissioning will bring, the managing director of a renowned research, development and demonstration consortium in the field of offshore wind energy was interviewed. The results of this interview are discussed here and can be found in Appendix C. The interviewee explained that their research is mainly focused on the efficient installation of larger monopiles, but that these technologies also allow for efficient decommissioning. The fact that complete decommissioning is being considered in these developments is evidence of an increased awareness of the industry's commitment. The development of HyPE confirms this, as developer RWE initiated the project because leaving part of the monopile in place was not compatible with its internal philosophy.

As the first decommissioning projects are coming up, developers need to anticipate the specifics of government policy. In turn, regulators are grappling with the technological uncertainty and do not want to make unrealistic demands that could hurt the growth of offshore wind. The industry also expects the government to start making demands related to the ecological enrichment function of foundations. Contractors have already begun tests with eco-engineering and artificial reefs. The development of GDP and HyPE aims to enable contractors to remove monopiles without having to destroy an artificial reef around them.

This demonstrates that the industry is actively working to develop the technology required for complete decommissioning and is pre-empting government policy. This is testament to the industry's awareness that complete decommissioning is the norm and exceptions will not be possible once proof of technical feasibility is established.

7.3 Emerging markets

Interviews were carried out with a manager at a transition consultation agency and a company specialized in decommissioning wind turbines and finding a second life for them. The proceedings of these interviews are discussed here and can be found in full in Appendix E and Appendix F. The interviews with the industry specialists indicated the emergence of novel markets as a result of the growing amount of work in decommissioning. This indication was substantiated with an analysis of the potential economic activity as a result of complete and partial decommissioning and recycling of the residual material flows.

Interviewee E is responsible for the Circular Wind Hub project within the company. The project was initiated by two Dutch ministries that saw the need for a circular and sustainable approach to the growing amount of wind turbines reaching end-of-life. Currently, there are consultations with three European institutions to lobby for new infrastructure for the circular treatment of old wind turbines. Considering that the Netherlands agreed to circularize 95% of its resources in 2050 and offshore wind energy is expected to play a major role in the energy mix by then, reusing, recycling and repurposing of wind turbines is inevitable.

This understanding was acknowledged by Interviewee F, which made him to co-found a company because of it. He assumes that complete decommissioning will be integrated in tender requirements in the foreseeable future and that nothing will be left in situ. He argues that monopiles and IACs are hardly reusable because of the degradation over time. So, OWF substructure materials will be mostly recycled.

A report by TNO, focused on the orientation of potential economic activities related to offshore wind farms decommissioning, states that the market for decommissioning and recycling is interconnected with the development of technologies and regulatory change. It also emphasizes the need for EU-wide policy, regulations and standards, to provide a level playing field in recycling waste throughout the EU (van der Meulen et al., 2021).

7.3.1 Economic potential of recycling

The potential economic activity originating from recycling the substructure materials was estimated over a period of 25 years. This is based on an overview of all monopile-grounded OWFs currently in operation or under construction in the North Sea. The overview was constructed based on publicly available information and confidential third-party data which the researcher was given access to. It contains all details on monopiles, IACs and scour protection and was used to calculate the potential revenue streams originating from residual material flows. The calculation can be found in Appendix N

The recycling of steel monopiles will generate 2733 kilotons of steel over the next 25 years in case of complete removal compared to 1671 kilotons of steel in case of partial removal. Combined with the 6-year average steel scrap price of €238,75 per ton, this results in an economic activity of €652 million and €399 million respectively for complete and partial monopile removal. Figure 7.1 illustrates how the turnover is distributed over 25 years.

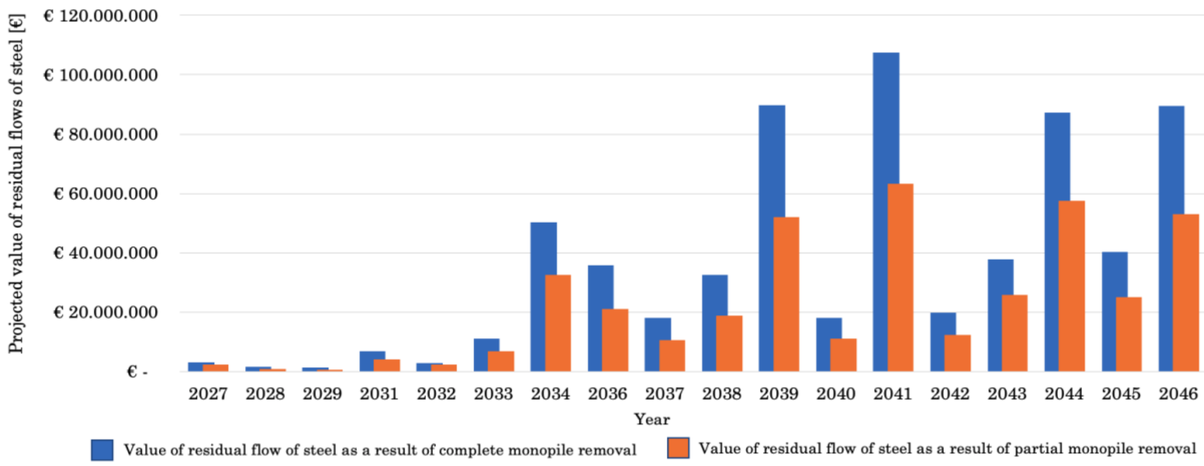

Figure 7.1: Annual projected scrap value of residual steel resulting from complete vs. partial monopile removal

The recycling of IACs is more complicated than steel monopiles, however only the scrap value of the copper/aluminum conductors inside the IAC will be addressed here. This estimation projects that over the next 25 years 198 kilotons of conductor material will be eligible for recycling, which corresponds to a monetary value of €453 million. The distribution of the projected turnover is illustrated in Figure 7.2.

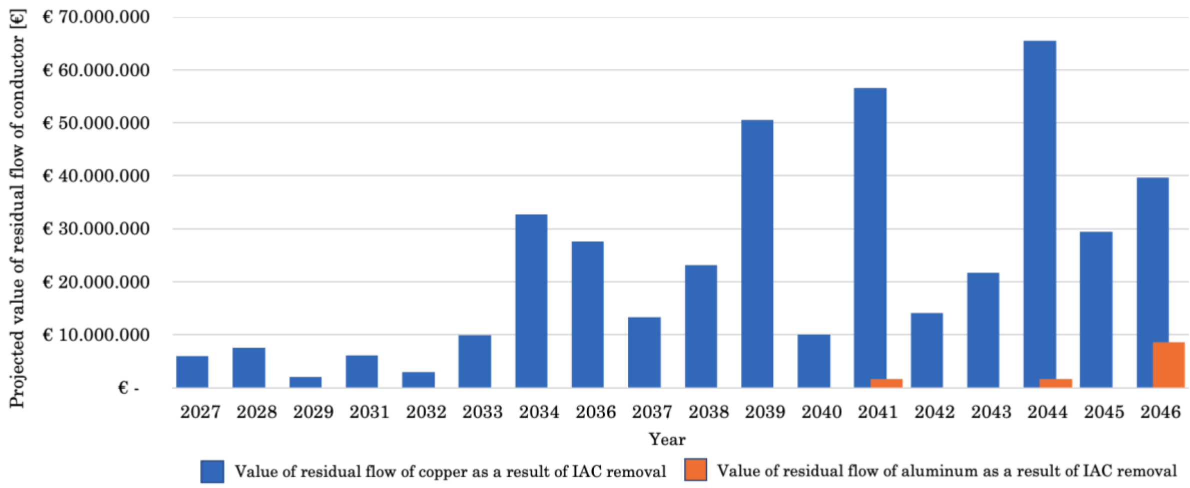

Figure 7.2: Annual projected scrap value of residual copper and aluminum resulting from complete IAC decommissioning

There is no information available regarding the value of used scour protection. The total weight of scour protection placed around monopiles in the North Sea is 251 kilotons.

7.4 Implications for market acceptance

The market acceptance of OWF decommissioning is inherently tied to the socio-political acceptance. Since developers essentially lease a plot from governments for the deployment of OWFs, regulations dictate decommissioning policy. Developers are obligated to adopt the proposed strategy for decommissioning, although not all developers truly adhere to that.

Developers have economic incentive to propose other strategies, however the market as a whole is actively preparing for complete decommissioning. The required decommissioning technologies are developed, the market is doing research into the economic potential of decommissioning activities and are constructing new infrastructures for the circular treatment of end-of-life OWFs.

This chapter has demonstrated that the state of market acceptance is positive at the general level. Technology development and initial experiences with decommissioning OWFs will be fundamental in the construction of the definitive government policy and consequently the market acceptance.

8. Conclusion

This thesis addresses the social acceptance of strategies for decommissioning offshore wind farms on the North Sea. It aims to gain a multidisciplinary view of the concept and to investigate which factors are important for social acceptance. As there is little agreement on what complex social phenomena can be simplified into a term such as "social acceptance", the term has been defined and conceptualized specifically for this research.

Social acceptance is defined in this thesis as the passive or active approval of decommissioning strategies, as reflected in the attitudes and behavior of individual or complex social actors, which can be measured at a particular point in time. The conceptualization of social acceptance was built upon the framework proposed by Wüstenhagen et al. (2007), which introduces three interconnected dimensions of social acceptance for renewable energy innovations. The dimensions were adapted to better fit this thesis. **Socio-political acceptance** describes the extent to which society as a whole supports the decommissioning of OWFs and is reflected in the policy that regulates it. **Community acceptance** refers to the degree to which communities are tolerant of the local impacts of OWF decommissioning. In the case of offshore wind farms, since there are no direct local communities to consider, NGOs were used as proxies for community acceptance. **Market acceptance** indicates the extent to which the market considers decommissioning and the motivations for doing so. Technological development and the emergence of new markets are important indicators of market acceptance.

International agreements on the protection of the marine environment in general, and the North Sea in particular, provide a narrow framework for national regulations on the decommissioning of offshore structures and installations. Apart from technical differences, the national laws of coastal states all dictate complete decommissioning as the default option for end-of-life OWFs. This entails complete removal of all components introduced into the marine environment during the installation, operation and decommissioning of the wind farm. States have the authority to make exceptions if circumstances allow. Although the default approach to decommissioning is complete removal, developers tend to consider other options. In particular, the extent of substructure removal required is often debated and has led to various decommissioning strategies. Based on technical limitations, extreme costs, or danger to personnel or the environment, developers often opt for partial decommissioning strategies. This means that either part of the foundation, the IAC or the scour protection is left in place. Developers are driven by an economic incentive and derive the legitimacy of their position from the history of decommissioning in the oil and gas sector.

Several interviews were conducted with policy makers, NGOs and academic and industry experts to determine what they consider important in decommissioning OWFs on the North Sea. Policy makers indicate that their main objective, the efficient and responsible roll-out of OWFs on the North Sea, depends on three main factors. Firstly, the feasibility and viability of the plots they allocate for offshore wind development. Secondly, how the offshore wind program fits into the overall strategy for the North Sea and thirdly, the level of support from other stakeholders. NGOs emphasize the importance of ecological research for decision-making related to OWF decommissioning. In some cases, substructures can facilitate ecological enrichment, but EIAs and a case-by-case approach are crucial in this assessment. Moreover, NGOs stress the importance of circular design and responsible resource and waste management. Academic and industry experts highlight the need for operational validation of novel technologies to take away risk and enhance complete decommissioning business cases. Also, the industry encourages governments to be more specific about decommissioning requirements and stand by their policies to reduce the risk of social backlash.

Answering the research sub-questions provided the argumentation for what factors are important for social acceptance of OWF decommissioning strategies in the Netherlands. First and foremost, a holistic view of offshore wind development on the North Sea by the industry is required. The complex trade-offs associated with decommissioning should be placed in the wider context of the numerous commercial activities at sea and the deteriorating health of the North Sea due to overexploitation of natural resources, pollution and habitat destruction. Failing to do so could threaten the reputation of offshore wind as a sustainable, renewable energy source, which could harm the energy transition and ultimately even the fight against climate change.

Secondly, a European detailed regulatory framework with clear standards and guidelines for decommissioning would provide a level playing field for all competitors. The clarity created would stimulate developers to design for decommissioning and recycling while boosting innovation. Further encouragement for innovation can be achieved by including decommissioning requirements in the tender criteria. This will increase the industry's incentive to consider complete decommissioning and recycling, which will provide the sustainable image appropriate for renewable energy generation.

Thirdly, long-term ecological research is key to underpinning whether OWFs can contribute to ecological enrichment in the North Sea. It is expected that the inclusion of nature-enhancing measures in the tender criteria will increase social acceptance of offshore wind development. Where independent EIAs point out that a structure still serves a valuable function at the time of decommissioning, authorities should consider a one-off exemption from complete decommissioning. It must be clear that such a decision applies only to that specific case and cannot be used as a precedent.

Fourthly and finally, transparent communication and collaboration in this sector are key to social acceptance. The co-use of OWF plots should be encouraged to alleviate spatial pressure on the North Sea and create shared objectives and responsibilities with other stakeholders. By ensuring that society and stakeholders are aware of the scientific arguments behind a particular approach, social unrest can be prevented.

