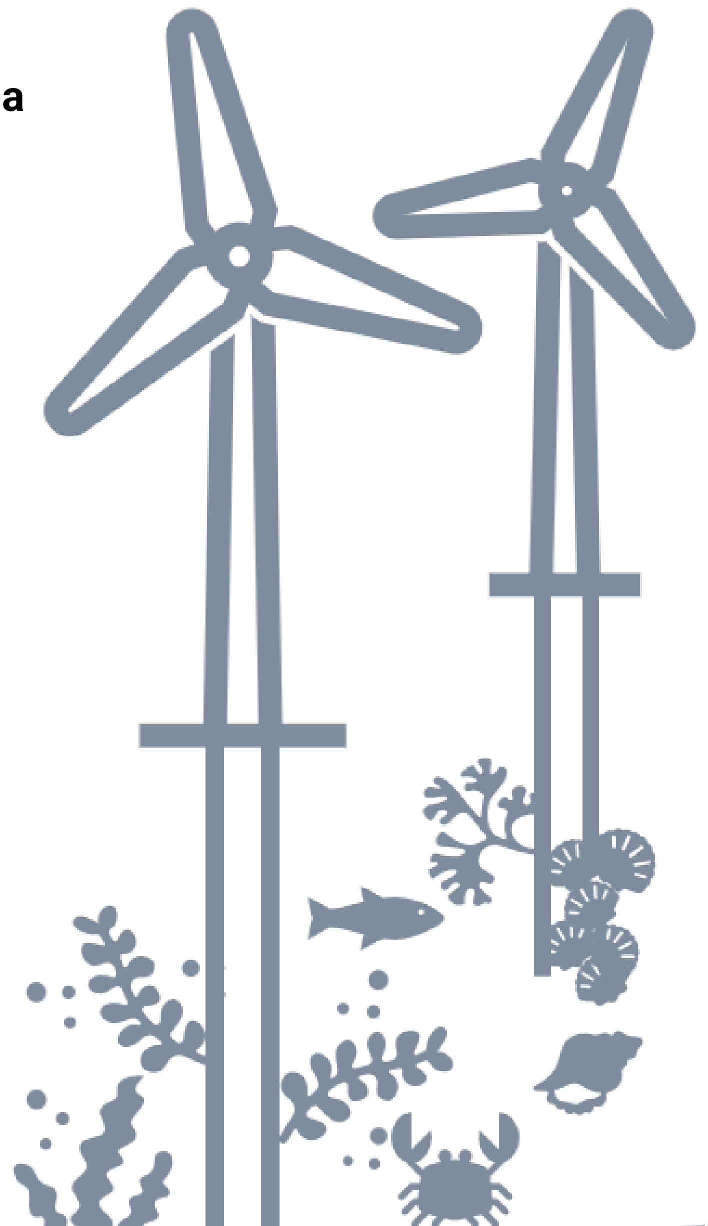
Upscaling Nature-Based Solutions for Offshore Wind: *headwind or tailwind?*

Master's Thesis - MSc Sustainable Business and Innovation

Daantje Klasema



Thesis for the degree of MSc Sustainable Business and Innovation

Upscaling Nature-Based Solutions for Offshore Wind: *headwind or tailwind?*

by

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to obtain the degree of Master of Science
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In collaboration with Heerema Marine Contractors

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Preface

"What you do makes a difference, and you have to decide what kind of difference you want to make." – Jane Goodall

We are at the dawn of the offshore energy transition. Now, we can choose what kind of difference we want to make with large-scale offshore construction, and how we will alter the maritime environment. Through this thesis, I hope to have provided insights into how we can support a nature-inclusive approach to offshore wind. Thus, I hope that the sustainable, innovative choices we make today will be regret-free and have a positive outcome for our future including the various aspects sustainability entails.

What difference do I want to make? That is the question I asked myself a few years ago, with a background in biology, fascinated by the diversity and pristine nature and wanting to engage with the mundane. Meanwhile, a few years later, I have not yet fully answered this question. Still, I have learned a lot, about the importance of sustainability for businesses, about the difficulties of the confluence of nature and man, and about myself, about my strengths, drivers, and barriers.

I want to thank Adriaan van der Loos for his great guidance. By continuously asking questions, you have empowered me to find the tools I needed even when I thought I did not have them. Also from Utrecht University, I want to thank Joeri Wesseling for his valuable comments on the proposal. I also want to thank Meike Kolthof for the opportunity to work with Heerema on the topic, for her valuable feedback on the thesis, for trusting me to go to Wind Europe, as well as for her guidance on personal development goals. I learned a lot from your personal, creative, and organized approach to leadership. Additionally, I would like to thank Joost van Arkel and Annabel Smith-Moorhouse for their feedback, ideas, and brainstorming sessions on this topic – keep up the good work! Furthermore, I want to express my admiration for the entire Healthy Ocean- and sustainability team at Heerema Marine Contractors. You are all wonderful and knowledgeable colleagues with great passion and expertise.

Lastly, I would like to thank my parents, sister, and Dolf for nurturing my curiosity, for all the walks along the beach, and for their unconditional love and support over the past years.

Daantje Klasema
Leiden, April 6, 2024

Abstract

Offshore wind's rapid expansion to meet green energy demands raises ecological concerns. Nature-based solutions (NBS) offer a way to create a positive impact on nature through restoration and habitat creation. NBS are currently in a pilot phase, the current challenge entails upscaling. However, upscaling NBS is challenging as these types of innovations have unique characteristics. This study investigates how NBS for offshore wind can be upscaled, employing a novel conceptual framework to evaluate drivers and barriers comprehensively. Through in-depth interviews and survey, an understanding is gained of NBS upscaling dynamics, aiding strategies to further implement NBS and ensure sustainable offshore wind development. This study determined that establishing a proof of concept through increased NBS pilots within Offshore Wind Farms (OWFs) is essential. Standardized international monitoring programs can evaluate and compare outcomes, clarifying uncertainty around effectiveness. The study highlights a misfit between the pace of offshore wind development speed and the time required to test NBS. Accelerating NBS testing, integrating them into tender criteria, and exploring nature-inclusive decommissioning is vital. Upscaling testing efforts is crucial to match wind farm development pace, promoting widespread NBS adoption, and ensuring long-term, sustainability in wind energy projects.

Keywords

Nature-based Solutions, Nature-inclusive Design, Biodiversity, Upscaling, Scaling, Offshore Wind, Offshore Wind Farms, Pilot Projects

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List of Abbreviations

CSRD	Corporate Sustainability Reporting Directive
EU	European Union
GNSBI	Greater North Sea Basin Initiative
GW	Gigawatts
IUCN	International Union for Conservation of Nature
MPA	Marine Protected Area
MSP	Maritime Spatial Planning
NBS	Nature-based Solutions
NEP	Nature Enhancement Projects
NID	Nature-inclusive Design
NNBF	Natural or Nature-based Features
NTZ	No-take Zone
OWFs	Offshore Wind Farms
R&D	Research & Development
TRL	Technology Readiness Level
VOD	Valley of Death
WHO	World Health Organization
WWF	World Wide Fund

1 INTRODUCTION

1 Introduction

The demand for green energy has fueled rapid developments in offshore renewable energy solutions (Rodrigues et al., 2015). The global consensus reached at COP28 underscored the need to transition away from fossil fuels as an essential measure to minimize climate change (UNFCC, 2023). To achieve this, a green energy mix is required. This is comprised of various renewable energy sources, with offshore wind being recognized as one of the leading innovations (Chenic et al., 2022; Xianping, 2011). As a result, offshore construction is undergoing significant transformation, shifting from oil and gas installations to the development of offshore wind farms (OWFs) (Araujo Fresky & Araujo de Itriago, 2023; Buljan, 2022; Wang, 2022). Hence, offshore wind is projected to grow substantially in the next decade (GWEC, 2023; Wind Europe, 2023). The current worldwide capacity of 64.4 gigawatts (GW) is projected to scale up to 380 GW by 2032, with nearly half of the market being in Europe (GWEC, 2023). In total, offshore wind energy is expected to reach around 450 GW by 2032. Yet, this doesn't even represent a quarter of the 2000 GW needed by 2050 to meet the mandates outlined in the Paris Agreement (Gielen et al., 2021). Thus, offshore wind has a pivotal role in global initiatives to cut CO2 emissions and is needed on a large scale to move away from fossil fuels.

To achieve these projected energy targets, substantial offshore construction is necessary, with an estimated need for around 5000 new turbines installed annually. This would entail occupying over 500,000 square kilometers of ocean space by the year 2050 (Putuhena et al., 2023). Adding this quantity of hard, artificial substrate alters the marine environment (Degraer et al., 2020), both positively and negatively. The most prominent positive impact concerns the use of offshore wind structures as shelter for animals across different taxa (Hammar et al., 2015; Wilson & Elliott, 2009). Additionally, species biodiversity and abundance can increase when fishing is prohibited in the vicinity of OWFs (Gill et al., 2020). The artificial structures can thus lead to habitat creation for marine life, enhance nature, and even restore biodiversity. However, turbines at sea also do alter the natural state of ecosystems e.g. affecting species composition, and hydrodynamics, which has been a topic of debate (Negro et al., 2020). In line with this, the construction, operations, and decommissioning of OWFs have been found to negatively affect marine ecosystems, impacting aquatic species, varying from invertebrates to mammals, and birds (Bergström et al., 2014; Mangi, 2013; Riefolo et al., 2016; Thomsen et al., 2006).

Offshore construction is needed for the energy transition, yet it raises concerns about the impact of offshore wind on marine ecosystems. This negative by-catch leads to a green-green dilemma; developing green energy should not result in disadvantaging another crucial sustainability objective, the conservation of nature and biodiversity (Trommetter, 2017; Dulluri & Rat, 2019). Therefore, it is crucial to thoroughly understand and address how OWFs impact the environment and to manage - and act on this impact. Effectively managing these effects involves lessening negatives and enhancing positives, such as creating habitats and restoring nature. In line with this, the World Wide Fund (WWF) (2021) emphasizes *"Offshore renewable infrastructure is still infrastructure. It needs to be subject to best-practice planning and design and requires rigorous evaluation"* (p.3). In doing so, the energy transition should not come at the expense of nature and biodiversity, a vital component for a sustainable, resilient future for humanity.

Notably, there is a growing recognition of the positive impacts of offshore wind through habitat protection and - creation. A concrete way to increase positive impact is by implementing nature-based solutions (NBS). NBS have emerged as a strategic, cost-effective implementation to enhance nature (Seddon, 2022) and defined by Cohen-Shacham et al. (2016) as *"actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"* (p.4). Within offshore wind, NBS, also referred to as nature-positive solutions (NPS), nature-inclusive design (NID), and nature enhancement projects (NEP) (Pardo et al., 2023), pose the opportunity to achieve marine habitat restoration according to multiple non-profit organizations (The Nature Conservancy, 2021; WWF European Policy Office, 2021). Currently, stakeholders in the offshore wind sector, e.g., developers, governments, and contractors, are exploring NBS. In The Netherlands, NBS are part of the non-price tender criteria for OWFs. Ecowende, a wind farm under construction at Hollandse Kust West, pilots various NBS, e.g., reefs from old pear trees. In the upcoming tender Ijmuiden Ver Alpha, NBS are crucial, with 45% of criteria points based on ecology (RVO, 2024). However, the use of NBS in the offshore wind sector is still in the pilot stage regarding implementation (O'Leary et al., 2022; Pardo et al., 2023; Riisager-Simonsen et al., 2022). The current challenge is transitioning from pilot projects to full-scale deployment of NBS (Frantzeskaki et al., 2019), also referred to as "upscaling". Upscaling these projects is essential to guarantee a sustainable and nature-inclusive development of green energy at sea.

However, upscaling is challenging, especially for societal beneficial innovations like NBS (Hendry et al., 2010). In the case of NBS, the benefits are not as straightforward as in other pilot projects since financial gains are less common (Mayor et al., 2021). Moreover, NBS typically involves more stakeholders, thereby the benefits are often dispersed among the different actors (Mguni et al., 2015). This requires improved coordination and communication, resulting in increased complexity during the upscaling process (Toxopeus & Polzin, 2021; Vreugdenhil et al., 2011). Following Cortinovis et al. (2022), scaling up NBS depends on the opportunities to integrate NBS into the existing infrastructure and to what extent NBS delivers benefits. Findings of what influences upscaling NBS are scattered and, thus, a knowledge gap remains on the factors that drive and hinder upscaling NBS and how to mainstream and integrate this into planning processes, decision-making mechanisms, and policy (Somarakis et al., 2019). Kapos et al. (2019) stress the urgency of such knowledge, emphasizing its role in supporting decision-makers and shaping sustainable policies. Especially in the European Union efforts are made to scale up NBS through, for example, the Horizon Europe mission on healthy oceans and seas (CORDIS, 2023; European Investment Bank., 2023).

A major knowledge gap remains around understanding upscaling NBS for offshore wind. The types of NBS for offshore wind are defined ambiguously, despite a growing interest in the subject both academically and within society (Pardo et al., 2023). Previous studies entail a literature review with the options for nature-positive approaches for offshore wind (Pardo et al., 2023), however, do not address the maturity of NBS and do not capture the current need how to scale NBS (Frantzeskaki et al., 2019). Furthermore, various outcomes have been observed on the factors that influence upscaling NBS, so currently there is no clear research framework available for upscaling NBS. Lastly, research has been primarily concentrated on land based NBS applications and has not addressed the maritime system, so questions remain on upscaling NBS for offshore wind. Therefore, it is crucial to comprehend the scope of NBS for offshore wind, identify the drivers and barriers for scaling up NBS, ensuring that the pace of energy transition does not compromise the natural transition.

This study has two objectives. First, the study aims to clarify the factors that influence upscaling NBS. Therefore, this study will adopt a structured, inclusive approach through a conceptual framework for evaluating factors that affect the upscaling of NBS. Second, given the predominant focus of NBS research on urban environments, this study aims to provide insights into the adoption and upscaling of NBS in marine systems, namely within the offshore wind sector. Given Europe's commitment to offshore wind as a renewable energy source, the strong projected growth in this sector, and the significant interest in NBS (European Investment Bank., 2023), this study will focus on the European offshore wind market. Most pilot projects for NBS are currently conducted in this region, thus here is most knowledge about what drives and hinders upscaling NBS for offshore wind. To collect this information, insights, and experiences from different actors within offshore wind energy were gathered through interviews and a closed-answered survey. These factors included developers, and contractors to NGOs, governments, and companies providing NBS.

The aims of this study result in the following research question:

What drives and hinders the upscaling of Nature-Based Solutions (NBS) within the European offshore wind market, and how can NBS be supported to be more widely implemented?

2 THEORY

2 Theory

2.1 The role of pilots in innovation

Innovation transitions from an initial idea to a well-established new technology, process, or project through the process of research and development (R&D). Within R&D, pilot projects constitute a vital component where innovations are tested in real-world settings (Lee, 2001). Pilot projects serve as an umbrella term for projects that are undertaken in the context of experimentation (Vreugdenhil et al., 2011) and have been described as 'seeds of change' (Wieczorek, 2018). During pilots, innovation can mature in protected spaces that shield these innovations from selection pressure such as (price) competition. Innovation becomes more mature during the pilot phase in two ways. First, the technology, products, processes, or systems are tested for function. Second, pilots are the first attempt to drive market diffusion and to test the commercialization of these innovations (Karlström & Sandén, 2004; Lefevre, 1984). Thereby, pilot projects shorten the time frame from the R&D stage to a commercialized phase involving commercial users and industry (Lefevre, 1984). Pilot projects are highly important in the transition from R&D to market diffusion, facilitating market access (Geels & Raven, 2006; van der Loos et al., 2020).

