The ideation process focused on circular strategies in the wind industry

ECHT

NEDERLAND CIRCULAIR! VERSNELLINGSHUIS

Ministerie van Economische Zaken en Klimaat

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This report is an initiative of het Versnellingshuis Nederland Circulair! (collaboration of Dutch ministry of Infrastructure and Water Management, VNO-NCW/MKB Nederland, MVO Nederland, and Het Groene Brein) and will be carried out as part of the 'Transitieagenda Maakindustrie' from the Dutch ministry of Economic Affairs and Climate Policy and executed by ECHT regie in transitie.

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Management summary

Onshore and offshore wind energy plays a critical role in the renewable energy ambitions of Europe. Supported by European and national policies, the wind energy industry is challenged to find ways to upscale its capacity output, as well as consciously use the earth's resources. With *the Circular Economy Action Plan*, the EU has made a circular economy an essential building block of the Green Deal. A rapid transformation towards a circular industry in the coming years is needed for the wind energy industry.

This report describes the results of the so-called Moonshot Project on Circular Wind Farms commissioned by Versnellingshuis Nederland Circulair! and executed by ECHT. The goal of Versnellingshuis Nederland Circulair! as well as the goal of this project, is to take concrete steps towards the integration of circularity in the wind industry and to realise transformations in the supply chain. This project has three phases: elaborate on circular strategies and action agenda topics, work-out concrete action agendas, execute those agendas. This report addresses the findings of phase 1 and makes action suggestions regarding phase 2.

In the ideation process, circular ideas and solutions are generated through a collaboration with industry experts at several stakeholder sessions and workshops. The first phase of this project has focused on identifying the challenges that come with the transition from a linear to a circular wind industry. More than 100 participating companies and governmental institutions active in the wind energy industry shared their views and knowledge, and showed their commitment to the circularity transition of the wind industry.

The participants of this project have identified circular opportunities that are translated into 9 circular action agenda themes / projects. As from spring 2021, the action agenda projects are initiated and aim – as from phase 3 – to accelerate the road towards a circular wind industry.

Conclusions

- The wind energy industry is very committed to making the transition towards a circular industry.
- The cost-driven focus hinders the transition to a circular industry.
- Current circular projects tend to focus merely on the recycling of materials.
- The quality of material must be better conserved.
- Collaboration between parties in the wind industry value chains and outside of the sector is required to implement circular strategies, and most efficiently pursued by having a joint (digital) discussion.
- The circular strategies have been subdivided in three domains: ‘Product design’, ‘Lifetime extension’, and ‘Re-application of materials’. The participants of this project mainly want to pursue circular strategies in the domains of ‘Product design’ and ‘Re-application of materials’.
- The use of a circular framework operationalised for the wind industry helps to structure the exploration towards and findings of circular strategies.

Recommendations related to the circular action agendas

- Pursue the action agendas as identified in phase 1 of this project, because the industry participants have indicated the importance of and commitment for phase 2 in this project.
  1. Circular permit and tender criteria regarding wind farm projects
  2. Modular design of the structural elements
  3. As much collaboration in design throughout the value chain as possible
  4. Environmental-specific foundation design and multi-use of wind farms
  5. Retaining data (e.g. on modules, components and material levels) for optimal decommissioning and circular strategies
  6. Responsibility of materials to enhance circularity
  7. Refinery and recycling plant(s) (e.g. rare earth elements (REE), Steel and composites)
  8. Circular clusters of companies around ports
  9. Platform for European wide circular collaboration
- Organise large involvement of industry partners for the action agenda projects.
- Keep the action agendas up to date, as it is a continuous road towards a circular wind industry.

Recommendations related to the value chain

- Create collaborations (like consortia) within the wind industry for proper alignment of circular businesses.
- Create synergies with related sectors for a smoother transition towards circularity.

Recommendations related to circular strategies

- Implement circular strategies in the order from R0 ’refuse’ to R9 ’recover’ to retain as much component and material value as possible.
- For the exploration and impact assessment of circular strategies in the wind industry, use the methodologies and the framework as presented in this report.