9. Discussion

For this study, several qualitative interviews were conducted to determine what factors are important for social acceptance of OWF decommissioning strategies. As this is an exploratory study, care was taken to select a wide range of experts from different disciplines. The use of methodological triangulation, combining the limited scientific literature available with interview findings and quantitative research, ensures the internal validity of the study.

The results show that socio-political acceptance is closely related to market acceptance. The interaction between policy makers and the industry contributes to a supportive policy framework that ensures sustainable growth in line with the envisaged deployment of OWFs. The default approach to decommissioning supports this, while leaving room for exceptions based on ecological research. This finding does not match the initial personal expectation that government policy is short-sighted in mandating complete decommissioning for all OWFs. A possible explanation for this discrepancy could be the limited awareness of the multi-faceted impacts of decommissioning among developers.

Determining the state of community acceptance of decommissioning OWFs has been more complicated. The lack of empirical evidence on the social impacts of OWF decommissioning and the absence of involved communities have led to the use of NGOs as proxies for social concerns in this research. The data collected in this context confirms the personal expectation that society overall is in favor of offshore wind development, but that the ecological impacts on the marine environment need to be carefully considered. It is advised to closely monitor the first substantial OWF decommissioning projects in other countries, as they are likely to take place sooner than in the Netherlands. This will allow active anticipation of factors critical to community acceptance that may have been overlooked in this research.

This research has produced a comprehensive exploration of the multidisciplinary landscape of OWF decommissioning. The analysis of the three dimensions of social acceptance as mentioned above, has led to believe that social acceptance of OWF decommissioning can be expected on the condition that the industry adopts a more holistic approach to offshore wind development. The widely envisioned transition to truly sustainable societies can only be achieved when the process of OWF deployment is fully compatible with marine biodiversity recovery, ocean resilience and marine spatial planning. This research provides the knowledge and insights required to construct effective policy and strategies in that regard.

The use of the theory by Wüstenhagen et al. (2007) in the theoretical framework of this research has caused some issues. The theory focuses primarily on the process of siting and deployment of onshore renewable energy innovations. In contrast to the subject of this thesis, which considers the inherently different process of removing renewable energy innovations offshore. As a result, the applicability of the theory was questioned in section 3.3. To reflect on the applicability of the theory, the following should be considered. The market acceptance of decommissioning is actually already embedded in the consenting process of offshore wind development. The industry enters into an agreement with the government, which enables them to develop OWFs in the public space. However, by entering that agreement they consent to carry out decommissioning how the authorities see fit. This makes market acceptance an inherent part of socio-political acceptance and should in this case be considered as such. Secondly, the theory addresses the difference between socio-political acceptance and community acceptance under the banner NIMBYism and therefore differentiates between society and local communities. While this is valid for onshore development of renewable energy innovations, the absence of local human communities affected in decommissioning them offshore, complicates the applicability of the framework. In order to increase the applicability of the framework, this research approached the concept of communities differently. So, although the theoretical framework provided a scientific basis and gave structure to the research, theoretical adjustments were inevitable to ensure the validity of the results.

The reader should bear in mind that given the long-term nature of OWF development, decommissioning projects may be subject to different social values than at the time of consenting. This study does not provide a timeless approach to social acceptance for OWF decommissioning, so active monitoring of operational experience is needed to update the state of knowledge in this regard. Empirical findings from future decommissioning projects will certainly lead to a revision of the results of this thesis.

This study has stressed the importance of thinking holistically when deploying OWFs in the marine environment. It also concluded that a European regulatory framework should be established that provides for comprehensive spatial planning and installation standards on the North Sea. However, this study is unable to encompass the entire policy framework for each country of interest. Although the conclusion is drawn from the perspective of the Netherlands, further research is needed to determine whether other countries would benefit. It should also be noted that the UK, with the largest installed capacity of offshore wind on the North Sea, has left the EU. This makes it much more complex to include them in such a framework.

As we move towards truly sustainable societies in the future, the efficient long-term integration of renewable energy sources into the marine environment will be vital. This includes co-use of OWF sites, ecological enrichment during operation and circular treatment of end-of-life. Although this research has explored the areas of interest, further scientific research is required. Recommendations for future research are provided below.

Once the industry has adequately prepared for the upcoming decommissioning projects, it would be interesting to see how society perceives the impact of the projects. A social scientist could determine this through random surveys of citizens. From an engineering perspective, it would be highly relevant to study the impact on design, when decommissioning is considered from the beginning. In order to achieve the desired symbiotic relationship between marine ecosystems and OWFs, further ecological research is required to underpin the necessary strategies.

It is important for future researchers to be aware of the technological complexity of offshore installation and decommissioning activities and offshore wind farms. Due to the high demand for OWFs, the ever-increasing size of turbines and the push for cost reductions, the industry is in a state of flux. Consequently, researchers should be aware of the rapid and continuous change in the environment, to which a basic understanding of the physics contributes.

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Appendices

A. Search terms and hits during literature search

B. Interview with participant A1

C. Interview with participant A2

D. Interview with participant A3

E. Interview with participant B1

F. Interview with participant B2

G. Interview with participant B3

H. Interview with participant B4

I. Interview with participant B5

J. Interview with participant C1

K. Interview with participant D1

L. Interview with participant D2

M. Case study of decommissioning reference offshore wind farm

N. Calculation of economic potential of offshore wind farm substructures

Appendix A: Search terms and hits during literature search

#	Natural language search terms		No. of hits	Relevant after screening
1	**"Offshore wind" AND "Decommissioning"**			
		Scopus	78	11
		ISI Web of Knowledge	51	9
2	**"Challenges" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	18	3
		ISI Web of Knowledge	51	4
3	**"Economic" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	16	6
		ISI Web of Knowledge	12	4
4	**"Environmental" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	14	11
		ISI Web of Knowledge	16	8
5	**"Social" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	3	2
		ISI Web of Knowledge	1	1
6	**"Social acceptance" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	0	0
		ISI Web of Knowledge	0	0
7	**"Public acceptance" AND "Offshore wind" AND "Decommissioning"**			
		Scopus	0	0
		ISI Web of Knowledge	0	0
8	**"Public acceptance" AND "Offshore wind"**			
		Scopus	28	5
		ISI Web of Knowledge	47	8
9	**"Social acceptance" AND "Offshore wind"**			
		Scopus	25	4
		ISI Web of Knowledge	47	5
10	**"Public acceptance" AND "Offshore" AND "Decommissioning"**			
		Scopus	0	0
		ISI Web of Knowledge	0	0
11	**"Social acceptance" AND "Offshore" AND "Decommissioning"**			
		Scopus	0	0
		ISI Web of Knowledge	0	0
12	**"Oil and gas" AND "Social acceptance" AND "Decommissioning"**			
		Scopus	0	0
		ISI Web of Knowledge	0	0

Appendix B: Interview with participant A1

Interviewee Identification

In order to obtain a comprehensive insight in the regulatory framework of offshore decommissioning activities, it was decided to interview participant A1. She is a postdoctoral researcher at the Groningen Centre for Energy Law and Sustainability at the University of Groningen. Her current research focuses on the legal aspects of energy transition in the built environment in the context of positive energy districts, particularly in cities with monumental buildings. Before this, she participated in Horizon2020 project PROMOTioN (Progress on Meshed HVDC Offshore Transmission Networks), where she studied the legal aspects of developing an electricity network in the North Sea and on the renewable energy sources that can be connected to such a network.

Her advanced knowledge into maritime law and the legal aspects of offshore renewable energy deployment qualifies her for an interview. The PROMOTioN research project she participated in also focused on the North Sea, which leads to expect that she can directly refer to the correct legislative literature.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Zoom video conference call. Vattenfall's product manager decommissioning also joined in on the call, as he also was interested into a clarification on the subject. The interview was scheduled on April 6th at 15:00 and lasted around 30 minutes. Since both the interviewee and the interviewer are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. A video-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for verification.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in the regulatory environment, so that can be determined what needs to be researched deeper and where this information is most likely available. The interviewee has been made aware that it is the researcher's objective to let her speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic. Note, the interview results are meant for the purpose of this thesis only and cannot be used for other projects without consent from the interviewee.

Questions

1. **Personal**
    - A. Could you please shortly introduce yourself?

2. **Regulatory Framework**
    - A. Could you please clarify how different regulations at Sea relate to each other? In terms of international and national law.
    - B. Could you elaborate some more on national law and how that differs per country bordering the North Sea?
    - C. Can you indicate the direct implications of these laws for the decommissioning of offshore wind farms?

D. Can you substantiate why current regulation does not apply to cables or pipelines?
E. Can you identify any shortcomings or good examples in the current regulatory framework?
F. Is there anything else that came to mind that might be of interest to this research?

Interview results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what she conveyed. The personal introduction that was given was used to shape the section interviewee identification, and will therefore not be displayed here again.

- To understand the interaction between national and international law, one should start with the principle of 'Mare Liberum', a principle drawn up by Hugo de Groot, a Dutch jurist and philosopher in 1609. According to this principle, the oceans and seas belong to everyone and all countries have free access to the sea to travel and trade. For centuries this principle prevailed and defined the rights for anyone at Sea. It took until 1982 before the United Nations had drawn up and ratified the Convention of the Law on the Sea (UNCLOS), which came into action in 1994. It defined the official maritime territory of coastal nations and the associated rights and duties. UNCLOS is the overarching international maritime treaty, which the nations that signed it, have to comply to. Although that does not include every nation, some parts of the treaty have become customary law, which apply to all nations.

- UNCLOS states that territorial waters of coastal nations extent 12 nautical miles from shore. The laws in this zone are basically the same as on land and states have full territorial sovereignty. The second relevant zone is called the 'Exclusive Economic Zone' (EEZ) and can reach up to 200 nautical miles from the coastline. Within this zone, coastal states have the exclusive right to explore and exploit the natural resources found in the waters. The seabed and subsoil in shallow seas such as the North Sea are part of the so-called 'Continental Shelf' which is regulated through similar rights and duties as the EEZ. The state has functional jurisdiction in these areas, meaning that it is limited to regulating the economic exploration and exploitation of natural resources and does not extend any further.

- UNCLOS has included the extraction of energy from wind, waves and currents and the construction of artificial islands, installations and structures under economic exploration and exploitation. Therefore, coastal states have full jurisdiction over OWFs in the territorial zone and functional jurisdiction over OWFs in their EEZ.

- The specific guidelines and standards for offshore activities under UNCLOS are given by the International Maritime Organization. They can be found online.

- The Oslo and Paris Convention (OSPAR) are extra guidelines agreed upon by the nations bordering the North-East Atlantic, better known as the North and Baltic Sea. OSPAR recognizes the jurisdictional right of States over the seas and, within this framework, the application of the main principles of international environmental policy to prevent and eliminate marine pollution and to achieve sustainable management of the maritime area.

- In the end, national law drawn up by individual states around the North Sea can build upon UNCLOS and/or OSPAR, but can never contradict them.

- National law of states bordering the North Sea can be found in a chapter of Dr. Nieuwenhout's PROMOTioN research (Nieuwenhout, 2017). To some extent, law applicable to offshore decommissioning is also described. The margins for decision-makers to deviate from national laws and regulations differs per country.

- In some nations decommissioning is regulated through law and others describe their requirements in the tender application.

- Waste management of offshore wind farms is rarely described in national policy

- The entire consenting procedure is enshrined in law, which often includes general stakeholder management. It does not include the details on stakeholder management.

- A notable blind spot in international law is the lack of regulation applicable to the removal of cables and pipelines. Agreements described in UNCLOS only applies to offshore installations and structures, which cables and pipelines are not. Nations aim to prevent 'spaghetti' on the seabed by drawing up specific national legislation regarding cables and pipelines. Due to growing numbers of internet cables, oil & gas exploration and increased activity in offshore wind, the management of the subsea cables and pipelines becomes more and more pressing.

- The reason that most national laws have complete removal as their default position but are open to alternatives, is probably so that the responsibility for finding better alternatives lies with the developers.

- Scour protection is probably categorized under installations and structures within UNCLOS.

- Policy change is often due to changes in values central to society. In the past, central values were:
  - <1960: Economic progress
  - 1960 – 1970: Ban on heavy metals and toxics
  - 2000 – 2010: Focus on environmentally friendly
  - 2010 – now: Circularity and sustainability

  The Brent Spar case was a notable turning point in history for offshore decommissioning policy.

Appendix C: Interview with participant A2

Interviewee Identification

Participant A2 studied physics at Utrecht University and then started working at Ecofys. There he worked for 26 years at the interface between sustainable energy technologies, policies and financing, and their interactions. He also was assigned as Operating Agent to a cooperation framework under the International Energy Agency on policy-related problems (IEA-RETD), and contributed in different roles to several reports of the IPCC. He has been self-employed for a number of years, working for a variety of clients. His directorship of GROW is currently his most extensive activity.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Zoom video conference call. The interview was scheduled on July 1st at 15:00 and lasted around 45 minutes. Since both the interviewee and the interviewer are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in the state of technology and the motives for developing innovations. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your function at GROW?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. Could you tell me about GROW?
      a. What is its mission
      b. What goals does it pursue?
      c. Which partners are involved?
      d. How large is the organization?
      e. How did GROW come about?

   B. What projects does GROW currently carry out with regard to decommissioning?
   C. Which GROW innovations have the most potential to have an impact on the decommissioning of the substructures of OWFs?
      a. What TRL levels do they have
      b. When are they expected to be deployed?