Companies engage in pilot projects mainly to test and introduce innovations while reducing risk (Turner, 2005) since the activities carried out as part of pilots are less costly and more easily reversible (Musselin, 2005). This makes pilots less risky, and therefore less frightening, for the stakeholders involved. Hereby, the bar to be involved in innovation and stimulating the development of new ideas and - technologies is lowered. Although there is high variation in the types and values of pilot projects, they have shared characteristics (Vreugenhil et al., 2010).

Pilot projects are not predetermined by the innovation only, but also interact with a wider socio-technological landscape (Huguenin & Jeannerat, 2017; Raven et al., 2007; Vreugdenhil et al., 2010). The socio-technological landscape i.e. the external and social context consists of *"background variables such as the material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macroeconomy, demography and the natural environment which channel transition processes and change themselves slowly in an autonomous way"* (Kemp & Rotmans, 2005, p.30). Context dependency is caused by the reliance on resources e.g. finance, protection, and specifications, that are needed to conduct a pilot (Geels & Raven, 2006) and the socio-technological landscape affects this. At the same time, the outcome of a pilot project can also influence the external and social context. For instance, pilot project outcomes result in learning, leading to changes in policy management practices (Brown et al., 2003). In addition, pilots may affect the actor network as Vreugdenhil & Rault (2010) state *"pilot projects establish communication between actors that usually do not cooperate"* (p.122) and hereby result in new partnerships.

2.2 Upscaling after the pilot phase

Before an innovation can expand, it reaches a pivotal juncture known as 'The Valley of Death' (VOD). At this critical stage of R&D, promising innovations confront substantial challenges, facing a heightened risk of failure. VOD represents the threshold between the prototype phase where the technical feasibility is tested and the commercial production or market diffusion stage (Auerswald & Branscomb, 2003; Ford et al., 2007; Nemet et al., 2018).

Pilot projects are successful when they have clear follow-up (van Mierlo, 2002). This follow-up can have multiple forms. First, pilot projects can lead to knowledge development or learning (Pawson and Tilley, 1997). Second, it can lead to changes in responses of systems or context, which is an indicator of wider change (Quist, 2007). Third, the use and main outcomes of pilot projects can be taken up by management or policy.

The diffusion of innovation theory (Rogers, 2003) describes that innovation must be widely adopted to self-sustain. Vreugdenhil et al. (2011) refined this theory for the pilot phase by bisecting the term in 'dissemination' and 'upscaling' (*Figure 1*). Dissemination entails that a pilot project results in other pilot projects or comparable management projects in other locations, times, or subjects. The context changes while the scales, issues, level of complexity, and type of stakeholder group remain comparable. Upscaling means that a pilot project will result in an expanded pilot, full-scale management projects, or even influence policy. Thus, the dimensions of the pilot project increase, literally a 'higher scale,' and thus the nature - and effect of the project changes. More stakeholders, interests, and uncertainties are included, and different processes may start to play a role.

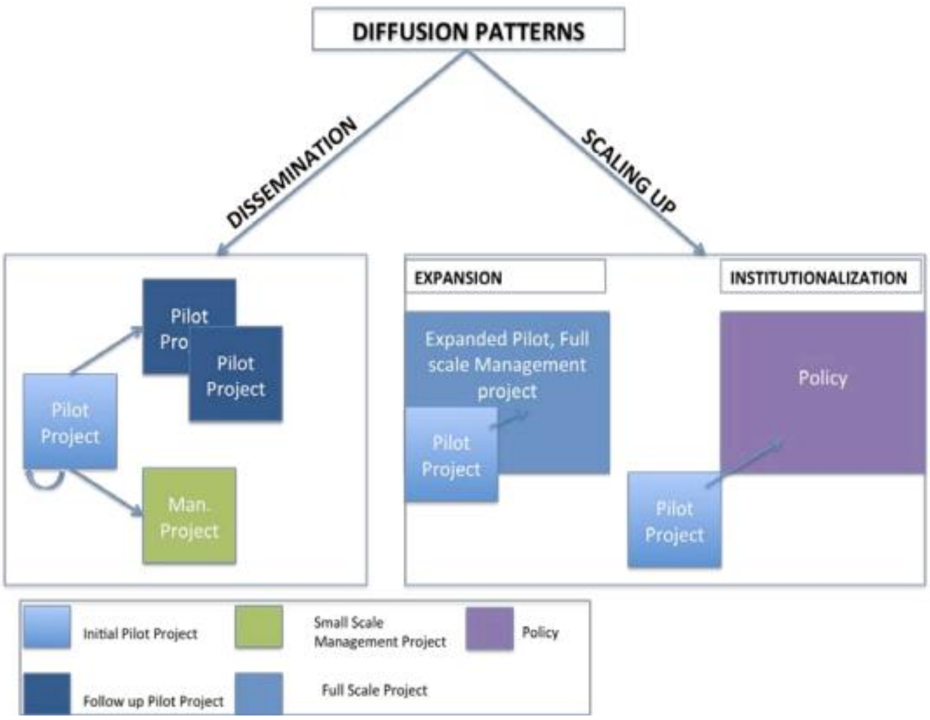

Figure 1. *Diffusion patterns of pilot projects adopted from Vreugdenhil et al. (2011)*

To track the upscaling process, the 'Technology Readiness Level' (TRL) is often used which entails the maturity level of an innovation. TRL unfolds in eight levels that represent step-by-step readiness, from idea to launch. When it comes to understanding the 'natural' and 'social' factors that shape the success of the pilot project, however, TRL falls short (Sartas et al., 2020; Van Cauwenbergh et al., 2022). Upscaling is embedded in broader systemic change in society including complex processes in political context and program management factors (Subramanian et al., 2011). Therefore, there is an increasing focus on social - and institutional readiness (Webster & Gardner, 2019). 'Scaling Readiness' evolved as a more inclusive approach for studying upscaling (Sartas et al., 2020) which analyses the conditions that make innovations ready for scaling and what actions could accelerate or enhance scaling. Scaling readiness takes into account the dependency on the wider socio-technological context (Fungo et al., 2022; Sartas et al., 2020; Schut et al., 2020).

Diving deeper into factors that drive upscaling pilot projects. A fit with the existing socio-technological landscape drives the upscaling of pilots like the networks between stakeholders and legislation that govern the innovation (Klerkx et al., 2012; Van Buuren et al., 2016). More specifically, Sartas et al. (2020) & Wigboldus et al. (2016) argue that upscaling relies on a collection of connected innovations, and requires the upscaling of other innovations or the downscaling of existing practices, the so-called 'innovation package'. Another factor that positively affects upscaling is the perception that the results from a pilot a reliable (Van Buuren et al., 2016).

But, quite often the notion from Woltering et al. (2019) *"pilots never fail, pilots never scale"* (p.2.) becomes reality. Characteristics of pilot projects i.e. freedom, needed additional resources, and small scale, can hinder the broader uptake of the pilots' results and outcomes by the existing policy regime (Vreugdenhil & Rault, 2010). Davis (2004) identified three common bottlenecks for scaling processes that mirror those encountered by pilot projects i.e., insufficient funding, lack of political will, and institutional mismatches.

These factors affect various aspects of the scale-up process, WHO and ExpandNet (2010) identified different layers to which these aspects can be linked. Starting with the first layer, the innovation refers to practice(s) that are scaled up e.g., introducing an innovative technology or replacing an outdated technology. The second layer is the resource team, organizations or individuals that directly facilitate the upscaling of the innovation e.g., through knowledge development or funding. A resource team includes, for example, researchers, NGOs, and program managers. The third layers consist of the potential users, organization(s) that seek to or are expected to engage in – or adopt the innovation on a large scale e.g., companies, consumers, or governments. The fourth layer describes the environment which are the conditions that are external to the user organizations but significantly affect the upscaling process. Examples include policies and regulations, economic landscape, and social pressure (*Appendix A*).

2.3 Nature-based solutions (NBS)

NBS is defined by Cohen-Shacham et al. (2016) as:

> *"Actions to protect, sustainably manage, and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."* (p.4)

NBS have experienced widespread adoption; however, there has been considerable confusion regarding their exact definition. Consequently, the International Union for Conservation of Nature (IUCN) established a Global Standard for NBS covering various criteria (*Figure 2;* Andrade et al., 2020)

First, NBS should address societal challenges, prioritizing benefits for humankind. Second, scalability is crucial, with the NBS design considering interactions between the economy, society, and ecosystems. Third, NBS must yield a measurable net gain in biodiversity and ecosystem integrity, subject to periodic evaluation and benchmarking. Monitoring should extend to identifying unintended adverse consequences from NBS. Additionally, NBS strategies should actively spot and integrate opportunities to enhance ecosystem integrity and connectivity. Fourth, economic feasibility involves documenting direct and indirect benefits and costs, specifying who bears these costs and enjoys the benefits. Fifth, governance processes supporting NBS should be inclusive, transparent, and empowering, ensuring diverse stakeholders' active involvement. Sixth, balanced trade-offs require a thorough evaluation of costs and benefits. Seventh, adaptive management based on evidence is crucial. To promote transformative change, openly sharing the design, implementation, and lessons learned from NBS is essential. Lastly, NBS should inform and enhance policy and regulation frameworks, aligning with existing governance structures and fostering supportive policies for uptake and mainstreaming.

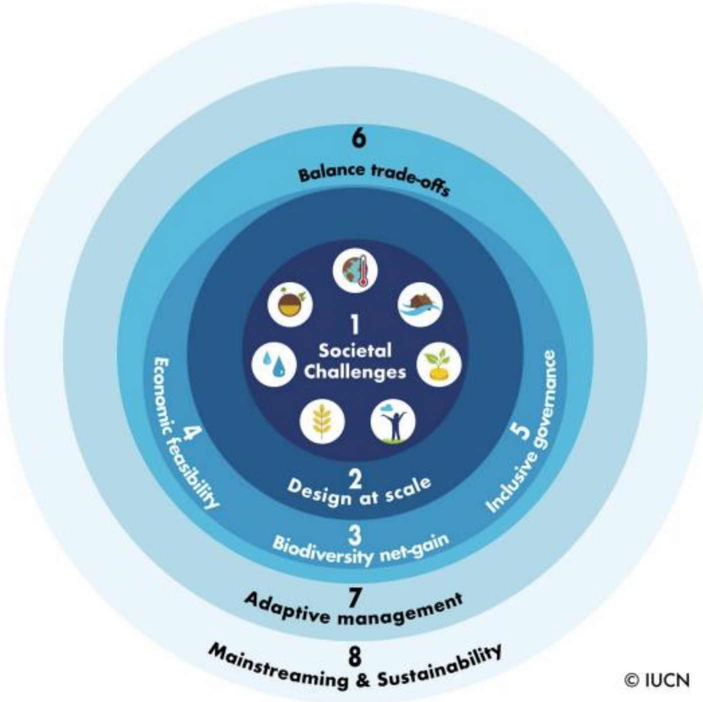

Figure 2. *The eight criteria for NBS according to the IUCN Global Standards (2020)*

NBS include a broad variety of applications whereby the created benefits are perceived both by nature as society (Andrade et al., 2020; Seddon et al., 2020). One of the main benefits of NBS lies in their ability to enhance the abundance and diversity of life, thereby fostering the resilience of ecosystems. When zooming out, the benefits for humanity come into focus. Supported ecosystems, in turn, ensure the provision of essential ecosystem services for society like food security (Xie & Bulkeley, 2020). Another example, NBS can improve resilience to climate change by providing natural buffers against extreme weather events, such as floods and storms (Seddon et al., 2020; Thackaberry, 2021).

2.3 Unique characteristics of NBS

NBS have unique characteristics, especially compared to general pilot projects e.g. technological innovation (Van Der Jagt et al., 2020). Including nature in these innovations introduces uncertainty into the outcomes of NBS as the dynamic ecological effects are less predictable (Bergen et al., 2001). Additionally, NBS are highly site-specific due to the varying ecological conditions e.g. species, and abiotic factors e.g. climate (Kapos et al., 2019; Somarakis et al., 2019).

Van Der Jagt et al. (2020) argue that NBS focus on integrating socio-ecological and socio-technical systems, opening the academic conversation on socio-ecological technical systems, and therefore developing a system perspective NBS. NBS require more agency, leadership, and long-term support to be successful. Also, the governance structure is more important due to the broad range of stakeholders involved (Mguni et al., 2015; Van Der Jagt et al., 2020), and thereby coordination and enhanced communication among stakeholders are crucial for NBS initiatives (Toxopeus & Polzin, 2021). Furthermore, monetizing socio-ecological benefits poses challenges for businesses, the complexity of assigning economic value to ecological benefits adds an extra layer of difficulty in assessing the financial returns associated with NBS implementation (Mayor et al., 2021). As Van Der Jagt et al. (2020) state *"additional research is required to develop a more elaborate understanding of the processes through which nature-based innovation develops over time"* (p. 213).

2.5 Conceptual framework: upscaling NBS

Again, NBS have unique characteristics. In line with this, upscaling NBS is not as evident as upscaling other, e.g. technological, innovations. Hendry et al. (2010) explain that societal beneficial innovations face more difficulties in bridging the VOD, with certain (other) factors influencing the scaling process of NBS.

Numerous studies, mainly focused on NBS in terrestrial and urban contexts, have investigated the upscaling of NBS and outlined the key factors influencing this process (e.g. Cortinovis et al., 2022; Dorst et al., 2022; McQuaid et al., 2021; Price, 2021; Sarabi et al., 2019). Nonetheless, the outcomes of these studies vary, and there is a notable absence of a comprehensive perspective on upscaling NBS (Price, 2021; Raymond et al., 2017). Therefore, this study utilizes a newly developed conceptual framework, in which the factors that affect the upscaling of NBS from existing literature are elucidated per layer for scaling: the innovation or application of NBS itself, the resource team i.e. current users and knowledge gatherers, potential users, or the broader environment that impacts the scaling-up process; the layers for upscaling innovation identified by World Health Organization (2009) (*Figure 3; Table 1*).

The first layer displays the innovation, which in this case NBS itself. Xie et al. (2020) argue that relevance of the NBS is needed in order to upscale, there must be a need. In the case of NBS, this implies that the innovation needs to address a societal challenge, also the first criterion for NBS according to IUCN (*Figure 2;* Andrade et al., 2020). As NBS include various types, which influence the complexity of upscaling. The factor type encompasses the proven effectiveness or maturity of the type of NBS, especially considering the uncertainty of effectiveness is a major barrier to NBS (Cortinovis et al., 2022; Hermans et al., 2020). Effectiveness is also highlighted twice in the criteria for NBS (*Figure 2;* Andrade et al., 2020). The final factor linked to the innovation layer is the ease of use of the NBS, referring to how easy it is to design, deploy, maintain, and decommission NBS (Hannon & Clifford, 2021; Kabisch et al., 2016).

The next layer involves the resources team, comprised of individuals and organizations currently involved with NBS. These actors have an influence on the following linked factors which can be drivers or barriers for the upscaling process. Starting with vision, planning, and strategy which refers to forward-thinking, and planning NBS on both short- and long-term by the resource team. This factor is found to be important for upscaling NBS (Gillespie et al., 2015; World Health Organization, 2009). Kabisch et al. (2016) explain that a disconnection between short-term actions and long-term goals is a barrier to NBS. The next factor includes leadership meaning attention and motivation for using and upscaling NBS which can either come from leader(s) - or the workforce of the resource team. Leadership can be a driver when NBS is highly prioritized in business operations, or conversely, a barrier when there is no attention given to it (Dorst et al., 2021; Wamsler et al., 2020). Financing is also highly important as the cost-benefit ratio is a crucial criterion for NBS (*Figure 2;* Andrade et al., 2020) and is proven to be both a driver for NBS e.g. cost reduction, and a barrier as NBS are harder to monetize (Dorst et al., 2021; Kapos et al., 2019; Sarabi et al., 2019; Seddon et al., 2020; Wamsler et al., 2020; Xie et al., 2020). This framework distinguishes financing in costs of scaling up (Johns & Torres, 2005), return on investments (Spiess-Knafl & Jansen, 2014), and external financial support (Smeds, 2020). As a proof of concept is crucial for NBS, monitoring is found to be important for upscaling NBS (Dorst et al., 2022; Sarabi et al., 2019; Seddon et al., 2021; Xie et al., 2020). Monitoring entails that the effectiveness of NBS is tracked and quantified to assess the positive impact of NBS and is performed by the resource team (Gillespie et al., 2015; Gündel et al., 2003). The final factor for this layer is learning. Learning is based on the knowledge that either is in-house or willing of a stakeholder to share their acquired knowledge on NBS (Andrade et al., 2020; Bossink, 2020; Dorst et al., 2021; Kabisch et al., 2016; Kapos et al., 2019; Sarabi et al., 2019; Wamsler et al., 2020).

