Towards sustainable decommissioning

The importance of lifespan extension and standardisation

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1. Introduction

Offshore wind energy is developing rapidly and is becoming one of the main focal points for the generation of renewable electricity in Europe. The installation of offshore wind turbines in the EU is growing exponentially, with a European ambition of 111GW in 2030 and 300GW in 2050 for the North Sea alone. Consequently, offshore wind energy plays a crucial role in phasing out fossil fuels.

While significant progress has been made in scaling up offshore wind energy and reducing the costs for offshore wind turbines, the spotlight has been primarily on new windfarm deployments. The critical issue of decommissioning offshore windfarms (OWFs) and related infrastructure at the end of their lifecycle has been relatively overlooked.

Given the knowledge that all the thousands of wind turbines, including cables which are being built should also be decommissioned, it is important to investigate how this can be done without compromising on other targets such as those set for nature restoration and circularity. In the previous paper "conditions for sustainable decommissioning of offshore wind turbines[1]", we elaborated on the relationship between OWFs and biodiversity, and the impacts that decommissioning can have on this. We also addressed how to minimise the impacts of decommissioning on nature and on how circularity contributes to sustainable decommissioning. Furthermore, we discussed alternatives for full decommissioning, and we introduced the steps necessary to achieve sustainable decommissioning. These steps resulted in policy recommendations regarding **sustainable decommissioning**, which is defined as a decommissioning process that integrates principles of nature conservation, restoration and circularity.

Life span extension and standardisation for mitigating impacts of decommissioning

This paper is a follow-up publication in which we argue that in order to further mitigate the environmental impact of decommissioning, we should strive to postpone the need for decommissioning through the life span extension of offshore wind turbines and their foundations. As the offshore wind sector scales up, informed decisions on decommissioning must be taken, particularly during the design phase of new projects. This paper therefore addresses guidelines to mitigate the impacts of decommissioning on underwater nature and to enhance circularity in the design phase for future offshore wind farms.

We will discuss the topics of life span extension and standardisation as key elements to consider in the design phase in OWF projects. The longer the lifespan of a turbine and its foundation, the less need for decommissioning since the decommissioning can be postponed.

At some point however, decommissioning will still need to be addressed. This is why we argued in the previous paper that decommissioning should be considered in the design phase of projects to make easy disassembly possible at the end of their life, and to ensure this is done with minimal disruption to nature and to optimise the recovery of critical materials.

Aim of this paper

This paper aims to illustrate the importance of the design phase for offshore wind turbines in order to meet biodiversity and circularity objectives. In addition, we aim to provide an initial analysis regarding life span extension and standardisations as aspects to focus on during the design phase for new offshore wind turbines to ensure positive effects on underwater nature and circularity. To do this, we introduce policy principles with a focus on sustainable decommissioning, life span extension and standardisation.

1) *https://natuurenmilieu.nl/app/uploads/Conditions-for-sustainable-decommissioning-of-offshore-wind-turbines.pdf*

Scope and reading guide

This paper considers the implications of the decommissioning of offshore windfarms built with monopiles. The turbine and associated infrastructure within the wind farm such as inter-array cables and offshore transformer substations for electricity transport are included. Geographically, we focus on the North Sea and Baltic Sea areas. Gravity-based foundations, floating wind, onshore wind farms and oil and gas assets are beyond the scope of this paper.

In Chapter 2, we discuss the relationship between life span extension and standardisation with sustainable decommissioning. We introduce strategies for life span extension and argue that the monitoring of standards is essential for gathering knowledge on the effectiveness and possible side-effects of standards.

In Chapter 3, we explore policy principles regarding life span extension and standardisation in more depth. This is followed by a set of recommendations for policy-makers in Chapter 4.

2. Towards sustainable decommissioning: standardisation and life span extension

In this chapter, we discuss the historical focus on lowering levelized costs of electricity (LCOE) and the positive and negative effects this development has had. This is followed by arguments supporting the need for standardisation to achieve sustainable decommissioning. In addition, this chapter highlights the need for life span extension in OWFs and the benefits this has for circularity ambitions and less disruption of underwater nature. The chapter ends with the need for monitoring to identify whether standards set require further improvement.