D. What are the motives behind these innovation projects?

3. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the future of OWF decommissioning?
   C. Where do you think the biggest challenges lie?

4. **Policy**
   A. What do you think of the current policy on decommissioning in the North Sea?
   B. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
   A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
   B. What factors do you think are important for social acceptance?

6. **Other**
   A. Is there anything else that comes to mind that I have not asked but that might be important?
   B. Do you have any questions for me?
   C. I am going to use the recording of this interview to compile a transcript, which I will then summaries according to the important insights that have come out of this interview. I will then send this to you and ask you if you agree with how I have summarized it.

Interview Results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless otherwise stated. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The introduction A2 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- GROW is a partnership, a consortium of knowledge institutions and industry based in the Netherlands, aiming at innovation in the field of offshore wind energy. It focuses mainly on Dutch financing instruments for innovation which (somewhat) constraints the scope of the research topics to the North Sea. It was founded in 2016 but had a slow start due to issues with the transitioning government. The current program ends in 2022, but plans are being made for after that. The consortium is actively seeking collaboration with external parties, for expertise that is not sufficiently covered by the partners.

Market

- Decommissioning is a theme in some research projects at GROW. These are primarily concerned with new ways of installing (larger) monopiles, but they also allow for efficient decommissioning. Three projects are highlighted.

- Gentle Driving of Piles (GDP) is a technique that uses vibratory equipment, but with low frequency and high frequency vibrators simultaneously in different directions. This results in lower energy requirements than conventional techniques and emits less noise. The concept has already been validated and is now being tested in different soil types. The main advantage of this technique is that the monopile can also be removed relatively easily using the same process. The concept is introduced and developed by Delft University of Technology. Assuming that the tests continue to confirm its effectiveness, GDP could be deployed around 2025.

- Sustainable Installation of XXL Monopiles (SIMOX) is another research project focused on validating the physics behind one-directional (vertical) vibratory installation and removal devices, with and without jetting to fluidize the soil. GDP and a pile driving technique called Blue Piling are also being investigated. This project uses laboratory research as well as onshore and nearshore testing. SIMOX is initiated by the industry as it will need to install monopiles larger than 11 meters in diameter in a few years. Since the reference technology, impact hammering, may not be practical or made compliant to noise regulations (easily) for these large monopiles, there is an urgent need for innovation.

- The third project related to monopile decommissioning is Hydraulic Pile Extraction Scale Tests (HyPE-ST) they are currently undertaking. The technique uses water pressure on the inside of the monopile to push the monopile out of the soil. This project was initiated by developer RWE, as they stated that leaving part of the steel monopile in place was not consistent with their internal philosophy. They expect that removing the entire monopile is certainly possible with a positive business case. They also expect that the government will eventually start making demands. The expectation is that governments will also start demanding that support structures contribute to ecological enrichment.

- There is currently no research within GROW on the removal of scour protection or cables.

- It is expected that ecological enrichment will soon play a significant role in government policy. Contractor Van Oord is already testing this with oysters around scour protection, and Boskalis developed a strategy for working with nature. GDP and HyPE-ST aim to enable contractors to remove an entire monopile without destroying artificial reefs around it.

Policy

- The first decommissioning projects are coming up and therefore developers/operators need to anticipate government policy. However, authorities are also struggling as it is still unclear what is realistic given the current state of technology. The government also does not want to make unrealistic demands, which could weaken the growth of offshore wind.

- Another GROW initiative is led by Deltares, who are working on a roadmap for symbiotic-inclusive-design for offshore wind (ROAD2SID). They are setting up different scenarios and looking at ways to combine certain functions of the North Sea. Where are the synergies and what are the barriers? This could also have implications for the extent of decommissioning. The aim is to prevent a technological lock-in and to prevent government policy from slowing down the development of offshore wind energy.

Brent spar

- The main difference with the Brent Spar is that almost all NGOs are in favor of offshore wind. Not only because of the ability to generate renewable energy, but they also point to the environmental benefits. It was different with O&G because the idea of oil was dirty and harmful to the environment.

Social

- When NGOs, developers and government agencies consider the environmental benefits at the early stages, they can work together towards a solution that has broader societal support. If the industry accepts its responsibility, the debacle of Brent Spar is unlikely to be repeated. This is one of the objectives of the ROAD2SID project.

Appendix D: Interview with participant A3

Interviewee Identification

Participant A3 is a professor in experimental biological oceanography. He is experienced in providing the EU with advice on fisheries, aquaculture and marine spatial use. Since 2020 he is the head of the department of Coastal Systems within NIOZ. In terms of the ecology of the North Sea, he has studied hydrography, oceanographic processes and frontal zones. So, he is familiar with how infrastructures like wind farms will create changes in physical properties of the seawater, that will affect productivity and the contentious issue of planning.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 28th at 14:00, lasted around 30 minutes and was carried out in English. The condensed results of this interview are presented below. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in the ecological impact of offshore wind development and decommissioning. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon a topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of his own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your background?
      c. What is your position at NIOZ?
      d. What is your expertise?

2. **Organization**
   A. What can you tell me about NIOZ?
      a. What is its mission?
      b. Who are NIOZ's clients?
      c. What kind of research does NIOZ participate in?

3. **Offshore wind**
   A. What is NIOZ's position on offshore wind?
   B. What do you consider the NIOZ's task in this arena?

4. **Ecological research**
   A. What research regarding offshore wind has NIOZ carried out?
   B. What research regarding offshore wind decommissioning has NIOZ carried out?
   C. What are the major impacted categories of offshore activities?

D. How does natural turbidity due to sea dynamics relate to human soil disturbance in terms of ecological impact?
E. What can you tell me about the facilitating function of offshore wind turbine substructures on marine ecosystems?
F. What can you tell me about the effect of fishing bans in offshore wind farms areas on fish stocks?
G. What can you tell me about the effect of noise mitigation measures during offshore activities?
H. On a general level, how concerned are you with the increased use of the North Sea for economic purposes, from an ecological and environmental perspective?

5. Other
A. Is there anything else that comes to mind that I have not asked but that might be important?
B. Do you have any questions for me?
C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it.

Interview Results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what she conveyed. The personal introduction that was given was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- NIOZ is a science provider that conducts fundamental research. NIOZ is the oceanographic facilitator for the Netherlands, so we do not have policy stances on issues such as wind farms or floating solar energy devices etc. It does study the historical and potential projected impacts of those types of things on the ecology and physics of those areas.

- The Department of coastal systems focuses on the Wadden Sea and near shore coastal areas, but also offshore areas and shelf seas, such as the North Sea.

- Clients of NIOZ include large-scale EU projects, Dutch ministries, NWO, Waddenfonds and some industrial partners. NIOZ only works for industrial parties when they are guaranteed the ability to conduct full research without results being censored or edited in any way. NIOZ also often collaborates with Deltares and Wageningen Marine Research.

- The department of Coastal Systems houses some experts on the impact of offshore wind farms on birds and bats and the physical impact of wind farms on the marine environment, in terms of stratification, productivity, siltation and suspended particle matter.

Ecological research

- Considering the ecological impact of offshore activities, there is a lot of uncertainty what exactly will happen at the base of the food web that fuels a lot of benthic or pelagic productivity. In terms of phytoplankton productivity, changes in stratification, changes in nutrient dynamics. The amount of phytoplankton productivity impacts the productivity of zooplankton, which is eaten by fish, which affects marine mammals etc.

- The impact on birds and bats depends heavily on which species you are looking at, which areas you investigate and the presence of flyways. There are some important flyways between the Dutch coastal area and the UK for example. Therefore, the location of the wind farm is very important in determining the impacts on flyways, and therefore on migrating birds and bats.

- The annual productivity cycle is different in different areas in the North Sea. Most of the Dutch part of the North Sea is shallow and well-mixed. However, there are areas of seasonal stratification, which is very important for driving the spring-bloom of phytoplankton, which then fuels zooplankton. Turbidity as a result of offshore installation/decommissioning processes limits the amount of light available in the water, which inhibits phytoplankton productivity.

- It is true that the North Sea is a very dynamic shelf sea by nature and that some of its areas have changed considerably throughout the years. It really depends where the benchmark is set. Oyster reefs, for instance, once were abundant in the North Sea, which would also have had a mitigating effect on natural turbidity. So, one should consider a moving benchmark of what can be considered a pristine natural system.

- The effect of fishing bans in wind farm areas and potential fish stock growth is complex. It is too easy to say that just because an area is closed for fishing and soil disturbance for 15 or 20 years, the effects will be solely positive of negative. There will be changes, that is clear. In my experience, long-term studies have not shown a change in the benthic communities as a result of elimination of soil disturbing activities, beyond the massive disturbance that occurred during the development. Of course, this development can be actively promoted, however it is not a natural phenomenon.

- The topography of the North Sea makes it very complex, as there is a shallow southern area and a deeper northern area. It is characterized with seasonal reversals, temperature tolerances and weird migration patterns, a complex, multi-sectoral and multinational issue.

- When an impact study focuses on an individual wind farm, some impacts might be considered negligible, although the cumulative impact of multiple wind farms in an area might be significant. The magnitude of the offshore wind farms installed in the North Sea could significantly reduce the amount of wind and potential mixing patterns in the North Sea. The magnitude of the associated consequences is uncertain as this has not happened before on such scale. Also, any kind of physical disturbance on processes that move silt and sand near the Dutch coast may potentially impact the barrier island systems such as the Wadden Sea, a World Heritage site.

Policy

- Policy should be aimed at the potential co-use of wind farm areas. This should be investigated thoroughly as potential benefits and negative impacts differ per location.

- Marine Protected Areas (MPAs) are designed around central fish habitat, which should account for juvenile and adult requirements. So, such an area is planned based upon the life history strategy of the species you are trying to protect. It is therefore ungrounded to use marine protection as an argument for a wind farm in a single location.

- Metal bridges or oil rigs that have been sunk, benefits local inwater communities because of the spatial complexity of the structure. Monopiles are not that spatially complex and there is doubt whether they can function as an artificial reef. However, it also depends on how the area develops during the course of the wind farm. When there is a lot of benthos or fish productivity in the area, it makes no sense to destroy it.

- In considering the energy transition, multiple aspects play a role. Renewable energy development, nature conservation but also cultural heritage, such as fishing-based communities. So, tradeoffs are unavoidable in that regard. As a scientist it is our job to provide science-based information and co-design scenarios which policymakers can use to decide what will be prioritized.

- What I am most concerned about is not necessarily in rich countries such as the Netherlands, but in developing countries that do not have the resources or funding systems for research into the impact of offshore wind development on natural environments. The Netherlands has several long-term studies, such as WOZEP, which will ultimately deliver very important results in how offshore wind developments affects the North Sea ecologically. The Netherlands will undoubtably become world leader in terms of research on the projected impact of wind farms and the co-use of complex shelf seas.

Appendix E: Interview with participant B1

Interviewee Identification

Participant B1 studied Civil Engineering at Twente University of Technology. He graduated on the subject of shared-use offshore wind farms at contractor van Oord. Subsequently he started working at ECHT, where he currently is a project manager on the level of energy and circularity. He is responsible for the project Circular Wind Hub and is in charge of the nature reinforcement projects in wind farms.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 8th at 13:00 and lasted around 45 minutes. Since both the interviewee and the interviewer are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for verification.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy and market developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at Business in Wind?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. What can you tell me about ECHT?
      a. What is its mission
      b. What goals does it pursue?
      c. Which partners are involved?
      d. How large is the organization?
      e. How did ECHT come about?
   B. What projects does ECHT currently carry out with regard to offshore wind?
   C. What are the motives behind these projects?

3. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the future of OWF decommissioning?
   C. Where do you think the biggest challenges lie?

4. **Policy**

A. What do you think of the current policy for decommissioning on the North Sea?
B. What recommendations would you have for policy on decommissioning on the North Sea?
C. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
   A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
   B. What factors do you think are important for social acceptance?

6. **Other**
   A. Is there anything else that comes to mind that I have not asked but that might be important?
   B. Do you have any questions for me?
   C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it. Are you okay with that?

Interview Results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction B1 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- ECHT is a project management agency. This means that ECHT carries out various types of **E**nergy, **C**ircularity, **H**uman capital and **T**ransition projects for companies, governments and knowledge institutions. They have a holistic view of the wind industry and are made up of engineers, policy experts and NGO-like individuals. They benefit from the large network of companies around them.

- One of their main projects is Circular Wind Hub. The initiative grew out of the Ministry of Economic Affairs and Climate and the Ministry of Transport, Public Affairs and Water Management, who saw a need for a circular and sustainable approach to the growing number of wind turbines approaching end-of-life. ECHT started by conducting many interviews and later hosted events around the topic. At the moment there are conversations with 3 major European institutions to lobby for subsidies to fund a new infrastructure for the circular treatment of old wind turbines.

- In addition, ECHT is reaching out to companies along the entire offshore wind value chain to gather their views on the subject. It is important to know their point of view in order to determine what is the best approach for consultation. ECHT also carries out quality assurance and control for wind turbines, so it is also involved with the physical aspect of offshore wind.