The third layer entails the potential users. The numerous factors linked to this layer relate to reaching, engaging, or informing these potential users to also engage with, use, or support NBS. Starting with communication, this factor spreads awareness among potential users, Thus, the quality and quantity of communication are important for the wider use of NBS (Dorst et al., 2022; Kabisch et al., 2016; Sarabi et al., 2019; Seddon et al., 2020; Tall et al., 2014). Furthermore, (the lack of) partnerships influences the use or upscaling (Kabisch et al., 2016; Kapos et al., 2019; Sarabi et al., 2019; Wamsler et al., 2020; Xie et al., 2020). Also considering that the positive outcomes are distributed among various groups involved, benefiting multiple stakeholders (Mayor et al., 2021; Schut et al., 2020). Partnerships take various forms such as collaboration or financial support through sponsorships. Often, partnerships are employed to share knowledge, streamline processes, spread costs, and thereby spread the risk of testing NBS among the involved parties.

The last, overarching layer is the environment, i.e. the socio-technical landscape (Huguenin & Jeannerat, 2017; Raven et al., 2007; Vreugdenhil et al., 2010), comprising factors external to the users but fundamentally influencing the prospects for upscaling. Firstly, the technological system refers to the technological factors and conditions that are indirectly linked to the NBS like the fit with the existing structure, feasibility of deployment due to installing options for example, and geography. Secondly, the political system entails policies, regulations as well as contractual requirements like in tenders that affect NBS (Dorst et al., 2021; Kapos et al., 2019; McQuaid et al., 2021; Xie et al., 2020). For instance, legal constraints may pose challenges to NBS testing, while the political climate and willingness impact NBS subsidization. Third, the political system plays a crucial role in NBS criteria, as it should inform and improve policy and regulatory frameworks, align with existing governance structures, and foster supportive policies for adoption and integration *(Figure 2;* Andrade et al., 2020). The economic system implies to the wider economic system around an NBS that affect the options for financing and thus deployment (Kapos et al., 2019). Fourth, the social system describes the wider social system including awareness for the societal challenge, value NBS can create, but also opponents of the use of NBS (Martire et al., 2022).

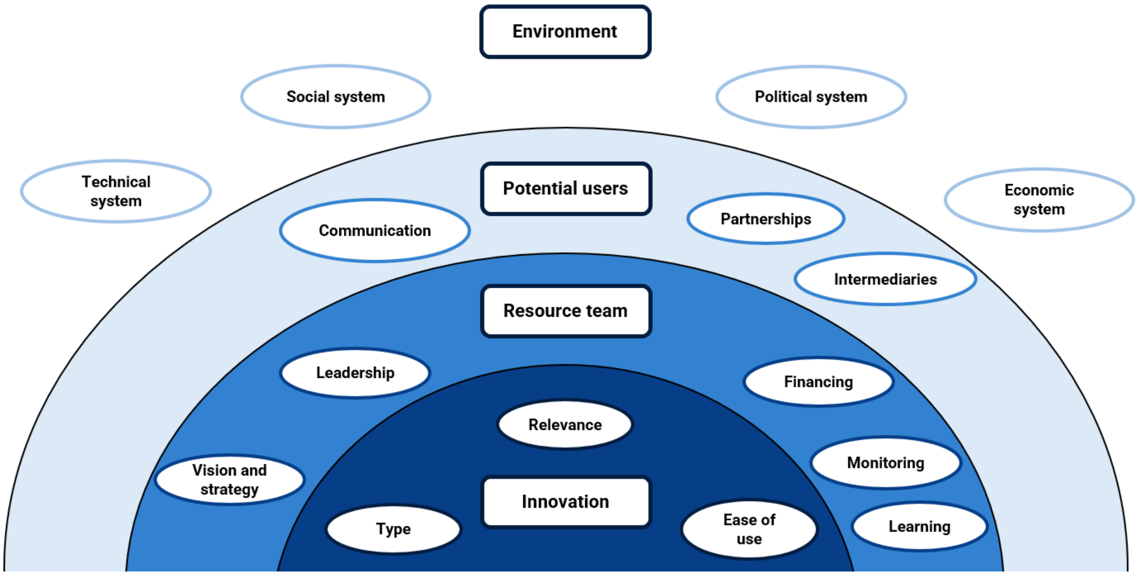

Figure 3. *Graphic presentation of the conceptual framework for upscaling NBS, layers for upscaling adopted from World Health Organization (2009) & IUCN (2020)*

Table 1. *Layers, factors and subfactors for upscaling*

Layers	Factors	Sub-factors	Source
Innovation	• ***Relevance***	○ Societal challenge	(Andrade et al., 2020 ; Xie et al., 2020)
	• ***Type***	○ Type/application ○ Effectiveness ○ Maturity	(Cortinovis et al., 2022)
	• ***Ease of use***	○ Engineering ○ Deployment ○ Maintenance ○ End-of-life	(Kabisch et al., 2016)
Resource team	• ***Vision and strategy*** •	○ Short-term planning ○ Long-term planning	(Dorst et al., 2021; Sarabi et al., 2019; Xie et al., 2020)
	• ***Motivation***	○ Leadership ○ Workforce	(Dorst et al., 2021; Wamsler et al., 2020)
	• ***Financing***	○ Cost ○ Financing ○ External financial support ○ Return on investment	(Dorst et al., 2021; Kapos et al., 2019; Sarabi et al., 2019; Seddon et al., 2020; Wamsler et al., 2020; Xie et al., 2020)
	• ***Monitoring***	○ Effect(iveness) quantified ○ Effect(iveness) monitored	(Dorst et al., 2022; Sarabi et al., 2019; Seddon et al., 2021; Xie et al., 2020)
	• ***Learning***	○ Knowledge availability ○ Evaluation	(Dorst et al., 2021, 2021; Kabisch et al., 2016; Kapos et al., 2019; Martire et al., 2022; Sarabi et al., 2019; Wamsler et al., 2020)
Potential users	• ***Communication***	○ Quality ○ Quantity	(Dorst et al., 2022; Kabisch et al., 2016; Sarabi et al., 2019; Seddon et al., 2020)
	• ***Partnerships***	○ Collaboration ○ Multi-stakeholder agreement ○ Sponsorship	(Kabisch et al., 2016; Kapos et al., 2019; Sarabi et al., 2019; Wamsler et al., 2020; Xie et al., 2020)
	• ***Intermediaries***	○ Person(s) ○ Organization(s)	(Kapos et al., 2019; Sarabi et al., 2019; Wamsler et al., 2020; Xie et al., 2020)
Environment	• ***Technical system***	○ Fit with existing structure ○ Feasibility ○ Geography	(Dorst et al., 2021; Kapos et al., 2019; Martire et al., 2022; Sarabi et al., 2019)
	• ***Political system***	○ Policy and regulation ○ Tender requirements ○ Other	(Dorst et al., 2021, 2021; Kapos et al., 2019; Xie et al., 2020)
	• ***Economic system***	○ Contractual requirements ○ Financing	(Dorst et al., 2021, 2021; Kapos et al., 2019; Wamsler et al., 2020; Xie et al., 2020)
	• ***Social system***	○ Awareness ○ Opponents ○ Value	(Dorst et al., 2021, 2022; Kapos et al., 2019; Martire et al., 2022; Wamsler et al., 2020; Xie et al., 2020)

3 BACKGROUND

3 Background

3.1 NBS for offshore wind

As NBS can protect, restore, and manage modified ecosystems, they offer a strategic approach to positively influence maritime spatial planning (MSP) within the context of OWFs (Cohen-Shacham et al., 2016; Stephenson, 2022). Within offshore wind, NBS can create value in terms of habitat creation (Bennun et al., 2021; *Appendix B*), resulting in biodiversity restoration, carbon sequestration, supporting recreational or commercial fishing, and nutrient filtration (European Investment Bank., 2023). Following Eggermont et al. (2015), marine NBS exhibit diverse functions and added value (*Appendix C*). This study identifies three relevant types applicable to offshore wind: enhancement through artificial design, sustainable use, and protection of marine ecosystems via marine protected areas, as well as the improved multifunctionality of managed ecosystems or nature-inspired design. Although nature-inspired design to mitigate negative impacts is included in NBS, this is excluded from this study, which concentrates on enhancing the positive impacts of offshore wind.

There is a growing interest in integrating nature into offshore wind. However, there is a lack of clarity regarding the specific categorization of NBS within the context of offshore wind. While extensive research and widespread utilization of the term NBS on land exists, the maritime environment has received comparatively less attention (Pardo et al., 2023). The offshore industry's limited embrace of NBS has resulted in the absence of a well-defined classification for solutions related to offshore wind within this established terminology. Pardo et al. (2023) have identified various applications as "nature-positive approaches," and according to the definition of Cohen-Shacham et al. (2016), these applications can be considered under the umbrella of NBS. This issue is not unique to the marine environment, overall there has been confusion over the term and what ‘counts’ as an NBS (Seddon et al., 2021), and much more work needs to be done to improve the conceptualization of NBS (Price, 2021). To help solve this, this study suggests a breakdown of the NBS specifically tailored for offshore wind, as illustrated in Figure 4.

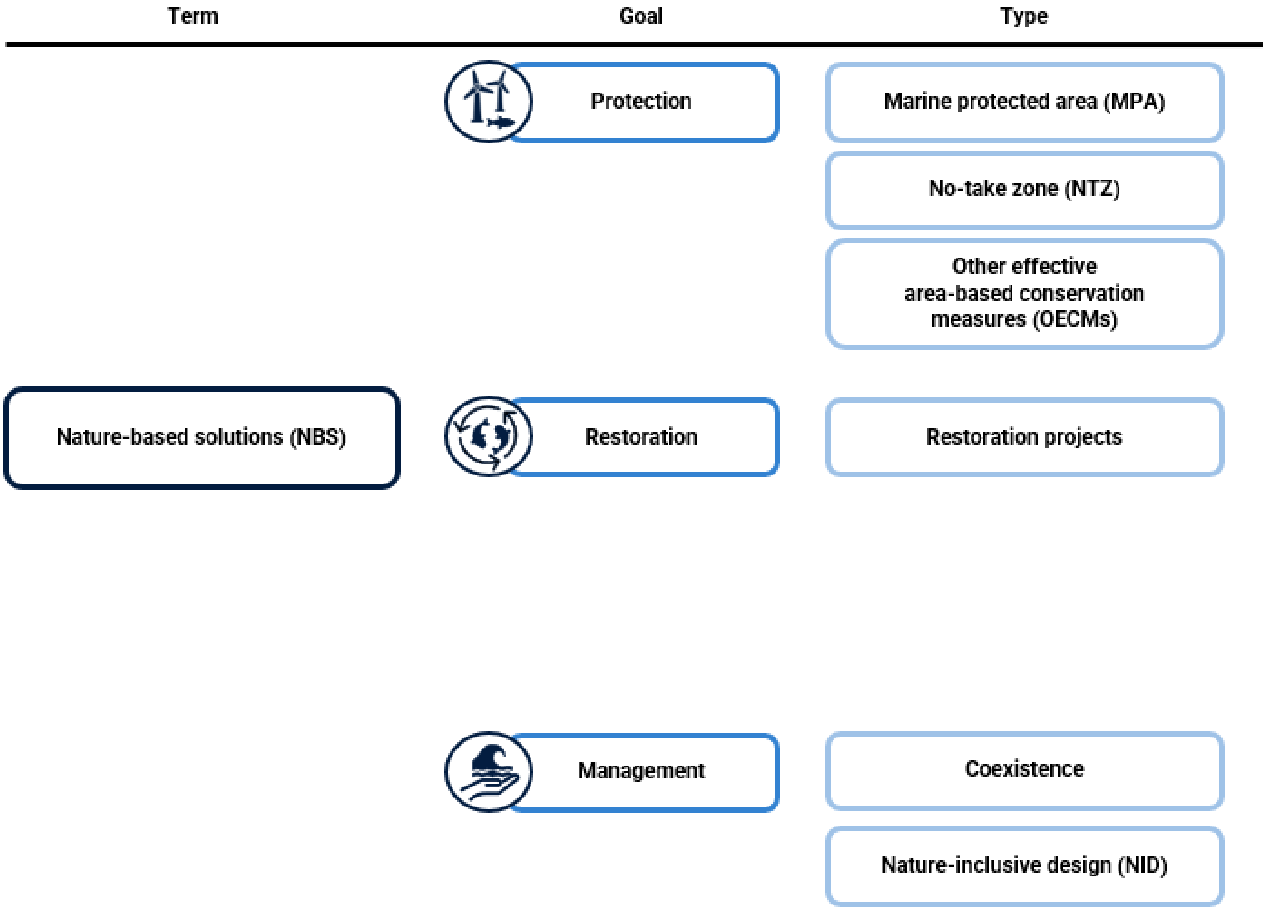

Figure 4. *Schematic breakdown of the types of NBS for offshore wind by group based on Eggermont et al. (2015), Pardo et al. (2023), and Riisager-Simonsen et al. (2022)*

The classification comprises three overarching goals i.e., conservation, restoration, and enhancement, under which various types of NBS for offshore wind can be categorized.

Protection. protection entails managing the environment in a manner that does not despoil, exhaust, or extinguish (Jordan, 1995). In the context of MSP and offshore wind, three types of NBS are distinguished:

- **Marine protected area (MPA)** is a geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Day et al., 2012; Pardo et al., 2023).
- **No-take zones (NTZ)** can be defined as MPAs in which the extraction of living and non-living resources is permanently prohibited, except as necessary for monitoring or research to evaluate effectiveness (Jones, 2006; National Research Council, 2000).
- **Other effective area-based conservation measures (OECMs**) are area other than MPAs. which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services (CBD, 2018).

Restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration International, 2004). Restoring nature represents a widely employed and effective strategy for supporting ecosystems that have undergone degradation. In the context of restoration initiatives, the selection of indicator species plays a crucial role in assessing the efficacy of the restoration process (Jordan, 1995). Typically, these targeted species are chosen based on factors such as reduced abundance, signaling a need for intervention, or their position in a higher trophic level, providing insights into the abundance dynamics at lower trophic levels.

- **Restoration projects** assist in the recovery of an ecosystem that has been degraded, damaged, or destroyed (Jordan, 1995)

Restoration is highly site-specific (Abelson et al., 2020; Coleman et al., 2020). For instance, European flat oysters (*Ostrea edulis*) or native oysters once formed extensive beds in European seas, particularly in the North Sea, but the abundance declined due to trawl fishing. Within several OWFs oyster restoration projects have been set up to bring back these reef builders in this area (Kamermans et al., 2018; Robertson et al., 2021).

Management within offshore wind, enhancement aims to improve ecological conditions through increasing and/or improving the habitat for biodiversity (Ido & Shimrit, 2015).

- **Coexistence** is described as the placement of multiple activities or uses within the same marine area, including safety zones where applicable (Stamford et al., 2013).
- **Nature-inclusive design (NID)** are options that can be integrated in, or added to, the design of an anthropogenic structure to enhance ecological conditions (Hermans et al., 2020).