Recommendations related to European dimensions of the wind industry

- Elaborate on the added value of an EU-wide collaboration platform in the wind industry that is focused on the transition towards a circular wind industry.
- It is recommended to keep the momentum and enthusiasm in this transition with among other stakeholder sessions and webinars.
- Create national focal points for European financing, legislation, and collaboration to support sustainable developments regarding circularity in the wind energy industry.

Nederlandstalige (Dutch) samenvatting

Onshore en offshore windenergie speelt een cruciale rol in de hernieuwbare energie ambities van Europa. De windenergiesector staat, gesteund door Europees en nationaal beleid, voor de uitdaging mogelijkheden te vinden om de huidige capaciteit op te schalen en, daarnaast, bewust gebruik te maken van natuurlijke hulpbronnen. In de Europese Green Deal is het *Circular Economy Action Plan* een essentiële bouwsteen. Voor de windenergie industrie is een versnelde transformatie naar een circulaire industrie de komende jaren essentieel.

Het rapport *'The ideation process focused on circular strategies in the wind industry'* beschrijft de resultaten van het Moonshot project Circulaire Windparken en is opgesteld in opdracht van het Versnellingshuis Nederland Circulair!. Het doel van het Versnellingshuis Nederland Circulair! is, net als het doel van dit project, concrete stappen te zetten richting de integratie van circulariteit in de windindustrie en om verandering in de supply chain te realiseren. Dit project kent drie fasen: het identificeren van circulaire strategieën, het uitwerken van circulaire strategieën met bijbehorende actie agenda-onderwerpen en het uitvoeren van deze agenda's. Dit rapport adresseert de bevindingen van fase 1 en doet suggesties voor bepaalde acties in fase 2.

In het ideevormingsproces werden tijdens verschillende stakeholdersessies en workshops circulaire ideeën en oplossingen geïdentificeerd, door samenwerking tussen experts uit de industrie. De eerste fase van dit project was gericht op het identificeren van uitdagingen die gepaard gaan met de overgang van een lineaire naar een circulaire windindustrie. Meer dan 100 deelnemende bedrijven en overheidsinstellingen die actief zijn in de windenergie industrie deelden hun mening en kennis en toonde hun inzet en betrokkenheid voor de circulaire transitie in de wind industrie.

De deelnemers aan dit project hebben circulaire kansen geïdentificeerd, welke vertaald zijn in negen circulaire actieagenda thema's/projecten. Vanaf voorjaar 2021 worden de actieagenda projecten opgestart, met als doel de weg naar een circulaire wind industrie te versnellen.

Conclusie:

- De windenergiesector is zeer gecommitteerd en zet zich sterk in om de transitie naar een circulaire industrie te maken.
- De kosten-gedreven focus belemmert de transitie naar een circulaire industrie.
- De huidige circulaire projecten zijn veelal gericht op het recyclen van materialen.
- De kwaliteit van het materiaal afkomstig uit de windturbines moet beter behouden blijven.
- Samenwerking tussen partijen, in zowel de waardeketen van de windindustrie als daarbuiten, is nodig om circulaire strategieën te implementeren. Dit kan het meest efficiënt worden nagestreefd door het voeren van een gezamenlijke (digitale) discussie.
- De circulaire strategieën zijn onderverdeeld in drie domeinen: 'productontwerp', 'levensduurverlenging' en 'hergebruik van materialen'. De deelnemers aan dit project willen vooral circulaire strategieën nastreven in de domeinen 'productontwerp' en 'hergebruik van materialen'.
- Het gebruik van het 'circulaire framework', toegepast op de wind industrie, helpt met het structureren van de verkenning van en bevindingen over circulaire strategieën.

Aanbevelingen met betrekking tot de circulaire actieagenda's

- Volg de actieagenda's zoals geïdentificeerd in fase 1 van dit project. De deelnemers uit de industrie hebben het belang aangegeven van een vervolgfase voor dit project middels de volgende actieagenda thema's:
    1. Circulaire vergunningen en aanbestedingscriteria voor windparkprojecten
    2. Modulair ontwerp van de structurele elementen
    3. Zoveel mogelijke samenwerking in ontwerp vanuit de gehele waardeketen
    4. Natuur-specifiek funderingsontwerp en meervoudig gebruik van windparken
    5. Het behouden en gebruiken van data (bijvoorbeeld op modules, componenten en materiaal niveau) voor optimale ontmanteling en circulaire strategieën
    6. Verantwoordelijkheid van materialen om circulariteit te verbeteren
    7. Raffinaderij- en recyclingfabriek (voor bijvoorbeeld zeldzame aardelementen (REE), staal en composieten)
    8. Circulaire clusters van bedrijven rondom havens
    9. Platform voor Europese circulaire samenwerking
- Organiseer grootschalige betrokkenheid van de industriepartijen voor bovenstaande actieagenda's.
- Houd de actieagenda's up-to-date, want het proces richting een circulaire wind industrie is doorlopend.