Policy

- Starting 2022, tenders for offshore wind will include a more detailed requirement for decommissioning. Bank guarantees are currently not expected to be sufficient. Waste management or circularity requirements are also expected to be included in the tenders. Not only will future wind farms be subject to these new regulations, the government also has the power to dictate terms for the decommissioning of existing wind farms. Considering that the Netherlands agreed to circularize 95% of its resources in 2050, this would mean that wind farms should also be reused, recycled or repurposed.

- Personally, the interviewee is a proponent of leaving scour protection in situ. Rock is a natural resource that is already present on some parts of the seabed in the North Sea. It has a positive ecological effect, which is becoming increasingly important in offshore wind. He also advocates removing monopiles and cables. In light of the circularity targets, it would be unacceptable to leave them in situ while technology allows for removal. His expectation is that governments will mandate the complete removal of foundations and cables.

- Most existing wind farms have been built with the help of subsidies. It would be strange to leave substructures in place afterwards under the norm of making more profits. A more proactive approach like nature enhancement activities on scour protection is likely to be much better received by society, setting a good example for the oil and gas industry. Public acceptance will be key to the future development of offshore wind.

- The argument that the direct impact of cable removal on the seabed is too severe and therefore they should be left in situ is not that strong, since it may not be that influential to the whole ecosystem. The area affected is very small compared to the total surface area of the North Sea. Sediment redistribution and bottom disturbance also occur naturally due to North Sea dynamics.

Market

- The impact of decommissioning activities on natural enhancement projects at the base of a wind turbine remains unclear. Caution will be very important around these biodiversity hotspots. If a developer argues that scour protection should remain after decommissioning for its ecological benefits, it would be strange to destroy that ecosystem during decommissioning.

- Developers are advised to investigate the use of more naturally occurring materials in offshore wind, as their limited ecological impact when left in situ will ease the process of decommissioning. Rock already occurs in the sea, but metals and plastics do not.

- It is also recommended that developers invest avoided decommissioning costs in enhancing nature or public acceptance, rather than use for profits.

Social

- NGOs often represent real concerns that exist in society and they do so out of intrinsic motivation. Although most of them probably do not like the way the North Sea is being burdened, some are positive about offshore wind development. Especially when developers and contractors approach installation and decommissioning respectfully and responsibly. NGOs can be expected to become more sympathetic to leaving scour protection behind, given its significant ecological value.

- The benefits of nature enhancement measures potentially extent far beyond the initial region of deployment. In 20 to 30 years, billions of oysters could develop from one deployed oyster bank. Therefore, the ecological impact of decommissioning is insignificant in comparison.

- Circularity does not necessarily mean that everything that is used must be recovered, reprocessed and recycled or reused. It can also mean that, by being left behind, it serves a new function, for example as with scour protection.

- Lifetime extension, repowering and circular decommissioning and waste management are the first steps towards a circular use of offshore wind.

- Regarding the fisheries. True social acceptance will be achieved if the fisheries are included in this decommissioning process. Some sort of symbiotic relationship would be optimal.

Appendix F: Interview with participant B2

Interviewee Identification

Participant B2 has a civil background and began working in 2004 at Windbrokers, a company specialized in the decommissioning of onshore turbines. When it merged with an Indian company, it became more concerned with manufacturing new turbines. From 2013 to 2018, B2 was Director Projects and Services at Lagerwey, which was later acquired by Enercon. There, he was responsible for the construction and maintenance of wind turbines that were under their responsibility. When Lagerwey was acquired by Enercon, he and a few others left the company and they formed Business in Wind. His personal experience in decommissioning is 1000+ onshore turbines, not so much offshore.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 19th at 13:00 and lasted around 30 minutes. Since both B2 and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy and market developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic. Note, the interview results are meant for the purpose of this thesis only and cannot be used for other projects without consent from the interviewee and Business in Wind.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at Business in Wind?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. Could you tell me about Business in Wind?
      a. What is its mission
      b. What goals does it pursue?
      c. Which partners are involved?
      d. How large is the organization?
   B. What projects does Business in Wind currently carry out with regard to decommissioning?
   C. What are the motives behind these projects?

3. **Market**

A. What is your opinion on the current approach to OWF decommissioning?
B. What is your opinion on the future of OWF decommissioning?
C. Where do you think the biggest challenges lie?

4. **Policy**
    A. What do you think of the current policy on decommissioning in the North Sea?
    B. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
    A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
    B. What factors do you think are important for social acceptance?

6. **Other**
    A. Is there anything else that comes to mind that I have not asked but that might be important?
    B. Do you have any questions for me?
    C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it.

Interview Results

This section addresses the key takeaways from the interview conducted with participant B2. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction B2 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- The core mission of Business in Wind is to find and buy used wind turbines, dismantle them and find a second life for them. In some cases, they also facilitate reinstallation and commissioning. When this is not economically feasible, recycling is the alternative. The second-hand market for wind turbines has grown very quickly. What sets Business in Wind apart is its experience in dismantling turbines in difficult locations and its ability to facilitate the entire decommissioning process.

- Over the years, there have been a few small decommissioning operations, but they have all been on a small scale. The coming years will mark a new trend that will require decommissioning at a rapid pace. There are many benefits to be gained in logistics, so it is vital to consider this carefully. The company has offered to decommission the offshore wind farm Irene Vorrink. The plan is to remove the complete monopiles in cooperation with Fugro, DOT, the Water Board and Vattenfall.

- The developers we are dealing with are too focused on repowering the area to think about decommissioning. We take away their worries in this process and facilitate the complete decommissioning. We can also remove foundations, (electrical) infrastructure and connections. We do the entire OEM scope, but in reverse order.

- Example: at the end of the year, we dismantle turbines in Belgium, refurbish them and reassemble and commission them in England. We will also organize the foundations and connections to the grid in collaboration with partners.

Market

- It is assumed that in the near future it will be decided that the entire substructure must be removed. This can already be seen in the RWS tender for the Maasvlakte, where they require that the entire foundation be removed afterwards. DOT has advised how this should be done. Ultimately, the idea is that nothing is left in situ.

- Reusing monopiles is simply not feasible. You have to deal with fatigue, uncertainty of condition and they are designed for a different capacity and shorter lifespan. Cables, on the other hand, still have value. Although, when it comes to aluminum cables, the cost does not outweigh the recycling value. The impact also depends on the removal method.

- We are also increasingly advising developers who ask us what it will cost to dismantle a wind farm in 20 to 25 years' time. Used wind turbines in good condition are worth something now, but it's expected that this small market will be flooded in a few years, making them virtually worthless. So, we are creating some sort of budget for these developers that they can then use to make a financial reservation with the IRS for decommissioning.

Policy

- Business in Wind has collaborated with TNO a few times to look at the politics around recycling offshore wind turbines. There are stories about recycling parties buying up the rotor blades and using them as landfill in Romania. To get rid of that, real recycling needs to become cheaper. Ultimately, policy must ensure that the most sustainable option is the most beneficial.

- We are also working with NWEA, VWEA and ECHT to make end-of-life policy accessible. Whereas in the past the focus has always been on the construction and operation of wind farms, now decommissioning is becoming truly relevant. We are trying to play an active role in this with Business in Wind.

- Every time a wind farm reaches end-of-life, there should be a specific assessment of the biological and ecological situation that ultimately determines the extent of decommissioning. It would not make sense to create a regulation for this, because that would run counter to the principle of specific and individual assessment.

Social

- Business in Wind does not suffer much from social discontent, often people are pleased when we come because we remove the turbines. However, we try to paint a positive picture of recycling and reusing wind turbines. Mainly to refute the false arguments of the opponents of offshore wind and its sustainability. Our aim is that nothing goes to landfill and everything is recycled.

- Society will demand that the default position is to remove the entire substructure unless you can show with good reason why the coral that grew on it is better off if something is left behind. This brings us back to project specific evaluation. Establishing criteria for this is very difficult because all projects are so different. Since society often judges by emotion and not rationality, it is very difficult to convince them of anything.

- Offshore wind developers have a reputation for being profiteers, so they have to be particularly careful that decisions are not made for financial reasons or look that way, because that would certainly bring public disgrace.

- It will be important to take end-of-life into account during design/installation. Research will make it possible to predict whether the impact of a particular decom strategy will be positive or negative.

Appendix G: Interview with participant B3

Interview Identification

B3 studied Civil Engineering before working in several positions offshore on Heavy Lift Vessels owned by a Dutch marine contractor. He has over 10 years' experience in preparation and execution in offshore operations in the transport, installation and decommissioning of O&G facilities. Within the offshore renewable energy industry, he focused on tender management for transport and installation (T&I), as well as leading the research and development programme for wind turbines generators installation by floating vessels.

B3 started working at Vattenfall as tender manager for Hollandse Kust Zuid OWF, focusing on T&I contracts for foundation, cable and WTGs. For 2 years he is responsible for the Installation and Decommissioning department. He manages the development of offshore (T&I) and decommissioning technologies of future offshore windfarms, including engineering, business case set-up (CAPEX), supplier strategy, risk management and stakeholder management. As a department head, he leads the T&I development managers, cost engineers and T&I engineers.

Interview Set-up

The interview was scheduled on August 4th at 13:00 and lasted around 30 minutes. Since both B3 and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy and market developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   - B. Could you briefly introduce yourself?
     - a. Who are you?
     - b. What is your position at Vattenfall?
     - c. What is your expertise?
     - d. What is your experience within the sector?

2. **Organization**
   - A. What can you tell me about Vattenfall and your department?
     - a. What is its mission
     - b. What goals does it pursue?
     - c. Which partners are involved?
     - d. How large is the organization?
   - B. What role does Vattenfall and your department have in offshore wind development?
   - C. What role does Vattenfall and your department have in offshore wind decommissioning?

3. **Market**

A. What is your opinion on the current approach to OWF decommissioning?
B. What is your opinion on the how developers/owners should integrate decommissioning in their strategies?
C. Where do you think the biggest challenges lie for the market within the context of decommissioning?

4. Policy

A. What do you think of the current regulatory framework regarding decommissioning on the North Sea?
B. What policy improvements would you suggest, if you would suggest any?
C. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. Social

A. What is in your opinion, important in achieving social support for decommissioning?
B. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?

6. Other

A. Is there anything else that comes to mind that I have not asked but that might be important?
B. Do you have any questions for me?
C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it. Are you okay with that?

Interview Results

This section addresses the key takeaways from the interview conducted with participant B3. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction B3 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- Vattenfall is responsible for development of offshore windfarms on running assets (foundations, inter-array cables, WTGs) and depending on the country/project for the development of non-running assets (offshore substations, export cables). Vattenfall primarily focus is on offshore windfarms in Europe as developer of offshore windfarms during all stages, being tender, consenting, construction, operations and decommissioning. In that perspective, the department I am heading is responsible for development, tendering and contracting of marine contractors for T&I and decommissioning of the offshore windfarms which are in construction, in development or in operation.

- Our department provides solutions in development stage and tender stage, for T&I methodologies of offshore windfarm components (e.g., WTG foundations, cables, WTGs and offshore substations). One year ago, tasked to set-up the decommissioning department for all running assets and development projects (5GW secured pipeline and 15 GW planned pipeline).

Market

- Vattenfall considers decommissioning during development stage, in the design of the Offshore Windfarm components, as well as the transport & installation philosophy, where often decommissioning is seen as reversed installation. Items which cannot be decommissioned by reversed installation need additional focus and engineering to come with future solutions with enough confidence on development of technology and economic investment. All in line with Vattenfall's corporate strategy of being 'Fossil Free within One Generation' as well as taking responsibility on the CO2 footprint and environmental impact of our activities.

- It is difficult to say how other developers and owners are looking into decommissioning of offshore windfarms. However, information which can be found in the public domain such as decommissioning plans (in the UK) or environmental impact assessments (EIA) for new windfarms (UK, Denmark, Norway) show a trend in statements (in EIAs) mentioning that decommissioning has less impact than the installation/construction phase of a windfarm.

- In many decommissioning plans for offshore windfarms, I see often statements that sub-sea structures remain in places, such as cables, scour protection and sometimes partly the monopile.

- Potentially these statements come from offshore decommissioning of Oil & Gas facilities where items like pipelines, cables and often foundation piles (main piles, skirt piles, pin piles) remain in a state where they are cut below the mudline. The applicability of the statement is comparable till a certain degree, however the size of an O&G facility is way smaller (with higher energy density per square meter for structures in ~100 m below seabed and all facilities above seabed) compared with offshore windfarms, where many structures are installed (since having a low energy density per square meter compared to Oil and Gas).

- In general, it seems that decommissioning is seen as a scope that does not need to be materialized soon so many governments, developers and suppliers are awaiting the first offshore windfarms to be decommissioned in order to learn and set the base.

- In my opinion, the development of an offshore windfarm should take the decommissioning and disposal fully into account in order to understand the impact on the design. This could change the design and T&I philosophy of offshore windfarm components in early stage. Taking decommissioning into account in early stage, gives the ability to influence the design without necessarily extra cost or complexity. In early stage, good choices can be made to better plan the decommissioning and disposal of an offshore windfarm, also securing control of CAPEX in later stage.

- It also creates a good timeframe to influence the supply chain and take contractors along in developing the right methodology in technology, operations, vessel / yard capacity and availability for a commercially viable price.

- Take the effort to close the loop when reviewing a concept or technology. Don't be opportunistic in early stage of development without fully checking the side effects on all (technically, commercially, economically, legally and till a certain extend politically and socially) factors.