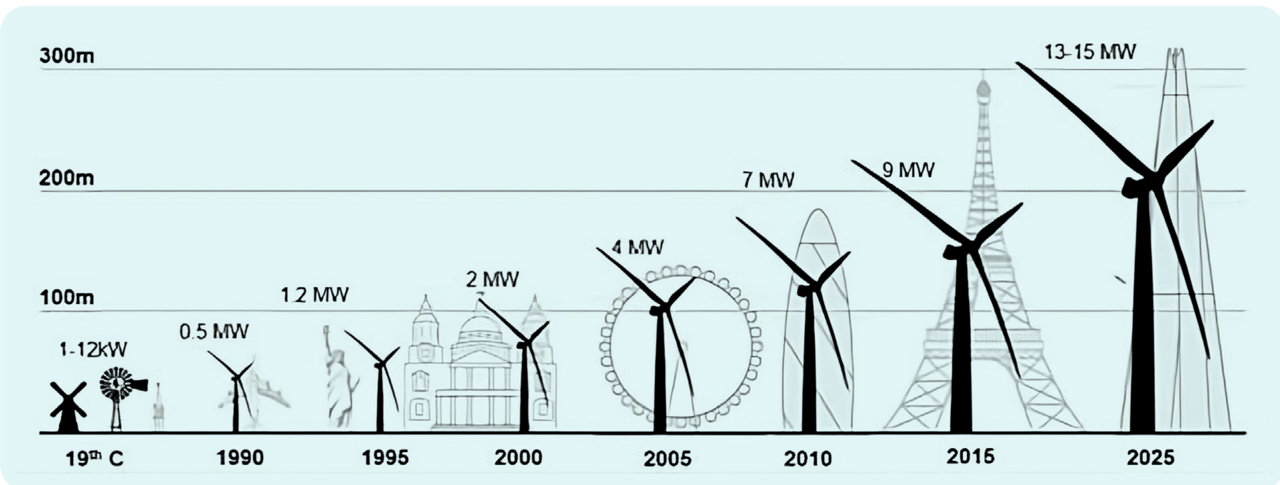
2.1 Power increase developments of OWFs

Currently, in tender procedures for offshore wind farms, the lowest LCOE bid tends to win[2]. This has resulted in competition being primarily focused on rated power (MW) of wind turbines[3] and in effect, larger wind turbines. This has proven beneficial when it comes to bringing down the LCOE, increasing capacity factors, reducing surface area usage and reducing the number of turbines in an OWF.

However, the added benefits of increasing the rated power of a wind turbine decrease the higher the rated power becomes, necessitating changes across the entire supply chain. To illustrate: an increase in rated power means that the entire turbine needs to be redesigned. This results in the need for larger components such as turbine blades, monopiles, wind turbine foundations and nacelles. In addition, offshore installation vessels need to increase in size to keep up with this development. Lastly, the cables used for connecting the individual wind turbines must keep increasing in size as well. This means that repowering an offshore wind farm requires the complete removal of all components, replacing them with components necessary for the higher capacity wind turbines.

This power increase has significant benefits for wind farms built before 2025 due to the developments in the rated power of the offshore wind turbines (see Figure 1). In the future however, the benefits of repowering a 16MW wind turbine with an 18MW wind turbine will not outweigh negative side effects. The benefits include a potentially slightly lower LCOE, fewer turbines to install, and lower sea area usage with equal energy output. These benefits come at a cost, however. For example, a higher capacity wind turbine needs more materials, a new foundation, different wind farm and grid layout, and faces longer production downtime for the location due to new construction activities.