The characterization of NBS for offshore wind is a bit more nuanced, exhibiting potential overlap among distinct types. For example, part of a restoration program may include the use of nature-inclusive design. Important to reiterate and emphasize that NBS starts from a societal challenge, i.e. a human interest, not just for the sake of nature (Andrade et al., 2020; Waylen et al., 2022). Pérez et al. (2024) identified a framework for choosing blue NBS, zooming in on the relevance i.e., societal challenge of different types of NBS for marine ecosystems. Main reasons to conduct NBS are acting on climate change, food – and clean water security.

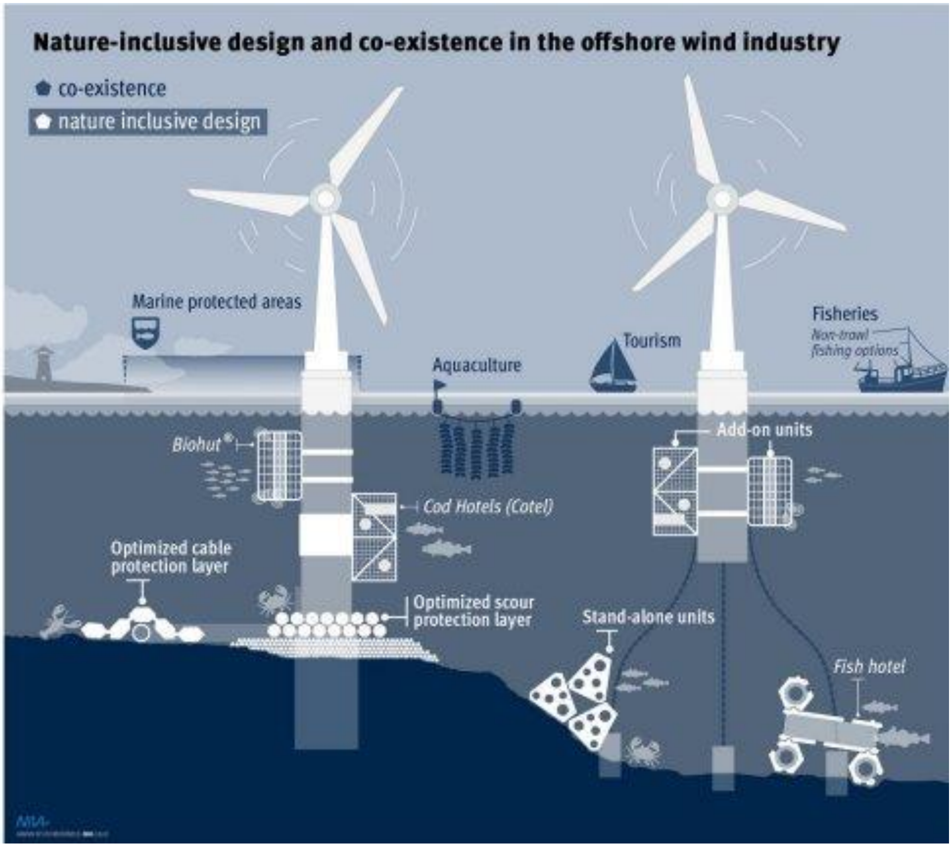

Figure 5. *Applications of NBS for offshore wind adopted from Pardo et al. (2023)*

3.2 European developments on NBS for offshore wind

The concept of NBS been pushed forward through (European) policies to promote synergies between nature –, society, and the economy resulting in NBS being widely adopted by companies (Cohen-Shacham et al., 2019; European Investment Bank., 2023; Seddon et al., 2020). However, there is indeed a significant difference in approach among European countries. For instance, the Netherlands is a pioneer in integrating ecological criteria and adding a positive impact through Nature-Based Solutions (NBS). Although this is not applied to every Offshore Wind Farm (OWF), it was a subject in one of the two plots in the recent tender for IJmuiden Ver; 45% of the tender points were related to ecology (RVO, 2024). Belgium also started to employ NBS in offshore wind. Other countries like Germany have measurements to mitigate negative impacts but do not see offshore wind as the place to make a positive impact. The last group of countries, including the United Kingdom, Norway, and Sweden, does have a national plan to create a positive impact, but this has not yet been translated into concrete tender criteria or requirements.

Companies are also increasingly concerned with NBS for offshore wind. For example, one of the largest offshore wind developers, the Danish company Ørsted, has launched a nature-positive strategy. Many companies claim to implement nature-positive initiatives, yet there exists a gap between what is necessary to achieve a resilient environment and what the industry has delivered thus far (zu Ermgassen et al. 2022).

4 METHODS

4 Methods

4.1 Research design

4.1.1 Research outline

This study aims to gain knowledge on the challenges of the upscaling process of NBS for offshore wind. As NBS in this industry are presently in the pilot phase, with pilot projects being tested and integrated into tender requirements for the first time, this question is urgent. This pilot phase presents an opportunity to delve into the factors that drive and hinder upscaling of NBS, as well as identify what these innovations need for further development.

To meet this aim, a deductive, qualitative approach was chosen. The data consists of two types of sources; interviews and a survey (Bryman, 2016). Semi-structured, in-depth interviews were held with various stakeholders involved with NBS for offshore wind (Barriball & While, 1994). Due to the various actor types and including the whole European market, the group was too large to interview all representatively. Therefore an additional survey was conducted among the European offshore wind market questioning what affects the upscaling of NBS in offshore wind (Greener, 2008). The unit of analysis is the responses of the survey and interviewees.

4.1.2. Operationalization

The survey and interviews examine 'upscaling' and 'nature-based solutions'. These concepts are explained at the beginning of the interviews and survey for consistency. The analytical framework i.e., the layers framework is formed by combining the layers of upscaling with factors influencing upscaling (*Table 1*). Both the interview guide and the survey questions are based on the factors of the conceptual framework.

4.1.3. Geographical scope

For two main reasons, the geographical scope includes the European offshore wind market: market size and the interest for NBS. Nearly half of the offshore wind capacity is located in Europe, the construction of OWFs is relatively mature in this area and projections indicate major growth in the upcoming years (Wind Europe, 2023). Therefore nature-inclusive construction is becoming increasingly important. Additionally, the EU supports the use of NBS (European Investment Bank., 2023), this is also apparent from the role of several European countries, including the Netherlands, which are pioneers in the use of NBS in offshore wind (Pardo et al., 2023).

4.2 Sampling strategy

4.2.1 Interviews

In-depth insights were collected through semi-structured interviews with individuals among the different stakeholder groups. The goal is to speak to a representative of each actor group, preferably spread across different regions in Europe.

The interviews were semi-structured. The interview questions were designed to elicit the participants' perspectives and practices regarding NBS in offshore wind, their interactions and relationships with other actors, and what factors either support or withhold the use and upscaling of NBS. An interview guide was used during the interviews to maximize the flow of valid, reliable information while minimizing distortions of what the respondent knows (Fowler Jr & Mangione, 1990; Gorden, 1969). The interview guide was based on the conceptual framework (*Table 2; Appendix E)*. All topics in the guide were discussed, in addition, there was also room for the interviewee to bring up topics and anecdotes to exemplify their experiences.

Sampling of the interviewees primarily occurred through convenience sampling via an online questionnaire where participants were asked if they were also open to participating in an additional interview (Babbie, 2020). In addition, purposive sampling was used to target underrepresented actor groups e.g., researchers, sustainability - or offshore wind managers within key offshore wind companies, were approached individually via mail. The network of Heerema Marine Contractors was also used for this purpose. In addition, the interviews were held at the WindEurope Annual Event in Bilbao, a conference on (offshore) wind in Europe with more than 12,000 participants. Sampling was stopped when all key actor groups had been interviewed. For anonymity purposes, the interviewees are identified by acronyms of the actor group (*Appendix D*).

A total of 25 interviews were conducted including industry players i.e., offshore windfarm owners or developers [OWN], installation companies [INS], and other industry players [OTH]. In addition, NBS providers [NBS], researchers or people working in R&D [SCI], non-profit organizations [NGO], and consultants [CON]. Governmental parties [GOV], and financial institutions [FIN] were also included in the interviews.

The interviews were conducted in person or via video conference, depending on the participant's preference and location. Each interview took between 45 - 70 min and was conducted in Dutch or English. The interviews were audio-recorded and transcribed for further analysis.

4.2.2 Survey

Additionally, a survey was designed in the form of a self-completion, multiple-choice questionnaire with vertical closed answers (Bryman, 2016) using the software Qualtrics. The goal was to gain additional information on opinions and experiences of upscaling NBS, therefore a Likert scale for answering the survey was chosen with the following options: "Strongly Agree"- "Agree"- "Neutral"- "Disagree" - "Strongly Disagree" - "Don't know". In addition, there was an optional open field to add explanations.

The survey (*Appendix F)* started with questions about the actor itself i.e., what actor group, the actor's influence on NBS, country of origin, and what types of NBS the actor is involved in. Continuing, the survey focused on what factors influence scaling up NBS in offshore wind based on the conceptual framework *(Table 1)*.

Purposive sampling was used for sending out the surveys. The survey was sent out via mail to the identified actor groups based on an Excel with potential information-rich companies, organizations, knowledge institutes, and persons with over 500 contacts. If only a general email address could be found, it was requested that the survey be forwarded to someone within the organization with an understanding of sustainability and offshore wind, preferably with knowledge about nature or biodiversity. To increase response rates, a document was sent along with information about the research. In addition, the survey was promoted at the WindEurope Annual Event in Bilbao. Here posters were put up with explanations and the QR code of the survey on them, and participants were asked to fill out the survey on the spot on a tablet. Sampling was stopped after the conference.

Overall, the survey has 58 respondents (*Appendix G*) with an average of 20 answers per question. It is worth mentioning that the survey had different respondents than the interviews since it was not actively promoted to the interviewees.

4.3 Data analysis

4.3.1 Interviews

The interviews were coded using ATLAS.TI. The codebook is created based on the previously mentioned framework (*Table* 1).

Data was coded using a descriptive coding technique, which allows for a systematic categorization of the data obtained from the interviews and identified patterns and themes that resulted in a clear overview of the topics researched. Data was analyzed using thematic analysis to gain knowledge on upscaling NBS through experts' knowledge, experience, values, opinions, and views on the topic. Thematic content analysis was used both deductively i.e. from the framework, and inductively i.e. from the new insights as the conceptual framework (*Table 1*) is an addition to current literature on upscaling NBS (Fereday & Muir-Cochrane, 2006). Quotes from the interviews are given throughout the description of the results to illustrate how the interviewees responded.

4.3.2 Survey

Given the low number of respondents, only descriptive statistics were performed (Bryman, 2016). Likert scale answers had multiple response options (e.g., "Strongly Agree" to "Strongly Disagree"), so the responses were aggregated into broader categories for easier analysis (e.g., combine "Agree" and "Strongly Agree" into one category). Furthermore, the responses to the open-ended options and - questions were thematically analyzed, like the interviews. The percentages were calculated with Qualtrics. The survey data served as a supplement to the interview data due to the low response rate and was added when it complemented or confirmed the interview results.

4.4 Ethical statement

Ethical handling and processing of sensitive or personal information was considered. All participants, both from the interviews and the survey, were informed about the purpose of the study, the company involved, and the anonymity of their responses before the survey and the interview. Participants were requested to agree to terms and conditions including a quest for consent at the beginning of the interview and the survey. Both in the data collection and in the subsequent data processing, the individual's name and the organization's name were anonymized. If the participant requested, the information used in the thesis e.g., quotes, was shared with the participant.

5 RESULTS

5 Results

The findings gathered from both the interviews and THE survey are presented here, offering insights to bridge the knowledge gap of upscaling NBS for offshore wind. To comprehend the upscaling process of NBS, the drivers and barriers are discussed per layer following the conceptual framework (*Figure 3; Table 1*).

5.1 Innovation

5.1.1 Increased relevance for NBS within offshore wind

NBS have gained attention over the past five years in the offshore wind industry (Pardo et al., 2023), mainly due to academic research on the negative effects of offshore wind during construction and operation [INS2; NBS1; NBS2; NBS3; NGO1; SCI4].

> "I think what you're seeing very much now is, what we see, that environment where we're building, we're also changing that, so we need to take that into account."

In line with this, the current poor state of the European seas is seen as a societal challenge and thus a driver to act [GOV1; INS3; NGO1; NGO2; NGO4; SCI3]. To then add another pressure such as offshore wind, is seen as unwise. Offshore wind development should be done with consideration for nature and thus with NBS. At the same time, the potential for positive impacts emerges as fishing and other stressors are prohibited in OWFs [INS1; NBS4; OWN3], as NBS4 confirms:

> "These offshore wind farms apparently started to develop a lot of biomass."

With the offshore wind industry maturing, technical feasibility challenges for OWFs are overcome, freeing up resources to focus on sustainability [CON2; OTH2; SCI2]. This slack has led to a heightened focus on developing comprehensive sustainability strategies, encompassing a positive impact on nature [NBS1; SCI4]. Integrating nature into these strategies is even essential for the future viability of companies within the industry, as OWN3 explains:

> "It is a part of your viability in the future. The scale at which wind farms will need to be built to achieve climate ambitions or realize energy transition means that you will inevitably have an impact on the marine ecosystem. So, you need to be very capable of understanding and mitigating that effect. You can not afford to not be aware anymore."

NBS for offshore wind are gaining relevance as European seas become more crowded. Competition for space demands optimal utilization, driving the adoption of multi-use practices, like integrating renewable energy structures with nature objectives [INS2; INS3; NBS1; NGO2; NGO4]. Governance acknowledges this, as it appears on the political agenda and in European strategy [G1; INS1; INS2; NBS1; NBS2; NGO2; OTH2; OWN1; OWN3; SCI3; SCI5].

5.1.2 Uncertainty about effectiveness

Whereas offshore wind is a mature industry, NBS for offshore wind is still in its infancy [NBS4]. According to NGO2, NBS are seen as an accessory in offshore wind design. This immaturity is due to an often-lacking proof of concept since testing and monitoring NBS has only just recently started [CON2; GOV1; INS3; OWN2; NBS1; NGO2; NGO4; SCI3; SCI5]. Therefore, there is limited knowledge on how to improve NBS [SCI2]. This lack of evidence brings uncertainty [NBS1; SCI5] and this forms a barrier for actors to engage, as SCI5 states:

> "There is some research being ongoing and monitoring and everything, but it is not a practice that has been here for decades. So, for them, it is still a testing thing. So, they are always like, okay, does it make sense for us to give money to something that we are not sure is going to work?"

NBS for offshore wind are highly site-specific [NBS1; NBS3; OWN2; SCI5] and the applications vary [SCI3]. The variety of solutions also contributes to the uncertainty of effectiveness [OTH2]. Pilot projects have a smaller scale. However, this conflicts with active testing in ecological conditions [NBS3; NBS4; OWN3] and succession processes [NBS2] (*Appendix I*). NBS3 states:

> "There is this concept of critical mass, which is you need a certain number and density of oysters to get an ecosystem to take off. And a few thousand oysters, tens of thousands of oysters are not getting you there."

Despite little being known, several interviewees questioned the effectiveness of adding even more artificial structures e.g., artificial reefs, and if this would be beneficial for ecology as offshore wind construction already adds a great amount of concrete [OTH2; OWN3; NBS2; SCI3], as SCI3 specifies:

> "Suppose NID does have a positive effect. But how far should you go with that? How many artificial structures will you add?"

5.1.3 NBS development and design, questions remain about decommissioning

Choosing a suitable NBS is difficult [IN3; NGO1] as developers often lack in-house knowledge [CON1; INS3]. While the current emphasis is on devising innovative and imaginative solutions, there is a shift back towards considering the purpose of NBS [OWN3; SCI3]. SCI3 highlights the importance of asking, "what do we want with it," as opposed to "why do I want," as the primary question when deploying NBS. Furthermore, the ease-of-use varies per type, add-ons and stand-alone units are found to be relatively easy [INS3; NGO1; NGO4; SCI2] while changing the existing structure e.g., water replenishment holes in the monopiles, requires more planning and is more difficult to implement quickly [INS1; OTH2]. Of the survey respondents, 57,2% agreed that NBS are easy to use, while 17,9% disagreed.