Aanbevelingen met betrekking tot de waardeketen

- Creëer samenwerking (zoals consortia) binnen de windindustrie voor een goede afstemming van circulaire initiatieven en bedrijven.
- Creëer synergiën met gerelateerde sectoren voor een soepele overgang naar circulariteit.

Aanbevelingen met betrekking tot circulaire strategieën

- Implementeer circulaire strategieën in de volgorde van R0 'refuse' tot R9 'recover' om zoveel mogelijk component- en materiaalwaarde te behouden.
- Voor de verkenning en effectenbeoordeling van circulaire strategieën in de wind industrie, raden we het gebruik van de methodologieën en het framework zoals gepresenteerd in dit rapport aan.

Aanbevelingen met betrekking tot de Europese dimensies van de windindustrie

- Werk de meerwaarde uit van een Europa breed samenwerkingsplatform voor de windindustrie, dat is gericht op de transitie naar een circulaire windindustrie.
- Houd het momentum en enthousiasme vast onder de degenen die hebben deelgenomen aan de stakeholdersessies en Webinars.
- Creëer nationale speerpunten voor Europese financiering, wetgeving en samenwerking ter ondersteuning van de duurzame ontwikkeling op het gebied van circulariteit in de windenergie industrie.

Table of content

1 Introduction

Starting collaborations that lead to viable business cases and show results

1. Introduction

Onshore and offshore wind energy plays a critical role in the renewable energy ambitions of Europe. The share of wind energy in the European electricity supply mix was 14 % in 2018. In the coming decades this share will grow towards 50% in 2050 (WindEurope, 2020b). Supported by European and national policies, the wind energy industry is challenged to find ways to upscale its capacity output, as well as to enlarge cost efficiencies in the coming decades, leading to a lower LCOE (levelized cost of electricity). Therefore, substantial investments are needed in technological, organisational, and systems innovations.

In addition to this increasing role of wind energy in the European energy system, the challenge exists of lowering the carbon and ecological footprints of the wind energy sector. This, among others, means that circularity should be integrated into (business) strategies and working methods in the wind energy industry. Putting circularity on the agenda is becoming ever more urgent as in the coming years a growing number of wind farms - mostly onshore wind farms – in Europe will reach their end of life.

To stimulate strategic and tactical steps towards circularity by companies active in the wind energy sector (e.g. wind farm developers, turbine manufacturers, transport and installation companies, operations and maintenance service providers), it is relevant to 1) enthuse and excite the wind energy industry for circularity, and 2) map circular opportunities supported by feasible business cases.

This report describes the so-called Moonshot Project (named The Circular Wind Hub in phase 2) on Circular Wind Farms. The goal of this Moonshot project is to achieve circular business cases for complex, large scale supply chains with actual investments from (businesses in) the wind energy industry. This report contains the results of phase 1, which was focused on bringing together various types of stakeholders from the wind energy industry to devise circular business opportunities and identify specific circular themes. Hereafter, phase 2 (1-2 years) aims to design concrete projects plans with committed stakeholders.

The ultimate ambition (phase 3) is to have circular-driven wind hubs and value chains in the wind energy sector. Driven by large scale implementation of innovative design, large scale technology development and end of life strategies. The project's focus is not limited to the Dutch wind energy industry, as it aspires to contribute to European policy and business movements on circularity in the wind energy sector. It also aims to be auxiliary in the formation of a European wind alliance that focuses on circularity.