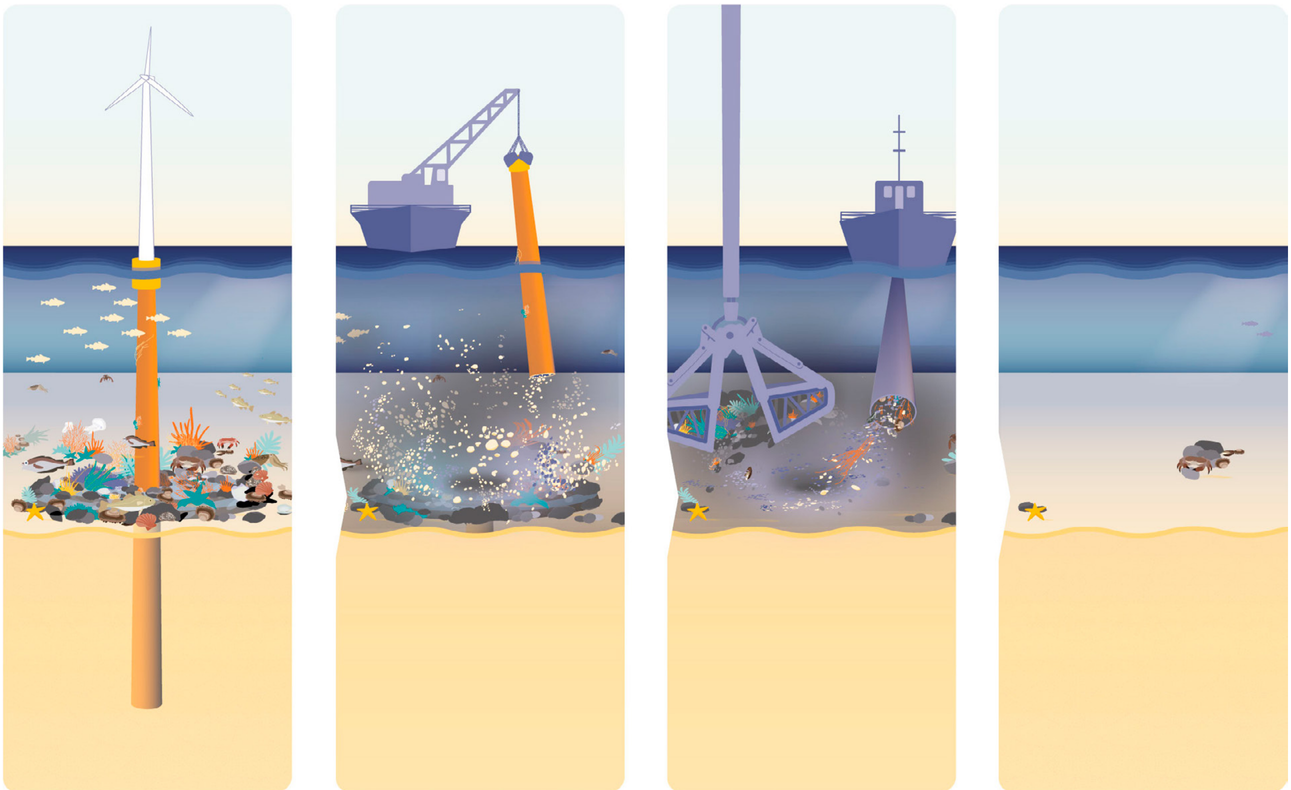
Figure 1: the evolution of wind turbine size and power output. Source: Bloomberg New Energy Finance.



2) *There are examples of tenders in which innovation and circularity is an award criterion. These are being applied as pilots in various locations, but they are not yet common practice.*
3) *The average offshore wind turbine rated capacity has grown from 0,5MW before the year 2000 to 8-12MW in 2023. (source: WindEurope & Irena.com).*

With respect to the settlement of marine species, full decommissioning of the existing infrastructure is required which eradicates almost all marine life (see Figure 2), as discussed in our previous paper. This illustrates the need to standardise wind turbines for new offshore wind farms and their foundations such as a cap on wind turbine size, increasing foundation life span, and improving component interoperability for easier repairs. These standards will be discussed further in this paper, after which there needs to be a thorough discussion with industry and the scientific community on which standards to develop in order to minimise impact on birds and bats, benefit underwater nature and circularity goals, and potentially lower supply chain costs.

Figure 2: The environmental impact of full decommissioning of an offshore wind turbine



2.2 Life span extension and standardisation

The lifespan of offshore wind turbines is limited. Current permits for OWFs in the North Sea and Baltic Sea allow a maximum duration of 35 years[4]. Extension of the life span of wind turbines will enable materials to be used longer, resulting in a lower material requirement in general. Additionally, the life span extension will allow decommissioning to take place at a later time, decreasing negative impacts on underwater nature.

There are multiple benefits related to life span extension:

- **Material efficiency:** extending the lifespan allows materials to be utilised longer, reducing overall material requirements.
- **Environmental impact:** delaying full decommissioning reduces negative impacts on underwater nature.
- **Cost savings:** extends the operational phase, leading to overall cost reductions.
- **Construction impact:** decreases the environmental footprint by reducing the frequency of new OWF construction.