About the ease of use at end-of-life i.e., decommissioning, more questions remain [CON1; NBS4; OWN3; NGO1; SCI1; SCI2; SCI3; SCI4; SCI5]. Deploying nature enhancement can be counterproductive if all need to be decommissioned in 30 – 40 years [OWN3; SCI2] and not enough attention is paid to this [SCI3]. As SCI2 states:

> "And then maybe it's not worth spending the resources on NBS."

On the other hand, NBS for OWFs could change the perspective of decommissioning compared to oil and gas due to the added ecological value [NBS2].

5.2 Resource team

5.2.1 Actors, motivation, and strategy

The resource team consists of the individuals and organizations that NBS initiated the pilots and facilitated and promoted the use or scaling up of NBS (WHO, 2009). Within offshore wind, several types of actors i.e., developers, contractors, governments, and knowledge institutes, participate in the resource team. An important part of the resource team, NBS providers, are often start-ups that lack resources [SCI2].

Attention for NBS often comes from a motivated workforce and is found to be a major driver [INS1; NBS4; NGO1; NGO4; OTH2; OWN2; SCI4]. Employees in the wind industry often possess an internal drive for sustainability, aiming to encompass all its facets, such as biodiversity and environmental preservation. Moreover, the influence of a sustainability team within the larger organization affects the use and scaling of NBS [SCI4], with integration into the engineering team being crucial for fostering innovative approaches [NGO2]. Additionally, strong leadership from top management is also key for companies engaged in NBS [CON1; NBS1; OWN2; INS2; SCI5]. This aligns with the survey findings, where 56% of respondents viewed this as a driver, while 4% disagreed. However, this leadership can be challenging to cultivate for companies with a background in oil and gas [CON2; OTH1; SCI2]. Consequently, incentivization becomes imperative for companies to prioritize sustainability [CON2; GOV1; NBS4], necessitating governmental leadership in this regard [GOV1; NGO3]. But this still varies greatly by national government. NBS4 underscores this necessity:

> "The primary motivation to act on this is the tender bids and the legal obligations that they have."

Integrating NBS early in the design process reduces costs and makes it easier to achieve than if the existing design must be modified later [CON2; OTH2; OWN1; OWN3; NGO4]. Where short-term planning helps scale up NBS, NBS are most of the time not included in the long-term strategy of OWFs [CON1; INS3; OTH2; OWN3; NGO1; NGO3; SCI3; SCI4], however, embedded in governmental stewardship which is growing [NGO2; OWN3]. In the survey, there was a division regarding the level of strategy for NBS. 32.2% believed there was a clear long-term plan, 21.4% were neutral, and 28.6% disagreed.

5.2.2 Financing: two sides of the coin

Most of the costs are not for the foundation of NBS itself, but the costs associated with the solutions [NBS2], like manhours for research, monitoring, and maintenance [INS2; OWN2; OWN3; NBS3; NBS4]. As NBS4 confirms:

> "It is not about the cost of the material; it is about the cost of the work. Seventy percent of those projects are the costs associated with the work. So, increasing the installation time. Or creating a liability or affecting service in the future."

Costs built up due to the long testing cycles [NBS2; SCI3]. The later the OWF design must be modified, the more expensive it becomes [GOV1; INS1; NGO1; NGO4; OWN3]. GOV1 stresses that inventing and developing an NBS yourself is expensive, especially since it also requires third-party control and monitoring. Additionally, the offshore environment adds another factor to the cost "the further out from the coast the higher the costs are" [NBS3; SCI5].

Due to the immaturity of NBS, substantial resources are required to deploy and evaluate these new additions to OWFs thereby forming a financial obstacle [CON1; NBS4; NGO2; OWN1; SCI4; SCI5]. Moreover, there exists considerable ambiguity surrounding the costs, with stakeholders not openly sharing this information [NBS3; NGO3; NGO4].

This lack of transparency complicates companies' decision-making processes regarding NBS adoption, particularly considering the anticipated cost escalation at a larger scale, as highlighted by NBS1:

> "But they are all experiments and with limited budgets. If you want to do a large-scale farm like this, we are talking about completely different numbers in terms of investments and OPEX requirements."

This magnitude of cost cannot be borne by research – and impact funds. As OWN1 with experience in NBS summarizes:

> "It costs money, and it doesn't make money. So, in the end, your whole business case for the wind farm automatically always gets worse. And it's less interesting to build a wind farm if you always have to in the future."

On the other hand, others argue that costs do not form the barrier to upscaling NBS [CON2; INS1; NGO1]. Costs play a role, yet when considering the comprehensive financing of offshore wind, their impact on the total picture is quite minimal [CON2; INS2; INS3; NGO1; NGO4]. NBS are described as the low-hanging fruit to do good [INS1], especially when integrated into the design at an early stage.

Costs are often covered by the developer [INS1; INS2; NGO4; SCI4]. Additionally, a combination of research funding, impact funding [NBS1], or R&D in this area by installers and other parties [INS2] finance the NBS. Banks and other investment funds are not specifically interested in NBS but do have an increasing interest in green investments including OWFs [FIN1; OWN3].

NBS contribute to a better state of the environment, but many interviewees struggle to see the monetary benefits [CON1; CON2; OWN1; OWN3; NBS1; NGO3]. There are no cost savings, unlike in dredging where this is evident e.g., through the reuse of materials for ecosystem restoration. Also, direct revenue cannot be generated, for example, from selling oysters or through tourism [NBS4]. Monetary return on investment, logically, is true NBS providers [NBS1; NBS3; NBS4]. Additionally, INS1 mentioned that installers can receive revenue as the knowledge - and the developed NBS can be sold abroad since the interest for NBS is growing. Furthermore, indirect return on investment can be a competitive advantage [GOV1; INS3; NBS1; NGO1; OWN3; SCI3] e.g., to win tenders, especially in countries with non-price criteria [GOV1; NBS4; OTH2; OWN1; OWN3]. Biodiversity could become a bottleneck for offshore construction like nitrogen currently is for building the Netherlands [OWN3], thus, a necessity for a future-proof organization [INS3]. More indirect return on investment is found in the wide acceptance of offshore wind [GOV1; NGO1; NGO3; SCI4], PR benefit [NBS3; NGO3], and attracting future workforce [NGO1]. Return on investment is a matter of perspective, who receives the benefits and who invests [FIN1]. The return on investment is often with NBS providers, or other actors e.g., fishermen who can catch more fish [FIN1; INS3], NBS4 states:

> "I think the way to scale it up is to bring a return on investment to the actual owners of the offshore wind farms or developers."

5.2.3 Monitoring is evolving, but concluding is difficult

Monitoring is an important part of the piloting process [GOV1; NGO3; OWN1], often a mandatory component in the tender [INS2]. This stimulates the technical development of monitoring [INS2; SCI3; SCI4]. The monitoring approach varies per site, while competition encourages the testing of different monitoring methods, the diversity in approaches makes it challenging to compare results [GOV1]. Third-party monitoring is necessary [NBS2], but there are no standards [NBS1] responsibility for monitoring varies, which is seen as a barrier [NGO1; SCI3]. Moreover, simultaneous testing of various NBS in distinct locations complicates the assessment of effectiveness [SCI3]. As cautioned by NBS1, drawing conclusions, especially when tied to revenue streams, demands careful consideration.

Despite ongoing technological advancements such as drones, planes, e-DNA, and satellites [CON1; INS2; NGO2; OTH2; OWN1; OWN2], monitoring offshore environments remains challenging [SCI2; SCI3]. Imaging from these technologies often fails to differentiate between living and deceased organisms, like shellfish [SCI5], and the corrosive effects of saltwater lead to rapid equipment deterioration [SCI3]. Safety restrictions often prohibit monitoring with divers [SCI2], and restrictions on ship anchorage within wind farms necessitate the rental of more expensive vessels, significantly inflating monitoring costs [NBS3; SCI2]. Moreover, there is a scarcity of suitable vessels available, as noted by CON2. Additionally, the worsening effects of climate change result in harsher weather conditions, reducing the time windows available for accurate measurements [CON2].

An even bigger challenge lies in data interpretation [CON2], and quantifying effectiveness [GOV1]. Selecting indicators or key species might be doable [OWN2], but a lot of knowledge of the ecological system is required, which is highly site-specific, and data is often missing. As OTH2 states:

> “What nobody has defined yet is what does good look like? What is positive? And that goes back to the question of who defines what is positive, and what is positive in one location may be completely different from what is positive in another location. So then, how do you ever get to a point where you say, "This offshore wind farm has biodiversity quality 10, and this one has biodiversity quality 7"?”

5.2.4 Knowledge is being gathered, but gaps remain

Knowledge gap on the effectiveness of NBS is seen as a major barrier [CON1; CON2; GOV1; INS3; NBS1; NBS4; NGO1; NGO2; NGO4; OWN2; OWN3; SCI2; SCI3; SCI5]. This includes the absence of a reliable quantity of in-water trial data [NGO1; NGO2]. Another knowledge gap exists on the impact of NBS on a larger scale as they are still human interference [CON1]. Also, the cumulative impact on populations and ecosystems is unknown [INS2; OWN2], especially in the long term [SCI5]. Furthermore, there is currently no comprehensive overview outlining what actions companies can take to enhance nature within OWFs [NBS4; NGO3]. The survey also highlighted the lack of knowledge. According to 39.1% of respondents, there is currently insufficient knowledge, while 26.1% claim to have adequate knowledge.

5.3 Potential users

5.3.1 Open communication and greenwashing

Developers often exhibit reluctance to disclose information regarding the types of NBS they design or test [CON1; CON2; GOV1; NBS1; NGO1; NGO4; SCI2]. Lessons learned are often not shared [INS2]. INS3 points out that the development of NBS is also a “way to win” so information is not openly shared. As CON2 explains:

> “Monitoring data costs a lot, so they have a big economic value. They have a big competitive advantage, also, because, perhaps in two years, another competitor wants to build a wind farm just next to it, and they can rely on their data and save millions.”

Yet communication is considered crucial, according to survey respondents. 82.6% agreed that communication promotes the use and scaling up of NBS, with none disagreeing.

If NBS are included in tenders, sharing the results of monitors is made mandatory, thus forcing open communication [GOV1; NGO1; OWN1; SCI5]. SCI3 points out that OWFs with NBS are still so fledgling that it remains to be seen if open communication around information from the tender will work. Also, the monitoring data is often not openly shared [NBS2]. Besides competitive advantage, the uncertainty of effectiveness hinders communication as no one wants to produce an idea that later does not work [CON2].

On an international level, communication, and knowledge sharing on NBS is scarce and remains superficial [CON2]. More detailed information is scattered among different organizations and work groups [NGO2]. INS2 points out the need for vertical communication e.g., between installer, developer, and government. Additionally, there is no platform for sharing information [NGO3; NGO4; OTH2; OWN3; SCI4], which is seen as a barrier. S5 disagrees and thinks everything is quite well aligned.

Communication also has a marketing purpose [INS1; NGO1; NGO2; NGO3; NGO4]. However, companies must be mindful of criticism due to the potential risk of greenwashing [CON2; INS3; NGO4; SCI3]. Some argue that the way NBS are promoted is already greenwashing [NBS3; NGO4]. As a survey respondent mentioned:

> "It is a bad idea generated by opportunism and PR. We should be looking at more coastal and delta nature restoration."

5.3.2 NBS changes partnerships

Partnerships foster knowledge development and sharing [CON1; INS1; INS2; INS3; OWN1; OWN3; SCI2; SCI3; SCI4] which was also confirmed in the survey, with 71.4% of respondents agreeing, and none disagreeing. Universities are integral to these partnerships, as their involvement not only necessitates the publication of results [OWN2; OWN3] but also facilitates third-party certification [INS2], often supported by research grants [NGO2]. However, partnerships between universities and developers may change due to universities increasingly disengaging from collaborations with companies in the oil and gas industry.

So, collaboration with consultants and knowledge institutes is essential [CON1; INS3; OWN1; SCI2; SCI3; SCI4]. However, due to a scarcity of expertise in ecology and nature, most developers rely on the same consultancy firms, potentially hindering innovation [SCI2]. Furthermore, significant shifts in relationships between NGOs and developers, especially in the oil and gas sector, have led to collaborative partnerships [CON2; NGO4]. Additionally, government-to-government collaborations are emerging e.g., the North Sea Basin Initiative [GOV1; NGO3].

5.3.3 Joint responsibility

While many highlighted the government's role, both national and international, as crucial in linking resource teams with potential users due to its ultimate responsibility for addressing societal challenges like biodiversity loss [CON2; FIN1; GOV1; INS3; NBS1; NBS2; NBS4; OWN1; OWN2; OWN3], others emphasized the responsibility of developers, contractors, suppliers, and other players in the offshore wind supply chain [CON1; NBS2; NGO2; OWN3; SCI3]. The survey primarily highlights the willingness of OWF owners, i.e., developers. 57.1% of the respondents agreed that this group promotes the scaling up of NBS, with none disagreeing. Collaboration being essential, all stakeholders were seen to share joint responsibility [INS2; NGO3; NGO4; SCI4; SCI5].

5.4 Environment

5.4.1Technical system

Considering the technical feasibility and the impact on the performance of wind turbines of NBS is crucial [OWN2] and represents a primary knowledge gap and potential obstacle for NBS within offshore wind [SCI5]. Integrating NBS into OWF design is technically feasible [CON1; CON2; INS1; NBS3; NGO4; OWN2; SCI4]. However, the complexity varies depending on the type of NBS, with adjustments to turbine design, such as incorporating water replenishment holes, proving more intricate than adding alternative scour protection methods [NGO4; OWN1]. Also, little research has been done on floating wind. Like oil and gas platforms, where marine growth was routinely removed, floating wind is more influenced by gravity, promoting marine growth and habitat creation might not fit with this type of offshore wind [OTH2], necessitating a project-specific evaluation of feasible NBS applications [OTH2].

Although it is considered technically feasible, NBS can influence the technical performance of OWFs and might form barriers e.g., steel fatigue, corrosion [OTH1], microarray damage, stability issues, and the necessitated increased maintenance [NBS1]. Therefore, using the space between turbines might be more attractive than adding it to the existing structure [CON2]. Moreover, incorporating scour protection introduces an additional layer of complexity, combining technical requirements with the enhancement of biological value, which requires extensive testing, as highlighted by OTH2:

> "Both aspects take quite a long time to prove, and the wonderful thing about nature is that it's entirely different wherever you are."

NBS2 emphasizes the importance of third-party validation to overcome barriers and learn from past mistakes:

> “10 years seems like a long time. [..] But then after 10 years, you see it on the water degradation, and you see damages that are associated with those structures rolling around on the water. And there are enough case studies from the past coming from artificial reefs that can be great examples for those. I think that the offshore wind industry cannot allow itself to go through the same processes.”

5.4.2 Political system

NBS has received more attention from the European Union (EU) e.g., through the European Green Deal and Biodiversity Strategy [CON2; NBS1]. However, these strategies are interpreted differently by each member state, which decreases effectiveness [CON2; INS2]. Governments may not impose requirements [INS1; NBS4; NGO2; OWN3; SCI4], and this lack of attention is even viewed as one of the main bottlenecks of upscaling NBS [NBS4; NGO2; SCI4]. With the introduction of mandatory non-price reporting guidelines by the EU, Corporate Sustainability Reporting Directive (CSRD), more offshore companies are focusing on their impact on nature as biodiversity is one of the objectives [GOV1]. However, international cooperation is lacking, and each European country has its strategy, tender setup, and monitoring program, even though they often share the same seas bordering their countries [NBS1; SCI3].