The project is an initiative of het Versnellingshuis Nederland Circulair! (a collaboration of the Dutch Ministry of Infrastructure and Water Management, VNO-NCW/MKB Nederland[1], MVO Nederland[2], and Het Groene Brein[3]) and the Dutch Ministry of Economic Affairs and Climate Policy. The Dutch initiative Versnellingshuis Nederland Circulair! supports companies to take concrete steps towards the integration of circularity in their businesses and to realise transformations in supply chains. The project is executed by the Dutch company 'ECHT regie in transitie' with specialists in the field of wind energy, circularity, and transition management.

[1] Both VNO-NCW and MKB Nederland are one of the largest employers' organisations in the Netherlands.
[2] MVO Nederland is a Dutch knowledge and network organization for companies and focuses on so-called new economy aspects like climate neutrality, circularity, inclusivity, and transparent and fair supply chains.
[3] Dutch network organisation of more than 140 scientists contributing to circular economy challenges and opportunities.

Purpose of this report

The purpose of this report is threefold. First, it will describe the methods that have been used to accelerate the ideation process. The report indicates specific developments and opportunities of circularity in the wind energy industry, based on desk research and interactive sessions with wind energy stakeholders.

Second, it describes the framework that has been developed to elaborate on circular strategies and that has proven to be useful in identifying and classifying circular strategies.

Third, this report offers general conclusions on the current state of circularity in the wind energy industry and makes recommendations for future steps in the transition towards a circular industry. In a follow-up project, nine concrete action agendas can be pursued that have been identified in the first phase of this project. These conclusions and recommendations aim to inspire European stakeholders on circularity in the wind energy sector.

Content of this report

Chapter 2 gives a brief overview of developments in wind energy and the need for the wind energy industry to integrate circularity in its (business) strategies. Chapter 3 provides background information on the project's phases and framework used in this project. Chapter 4 describes the process and outcomes of the stakeholder sessions held between June and November 2020. These sessions have led to the definition of 9 specific circular themes that could be transformed into concrete circular agenda actions, which the wind energy industry stakeholders can take up from December 2020 (phase 2 of the initiative). The action agenda themes are further explained in chapter 5. The last chapter provides conclusions and recommendations regarding 1) circular strategies and action agendas, 2) methods and processes for stakeholder mobilisation on circularity, and 3) European opportunities for collaboration on circular strategies in the wind energy sector. The document has 4 appendices, including a technical appendix covering the project's research (based on desk research and the stakeholder sessions) on circularity in the wind energy sector.

2 Circularity in the wind industry

2. Circularity in the wind industry

2.1 Wind energy outlook

Europe is exploring its potential to reach the goals set by the Paris Climate Agreement and the European Green Deal. The Green Deal considers the wind industry to be an essential part of the transition towards a carbon-neutral society. The wind energy sector made improvements in their business case over the years resulting in onshore wind being the cheapest form of power generation in Europe, with offshore wind not far behind (WindEurope, 2020a). The European Union has set ambitious targets for the wind energy industry to reach carbon neutrality (European Commission, 2020b). It has implemented policies like the EU strategy on offshore renewable energy to reach these targets. The total wind energy capacity is set to double in the coming 10 years. In 2050, the European Commission has set its targets on a sixfold increase in the current wind energy capacity, see figure 1.