4) *https://windopzee.nl. 40 years in total, which include construction and decommissioning phase*

Strategies for life span extension
To increase the life span of offshore wind turbines, the **standardisation of design elements** is crucial. This also means that identifying the life span of various wind turbine components is particularly important. Turbine blades for instance are subject to the highest stresses, have the shortest life span, and can be replaced relatively easily. The scour protection and the foundation should function for a longer time, are difficult to replace and have a significant impact on the marine environment when they are replaced.

Life span extension includes the circular strategies of repair, refurbish, remanufacture and repurpose. Translating these concepts to the wind industry means[5]:

- Wind farm level: repowering and life span extension
- Structural elements: designing foundations for longer use and future turbine re-use.
- Component level (subsystems, modules, components): strategies to promote re-use, repair, refurbish, remanufacturing and repurposing of components.

These strategies would result in industry-wide standards that could dramatically improve circularity, significantly reduce the impacts on nature, reduce wind turbine downtime, and potentially lower costs.

2.3 Monitoring

Offshore wind will experience significant growth in the coming years, but there is no consensus yet on the effectiveness and possible side effects of standards. It is therefore important to assess and monitor the impacts of certain standards. The lessons learned through monitoring will teach us that standards may need adjustment, and new innovative designs can be phased in. It is too early to legally solidify such a standard. Based on scientific insights, consensus on for instance the best tip height and design of turbine elements must still be reached.

Components of the wind turbine can be designed to achieve longer life spans. However, innovations can only be assessed in real life after many operational years. Extending a turbine's life beyond its usual design life of 25-35 years requires the owner to demonstrate - through inspections, operational data, or both - that the annual probability of failure of structural components is still acceptable, considering the maintenance history and component-failure modes[6].

5) *Lobregt, M., Kamper, S., Besselink, J., Knol, E., & Coolen, E. (2021). The ideation process focused on circular strategies in the wind industry. https://open.overheid.nl/documenten/ronl-83d842f26b78b2269c42aa481c83e373e2d0d213/pdf*
6) *MegaVind. Strategy for Extending the Useful Lifetime of a Wind Turbine https://megavind.greenpowerdenmark.dk/files/media/document/Strategy%20for%20Extending%20the%20Useful%20Lifetime%20of%20a%20Wind%20Turbine.pdf*

3. Towards sustainable decommissioning: Policy principles

Several principles can be applied to policies targeting standardisation and life span extension. These benefit the cost effectiveness of offshore wind farms, improve circularity and sustainable material use, but also help to reduce negative impacts and possibly have a positive effect on local biodiversity in the long run. These principles include standardisation principles and conditions that decrease the frequency with which decommissioning takes place. These principles are:

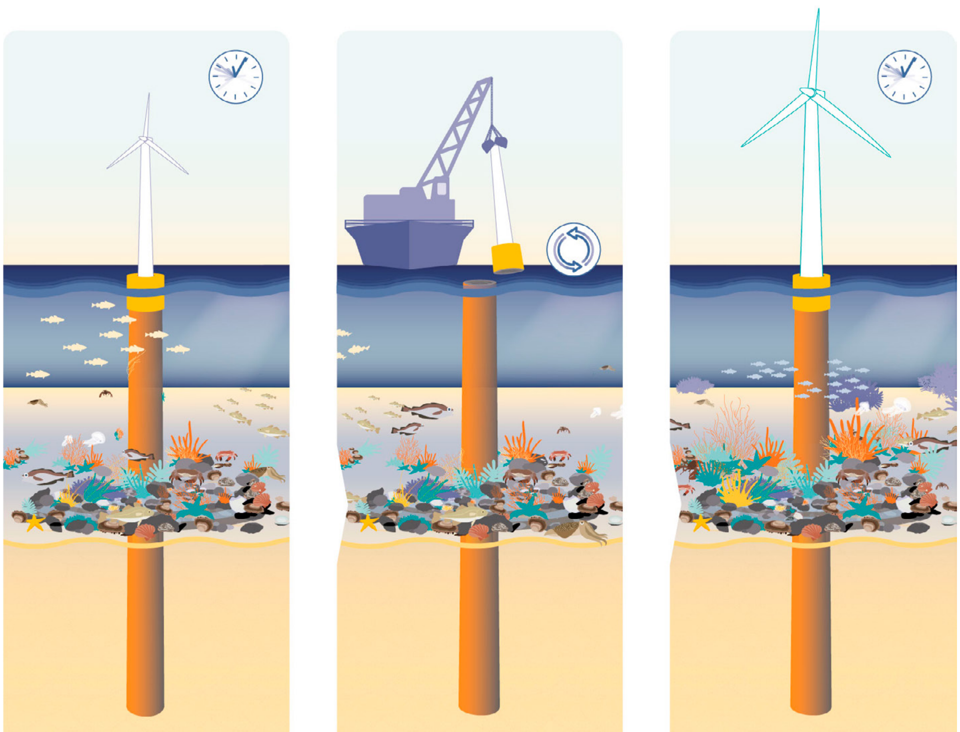
1. Increasing life span of wind turbine foundation
2. Capping the size of wind turbines
3. Standardisation of a minimum life span requirement for offshore wind turbines and their foundations
4. Adopt a modular approach to design
5. Standardisation of the components used in wind turbines
6. Increase compatibility between different wind turbine components for better functionality
7. Incorporate standards for nature-inclusive designs
8. Enable flexible permitting for new offshore wind farms.