- Offshore decommissioning in the oil and gas sector learned that a good supply chain and technology environment is set-up by joint industry projects, early development of technologies and focus on the supply chain for the offshore removal and transport and onshore disposal.

- The biggest challenge will be on the number of offshore windfarms that are planned to be constructed in the future on a global level, in the end generating a huge number of components to be safely and in a responsible way decommissioned at the end of lifetime.

- Focus on lowest cost of energy (LCOE) could create opportunism or conservatism on lowering the CAPEX requirement for decommissioning in early stage to meet the commercial standard of the offshore wind industry, resulting in underestimation of the decommissioning scope.

Policy

- I think the regulatory framework is often very clear stating that areas for offshore windfarm development should be re-instated as before construction of the windfarm.

- What could be improved is the focus defining the framework to a deeper level, taking into account the practical execution of the regulatory framework. Focus should then also be on this framework during Tender and/or Consenting stage and pinpointing what the requirements are for the development of an offshore windfarm (full removal, less impact on environment, same state as before construction, potential a new approach which will be in line with future policy with regards to the consented and developed area)

- Governments have (or should have) the overview of how they would like to develop the areas for the coming decades or even centuries and therefore the rightful owner of the framework. It is important to keep a continuous dialogue between stakeholders so the framework is feasible to be executed.

- In the Netherlands we have a great system and transparency in offshore wind. High quality deliverables are provided (soil data, met-ocean data, consenting requirements) when tendering and developing a new offshore windfarm. Next step is to focus on the practical execution of decommissioning.

Social

- In achieving social acceptance for decommissioning OWFs, I think transparency by the developer on what is happening and keeping relevant stakeholders in the loop is most important. The developer can create social support by creating transparency and communicating this clearly to all relevant stakeholders in the decommissioning strategy of a specific windfarm or in line with the strategy of the company.

Brent Spar

- Regarding the brent spar public outcry, I think that can also happen with offshore wind but all depending on the impact and accompanied arguments. Therefore, transparency is necessary on all the subject matters being discussed in this master thesis.
- Due diligence needs to be performed by the developer in order to develop a strategy and execution plan for decommissioning. In the due diligence process following aspects should be taken into account: technical feasibility, economic feasibility, environmental impact, societal impact in combination with the legal requirements and governmental policy.

Appendix H: Interview with participant B4

Interview Identification

After studying Mechanical Engineering, B4 worked several years at an engineering firm. He started working in the offshore industry in 2006 at a large Dutch offshore contractor. After that, he worked for 2 other large offshore contractors. The projects executed were mainly offshore installation & removal projects for the Oil & Gas industry. The roles he fulfilled range from Installation Engineer, Engineering Manager, Technical Project Manager and his current role as Product Manager. In 2020 he joined Vattenfall as product manager decommissioning, where he was tasked to set-up decommissioning for all running assets (in total 10 OWFs) and development projects (5GW secured pipeline, 15GW planned pipeline).

Interview Set-up

The interview was scheduled on August 4th at 14:00 and lasted around 30 minutes. Since both B3 and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy and market developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at Vattenfall?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. What can you tell me about Vattenfall and your department?
      a. What is its mission
      b. What goals does it pursue?
      c. Which partners are involved?
      d. How large is the organization?
   B. What role does Vattenfall and your department have in offshore wind development?
   C. What role does Vattenfall and your department have in offshore wind decommissioning?

3. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the how developers/owners should integrate decommissioning in their strategies?
   C. Where do you think the biggest challenges lie for the market within the context of decommissioning?

4. **Policy**

A. What do you think of the current regulatory framework regarding decommissioning on the North Sea?
B. What policy improvements would you suggest, if you would suggest any?
C. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
A. What is in your opinion, important in achieving social support for decommissioning?
B. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?

6. **Other**
A. Is there anything else that comes to mind that I have not asked but that might be important?
B. Do you have any questions for me?
C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it. Are you okay with that?

Interview Results

This section addresses the key takeaways from the interview conducted with participant B4. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction B4 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- Decommissioning is part of the Marine Logistics & Installation department. Marine Logistics & Installation is the center of competence in the areas of offshore installation, offshore construction and logistics solutions for offshore installation and maintenance, within the backbone of Engineering.

- Marine Logistics & Installation is engaged from the early phases of a development project, in supporting the business cases, developing the building blocks for the development portfolio, the installation, construction and maintenance of an offshore wind site and finally decommissioning of the wind farm.

- Effectively the Decommissioning Department is providing solutions and associated budgets for, removal & disposal of offshore windfarm components (e.g., Wind Turbine Generator, foundations (including potential scour protection), Inter-Array Cables, Export Cable and Offshore Substations).

Market

- The transition to an energy system based on renewable energy sources is in full swing. Offshore wind farms are and will continue to be built in order to contribute to a more sustainable energy mix. However, with an expected operational life of 20 – 25 years for offshore wind farms installed in the early 2000s, decommissioning will become an important consideration. Consequently, the topic of decommissioning offshore wind farms is gaining traction within developers, marine contractors, ports and tooling suppliers.

- Having said that, developers still have a quite opportunistic approach towards decommissioning of offshore wind farms. When asked how a certain offshore wind farm will be decommissioned, the answer is quite often that everything will be decommissioned by reversed installation. This is view of decommissioning is too simplistic and is in reality in most cases not possible for the foundations, inter-array / export cables and offshore substation. For these subsea structures a dedicated removal methodology including specialized technology is required.

- Decommissioning should be part of the full lifecycle of the Offshore Wind Farm. Hence, decommissioning should be already considered during the development phase of an offshore wind farm. This to ensure that full removal of the offshore wind farm can be performed in a cost-effective manner at the end of the operational lifetime.

- All stakeholders are currently focused on their own interest (which is obvious though). So, I reckon that the biggest challenge is adopting a holistic approach towards decommissioning and re-using the same area again for renewable energy generation.

Policy

- In all fairness I think the current regulatory framework for the North Sea region is pretty clear. Effectively the regulatory framework in the following European countries (The Netherlands, UK, Scotland, Germany, Denmark and Sweden) requires full removal of the Offshore Wind Farm.

- The BEIS Guidance note states for Offshore Renewable Energy Installations (OREI) in the UK the following:

  "7.2.1 It is expected that all installations and structures will be fully removed at the end of their operational life to minimize residual liabilities and that approval of decommissioning programs will be based on this assumption. "

- Obligations under the Production License (Elproduktionstilladelse) in Denmark state the following:

  "The Concessionaire must, at its own cost, restore the area to its former condition, including carry out clean-up and tidying as necessary in the area, as well as decommission and entirely remove the electric electricity generating facility according to a decommissioning plan approved by the DEA."

- Nevertheless, the majority of the Decommissioning Programs available in the public domain consider leave subsea components *in situ*.

- It is my recommendation for the regulator to adhere themselves to their own regulatory framework. Be strict, be fair and be transparent wrt the obligations. Hence ensure that the expectations are clear and provide an equal playing field for the Developers. At the moment you see the tendency that developers refer to Decommissioning Programs from other developers which in most cases propose to leave the majority of the subsea structures *in situ*. The argument developers use for their proposal to leave subsea structures is that other developer also propose to leave subsea structures *in situ*. Quite often this is not based on technical limitations nor an environmental impact assessment.

Social

- What is important in achieving social acceptance for decommissioning OWFs is to focus on the total value chain and circularity of the Offshore Wind Farm. Maybe responsible "end of life management" can even be a selling point of developers. Just be open and transparent of the issue you face and share this with the society. I think the way The Ocean Clean-up is communicating openly their failures and successes is the way to go.

- The role of a developer in achieving this social acceptance is proper stakeholder management.

Brent Spar

- The topic of blade waste material is very visible to the public eye. I think how the industry will deal with the blade waste material is key in preventing a social uprise like with the Brent Spar. The developers have acknowledged the importance of handling the blade waste material in an environmental sound manner already. Land filling is, or will be, forbidden in most European countries, so to my opinion this topic is in hand and should not cause any social uprise.

- How developers deal with the subsea infrastructure is less visible to the public eye and less likely to cause a social uprise. Nevertheless, how the waste of the subsea infrastructure is handled by developers is equally important.

Appendix I: Interview with participant B5

Interviewee Identification

Participant B5 has 4 years' experience as sector specialist at NWEA, of which the last year he specialized in offshore wind and represents the industry's interests. Before that, he worked at NWEA on social issues of wind energy, such as corporate social responsibility, recycling and the labour market. His specific task is to collect and distill the major viewpoints of NWEA's members and actively lobby at governments and NGOs.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on August 3rd at 15:00 and lasted around 30 minutes. Since both the interviewee and the interviewer are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for verification.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy and market developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon a topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at NWEA?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
      a. What can you tell me about NWEA?
      b. What is its mission
      c. What goals does it pursue?
      d. Which partners are involved?
      e. How large is the organization?
      f. How did NWEA come about?

3. **Decommissioning**
   A. What is NWEA's stance on the dilemma between partial and complete decommissioning of substructures of OWFs?
   B. How is NWEA involved in preparing its members for decommissioning?
   C. In light of future offshore wind development, some say it is best to actively pursue complete decommissioning as this will result in the least obstructions in the future. What is your opinion on that?
   D. Where do you think are the largest challenges in decommissioning?

4. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the future of OWF decommissioning?
   C. Where do you think the biggest challenges lie?

5. **Policy**
   A. What do you think of the current policy on decommissioning in the North Sea?
   B. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

6. **Social**
   A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
   B. What factors do you think are important for social acceptance?

7. **Other**
   A. Is there anything else that comes to mind that I have not asked but that might be important?
   B. Do you have any questions for me?
   C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it. Are you okay with that?

Interview Results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction B5 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- NWEA is the Dutch industry association for wind energy. It currently employs 10 people fulltime, of which 6 are sector specialist. NWEA has around 300 members, all companies active in the Dutch wind sector. They actively participate with representatives in various working groups, committees and subcommittees to discuss specific topics and arrive at conclusions together.

- NWEA began as an interest group when wind power was mostly deployed by farmers and other individuals. Since the energy transition, many multinationals have invested in wind energy, both onshore and offshore, which is how the member base of NWEA changed. In terms of influence and status these new members are major players in the industry, all owning a large share of the market.

- NWEA performs in the policy arena and although its accomplishments are very important for its members, they are not always visible to the public. Per example, NWEA lobbies for acceleration of the roll-out of the offshore wind programme of the Dutch government.

- Besides lobbying for wind farm specifics, such as installed capacity or number of turbines, NWEA also pursues optimal development conditions. Because a windfarm that is not profitable, will not be built.

Decommissioning

- With regards to the specific dilemma of partial vs. complete decommissioning, NWEA does not have a concrete stance. We notice that our members also differ in that regard and that they worry about the potential social response to different scenarios.

- When there is proof that an offshore wind farm foundation has evolved and has significant ecological value, it seems unsensible to remove and destroy that value. At the same time, we as a sector do not want society to imply that the offshore wind sector does not clean up its mess. In that regard we vacillate between those views, as do most of our members, I guess.

- Personally, B5 thinks that the coming years will show significant investments in the creation of ecological value around turbine foundations and it will be almost unthinkable to remove that when decommissioning takes place. On the other hand, it depends on ecological research whether the ecological situation is actually desirable. He expects that additional regulations regarding decommissioning will be introduced, but remains positive on the chances of partial decommissioning, where appropriate.

Policy

- B5 expects that decommissioning and waste management will receive increasing attention over the following years. The Hollandse Kust West tender lots already focus on specific topics such as ecology and system integration. The expectation is that future tender requirements will prescribe decommissioning in detail.

- If this is not regulated, it becomes very difficult to make a business case for it. We have already seen this in the recycling of wind turbine blades, when this was not yet prescribed. When it becomes regulated, companies will automatically look for ways to solve the problem and often succeed.

Market

- B5 acknowledges that the market recognizes that there are long-term implications of partial decommissioning that may complicate the future of offshore wind development. What he has also seen in recent years, however, is that the government has almost purely focused on cost reduction. Offshore wind had to become as cost effective as possible, as quickly as possible, along the entire value chain. As a result, there has been little attention paid to decommissioning, as those costs will come many years later.

- This illustrates the peculiar situation of having a booming market, where there should be enough room for profitability, but because cost reduction has been pushed so hard, the margins are wafer-thin. This is a high-risk business, which also explains why the developers did not do more than was asked of them in the tender. Because if something goes wrong, the costs are immediately too high.

Social

- B5 does not particularly expect social outcry caused by decommissioning scenarios, unless decommissioning is not carried out at all and the components are left in the North Sea. However, it is not expected that governments will allow this and the financial security provides some insurance. For now, we assume that if oyster banks or mussel beds have developed around wind farms, developers will not be obliged by the government to destroy it.

Other

- Decommissioning leads to more shipping movements, which results in more costs and emissions. As a sector, we are also working hard towards zero-emission shipping, because as a construction sector we are subject to strict standards regarding nitrogen and carbon dioxide emissions. In addition, some sound mitigating measures, such as the bubble screen, are also very energy-intensive and we really need to get rid of them.