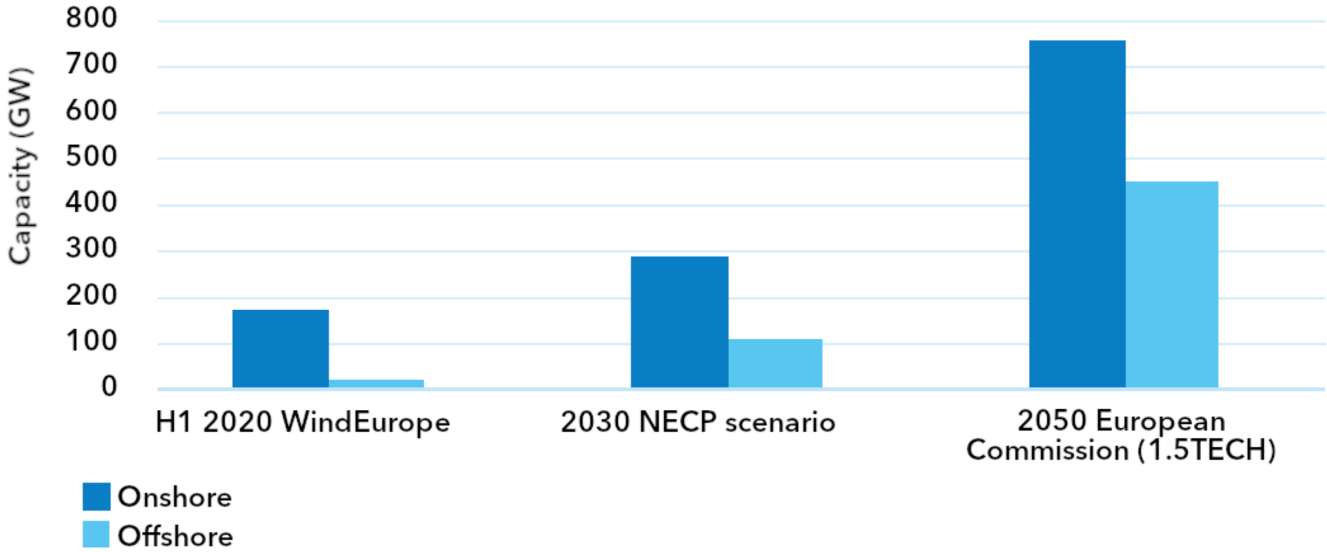

Figure 1: Wind energy capacity scenarios for Europe: NECP scenario[1] and European Commission long-term strategy[2] (WindEurope, 2020a)

2.2 Wind farms reaching End-of-Life

Developments in the wind energy industry have led to technologically complex and commercially viable turbines. However, because of the long lifetime[3] of wind turbines, the wind industry is encountering new problems. The residual flow as defined in this report consists of wind turbines that are being decommissioned. The residual flow of wind turbines will increase at a high rate in the coming years. Because the average lifetime of currently installed wind turbines is 20-25 years, the first large batch of wind turbines is reaching its End-of-Life (EoL) soon.

[1] NECP scenario relates to the National Energy and Climate Plans of European countries.
[2] The 1.5TECH scenario is one of the scenarios worked-out by the European Commission (2018).
[3] This report uses the definition of the lifetime of a wind turbine as is used in Hajonides et al. (2020), by which the operational lifetime is meant.

The largest share of currently installed wind turbines is onshore. Therefore, the residual flow of wind turbines will primarily contain onshore wind turbines (WindEurope, 2020a). However, offshore is catching up, as is shown in figure 1 and 2. Furthermore, the report[4] by TNO commissioned by SmartPort (Hajonides et al., 2020) researches and emphasises the size of the residual flows of wind turbines in the southern North Sea[5]. Appendix D further elaborates on the different residual material streams related to offshore wind farms in the southern North Sea.