Focusing specifically on tenders for offshore wind projects, there is a growth of incorporating nature enhancement into the bidding process by introducing non-price tender criteria, which is considered a main driver for NBS [CON1; CON2; INS1; INS2; NBS2; NBS3; NBS4; NGO3; NGO4; OWN1; OWN2; OWN3; SCI; SCI3; SCI4], mainly in the Netherlands [CON1; INS1; INS2; NBS2; OWN1; OWN2; OWN3; SCI3]. These criteria are yet limitedly applied [GOV1; INS3; SCI3], leading to occasional ecological missteps [SCI3] and rapid, complex changes [SCI4], which can be challenging to navigate [NGO3]. Herein also lies a significant role for the industry, which often has a say in shaping tenders and other regulations, educating the regulator [GOV1; NBS2]. Nonetheless, there is significant interest from other countries in understanding the tender process [GOV1], and expected more countries will adopt tender criteria for nature [NGO2; OWN2; SCI3; SCI4], as SCI3 confirms:

> “The Netherlands is certainly a pioneer in also indeed making it mandatory within the tender, but I think it won't be long before that also is adopted in other countries in the same way."

These non-price criteria ensure innovation and open monitoring which provides much-needed knowledge development [CON2; NBS2]. Some governments choose that impacts can be bought off instead of actions, however, according to CON2 this works less well since the money then does not often go to marine nature restoration. An alternative is nature enhancement as a standard component of policy such as in plot decisions [GOV1; NGO3]. As GOV1 describes:

> "If we as a government were to let go of that, then perhaps they simply wouldn't consider it. If it is not necessary. So, I think that's why it's important for us as a government to maintain course and make ecology an important part of the deployment of offshore wind."

Regulations vary from country to country, but across Europe, they often serve as a barrier to NBS. For instance, the use of drones for monitoring is impeded by privacy legislation [OWN1]. The permitting process for NBS specific is perceived as a significant barrier [CON1; OWN3], and it ranks high on the industry's agenda [SCI4]. There is no clear pathway for obtaining permits, such as for the establishment of oyster reefs [GOV1; INS3; NBS3]. As NBS3 explains:

> “The main bottleneck is licenses, permission [...] Because there is no, at the time when sort of nature protection legislation was made, there was no such thing as active restoration. So, the way that nature protection exists legally now is everything needs to freeze in place. And any deviation from this baseline is bad, which leaves no room. It leaves no room for it getting worse, which is good, but it also leaves no room for getting better. So, we are locked in a degraded baseline.”

Stringent regulations have the potential to impede piloting [OWN3], especially when there is no regulatory framework conducive to scaling up initiatives [OWN3]. Furthermore, the absence of a robust framework for monitoring can also pose challenges [OWN3].

Another influential factor is the political climate, with Europe becoming increasingly divided and a decrease in political willingness, which could serve as a barrier to NBS within offshore wind [OWN2]. This trend is also evident in the (possible) implementation of the Nature Restoration Law [NGO4].

5.4.3 Economic system

The wider economic landscape for offshore wind has undergone significant changes in recent years. There are fewer to no subsidies available while the margins in offshore wind are low [OWN1; SCI2]. Excessive restrictions for NBS could add a stressor [FIN1; GOV1; OWN1]. On the other hand, wind energy is becoming increasingly profitable [NGO3]. However, for NBS providers, funding has become expensive and inaccessible [NBS1]. Investment logic has shifted from being profit-driven (risk/return) to emphasizing social and environmental impact

[FIN1; INS1]. Although this money for wider investment in green energy is not yet reflected for NBS specifically, which still depends on research grants and impact funds.

5.4.4 Social system

The development of offshore wind faces resistance as there is a societal fear of too many technical structures in the sea [CON2; NBS2; NGO4]. Especially in development markets e.g., the United Kingdom, and the United States where the developer needs permission from stakeholders, this issue is increasingly problematic [IOTH2; NGO2]. NBS hold the potential to mitigate this societal challenge of biodiversity loss. Therefore, social awareness is recognized as a major driver for NBS within offshore wind [CON1; FIN1; NBS1; NBS4; NGO3; NGO4; OWN3; SCI4]. As noted by NGO4:

> "Offshore wind is just one sector in the sea, but it can be a great example of a newbie who is starting in a very, very good way. [..] Opposition to offshore wind comes from civil society because of the fear of the environmental impact but if you do it in the right way from a wind developer's point of view you will not get this opposition."

Considering the importance of societal awareness, many people lack knowledge of the topic [INS1; OWN1], with the industry not being at the forefront of public agendas [SCI4]. Additionally, there is a challenge in aligning stakeholders, including insurance companies, developers, and government entities [CON2; OTH2]. Furthermore, some argue that adding more structures could be counterproductive [NBS3; SCI4].

5.4.5 Ecological system

A system that is not described in the conceptual framework but does affect the scaling up of NBS is the ecological system. The place- and time-specific nature of ecology must be considered, for example, the types of NBS will vary greatly by region, even in the same seas or countries. For example, abiotic factors such as hydrodynamics can vary, there is not enough consideration of this at present [NGO2; SCI3; SCI5]. In addition, the scale of ecology and ecosystems must also be considered; scaling up is necessary to achieve this scale and efficiency as stressed by NBS3.

NBS monitoring differs significantly from regular installations, requiring a distinct approach [INS3]. Ecology, being dynamic and context-dependent, undergoes constant change and succession, often leading to uncertainties regarding long-term or indirect effects such as predator-prey relationships [NGO2; SCI5].

5.5 Drivers and barriers

From the interviews and the survey, the following key drivers, and barriers to scaling up NBS within offshore wind have resulted (*Table 2*).

Table 2. Key drivers and barriers for upscaling NBS for offshore wind

Layers	Factor	Drivers	Barriers
Innovation	**Relevance**	• Degraded **ecosystems** and **biodiversity loss**	
	Type	• Increasing **proof of concept** due to research	• **Uncertainty of effectiveness**
	Ease-of-use		• Little knowledge of **end-of-life**
Resource team	**Vision and strategy**	• Integration in **strategy** and **early planning**	• No **long-term** planning for NBS in OWF
	Motivation	• **Internal motivation** to support nature	
	Financing	• Indirect return on investment **competitive advantage**	• **Amount of** – and **uncertainty around costs** • Reliant on **research-** and **impact funds** • No direct **monetary benefit**
	Monitoring	• Mandatory in some **tenders**	• Difficulties with **data interpretation** and quantifying effectiveness
	Learning		• Lacking **knowledge availability** and skilled people
Potential users	**Communication**	• **PR** and **marketing** opportunities	• **Greenwashing** potential • Lacking **international communication**
	Partnerships	• Collaboration between **knowledge institutes** and the **industry** • **More cooperation** between **NGOs** and **large offshore companies**	• Missing **international cooperation**
Environment	**Technical system**		• Potential influence on **technical performance;** steel fatigue, and stability issues leading to increased maintenance.

	Political system	• **Non-price tender criteria**	• **Tender requirements** being too strict or too loose • **Unclear permitting process** for **NBS** in OWFs
	Economic system		• **Smaller profit margins** of offshore wind
	Social system	• Added **societal value** • Improves **perception** of **offshore wind**	• Low quantity of **societal** – and **political awareness**
	Ecological system		• **Dynamic character** of the ecological **system** • **Misfit** between the **speed of the energy transition** and **testing cycle ecology**

6 DISCUSSION

6 Discussion

6.1 Upscaling NBS for offshore wind

NBS for offshore wind are currently in a pilot phase. Pilot testing serves two primary purposes: assessing functionality and facilitating commercialization (Karlström & Sandén, 2004; Lefevre, 1984). Functionality testing has only recently started for NBS for offshore wind, thus, there is still little known about its effectiveness. Uncertainty of effectiveness is one of the most common barriers to upscaling NBS (Sarabi et al., 2019; Seddon et al., 2021). For NBS for offshore wind, testing functionality is more difficult due to a lack of (in-house) knowledge on the baseline, and the status of marine ecosystems, which makes choosing indicators and data interpretation difficult. The absence of monitoring standards impedes comparison across sites. Moreover, ecological measurement necessitates time given biological processes such as marine growth and succession. Thus, this study indicates that there is a mismatch between the rapid pace of energy transition and the time needed for evaluating the effectiveness of NBS.

This uncertainty for effectiveness makes companies less likely to want to commit to NBS, which lowers the speed of testing. On the other hand, the uncertainty of effectiveness evokes resistance as greenwashing potential arises. This is in line with previous studies (e.g. Alva, 2022; Scolobig et al., 2023) linked greenwashing to NBS. This also raises doubts about including NBS in tenders. While the tender criteria serve as the main driver and incentive for developing NBS, marketing often emphasizes "eco-friendly" and "biodiversity-positive" aspects without sufficient evidence to support these claims. Additionally, tenders may assign economic value to monitoring data, potentially leading to less transparent communication.

During the pilot phase, alongside functionality, commercialization is tested (Karlström & Sandén, 2004; Lefevre, 1984). Although monetary return is less common (Mayor et al., 2021), NBS must be economically feasible with a balanced trade-off between costs and benefits (Andrade et al., 2020). This study confirms that achieving direct monetary returns for NBS is challenging. Additionally, it points out that currently, the stakeholders who invest the most, such as developers, cannot expect direct monetary returns, unlike other e.g., NBS providers. However, this study demonstrates that indirect return on investment is applicable, as evidenced by a competitive advantage to be gained e.g., selling solutions, winning a tender, or gaining PR benefits. A competitive advantage is often a reason for testing and piloting in the first place (Wieczorek, 2018). Remarkably, an addition to existing knowledge of NBS as a competitive advantage is only associated with obtaining subsidies (Brears, 2022).

The current challenge entails upscaling from pilot projects to expanded pilot, full-scale management projects, or even influence policy (Frantzeskaki et al., 2019; Vreugdenhil et al., 2011). The main drivers for this process include the motivation that comes from companies themselves, acknowledging the societal challenge posed by the current state of maritime ecosystems and the responsibility that comes with adding additional pressure e.g., offshore wind. Motivation and awareness are recognized as main drivers which aligns with previous studies (e.g. Dorst et al., 2021; Wamsler et al., 2020). In line with this, partnerships also drive upscaling. Partnerships ensure that knowledge about effectiveness is shared, and costs can be reduced by spreading them across different parties. Remarkably, this study indicates that partnerships not only encourage the use of NBS but also vice versa. Including nature in offshore wind projects has led to NGOs collaborating with (former oil & gas) companies for the first time aligning with Vreugdenhil & Rault (2010).

Barriers to upscaling include obstacles mentioned in the pilot phase i.e., uncertainty of effectiveness, and difficulty in monetizing NBS. However, the findings of this study demonstrate that scaling up to extended pilots is necessary to assess effectiveness. Since the scale of the current pilots is so insignificant compared to the scale of nature, critical mass is not achieved, thus adding little value to nature. Yet, one of the major barriers is the cost, particularly for such a large scale and these expenses cannot be covered solely by research and impact funds.

This study offers key insights into how to overcome barriers and how can NBS be supported to be more widely implemented. In the short term, there needs to be more clarity regarding a proof-of-concept for NBS, especially given the rapid, large-scale rollout of offshore wind. Primarily, testing NBS should be more integrated into offshore wind farms across Europe, as large-scale testing currently only occurs in the Netherlands. NBS pilots often rely on research, impact funding, and lack attention from investors other than OWF owners. Therefore, more funding needs to become available for research into expanded pilots to measure their effectiveness. Additionally, there is a need for (international) standards for monitoring NBS to enhance comparison and learning between sites.

6.2 Offshore-specific conditions

Although not the main objective, another key output is specific conditions for the maritime environment for scaling up NBS as previous research on upscaling NBS mainly focused on land-based applications and the urban environment (e.g. Davis, 2004; Dorst et al., 2021; Frantzeskaki et al., 2019; Kabisch et al., 2016).

First, it is worth noting that the umbrella concept 'NBS' is not commonly used in offshore infrastructure, particularly within the context of offshore wind projects (Pardo et al., 2023). Instead, vague concepts such as 'nature-positive approaches' are used. Nonetheless, the concept of NBS has garnered widespread usage, and insights gained from research on scaling up NBS can be extrapolated to offshore environments, including offshore wind projects (Pérez et al., 2024; Riisager-Simonsen et al., 2022). This study has outlined the components of NBS within offshore wind projects (*Figure 4*), thereby contributing to a clearer understanding of their application in this context.

Second, the geographical distance from land in offshore environments introduces numerous factors that affect upscaling. NBS address significant societal challenges, where considerations of value and societal awareness play pivotal roles in their adoption (Kapos et al., 2019; Martire et al., 2022; Xie et al., 2020). However, the farther away from populated areas, the farther away from the public eye and the lower the direct involvement of individuals in advocating for NBS initiatives. Consequently, the positive impacts of NBS, such as improved water quality or enhanced biodiversity, may not be as readily observable compared to more observable outcomes like coastal restoration efforts. This lack of direct visibility could pose a specific barrier to the widespread adoption of NBS in maritime environments. Additionally, offshore settings entail heightened costs associated. Notably, the monitoring and maintenance of NBS incur substantial expenses, leading to delays in assessing their effectiveness and, consequently, hindering their scalability in offshore contexts.

Third, NBS have the potential to change the way offshore construction is perceived as the ecological impacts have been acknowledged as potential downsides of the scaling up of OWF

(Steins et al., 2021). As a result, scaling up NBS may also have a positive effect on the perception of scaling up offshore wind.

Fourth, international, and especially European, cooperation drives upscaling NBS (Faivre et al., 2017), especially in the maritime environment. Seas and oceans cross several national borders, and because of this, lessons learned from the projects are not country specific. International collaborations and knowledge sharing are therefore especially important for the maritime environment and could potentially alleviate the aforementioned barriers. A prime example of this is the Greater North Sea Basin Initiative.,

Fifth, there has been a notable lack of emphasis on the end-of-life phase of NBS thus far. This aspect is especially applicable in the context of offshore wind, given that OWFs undergo decommissioning at the end of their operational lifespan. It is counterproductive to establish structures like artificial reefs and oyster beds if they would require decommissioning within 20-30 years. However, the potential added value for ecosystems may reshape discussions surrounding decommissioning processes. Consequently, it is imperative to incorporate long-term strategies for NBS, including thorough planning for their end-of-life phase, particularly in offshore environments.

6.3 Conceptual framework for upscaling NBS

Reflecting on the conceptual framework for scaling up NBS, several factors were modified because of the interviews (*Figure 6*). The factor 'leadership' has been replaced by 'motivation;' interviewees more often mentioned a motivated workforce as a driver than leadership. Motivation entails both, so motivated workforce and - leaders. In the next layer, potential users, a sub-factor is added to the factor 'communication,' During the interviews the purpose of communication around NBS use often came up. On the one hand, marketing and PR are a reason to openly communicate NBS. On the other hand, a negative purpose e.g., greenwashing, was mentioned. Both negative and positive were found to affect the upscaling process. Therefore, 'communication purpose' is added as a subfactor to the factor 'communication.' The factor 'intermediaries' have not been recognized as important in both interviews and the survey. This study indicated actor group has its role therefore replaced by the factor 'responsibility,' given that the various stakeholder groups each bear responsibility for the success of scaling up, and this is more applicable than appointing an organization or - person. A sense of responsibility can persuade potential users to participate in NBS, however, this study showed that this can also be a bottleneck if actors do not feel this responsibility aligning with previous literature (Wilk et al., 2021). Lastly, the factor 'ecological system' is added to the conceptual model. Upscaling NBS is highly site-specific, which is often overlooked. So, a fit between the NBS and the existing ecological system strengthens the functionality of NBS, and thus, is also an important aspect to consider when examining the upscaling process of NBS.