Appendix J: Interview with participant C1

Interviewee Identification

Participant C1 is project manager for "nature-friendly energy" at Stichting De Noordzee. Together with a team of ecologists she is actively engaged in discussions around offshore wind and the Energy Agreement and strives to highlight the importance of ecological research in the process.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 15th at 16:30 and lasted around 30 minutes. Since both the participant and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in the standpoint of environmental NGOs on offshore wind and decommissioning. The interviewee has been made aware that it is the researcher's objective to let her speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon the topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic. Note, the interview results are meant for the purpose of this thesis only and cannot be used for other projects without consent from the interviewee and Stichting De Noordzee.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at Stichting De Noordzee?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. What can you tell me about Stichting De Noordzee?
      a. What is its mission?
      b. What is the size of the organization?
      c. Who do you cooperate with?
      d. How did Stichting De Noordzee come about?

3. **Offshore wind**
   A. What is the foundation's position on offshore wind?
   B. What do you consider the foundation's task in this arena?

4. **Decommissioning**
   A. What is the foundation's position on decommissioning?
   B. What is important in considering decommissioning?

C. What is your opinion on the current governmental policy with regards to decommissioning?
D. Should fisheries be considered in decommissioning decision-making?
E. What do you think will be important in achieving social acceptance for decommissioning?
F. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?

5. **Other**
   A. Is there anything else that comes to mind that I have not asked but that might be important?
   B. Do you have any questions for me?
   C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it.

Interview Results

This section addresses the key takeaways from the interview conducted. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what she conveyed. The personal introduction that was given was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization:

- Stichting De Noordzee is a moderate environmental NGO, meaning that they adopt a benevolent attitude in discussions and refrain from purposefully obstruct constructive negotiations. However, although they search for common ground with other stakeholders, they certainly do not agree automatically with everything proposed. This approach differentiates them from other environmental NGOs. Furthermore, the foundation acts on the basis of four pillars:
  - The clean sea: deals with cleaning up beaches and keeping out plastics and other debris from the Sea.
  - Space for nature: addresses initiatives for nature reinforcement measures
  - Sustainable food: concerns sustainable fishing and aquacultures
  - Nature friendly energy: pursues minimal damage from offshore energy generation and optimal use of environmental opportunities

- The foundation is not a research agency, so only a limited amount of research is done inhouse. The main goal is to make the government aware of the importance of ecological research in and near wind farms on the North Sea.

- Collaboration with other NGOs is become more and more important, not only in the Netherlands but also international. In the past six years, there have been many developments to ensure the Dutch part is in good order. Now the focus shifts to cooperation with Belgium and Germany for instance.

- Recently, the foundation has also been involved in issuing the new tenders and is asked what is ecologically important. They suggest a number of things and it is then up to the government to see what is feasible.

Offshore wind

- Fundamentally, we are in favor of offshore wind. We believe the energy transition is required to achieve our climate targets and offer perspective for the future. Offshore wind is an important part of that strategy and will generate a significant part of the Dutch demand.

- We do fight for more research: not just some general research but research budgets for every individual case. In order to achieve that we take part in negotiations and offer advise where research is needed.

Decommissioning

- With regards to decommissioning, we feel that it is important to approach it on a case-by-case basis. We therefore do not have one general standpoint on offshore wind farm decommissioning.

- Energy, biodiversity and nature reinforcement should be assessed equally in considering decommissioning.

- We also investigate what is legally possible with regards to deviating from default decommissioning scenarios. In addition, how do we deal with responsibility for any structures left behind?

- The current regulations and policy are not yet comprehensive with regards to decommissioning. The foundation argues that these laws and regulations should be looked at urgently. I have the impression that the government is aware of this but that there is now much more focus on implementing the North Sea Agreement. It's also difficult because you're now dealing with an interim government.

- The industry's and government's willingness to adapt to individually diverging research results to come up with custom strategies per wind farm, will primarily shape the public's perception and subsequently its acceptance.

- The future of the fisheries on the North Sea depends on their cooperation. We would love to have the fisheries rejoin the discussions, as negotiations are currently conducted without their presence. Sustainable and safe fishing can be part of the North Sea Agreement.

Appendix K: Interview with participant D1

Participant Identification

Participant D1 studied food technology in Wageningen. In 2006 he started working for RVO and in 2010 he worked on his first tender process for offshore wind. The Gemini and Luchterduinen wind farms won the tender and received subsidies from the Dutch government. Since 2013 he is responsible for all offshore wind tenders in the Netherlands.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 13th at 16:00 and lasted around 30 minutes. Since both D1 and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon a topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at RVO?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organization**
   A. Could you tell me about RVO?
      a. What is its mission
      b. What goals does it pursue?
      c. How does RVO relate to offshore wind development?
      d. How does RVO relate to offshore wind decommissioning?

3. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the future of OWF decommissioning?
   C. Where do you think the biggest challenges lie?

4. **Policy**
   A. What do you think of the current policy on decommissioning in the North Sea?

B. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
   A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
   B. What factors do you think are important for social acceptance?

6. **Other**
   A. Is there anything else that comes to mind that I have not asked but that might be important?
   B. Do you have any questions for me?
   C. I am going to use the recording of this interview to compile a transcript, which I will then summarize to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarized it.

Interview Results

This section addresses the key takeaways from the interview conducted with participant D1. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction D1 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organization

- The Ministry of Economic Affairs and Climate (EZK) is responsible for the policy around offshore wind. But the implementation of this policy is in the hands of the RVO. The RVO is also the executive body of the Ministry of Agriculture, Nature and Food Quality. Permits for offshore wind are issued by the RVO as it is responsible for the tenders. With regard to decommissioning, Rijkswaterstaat is the enforcement and supervisory body. The bank guarantees for decommissioning, on the other hand, are in the hands of the RVO. This is a financial guarantee of €120.000 per MW installed capacity that a developer/operator must pay at some point. After the operator has removed everything according to their agreement, the bank guarantee is released.

- In 2013, the Energy Agreement was drafted in which Minister Kamp reached agreements with the industry, social partners and NGOs. A large subsidy was made available for 5 wind farms of 750MW on the condition that the industry works towards a 40% cost reduction. Meanwhile, 2 of these farms are operational and the last one is due to be built in 2023. By then, all agreements from the Energy Agreement regarding offshore wind will have been fulfilled.

Policy

- As far as decommissioning is concerned, it is all quite abstract: a license is granted for 30 to 35 years and in the last year of that period production must cease and decommissioning must begin. What approach to decommissioning must be taken, and to what extent, really depends on what the park looks like at the time of decommissioning? It is also not permissible to start decommissioning too early; it can only take place from the 24th year onwards. At the same time, it is also difficult because at that time it was not yet clear whether a wind farm could actually last that long.

- The RVO leaves the assessment of the environmental impact of decommissioning to RWS. RWS has always said that a wind farm should be removed in its entirety unless the subsea part is part of an ecosystem worth preserving. If that is the case, then consideration needs to be given to whether complete decommissioning is the right choice or whether it would be better to leave as much as possible behind, except for those things that are necessary for safe navigation.

- With regard to fisheries, the substructures can be accurately located. Therefore, even if they are partially removed, fishing will be able to resume after decommissioning. The fisheries just need to know where to sail around. In principle, this is the same as with wrecks on the seabed. But again, that's between RWS and the fishing companies. The expectation is that once a wind farm is decommissioned, an area designated for wind energy will simply be redeveloped.

- The larger, newer wind farms in particular have a permit for a maximum of 40 years. So, they would have to be removed by 2056 at the latest. The question is whether we will still have an energy problem by then or whether everyone will look back on this time with a smile as to how we tried to produce sustainable energy.

- There is a chance that decommissioning small wind farms in the coming years will set a precedent that operators will use as a guide for their decommissioning strategy for larger wind farms. Egmond aan Zee, for example, still falls under the old regulation of the Water Act. Newer wind farms are bound by the Wind op Zee regulation. So, it could be that RWS would argue that the reasoning is not comparable. But the expectation is that the first decommissioning projects can serve as an example and that a lot can be learned.

- Brent Spar is a very different story, as it involved a major oil rig at the time. Greenpeace also went a bit too far with their campaign, which was ultimately very successful. Shell gas stations were completely empty, no one went there to refuel. If society as a whole is against something, a company will make that U-turn. The company may be right, but if it costs a lot of money, it's better to go along with it. In the past, before there was large scale fishing in the North Sea, 1/3 of the North Sea was covered with reefs. Once it is possible to reclaim some of those reefs by means of offshore wind, I can't imagine people being against it from a social acceptance standpoint. So no, I don't think we'll see Brent Spar scenes again when offshore wind farms are decommissioned.

- Requirements for decommissioning will not be part of the tender for a relatively long period of time. This is for the simple reason that wind farms will last longer and longer. Hollandse Kust West is the next tender. On one lot, we will make the difference in terms of ecology, on the other lot in terms of system integration. The moment you make decommissioning part of your tender, there is a chance that after 40 years you will have to deal with a party that does not do what it said it would do. In a tender, you want to tender something that you can assess well beforehand, but also enforce well afterwards. The studies that are done by the government in advance of tenders are of great value because there is enormous competition between companies to develop wind farms. What you don't want is someone winning the bid on the basis of commitments over 40 years.

Appendix L: Interview with participant D2

Participant Identification

Participant D2 is programme manager Offshore Wind at Rijkswaterstaat since 2019. Before that he worked at the Ministry of the Interior and Kingdom Relations (BZK) and the Ministry of Infrastructure and the Environment (I&M) on offshore wind projects. D2 is working since 2016 on the deployment of offshore wind.

Interview Set-up

The ongoing Covid-19 pandemic limited the author to carry out the interview online by means of a Microsoft Teams video conference call. The interview was scheduled on July 26th at 14:00 and lasted around 45 minutes and on August 2nd at 14:00. Since both D2 and the author are Dutch natives, the interview was carried out in Dutch. The condensed results of this interview, which will be presented below, are therefore translated from Dutch to English. An audio-recording of the interview was made in order to guarantee a meticulous transcript. Afterwards, the proceedings of this interview have been sent to the interviewee for validation.

The interview itself can be categorized as a semi-structured interview, in which the interviewer tried to steer the conversation into the areas of his interest. The main objective is to gain insight in policy developments. The interviewee has been made aware that it is the researcher's objective to let him speak as much as possible. The questions below are therefore more of a guide to ensure that the researcher obtains all the information he desires and will only be used when the interviewee does not touch upon a topic himself. In order to guarantee total objectivity, the questions asked are broad and open-ended and allow the interviewee to inform the interviewer of her own perceptions on the topic.

Questions

1. **Personal**
   A. Could you briefly introduce yourself?
      a. Who are you?
      b. What is your position at RWS?
      c. What is your expertise?
      d. What is your experience within the sector?

2. **Organisation**
   A. Could you tell me about RWS?
      a. What is its mission
      b. What goals does it pursue?
      c. How does RWS relate to offshore wind development?
      d. How does RWS relate to offshore wind decommissioning?

3. **Market**
   A. What is your opinion on the current approach to OWF decommissioning?
   B. What is your opinion on the future of OWF decommissioning?
   C. Where do you think the biggest challenges lie?

4. **Policy**
   A. What do you think of the current policy on decommissioning in the North Sea?
   B. Why is it that Dutch policy regarding decommissioning is so different to that of the UK?

C. According to current international and national legislation, complete decommissioning is the default option. However, it seems that developers do not always assume this. How do you see this?

5. **Social**
   A. You are probably familiar with Shell's Brent Spar, where the decommissioning decisions were made according to rational and scientific reasoning. Yet there was a large public outcry against this. How do you think we can prevent this from happening with offshore wind?
   B. Is there any kind of citizen involvement in the decision made regarding offshore wind on the North Sea?
   C. What factors do you think are important for social acceptance?

6. **Other**
   A. How does the RWS determine the BAT and BPEO?
   B. Is there anything else that comes to mind that I have not asked but that might be important?
   C. Do you have any questions for me?
   D. I am going to use the recording of this interview to compile a transcript, which I will then summarise to the important and relevant insights given. Subsequently, you will be contacted and asked whether you agree with the way I have summarised it.

Interview Results
This section addresses the key takeaways from the interview conducted with participant D2. The responses have been summarized for practical reasons and are not direct quotes from the interviewee unless stated otherwise. The interviewee is aware of the summary and has agreed that what follows captures what he conveyed. The personal introduction D2 gave was used to shape the section interviewee identification, and will therefore not be displayed here again.

Organisation
Rijkswaterstaat has two functions on the North Sea. In the first place it is the designated authority for the Dutch part of the North Sea. That includes supervision, enforcement, issuing permits, coordination and all management functions of the waterworks. The second is an advisory and contracting function in which the accumulated knowledge is applied as a contractor of assignments from a diversity of Dutch ministries. They carry out counselling and facilitate activities on the North Sea. The Offshore Wind programme that D2 is overseeing is situated on the contracting side of this spectrum. They have been tasked by the Ministry of Economic Affairs and Climate to roll out/deploy the Offshore Wind programme as (cost)efficiently as possible. Where possible within the rules and agreements within RWS and the Dutch planning system and regulations.

General policy

- On the North Sea, the following applies: everything that is installed and is no longer fully in use must be removed. That is the starting point, which has also been laid down in OSPAR.

- OSPAR is a protection against the negative impact of human activities on the North Sea. You also see that OSPAR 98/3 leaves little room for partial removal, artificial reefs, etc.