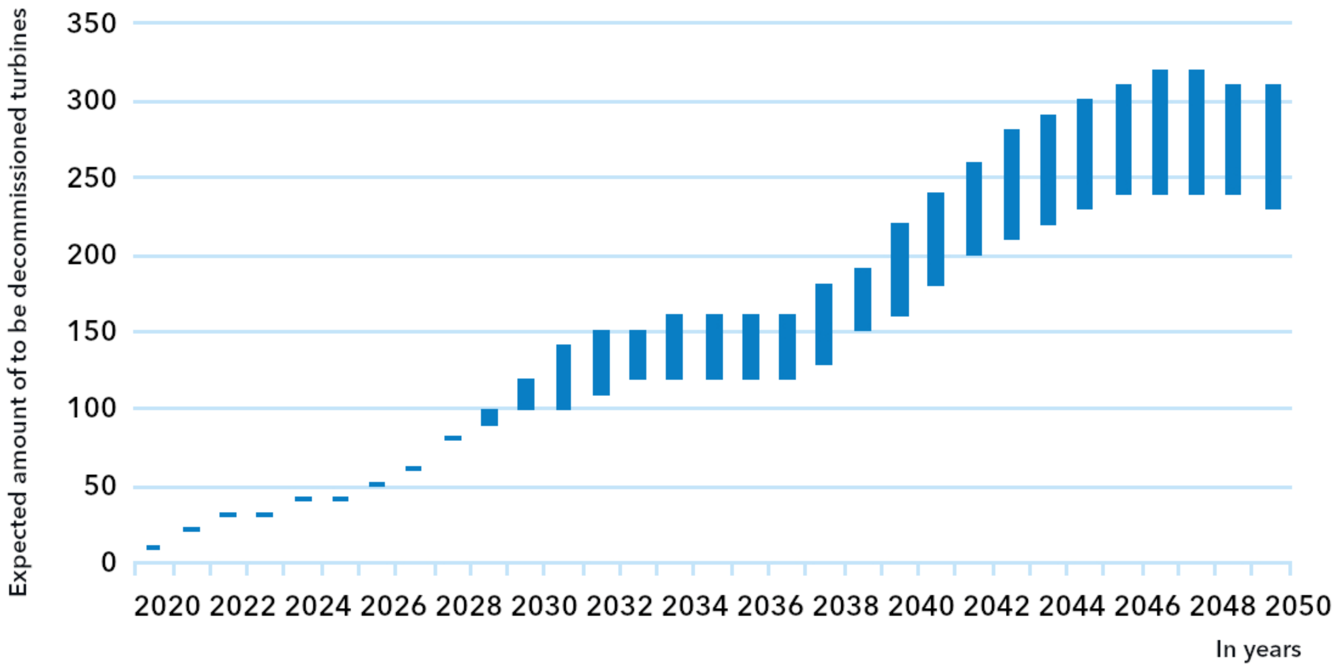

Figure 2: The residual flow of the expected amount of offshore wind turbines in the southern North Sea area (Hajonides et al., 2020)[6]

The large share of EoL turbines also poses great opportunities. Both the structural elements as the materials of wind turbines[7] could be processed for re-use in other structures or products. The residual flows show large potential for interesting business cases.

2.3 Circularity ambitions

Circularity is driven by the ambition to consciously use the earth's resources while taking responsibility for a 'healthy' globe. Faced with increasing amounts of waste, many European governments are preparing new policies to change the way we use our resources. The Dutch government has set a target at minimal 50% less virgin materials usage (minerals, metals, and fossil resources) in 2030 and a fully circular economy in 2050 (Rijksoverheid, 2016, 2019) in which it reduces its dependence on external suppliers. Additionally, Europe is developing new strategies, such as the European Green Deal (European Commission, 2019) and the New Circular Economy Action Plan (European Commission, 2020a), to reduce waste and make the transition to a circular economy, also in the wind energy industry.

[4] This report is commissioned by Smartport which is a joint venture between the Port of Rotterdam Authority, Deltalinks, the Municipality of Rotterdam, TNO, Deltares, Marin, Erasmus University, and Delft University of Technology.

[5] The southern North Sea in the TNO report (Hajonides et al., 2020) contains the following areas: UK03, UK04, BEG01, NL01 and DE01.

[6] It is assumed that residual flow developments of wind farms in the southern North Sea are similar to the rest of Europe.

[7] This report defines the structural elements of a wind turbine as the foundation, cables, nacelle, blades, and the tower. This is further explained in chapter 3.4.

Kadri Simson, European Commissioner for Energy, stated the following during the third stakeholder session of this project:

"*The circular economy is a key element of the European Green Deal. If we do not change our habits, we will need three earths by the year 2050. Circularity is also important for how we generate wind power. While the energy is renewable, the wind turbines are not. Not yet. Working together across the entire value chain is crucial. We need collaboration between stakeholders, public and private. In Europe and beyond. Let us take the next steps together!*"

The coming years will be crucial for the wind industry in the transition towards a circular industry. The first large batch of wind turbines is quickly reaching the end of its lifetime. At the same time, the wind industry is installing a new, unprecedented capacity of wind energy. This poses new questions, such as: How can we use the wind turbine parts or materials that are coming available with minimal loss of quality? How can we restore or even enhance nature surrounding wind farms? How can we design new turbines with circularity in mind?

The wind industry already made good efforts to become fully circular (Appendix A and C). It is estimated that 85-90% of wind turbines can technically already be recycled (ETIP, 2020; Garcia Sanchez et al., 2014; Umwelbundesamt, 2019). The waste treatment of blades (largely made from composites) is considered to be the main challenge in wind turbine recycling, and the industry is acting on it. Many projects work on cost-effective recycling methods and new designs for easier and more circular disposal in the future. If the current composite recycling techniques reach their potential, turbines could come closer to 100% recyclability. Evidence of actual recycling rates remains thin on the ground. Besides, even when all materials are recycled, a large loss of quality (for instance length of fibres) of the structural elements or materials can still occur.