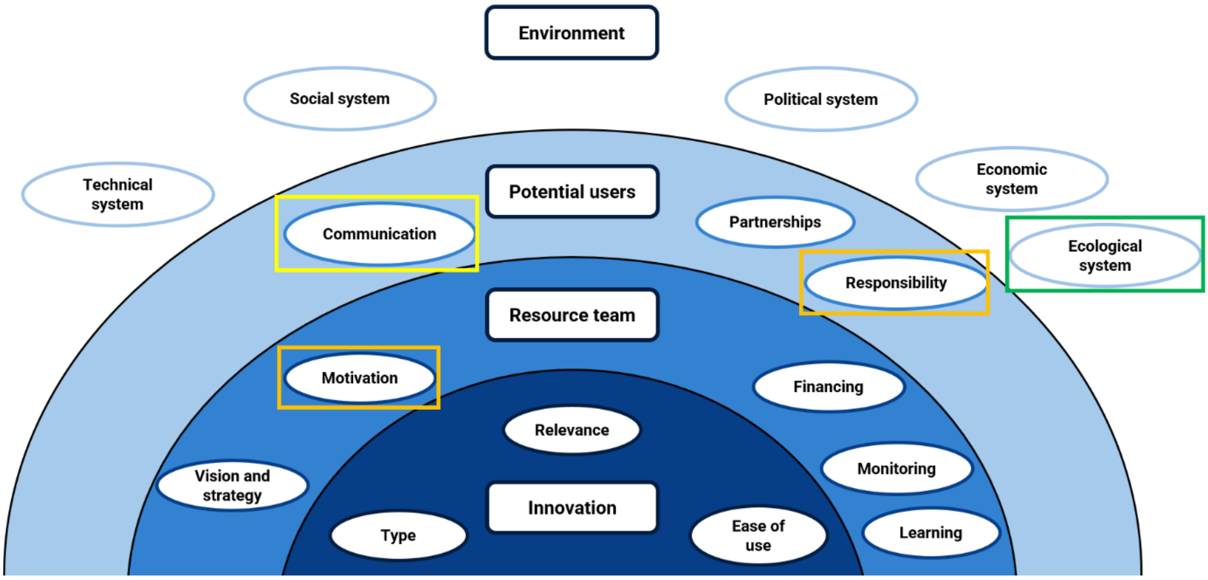

Figure 6. *Revised conceptual framework for upscaling NBS; yellow square indicates added sub-factor, orange square indicates changed factor, green square indicates added factor*

6.4 Policy recommendations

Based on the results, the following recommendations are made to enhance governance for upscaling NBS. First, it is recommended to incorporate non-price tender criteria emphasizing action in offshore wind tenders. Instead of implementing NBS, nature enhancement can be bought off, but this is proven to be insufficient as these funds often divert to other sustainability ambitions of governments. Non-price criteria stimulate NBS implementation, fostering innovation and offering competitive advantages, thus ensuring a return on investment. However, these criteria introduce competitiveness, potentially leading to keeping information confidential regarding monitoring data, costs, and best practices which hinders open communication. Long-term strategies should entail integrating NBS into OWF requirements to enhance transparency and collaboration. This shift necessitates further proof of concept and evaluation of benefits for developers as competitive advantage is removed.

Enhancing international cooperation and knowledge sharing is imperative, given that many European countries share the same seas. Presently, such collaboration is limited, particularly in the Mediterranean region, where data on nature enhancement within offshore wind projects is already scarce. Specifically, establish international monitoring standards or provide clearer industry guidance on nature inclusion, including allowing a portion of the turbine foundation to remain in place during decommissioning.

6.5 Reflection and further research

This study provided insights into upscaling NBS for offshore wind in Europe through interviews and surveys. Both data sources explored respondents' experiences and opinions, sometimes yielding conflicting results due to stakeholders' varied roles e.g., NBS providers earn from NBS whereas OWF owners do not, leading to differing views on financing. While stakeholder groups were divided in both the survey and interviews and replication occurred, this potential bias should be noted.

Additionally, the respondent pool mainly consisted of countries bordering the North Sea, with the majority being Dutch. As a result, this study primarily generated insights into fixed-bottom wind turbines, with little mention of NBS for floating wind. This can be explained by the extensive testing of NBS in Northern Europe, where there is more information available on NBS. As described in the results, attention to NBS also relates to the maturity of the wind market, as floating wind is still under development. Therefore, the results of this study are not directly applicable to the Mediterranean region. However, the drivers and barriers can provide knowledge for testing and scaling up for NBS when these are applied to floating wind.

The survey was intended as a complement to the interviews, as time constraints prevented the inclusion of all actor groups per European country. However, it was challenging to recruit respondents for the survey, despite promotion at a wind event attended by 12,000 people. One explanation could be that the term NBS is not widely used, which may have hindered response rates. Additionally, the low response rate may be since NBS are not yet widely utilized. As a result, the survey could not provide insights into the drivers and barriers specific to each country or actor group, and only descriptive statistics were applied.

To enable upscaling NBS in offshore wind, a proof of concept is required. This necessitates further research into how to measure and quantify biodiversity underwater. Furthermore, there are many questions and uncertainties regarding the decommissioning of OWFs and NBS. More research is needed to explore how decommissioning can be nature inclusive. Subsequent research also could involve longitudinal analysis of the use of NBS in offshore wind, examining changes in the proof of concept and the effects on barriers, thus enhancing the robustness of our findings.

Further research can be built upon this study as it highlights various promising topics. First, this study highlights a discrepancy between the pace of energy transition and the time required to measure its impact on nature for offshore wind. Follow-up research could dive deeper into to what extent the high pace of the energy transition is a problem for testing the ecological effects in other industries e.g. (deep sea) mining. Additionally, a couple of companies in the offshore wind industry currently claim to be(come) nature-positive, while there is a lot of uncertainty around the actual effects of NBS on marine life. This leads to an interesting research avenue around corporate sustainability. Furthermore, the influence of geographical distance on societal awareness is highlighted, which has implications not only for offshore wind but also could apply to (deep sea) mining, agriculture, and forestry conservation efforts.

7 CONCLUSION

7 Conclusion

7.1 Headwind or tailwind?

To include nature in the energy transition, this study aimed to understand how NBS for offshore wind can transition from the pilot phase. The upscaling process of NBS was assessed through the development of a comprehensive, concrete conceptual framework, interviews with various stakeholders in the offshore wind sector with expertise in NBS, and a survey with knowledgeable respondents. This generated findings for the following two-part research question:

What drives and hinders the upscaling of Nature-Based Solutions (NBS) within the European offshore wind market, and how can NBS be supported to be more widely implemented?

This study identified the following drivers for upscaling NBS: motivated workforce, early integration of NBS in the design of OWFs, non-price tender criteria, and a thereby potential competitive advantage to be gained. Furthermore, partnerships between knowledge institutes -, NGOs, and offshore wind companies are a main driver for sharing knowledge and spreading costs. Barriers include uncertainty around costs. Inadequate international communication, too strict - or loose tender requirements, and unclear permitting processes pose additional challenges. Foremost, the uncertainty of effectiveness hinders upscaling NBS as monitoring is difficult, - time-consuming, and the data is difficult to interpret, and approach varies per site. Therefore, this study concludes there is currently a misfit in the speed of offshore wind development and the time required to evaluate the effectiveness of NBS.

To overcome existing barriers and facilitate the wider implementation of NBS, several key strategies can be pursued. Firstly, it is imperative to establish a proof of concept, which can be achieved through the execution of a greater number of NBS pilots within OWFS a practice not yet widely adopted across many European countries. By implementing a standardized international monitoring program, the outcomes of these pilots can be systematically evaluated and compared, fostering transparency, and enabling a deeper understanding of their efficacy. In terms of governance, while the integration of non-price tender criteria represents an initial step, the competitive advantage lies in advancing toward making nature enhancement a mandatory requirement in tender processes.

To conclude, NBS have had favorable winds in recent years, but it is imperative to maintain that momentum. The awareness among companies, policymakers, and society has led to the testing of NBS. However, this study shows the pace of NBS testing lags behind the rapid development of wind farms and is often conducted on too small a scale. Therefore, it is crucial to accelerate the testing of NBS, integrate them into non-price tender criteria, and explore how to ensure that these nature-inclusive wind farms are decommissioned in a nature-inclusive manner in the short term. This multifaceted approach is essential for promoting the widespread adoption of NBS in wind energy projects and ensuring their long-term sustainability and environmental benefits.

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9 Appendix

Appendix A: Layers of upscaling

Layers	Definition	Examples
Innovation	The innovation refers to practice(s) that are scaled up, a package of interventions, often consisting of several components.	• Introducing a new technology • Replacing outdated technology
Resource team	The resource team refers to the individuals and organizations that seek to promote and facilitate wider use of the innovation, initiated, or invested in the pilot.	• Program managers • Researchers • NGOs
Potential users	Potential refers to the institution(s) or organization(s) that seek to or are expected to adopt, - engage in -, and implement the innovation on a large scale.	• Companies • Consumers • NGOs
Environment	The environment refers to the conditions and institutions that are external to the user organization but fundamentally affect the prospects for scaling up.	• Policies and regulations • Economic landscape • Societal pressure

Adopted from (World Health Organization & ExpandNet, 2010).

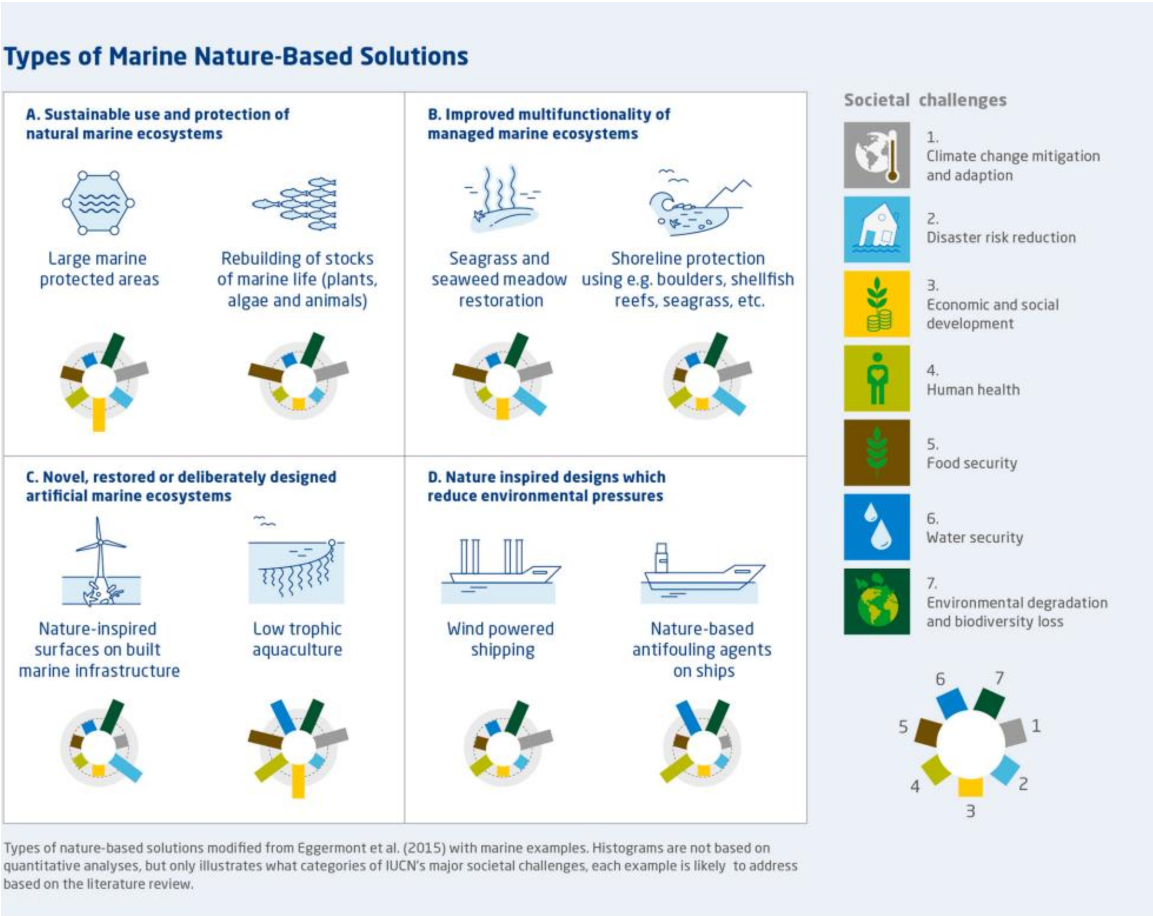
Appendix B: Overview environmental impact offshore wind

Pressure	Impact	Construction	Operation	Decommissioning
Foundation occupation, operating wind turbines	**Barrier effects**		x	
Light, operating wind turbines, ship traffic	**Collision**	x	x	x
Underwater cabling	**Electromagnetic change**		x	
Foundation occupation, operating wind turbines	**Hydrodynamic change**		x	
Light, noise, operating wind turbines, ship traffic	**Disturbance, behavioural change**	x	x	
Light, noise, operating wind turbines, ship traffic	**Physical damage**	x	x	
Ship traffic	**Introduction invasive species**	x	x	
Light, noise, emissions, other	**Pollution**	x	x	
Foundation occupation	**Seabed habitat loss, degradation and transformation**	x	x	
Foundation occupation	**Habitat creation**	x	x	x
Foundation occupation	**Trophic cascade**	x	x	x

= medium positive impact
= high positive impact
= unknown
= low negative impact
= medium negative impact
= high negative impact

Based on Bennun et al. (2021) & WWF European Policy Office (2021)

Appendix C: Types of Marine NBS



Adopted from Eggermont et al. (2015) Riisager-Simonsen et al. (2022)

Appendix D: Overview interviews

Number	Code	Actor type	Date	Interviewee's role
1	**SCI1**	Science/RD - academic	25/01/2024	Researcher
2	**OWN1**	Industry player - owner OWF	25/01/2024	Project Engineer Offshore Wind
3	**INS1**	Industry player - installer	29/01/2024	Project Manager to Business Unit Director Northern Europe
4	**OTH1**	Industry player - other	30/01/2024	Team lead Structural Engineering
5	**OTH2**	Industry player - other	30/01/2024	Global Solution Owner Offshore Wind Planning
6	**NBS1**	NBS provider	31/01/2024	CEO
7	**OWN2**	Industry player - owner OWF	01/02/2024	Senior Biodiversity Specialist
8	**INS2**	Industry player - installer	06/02/2024	Environmental Engineer
9	**INS3**	Industry player - installer	08/02/2024	Program Manager Biodiversity and NBS
10	**GOV1**	Government - national	08/02/2024	Program Manager Offshore Wind and Energy System
11	**SCI2**	Science/R&D - academic	14/02/2024	Researcher
12	**NBS2**	NBS provider	14/02/2024	CEO
13	**CON1**	Consultant	15/02/2024	Landscape planner
14	**FIN1**	Financial institution - bank	16/02/2024	Economist Energy Market and Energy Transition
15	**SCI3**	Science/R&D - other	16/02/2024	Senior Researcher
16	**SCI4**	Science/R&D - academic	16/02/2024	Doctoral Researcher
17	**NBS3**	NBS provider	19/02/2024	CEO
18	**OWN3**	Industry player- owner	21/02/2024	Bioscience Lead
19	**NGO1**	NGO	27/02/2024	Project Lead
20	**NGO2**	NGO	28/02/2024	Senior Researcher and Project Manager
21	**NBS4**	NBS provider	28/02/2024	CEO
22	**NGO3**	NGO	29/02/2024	Policy officer
23	**SCI5**	Science/R&D - academic	06/03/2024	PhD Candidate
24	**NGO4**	NGO	22/03/2024	Manager Offshore Energy and Nature
25	**CON2**	Consultant	22/03/2024	Senior Advisor Offshore Wind

Appendix E: Interview guide

Factor	Questions

Introduction	• For which company/organization do you work?
	• What is their role in the offshore wind sector?
	• What is your role?
	• Do you, or the company/organization you work for, have any involvement you may have with nature-based solutions?
	• If yes,
	  ○ What types of nature-based solutions are implemented?
	  ○ What is your role regarding these nature-based solutions?