- Also, the London Protocol/Convention applies. This is the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. It includes the deliberate discharge into the sea of waste and other substances from ships, aircraft and platforms/oil & gas rigs, it does not include discharges from land. Because the convention originates form 1972, offshore wind installation is not mentioned in the original protocol, but are nowadays widely considered included.

- In some cases, with offshore mining and oil and gas extraction, pipelines remained on the seabed if the chance on harming for the environment was bigger than leaving it in situ. This can have significant economic and technical consequences in case of redevelopment of the area, for instance for offshore wind. Therefore, we do more and more to enforce old infrastructure to be fully dismantled and removed.

- The more structures and installations are abandoned and left behind on the North Sea, the more this obstructs redevelopment or re-use (like fisheries e.g.) of the designated area after decommissioning. Therefore, we still assume complete removal in our policy, embodied in the tender procedures. In the tender application, the developer agrees to deposit a bank guarantee that, in case the company defaults, covers the cost of decommissioning and removal for the authorities.

- During North Sea Agreement discussions, we talked with NOGEPA and NWEA about the possibility to leave certain structures and installation in situ, however, OSPAR is leading in that regard and therefore everything should be removed. We consider cables, pipelines and scour protection to be an inherent part of an installation and therefore they are regulated under OSPAR.

- The North Sea Agreement contains an agreement on complete offshore installation decommissioning and removal. Article 4.5 states: "The obligations for designating and protecting nature areas arising from international regulations, including the OSPAR Convention (OSPAR MPSs), the Birds Directive and the Habitats Directive (Natura 2000 areas) and the Marine Strategy Framework Directive (spatial protection measures) will be fully implemented and enforced." This is signed by all relevant stakeholders (except Fisheries), from interest groups to NGOs and governmental agencies.

- Research indicates that ecological processes are too complex to design general wind farm policy for. That is why we adhere to a 'no, unless' kind of policy. In case an exemption is granted, it must be very clear that it only applies on that specific case and the case must show a clear benefit for nature and the present marine ecology.

Site decisions

- In the Netherlands, for each wind farm, the government assigns plots and site decisions. The site decisions follow each other up, since this allows for intermediate learning and the application of new knowledge in policy and new site decisions.

- In terms of learning curves, it would make no sense to ask developers to submit a work or operational plan for the decommissioning 40 years in advance. So, we expect to developers to communicate their decommissioning plan at least four weeks in advance of the actual decommissioning, which should be based upon the Best Available Technology (BAT) and the Best Practicable Environmental Option (BPEO).

- Complete decommissioning is mandatory and is embedded in the Water Act, the site decisions and the tender procedure. Only the Minister of Economic Affairs and Climate can decide to grant an exemption.

- The site decision defines the spatial requirements for the layout and operations of a wind farm and thus also determines the requirements for the tendering process.

National developments

- A ruling by the Council of State recently halted the construction of several onshore wind farms, which can result in many onshore wind farms being opposed. This increases the pressure to achieve climate targets through offshore wind.

- The decommissioning of the first wind farm in the Dutch part of the North Sea will become relevant in a few years. OWEZ and PAWP are the wind farms for which their license will terminate.

- In order to determine BAT and BPEO in the future we have started with inhouse research and keep a watchful eye on Denmark, as they start with decommissioning sooner. Offshore wind is growing so fast that most of the learning occurs while doing. We experienced this during the roll-out of offshore wind and expect this to be the same with decommissioning.

International developments

- The London Protocol sets out what can and cannot be dumped into the North Sea. As long as it is used, it is not considered waste. This is to ensure that the North Sea can be used in a multi-functional way.

- The system in the UK is inherently different from that in the Netherlands. The Crown Estate allocates plots to developers and expects them to manage all relevant peripheral issues. In that, the UK government is more distanced in offshore wind development than the Dutch government, where it is strictly regulated and centralized.

- CEAF (Common Environmental Assessment Framework) is an international research collaboration which aims to align national policies and standards, on noise mitigation measures for instance. The Political Declaration signed by North Sea energy ministers on energy cooperation between North Sea countries (June 2016) included agreements about the development of a common framework for reporting on environmental effects (CEAF = Common Environmental Assessment Framework). This instrument can be used to support collaboration (on a voluntary basis) in the area of marine spatial planning. It can also contribute to collaboration in the field of ecological research and monitoring.

- They do this by means of a system- and scenario study, however, the covid-pandemic and Brexit have caused the process to slow down.

Business

- The author states that on the basis of his current/to date research he comes to the hypothesis that most wind farms owners strive for partial decommissioning based on economic reasoning. D2 reacts with: they probably derive the legitimacy of their position from the mining history, in which developers were allowed to carry out partial decommissioning. However, we as a society are now paying the price for that and are therefore not allowing it anymore. To assume that this will continue to be possible is simply opportunistic.

- When we would allow partial decommissioning, and thereby allowing a certain impact on the North Sea ecology, this would limit future wind projects in the impact they are allowed to have and thereby complicate their business case. This would reduce the chance of successful roll-out of the required offshore wind farms to achieve climate targets.

- So, I strongly recommend developers to assess their impact on a meso-level instead of the current micro/individual project-level. He asks them and the author (currently working for Vattenfall) to investigate what the consequences of your decommissioning approach are to the future of offshore wind and other functions on the North Sea, instead of just focusing on your individual convenience. I would expect NWEA to proactively pursue complete decommissioning, as it supposed to ensure the most sustainable and best economic growth for the sector. Commissioning new wind farms that during their build are troubled by rubble and waist is not in their interest.

- What interests me, is why developers assess scenarios for future repowering during the first commissioning phase with great scrutiny and interest, but do not consider easy and efficient decommissioning options in the same way. When complete decommissioning is considered as default option, this can be accounted for in turbine design and park layout and technological innovation can drive down costs. However, developers do not seem to be interested in this according to the researcher's hypothesis, it would be interesting if your thesis could shed some light on this. Is it because of uncertainty about decommissioning and at comes with it, economic thinking, pushing toward a 'level playing field' with former oil and gas practices or a bit of wishful thinking?

- During offshore wind expertise sessions, developers get the chance to ask questions about a tender and its requirements. Surprisingly in hindsight of the hypothesis, we rarely get decommissioning related questions, and if we do, they question the concept of decommissioning, instead of the extent. It focuses more on conceptual thinking instead of envisioning a sustainable future.
- After TenneT investigated the feasibility of using the jacket of old mining platform as a foundation for an Offshore High Voltage Substation (OHVS), they concluded that modifications would be too comprehensive and expensive. However, it also shows that "the Euro rules", and in order to reach a better world, we might have to accept some extra costs. Just like offshore mining has been given decades to become as efficient as possible, offshore renewable energy should be given a learning curve. Only the present time frame and context dictate a much steeper curve (including costs).

Co-use

- The soil-disturbing fishing industry in the Netherlands is faced with the consequences of the newly spatial use of the North Sea by the offshore wind development, as their fishing grounds are getting restricted. Partial decommissioning intensifies this issue further because some fisheries increasingly run the risk of their nets getting caught on remaining infrastructures and cables and thereby decreasing the space for safe fisheries.

- With partial decommissioning, refugia for fish and benthos are increasing. However, the question is whether this is in line with the desired ecological carrying capacity/ ecosystem development of the North Sea and KRM objectives for species conservation and growth. Is the argument legitimate if it cannot be proven that partial decommissioning leads to added value for ‘the right’ and/or indigenous or by policy indicated species?

- Apart from inconvenience in redevelopment of wind farm areas and for fisheries, the abandoned structures and installations can be inconvenient for other users of the sea. E.g., deploying sensors, radio antenna and other beacons to safely navigate, for the surveillance of and research the North Sea and air space above it.

Ecology

- Scour protection does stimulate benthos and fish productivity; however, it also acts as a stepping stone for invasive species, e.g., the North Atlantic Lobster. This all weighs in in determining whether partial removal is approved or not.

- The cumulative impact on stratification, currents, sedimentation and the food web by offshore wind farms on the North Sea, is often not considered. As part of the Wozep programme (Offshore Wind Ecological programme) Deltares and KNMI (by its own initiative) are conducting comprehensive research into these effects, where KNMI focuses on air currents and weather development and Deltares on the sea and underwater system. The reports of the latter mentioned can be consulted at the Noordzeeloket (link provided). The KNMI findings will follow later this year or early 2022.

Social impact

- It could be argued that offshore wind farms have more social impact than oil rigs, since they are installed closer to shore and are therefore more visible (except for Q13-A just of the coast (7 NM out) of Schevingen).

- The public debate about the conservation or removal of newly generate nature around offshore wind turbine foundations can become an ethical dilemma. Until now, this subject is not a heavily debated subject by people involved. Other topics have more priority in the current time frame of deployment. But just as mentioned earlier at the paragraph “Business” it’s worthwhile to look into this from an early stage,

- In the Netherlands, there are no consultation sessions on a developer’s working plan. Citizens are free to respond or take legal action in case of governmental decisions, policy plans and site decisions.

- It is expected that the North Sea consultation sessions in the future will be focusing more on the subject of decommissioning as the social impact becomes more apparent and clearer in actual occurring projects. So far, the focus has been on the efficient roll-out of offshore wind farms and collaboration between stakeholders.

- Some would say that NGOs can be divided by their core values. The first group’s main concern is the environment, e.g., Greenpeace. The second cares more for nature (e.g., WWF). This can also lead to opposing views with regards to decommissioning.

- There will be different interests within industry organizations. The author asks if one solution is possible achievable. D2 response: It is utopian to strive for unanimity on the question of total or partial decommissioning. The interests of industry and society must be in balance. So, therefore we need a “no, unless” approach to keep room for tailor made solutions if they are needed.

Brent Spar

- Since the Brent Spar case in 1995, our interest/view on decommissioning in the North Sea has changed fundamentally. The spatial pressure on land and increased offshore activities has raised the amount of research into the North Sea. This heightened our level of knowledge and increased the public's awareness of the importance of an ecological healthy sea. This leads me to say that I do not expect another controversial offshore activity like building islands for housing of airports being approved anytime soon in The Netherland.

- The political, social and business perception must be in line and focus on proactively engaging in complete decommissioning and the ecosystem development goals of the North Sea. Please also refer to the EU Sustainable Development Goals and Goal number 14 especially: Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Appendix M: Case study of decommissioning of reference offshore wind farm

1. Reference Offshore Wind Farm

In order to assess the high-level costs for removal and disposal of a commercial OWF a case study has been carried out. For this case study a so-called reference OWF is used. This reference OWF represents the typical components and dimensions of an OWF constructed and commissioned in 2002 - 2003. An overview of the generation assets is presented in the table below.

Parameter	Value
Number of WTGs	80
Type of foundation	MP & TP
Connection between MP & TP	Grouted
Length of IAC	60 km
Distance to disposal yard	20 Nm
Water depth	6 -14 m

1.1 Wind Turbine Generator

The WTGs of the offshore wind farms installed in the early 2000's range from 2 to 3 MW rated capacity. The WTG of the reference offshore wind farm has the following specifications:

Parameter	Value
Capacity	2 MW
Blade mass	7 mT
Blade length	40m
Hub mass	17 mT
Nacelle mass	65 mT
Tower mass	148mT

1.2 Monopile and scour protection

The foundations of the reference wind farm consist out of a steel monopile, transition piece (grouted to the monopile) and scour protection. See the overview below.

Parameter	Value
Monopile diameter	4m
Monopile length	30 – 33m
Monopile mass	230 mT
Penetration depth	21 – 24m
Transition piece height	13 – 18m
Transition piece mass	290 mT
Type of scour protection (SP)	Rock
Installed volume SP per location	473 m^3

1.3 Inter-Array Cables

The reference wind farm is divided into five strings with sixteen WTGs per string. For the inter-turbine connections between the wind turbines, inter-array cables with different diameters are used, depending on the loads in the string. The five strings are consequently connected with IACs to the OSS. The IACs of the first commercial sized OWF typically contain copper conductors. See below for the IAC specifications used for the reference wind farm:

Parameter	Value
Total length	60 km
Burial Depth (min/max)	1m / 2m
Cable mass in air	20 – 40 kg/m
Number conductors	3
Conductor material	Copper

2. Removal scenario's

Although the regulations for decommissioning of offshore wind farm are clear (i.e., full removal should be the default position) each OWF decommissioning plan considers different requirements with respect to the extent of the removal scope. In order to assess the difference in costs for the different requirements, four different scenarios are analyzed, which are shown below.