This report offers a holistic approach to circularity on wind farms. Multiple circular strategies have been assessed that follow a broad spectrum of circular retention strategies, ranging from repurposing structural elements to recycling materials. Furthermore, where possible, this project aims to contribute to existing projects and initiate projects on themes that have not been worked on yet.

A framework is created to use as a reference to elaborate on circularity strategies for the wind industry and to define relevant action agenda topics regarding circularity in the wind energy sector. This framework is further explained in chapter three.

3 Towards action agendas on circularity in the wind industry

3. Towards action agendas on circularity in the wind industry

3.1 Introduction

Within the boundaries of this project, three phases have been defined regarding the steps towards specific and concrete action agendas on circularity in the wind energy sector:

- Phase 1: initial mobilisation of companies in the wind energy sector to elaborate on circular strategies and to define specific circular action agenda topics.
- Phase 2: stakeholders will work out the specific topics into concrete circular action agendas.
- Phase 3: execution of these action agendas.

These three phases will be further explained in paragraph 3.2. This document gives a recap for phase 1 and the first draft for phase 2.

For phase 1 the involved team of experts of ECHT have created a framework as a reference for stakeholders (mostly companies) to elaborate on circularity strategies in the wind energy sector and to define specific circular action agenda topics. In paragraphs 3.3, 3.4, and 3.5 the three dimensions of the phase 1 framework will be described, being wind farm structural elements, the focus of the circular strategies, and time span regarding circular strategies.

3.2 Three phases towards the implementation of circular action agendas

The first phase has run in 2020 and resulted in multiple industry-wide meetings, as well as this report. In this phase, the industry has identified multiple circular themes and expressed its commitment to pursue these themes. The first phase is further described in chapter 4.

The second phase will run in 2021 and focuses on finding solutions and business cases among the themes that are established in the first phase. Chapter 5 offers a first elaboration of the topics that are defined to give content to the start of the second phase of the project.

The third phase is expected to run from 2022-2025 and will be used to implement the circular initiatives and business cases that have resulted from the second phase. The third phase is dependent on the results of the second phase and will therefore not further be discussed in this report.

Figure 3 gives a schematic overview of the phases including goals per phase, and the methods used. The core method for phase 2 will be the creation and activation of working groups per circular action agenda topic.

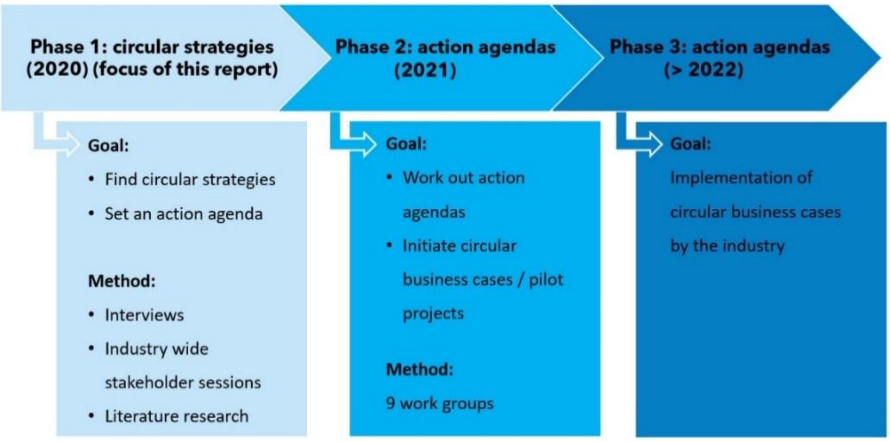

Figure 3: Wind industry circular framework by ECHT

3.3 Wind industry circular framework

As indicated, ECHT has created a framework to use as a reference to elaborate on circularity strategies for the wind industry and to put initiated action agenda topics into the perspective of circular strategies. This framework is the guideline for this project in identifying the action agenda and assessing its effectiveness and completeness. In the current, more linear industry, business processes still occasionally lead to incineration or landfill of materials. This framework provides the guideline to change these linear processes to more circular methods. The framework, based on various frameworks and models[8], consists of three domains: the wind industry domain, circular strategies domain, and the ecological/environmental domain. These three domains together form the framework created for and used in this project for phase 1. Figure 4 shows this framework. In the following paragraphs, the three domains are introduced.