Innovation	• Why has NBS become more relevant in offshore wind?
	• What are the different types of NBS within offshore wind you know of?
	• To what extent are NBS currently easy to use?
	  ○ Engineering
	  ○ Deployment
	  ○ Maintenance
	  ○ End-of-life

Resource type	• Is there a plan and strategy for upscaling nature-based solutions?
	• To what extent does leadership play a role in projects involving nature-based solutions?
	• Who would you consider to be the leader in nature-based solutions?
	• What is the biggest hurdle in financing nature-based solutions?
	• Could you provide more information about the costs associated with a nature-based solutions project?
	  ○ How high are these costs?
	  ○ Who typically covers them?
	  ○ Do you believe the costs pose a barrier?
	• To what extent do you believe that a company investing in nature-based solutions can expect a return on investment, considering that these solutions are seen as an investment in nature?
	• External financing
	  ○ Are there any subsidies?
	  ○ Which players (e.g., banks, insurance companies, or other investors) are important to finance nature-based solutions for offshore wind?
	• To what extent can the positive impact on nature be monitored, and do you believe this measurement influences the success of nature-based solutions?
	  ○ Who takes the lead in monitoring?
	  ○ Who is responsible?
	• Is there a sufficient availability of knowledge on nature-based solutions in offshore wind? How does this knowledge or lack thereof impact their adoption and upscaling?
	• Do you think nature-based solutions are well evaluated, and how lessons learned contribute to the success of future projects?

	○ If relevant: What are lessons have you learned during such a project and how was this integrated in future projects?
Potential users	• To what extent is there open communication and innovation about nature-based solutions? • What role play partnerships in supporting the implementation and upscaling of nature-based solutions for offshore wind? • Could you share insights from successful partnerships and key factors contributing to their success?

Environment	• To what extent is it technically feasible to integrate nature-based solutions into offshore wind design?
	  ○ Legal
	• How does your national government support/hinder nature-based solutions?
	  ○ Financial
	  ○ Legal
	• How does the European Union support/hinder nature-based solutions?
	  ○ Financial
	  ○ Legal
	• Which stakeholders are pushing, and which stakeholders are hindering the use and upscaling of nature-based solutions for offshore wind? Why?

Wrap-up	• What is the main bottleneck for upscaling nature-based solutions? Why? • What are the main drivers for upscaling nature-based solutions for offshore wind? Why? • Which type of stakeholder is most responsible for conducting nature-based solutions in offshore wind? Why?

Appendix F: Survey questions

Q1 Introduction

In this study, we want to learn about the use and upscaling of nature-based solutions (nature inclusive design like artificial reefs, fish hotels; restoration projects; conservation efforts) in offshore wind. Participation in this survey is voluntary and you can quit the survey at any time without giving a reason. Your answers to the questions will be confidential, and anonymous. We will process your data-by-data protection legislation (the General Data Protection Regulation and Personal Data Act).

I agree that:

• the collected data will be obtained and stored for scientific purposes.

• the collected, completely anonymous, research data can be shared and reused by scientists to answer other research questions.

I understand that:

• I have the right to withdraw my consent to use the data if they can be identified.

○ Yes (4)

Q2 What country is your organization based in?

▼ Afghanistan (1) ... Zimbabwe (1357)

Q3 What is your organization's primary role in the offshore wind sector?

- ◯ Coalition - nature-based solutions (1)
- ◯ Coalition - offshore (2)
- ◯ Consultancy - environmental (3)
- ◯ Consultancy - financial (4)
- ◯ Consultancy - offshore wind (5)
- ◯ Financial institution - bank (6)
- ◯ Financial institution - other (7)
- ◯ Government - EU (8)
- ◯ Government - national (9)
- ◯ Government - regional (10)
- ◯ Industry player - electricity utilities (11)
- ◯ Industry player - designer (12)
- ◯ Industry player - developer (13)
- ◯ Industry player - installer (14)
- ◯ Industry player - electricity/energy company (15)
- ◯ Industry player - manufacturers (16)
- ◯ Industry player - maintenance (17)
- ◯ Industry player - other (18)
- ◯ Industry player - owner OWF (19)
- ◯ Nature-based solution - other (26)
- ◯ Nature-based solution - provider (20)

- NGO (21)
- Other (22)
- Science/R&D - academic (23)
- Science/R&D - other (24)-
- Science/R&D - testing facility (25)

Q3A Is your organization currently involved in nature-based solutions (; artificial reefs, oyster restoration, kelp curtains, fish hotels etc.) for offshore wind?

- Yes (1)
- No (2)

Q3B If yes, what kind of nature-based solutions are you using/involved in?

- Artificial reefs (1)
- Cable protection layers (2)
- Fish hotels (3)
- Frond mats (4)
- Jacket sleeves (5)
- Oyster restoration (6)
- Resting platforms for birds (7)
- Scour protection layers (8)
- Other, namely: (9) ____

Q4 Nature-based solutions are reliable, easy-to-use options to support nature and biodiversity within offshore wind farms.

Q5 There is a high market demand for nature-based solutions in the offshore wind sector.
Q6 Pressure from society drives the use and upscaling of nature-based solutions for offshore wind.

Q7 Companies engaging in nature-based solutions for offshore wind have a clear vision of using and upscaling nature-based solutions.

Q8 Leadership drives the use and upscaling of nature-based solutions for offshore wind.

Q9 The costs of nature-based solutions are clear and manageable.

Q10 Costs do not form a barrier to using and upscaling nature-based solutions.

Q11 Nature-based solutions for offshore wind reach a return on investment.

Q12 Return on investment is not a barrier to using and upscaling nature-based solutions for offshore wind.

Q13 External financial support (; funds, subsidies, loans) drives using and upscaling of nature-based solutions for offshore wind.

Q14 The positive impact of nature-based solutions for offshore wind on biodiversity is monitored and evaluated.

Q15 There is enough knowledge available regarding nature-based solutions in offshore wind for wide adaptation.

Q16 Projects with nature-based solutions are evaluated and lessons are learned for further projects.

Q17 Communication among stakeholders contributes to the use and upscaling of nature-based solutions for offshore wind.

Q18 Partnerships support the use and upscaling of nature-based solutions for offshore wind.

Q19 Intermediaries, influential persons, - companies, or - organizations, are interested in using nature-based solutions for offshore wind.

Q20 Technological factors (; windmill design, construction possibilities) of offshore wind allow for the use and upscaling of nature-based solutions.

Q21 Owners of offshore wind farms support the use and upscaling of nature-based solutions.

Q22 Energy companies support the use and upscaling of nature-based solutions for offshore wind.

Q23 Your national government supports the use and upscaling of nature-based solutions for offshore wind.

Q24 The European Union financially supports the use and upscaling of nature-based solutions for offshore wind.

Q25 The European Union regulatory (; Corporate Sustainability Reporting Directive, EU Biodiversitty Strategy) supports the use and upscaling of nature-based solutions for offshore wind.

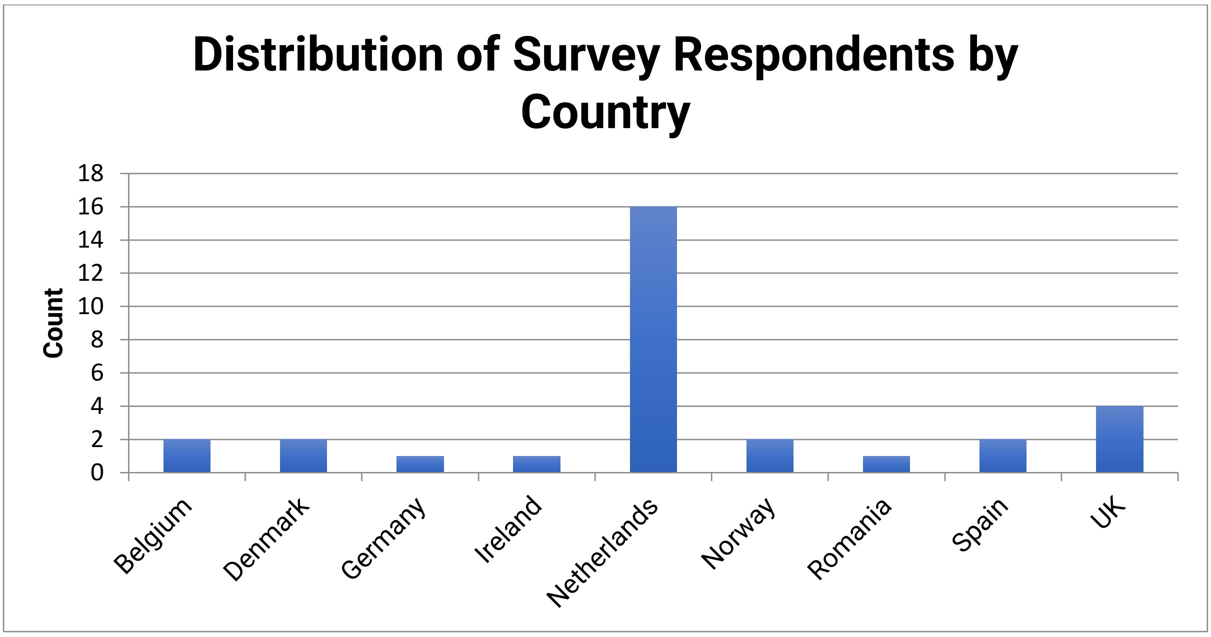
Q4 – Q25 were answered with:

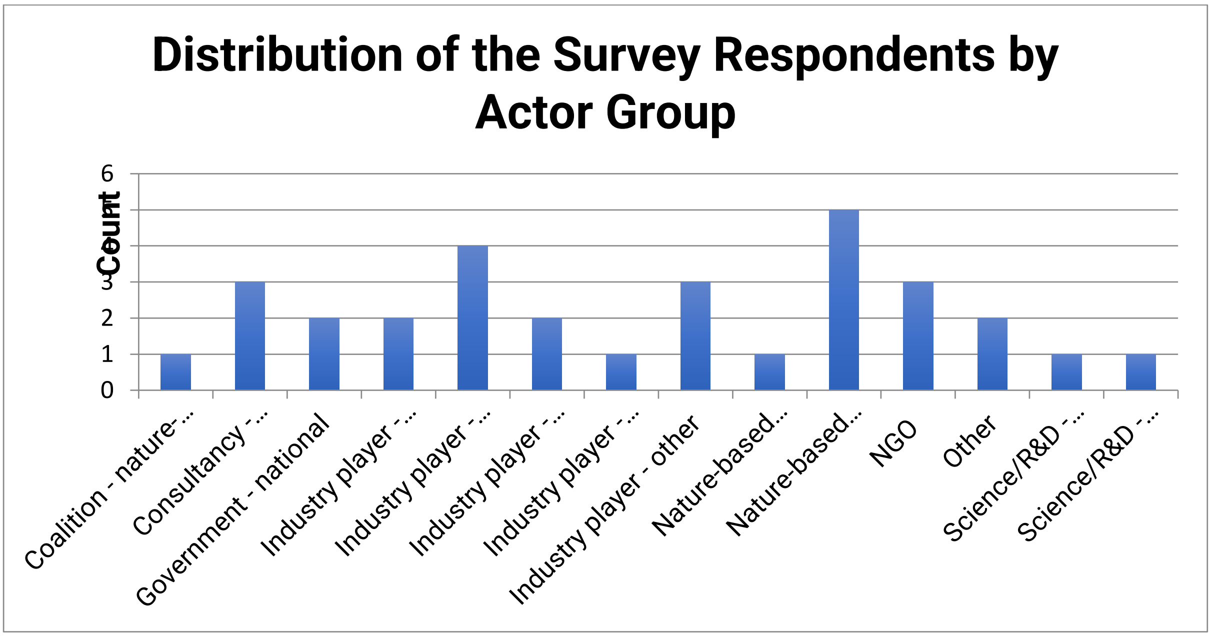
- ☐ Strongly Agree (1)
- ☐ Agree (2)
- ☐ Neutral (3)
- ☐ Disagree (4)
- ☐ Strongly Disagree (5)
- ☐ Do not know (6)
- ☐ OPTIONAL: Explanation (7)

____

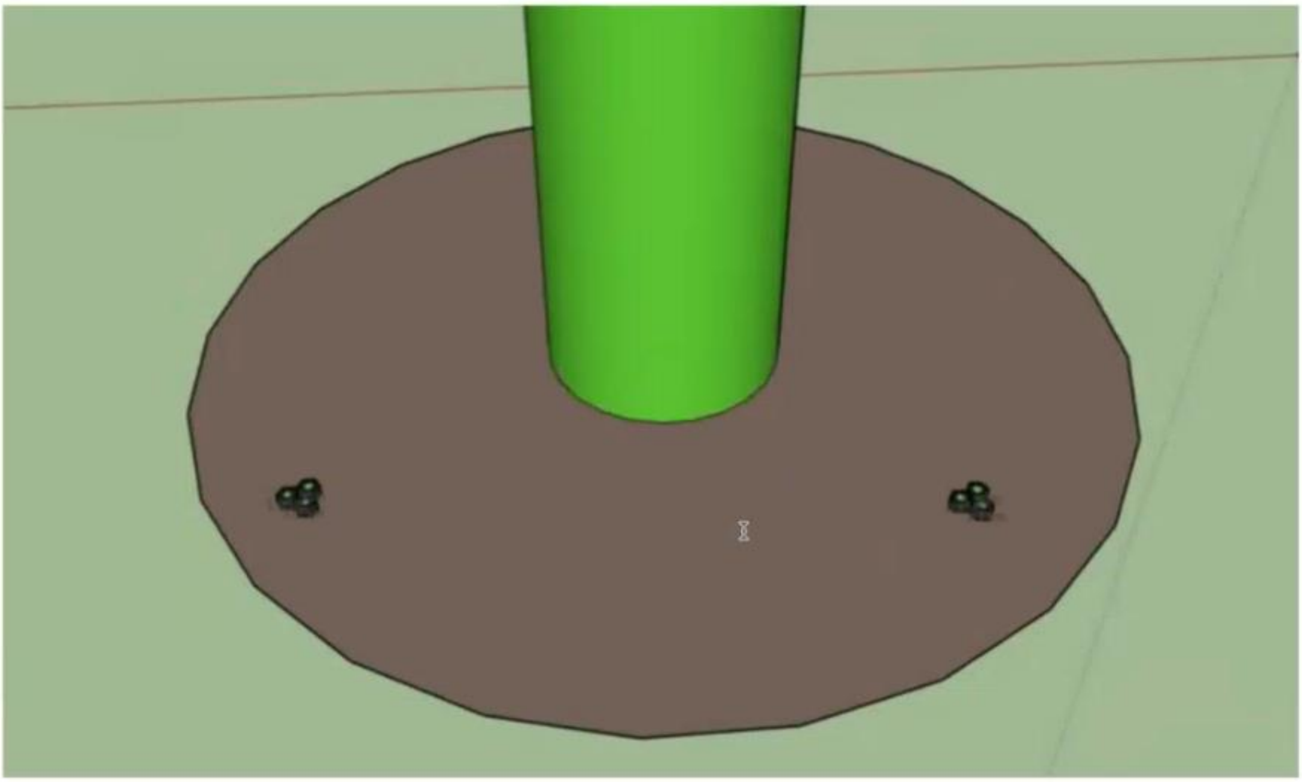
Q26 Is there anything else you would like to share regarding your view on nature-based solutions in offshore wind?

____


Distribution of Survey Respondents by Country
Count
18
16
14
12
10
8
6
4
2
0
Belgium
Denmark
Germany
Ireland
Netherlands
Norway
Romania
Spain
UK


Distribution of the Survey Respondents by Actor Group
Count
6
3
2
1
0
Coalition - nature-...
Consultancy - ...
Government - national
Industry player - ...
Industry player - ...
Industry player - ...
Industry player - ...
Industry player - other
Nature-based...
Nature-based...
NGO
Other
Science/R&D - ...
Science/R&D - ...

Appendix I: Size of used artificial reefs compared to monopile



Provided by NBS provider Oceanus International