These principles will be described in further detail in the following paragraphs.

1. Increasing life span of wind turbine foundation

The foundations of OWFs currently have a relatively short lifespan. As soon as the permit period for the site expires, policy dictates that the foundations must be fully removed. In the context of sustainability, nature protection, and circularity, there is ample reason to develop, enlarge, and reinforce these foundations to make them last much longer. There needs to be an element of overengineering to account for turbines with higher capacity in the future. By doing this, nature will be left undisturbed for a much longer period, and materials will be used for a longer duration. This would make a dramatic contribution to the preservation of nature and natural resources. See the figure below for a schematic representation of this concept.

Figure 3: a schematic representation of life span extension of the wind turbine and the reuse of its foundation. The foundation is designed (overengineered) in such a way that it is suitable for a larger, modern turbine.



2. Capping the size of wind turbines

Wind turbines are continuously increasing in size to bring down costs in the current market. Capping the maximum size of individual wind turbines can help to ensure that the industry focuses on other aspects of offshore wind energy, such as sustainable decommissioning, increasing circularity, material efficiency, and reducing maintenance costs through standardisation and modular designs. Improving these aspects reduces negative impacts on the environment throughout the lifespan of the turbine. This will also create room to work on life span extension because an end-of-life turbine can be replaced with a near-replica without the need to make drastic changes to the wind turbine foundation or cabling. A lot of research is needed in order to fully understand the optimal size of wind turbines[7]. This standardised tip-height should not only be based on technical efficiency aspects but also on ecological impact. For example, there is insufficient knowledge regarding the optimal size of turbines for birds. Introducing such a standard can also be location- or country-specific. Additional research and experimentation are needed, however. As stated before, thorough monitoring is crucial to assess the standard's effectiveness and to evaluate if adjustments are needed at a later stage.

3. Standardise a minimum life span requirement for the wind turbine and its foundation

The lifespan of wind turbine foundations is a critical factor in the overall lifespan of offshore wind farms. By setting a minimum life span requirement for wind turbine foundations, wind farm operators can ensure that foundations are designed and constructed to last a specific period of time. This would ideally be a lifespan that allows for reuse. When foundations are designed in such a way that their life span increases significantly, this ensures that they can be reused for future wind turbines.

4. Adopt a modular approach

Innovation on the design of the foundation for offshore wind farms, for example, can help to increase their modularity, longevity and sustainability. Standardisation of the most sustainable designs can also make it easier to replace individual wind turbines and their components without having to replace the entire foundation, which can be a costly, time-consuming process that disrupts marine biodiversity. Standardised wind turbine foundation designs can facilitate easier maintenance and repair which in turn can extend the wind farm's lifespan.

As an example for modularity, the foundation can have a longer life span than the turbine. More research is needed to learn to what extent a foundation can be reused for an OWF's second permit period. The foundation can attain a longer life span by increasing the amount of steel, leading to increased material use. Additionally, the further development of concepts such as *slip joints*[8] can make it easier to detach the turbine from the foundation and add a new turbine, reusing the foundation for a second permit period.

5. Standardise the components used in wind turbines

Standardising the components of wind turbines will help to reduce production and maintenance costs, increase efficiency, and improve reliability. By using standardised components, manufacturers can streamline their production processes and reduce the costs associated with customisation. Standardisation can also make it easier to maintain and repair wind turbines by avoiding vendor lock-in, which can reduce downtime, extend life span, and increase the load factor of offshore wind farms.