Scope	Scenario 1	Scenario 2	Scenario 3	Scenario 4
WTG	Full removal			
TP	Full removal			
MP	Full removal	Full removal	Full removal	Partial removal
IAC	Full removal	Full removal	Leave *in situ*	Leave *in situ*
SP	Full removal	Leave *in situ*	Leave *in situ*	Leave *in situ*

3. Estimated costs for decommissioning

For the estimation of the costs for decommissioning Vattenfall's in-house developed decommissioning cost model has been used. The following key parameters have been used:

- **WTG removal scope:** A generation 1 jack-up barge is used for reversed installation of the WTGs. The jack-up barge is used to store four sets of WTGs and shuttle back and forth to the disposal yard.
- **TP and MP removal scope:** A generation 2 jack-up barge is used for removal of the foundations. For the partial removal of the monopile internal AWJ is selected as the technology for cutting the monopile below the natural seabed. For complete removal of the monopile the VLT is selected. The jack-up barge is used to store three sets of transition pieces and monopile and shuttle back and forth between the disposal yard.
- **Scour protections removal scope:** A backhoe dredger and barge is selected for removal of the scour protection.
- **IAC removal scope:** A cable laying vessel is selected for the removal of the IAC

The estimated costs for decommissioning of the four selected scenarios are as follows:

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Offshore removal	€58,9 mln	€51,3 mln	€50,3 mln	€44,8 mln
Onshore disposal	€15,4 mln	€13,2 mln	€12,7 mln	€10,8 mln
Project Management & Contingency	€6,9 mln	€6,1 mln	€5,9 mln	€5,2 mln
Recycling	(€21,3) mln	(€20,1) mln	(€16,2) mln	(€13,8) mln
Total cost	**€59,9 mln**	**€50,5 mln**	**€52,7 mln**	**€47,0 mln**

4. Sensitivity analysis monopile removal

4.1 Business case monopile removal

The economic business case of complete or partial removal, needs to be analysed and evaluated in order to create context of the complexity of the question whether a foundation is to be completely or partially removed. Economical evaluation will be based on technical review of the potential removal technologies. This section shows the complexity and sensitivity of applying future technologies on existing OWF monopile foundations and the potential effect on the cost level and bandwidth of the offshore removal and transport.

4.2 Technical feasibility monopile removal methodologies

Generally, when a technical solution is not considered to be feasible, at least an alternative technology should be provided in order to create a base plan for technical feasible business case. This also applies when there is low confidence in a technology reaching the required TRL in time for decommissioning. When a technology is considered feasible and applicable in the required timeframe, an economic assessment is made.

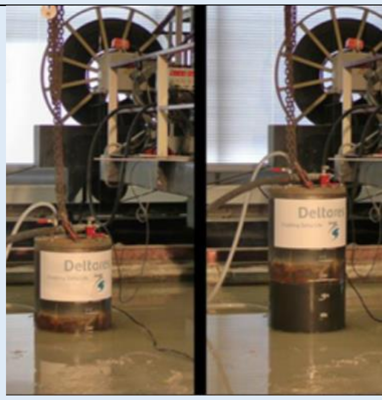
Technical feasibility depends on the following factors:

1. TRL of the removal technology. The state of development of a technology will influence the technical feasibility.
2. Applicability of the removal technology for the respective foundation, for example:
    a. Soil conditions. Certain soil types can increase the shaft friction, increasing the force needed to remove the pile. It can occur that the tool or methodology is not designed for such loads.
    b. Structural integrity of the foundation. When the structural integrity of the foundation has been compromised, certain technologies might not be suitable for safe removal of the monopile.
        i. Vibrations or loads originating from a VLT could further deteriorate the structural integrity of the pile and/or flange.
        ii. Internal pressure applied during the HyPE methodology could exceed the structural integrity of the monopile

The monopile removal technologies as mentioned in 4.3.1 are applied on the reference OWF and are analyzed to create a delta between the cycle time and total duration. Please note the following:

- Partial removal by AWC is not reviewed since the same cycle time duration for AWJ cutting would be used
- Complete removal by GDP will not be reviewed either for this analysis, since the TRL level is such that in this stage no delta will be expected with using a VLT

The table below elaborates on which technologies are reviewed and compared for the sensitivity analysis.

Partial Removal	Complete Removal	
AWJ	**VLT**	**HyPE-ST**
TRL: 8 Current status: - Technology available → Scaling up Track record: - Removal of MP's of OWF Utgrunden	TRL: 8 Current status: - Technology available → Scaling up Track record: - Removal of MP's of OWF Lely	TRL: 3 Current status: - Proof of concept in laboratory Track record: - Scale testing performed 1:20
		

4.3 CAPEX Offshore Marine Spread

In general, the Capital Expenditures (CAPEX) for an OWF developer for offshore T&I and decommissioning is predominantly affected by the total duration that an offshore marine spread needs to operate. The offshore marine spread includes the offshore installation vessels including personnel, grillages and equipment.

The CAPEX for the Offshore Marine Spread is roughly 60 to 75% of the total decommissioning budget. The other part is CAPEX related to Project Management, Engineering, Financial Security, Procurement or hiring of structures (e.g., grillages) and tools/equipment and yard cost. The sensitivity of the economic value is investigated in order to show the difficulty of defining the economic value of decommissioning based on a certain technology. This is without accounting for the uncertainty of vessel availability and the amount of demand for the vessels, which both heavily affect day rates of these vessels.

To provide context on the economic value of the use of a technology during OWF decommissioning, the impact on CAPEX for offshore marine spread day rate and total duration is made. A rough calculation to get a better view on potential impact of decommissioning technologies in a business case.

CAPEX Offshore Marine Spread = *Duration in days* x *Vessel Dayrate*

4.4 Offshore cycle time and total duration

Each methodology, depending on the extent of removal, type of foundation and TRL, will have a different duration. The economic value will be calculated for every technology, in terms of cycle time. A *cycle* is the duration of the removal of one foundation and the relocation of the vessel to the next foundation. The Marine Spread will be affected by weather conditions (wind, waves). For the business case, the basis will be including W*aiting on weather* with P50 approach. For P50, there is a 50% chance the actual weather downtime will be less, and a 50% chance the actual weather downtime will be higher. For the reference windfarm, a workability of 85% is taken into account and 15% downtime due to adverse weather. Before the offshore execution starts, the Jack-up needs to be prepared (mobilized) by means of bunkering, preparing the deck (welding grillages, change lay-out) and crew changes. After the project, the vessel will be de-mobilized. A total of 5 days for mobilization and 3 days for demobilization is envisaged.

The table below summarizes the outcome of the total duration for the partial or complete removal of the monopile foundations. The offshore cycle time, waiting on weather and (de)mobilization durations are incorporated into the total duration in which the marine spread is operating.

	Partial Removal	Complete Removal	
	AWJ	*VLT*	*HyPE*
1 Offshore Cycle [hours]	48	38	58
Total duration [days]	223	183	262

4.5 Day rate Marine Spread

For the reference windfarm, the vessel requirements and capacity have been reviewed in order to facilitate the removal of a complete or partial monopile removal. As well a benchmark on the potential cost of big contributors, such as the mission equipment and personnel on board of the vessel. The table below shows the rates envisaged per technology for removal of a monopile from the reference windfarm.

	Partial removal	Complete removal	
	AWJ	*VLT*	*HyPE*
Jack-up dayrate	€65 k	€80 k	€80 k
Equipment rental	€15 k	€25 k	€15 k
Personnel	€30 k	€30 k	€30 k
Total	€110 k	€135 k	€135 k

4.6 Economic Impact – CAPEX Marine Spread

Now the cycle times and total durations of the several removal methodologies have been analysed, in combination with the day rates for the marine spread, the total cost for the marine spread can be calculated. The table below shows the total cost of the marine spread for the partial or complete monopile removal in the reference windfarm.

	Partial removal	Complete removal	
	AWJ	*VLT*	*HyPE*
Duration [days]	223	183	262
Day rate [€/day]	€110 k	€135 k	€135 k
Total	€24.5 mln	€24.7 mln	€35.4 mln

4.7 Delta in scrap value residual steel

One of the factors that still needs to be taken into account, is that complete monopile removal allows for more steel to be recycled. In case of complete removal, a total of 18,400 mT of steel monopile is removed. In case of partial removal, approximately 2/3rd of the monopile remains in the seabed, resulting in a delta between partial and complete removal of 2/3 x 18,400 = 12,267 mT. Assumed a €175 per ton steel scrap (after the disposal processing cost), resulting in a CAPEX decrease of 12,267 x 175 = €2.15 million.

4.8 Sensitivity of economic values of different technologies

The sensitivity analysis shows that complete removal of the monopile foundation could on one hand deliver the best economic approach for this specific component removal. However, on the other hand it could substantially worsen the business case.

	Partial removal	Complete removal	
	AWJ	*VLT*	*HyPE*
CAPEX marine spread	€24.5 mln	€24.7 mln	35.4 mln
Scrap value	-	- €2.15 mln	- €2.15 mln
Total	€24.5 mln	€22.6 mln	€33.2 mln

Thus, the complete removal of the monopile foundation is consistent with the regulatory framework, which requires that the site returned to its former state after decommissioning. However, if the structural integrity of the monopile is such that it cannot accommodate the use of the VLT, an alternative technology may need to be proposed. If too much friction is expected, the inner soil plug could be dredged (increasing cycle time and therefore CAPEX). Another option is the implementing HyPE, however the low TRL gives no insurances with regard to performance. The sensitivity case emphasizes that a lot of consideration is needed before a subsea structure is removed. It depends on many factors, of which technology is one of the biggest contributors.

An example from another offshore decommissioning industry is the oil and gas industry, where subsea piles often remain on the seabed after the jacket has been decommissioned, due to the technical complexity or the extreme efforts and CAPEX required to completely remove the piles, including the impact on the seabed.

However, this approach cannot necessarily be applied to OWF monopile decommissioning, as the footprint of an OWF is larger than that of a typical O&G field with the same energy output. In addition, it is very likely that an OWF area that is redeveloped several times will encounter problems during redevelopment if existing substructures remain.

Appendix N: Calculation of economic potential of recycling OWF substructures

This calculation is based on the all monopile-grounded OWFs currently in operation or under construction in the North Sea. It assumes all OWFs have a lifetime of 25 years.

Monopiles

All 59 monopile-grounded wind farms currently in operation or under construction on the North Sea have been concluded in this calculation. Information such as the monopile diameter $\emptyset_{mp}$, monopile length l_{mp}, monopile weight w_{mp} and sea depth d_s have been retrieved from third-party data. This allows for the calculation of residual material flows for both partial as complete monopile removal. To make the calculations comprehensible and generally valid, the following assumptions were made.

1. Monopiles rise 10 meters above sea level
2. Monopiles are cut 1 meter below sea bed during partial decommissioning
3. The penetration depth of the monopile d_{mp} is equal to $l_{mp} - d_s - 10$

After calculations with the characteristics of the aforementioned OWFs, the magnitude of the residual material flows becomes apparent. Over the next 25 years, 2733 kilotons of steel become available in the case of complete decommissioning. This compares to 1671 kilotons of steel in the case of partial decommissioning.

In order to convert this information into potential monetary value, assumptions must be made about the scrap value of steel over time. Between 2015 and 2020 the price has ranged between $175 and $400 per ton, however last year characterizes significant growth, with peaks up to $560 per ton (London Metal Exchange, 2021). This is most likely due to increased demand in steel due to governmental stimuli packages during the covid-pandemic, combined with a shortage in supply and inventory. Because it is unsure whether steel scrap prices will settle to their former range, the average price is calculated over the entire period. Therefore, the average price of €238,75 per ton of steel scrap is applied on the data.

Combining the steel scrap price with the residual material flows will lead to the annual projected value of residual steel originating from monopiles. According to this data, over the next 25 years a total of €399 million will become available in case of partial decommissioning, in contrast to the €652 million that will become available with complete decommissioning.

Inter Array Cables

As inter-array cables contain vast amounts of valuable conductor materials, such as copper, their potential economic impact is significant. Compared to the simplicity of monopile recycling, the recycling process of insulated cables is much more complex.

To make the calculations comprehensible and generally valid, a series of assumptions have been made. These are based on a study by Schlemmer and Greedy (2015) into the effects of 66kV IACs in OWFs. First of all, it is assumed that the cables and internal conductors remain in good condition after their 25-year lifetime. In reality, when this is not the case, the waste processor discounts the scrap value in line with the extent of degradation. Secondly, in order to estimate the total weight of IACs in an OWF, a weight w_{IAC} of 40 kg/m is assumed for copper-conductor IACs and 38 kg/m for aluminium-conductor IACs. The value for aluminum has been calculated using a density ratio of 0,52 and the conductivity ratio of 0,6 of aluminum to copper.

Moreover, to estimate the metal content of IACs ρ_{IAC}, it is assumed that a default copper conductor has three cores with a surface area of 630 mm^2 each. For aluminum conductors, this value is 1071 mm^2, as a result of the lower conductivity. This results in a metal content of 42% and 39% for copper and aluminum conductor IACs respectively.

To arrive at the total projected annual scrap value of the residual copper and aluminum flows, an assumption must be made with regard to the scrap price of copper and aluminum. It has been decided to use the 10-year average prices of €5563 per ton copper (Macrotrends, 2021) and €1557 per ton aluminum (Mining, 2021).

In total, the complete removal of IACs enables the recycling of 198 kilotons of conductor material, with an economic value of €453 million over 25 years.

Scour protection

Scour protection used for monopiles and IACs usually consists of different types and sizes of rock and gravel, dependent on site-specific characteristics. To make the calculations of annual residual flows of scour protection comprehensible and generally valid, the following assumptions have been made.

The scour protection around the monopile is set to have a diameter of four times the monopile diameter and has a thickness t_{sp} of 1 meter (Lengkeek et al., 2017). Its density ρ_{sp} is assumed to be 2650 kg/m^3 (personal communication, March 20, 2021).
Since there is no information available regarding the value of used scour protection, this section is limited to mapping the residual flows of scour protection material over time. Based on a 25-year lifetime of OWFs, a total of 251 kilotons of scour protection will become available until 2046.