7) *Currently, stakeholders are advocating the maximum size of 1,000 ft: The North Seas Standard: enable growth with wind turbine standardization - NWEA*
8) *https://www.energyfacts.eu/van-oord-successfully-installs-worlds-first-submerged-slip-joint/*

Standardisation still faces a variety of barriers:

- There is a lack of transparency within the value chains, making it more difficult to set the best requirements for standards.
- Companies that innovate do not share all their knowledge as this would put their competitive advantage at risk. This also makes it more difficult for governments to set the best requirements.
- The sector is not done innovating. It could take some time before the components achieve their optimal design which can then be set as a standard for new wind turbines.
- The optimal design when it comes to impact on nature is not known yet. Ongoing research is needed in combination with an adaptive approach.

6. Increase compatibility between different wind turbine components for better functionality

Standardising the connection methods for wind turbine components can help reduce the costs associated with installation and maintenance. With standardised connection methods between turbine components, manufacturers can streamline their production and reduce the likelihood of errors or malfunctions during replacement and extend wind farm life span. Standardisation of connection methods can also make it easier to maintain and repair wind turbines, which can reduce the downtime of turbines and increase the overall operability of offshore wind farms. This is a critical factor for improving circularity and extending the life span of OWFs.

7. Incorporate standards for nature-inclusive design

OWFs can be designed in a nature-inclusive way to support underwater nature and mitigate negative environmental impacts. Underwater measures can be taken to either enhance the effect that the addition of hard substrate has on the environment or use methods that avoid hard substrate in an ecosystem where its presence is undesirable. The measures under consideration should always be based on local ecology. Furthermore, taking into account sustainable decommissioning in the design phase can also benefit the nature-inclusiveness of the wind turbine. For example, innovative decommissioning techniques that minimise seabed disturbance can aid in mitigating negative impacts on biodiversity.

8. Enable flexible permitting for new offshore wind farms within the same area

An important barrier to the standardisation of wind turbine foundation design is the inherently temporary nature of the permits granted. Even with an extended permit duration of up to 40 years, the location of wind farms can potentially be designated for an application other than electricity generation with wind turbines after the permit expires. The expiry date of permits for offshore wind farms can limit their lifespan and prevent them from reaching their full potential. Policy needs to be adapted to ensure the continued use of existing foundations and minimise seabed disturbance.

In order to promote the longevity and circularity of offshore wind farms, flexible permits should therefore be granted to allow for life span extension. By extending the life span of offshore wind farms beyond the original permit expiry date, wind farm operators have a stronger incentive to use wind farm components that can easily be replaced. The legal conditions for extending the lifespan must be clear to ensure an incentive for wind farm developers to innovate.

4. Recommendations

With respect to life span extension, we have the following recommendations for policymakers to incorporate in national and European policy, in collaboration with the offshore wind sector:

- **Standardise designs** for wind turbines. This also includes setting a minimum life span requirement for wind turbine foundations, making them reusable and standardising the design to enable the replacement of wind turbines without disturbing the surrounding biodiversity.
- **Standardise/cap the maximum and minimum tip height** of wind turbines. This is intended to stop the increase in size of wind turbines since we are reaching an optimal size when looking at costs and rated power. This ongoing growth adversely affects the costs of construction and materials and makes the repowering of high-capacity wind farms unnecessarily expensive. The most ideal standard when it comes to nature is not fully known yet, so we need sufficient flexibility with regard to the standardisation, monitoring and possibilities for adjustments based on scientific insights.
- **Increase interoperability** for wind turbine components. Set a standard for the use of connection methods for wind turbine components to lower installation and maintenance costs. This can enhance the efficiency of installation processes and contribute to the increased overall availability of offshore wind farms.
- Ensure **flexible permit extension** or longer permits to ensure that offshore wind farms are designed with a longer life span in mind.
- Standardisation requires an increase in **value chain transparency**. Active collaboration between industry stakeholders and governments is needed to develop effective standards for promoting responsible business conduct throughout the value chain, from extracting raw materials to the end-of-life stage.
- Ensure that any extra expenses associated with the lease of an offshore wind farm lot do **not hinder the achievement of broader objectives** related to nature and circularity.

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