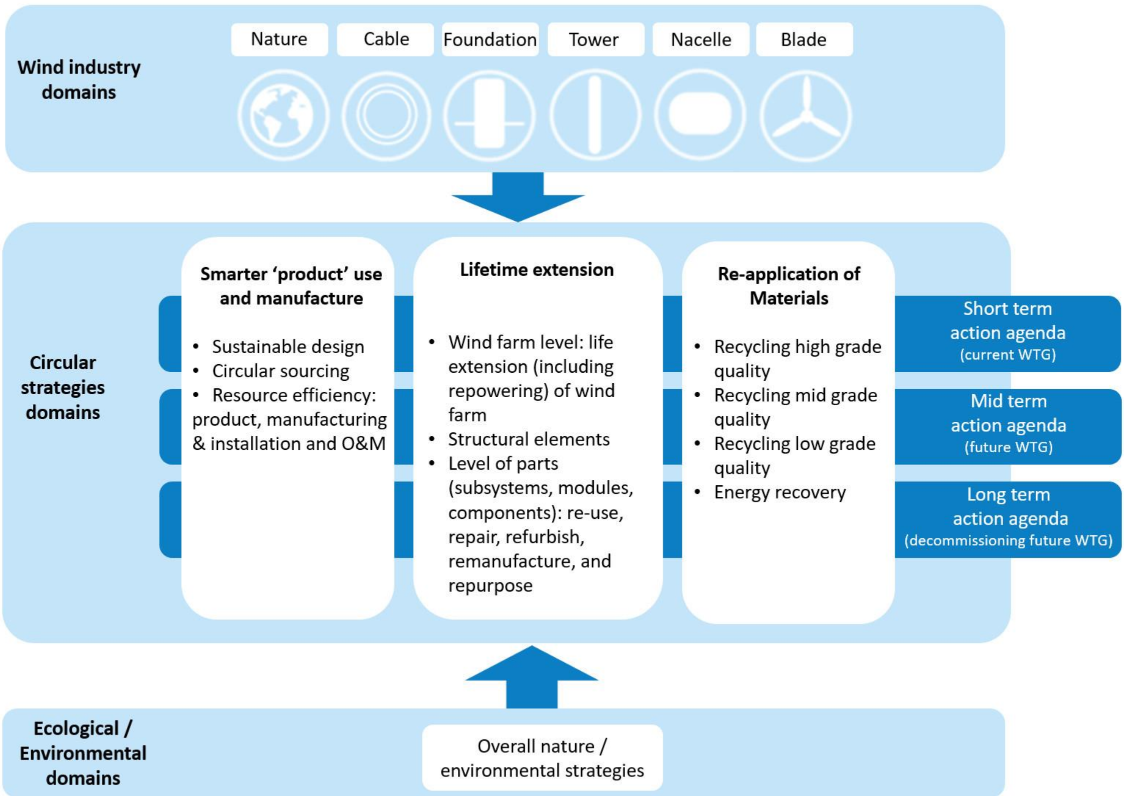

Figure 4: Wind industry circular strategies framework by ECHT, inspired by e.g. Billieu (2020), PBL (2017), and PwC (2019)

[8] Billieu (2020), PBL (2017) and PwC (2019)

3.4 Domain 'wind farm structural elements'

As indicated, the created framework for elaborating circular strategies in the wind energy sector consists of various domains. One of these domains is related to the structural elements of a wind farm. This research has set the scope of circularity on the level of wind farms in their entirety, containing all structural elements of wind turbines and the nature around the turbines (and the wind farm). The following structural elements of a wind farm are distinguished within the boundaries of the current project (figure 5):

1. Blades
2. Nacelle
3. Tower
4. Foundation
5. Cable
6. Nature

In figure 5, a simplified schematic picture shows the main differences between off- and onshore turbines. The main differences are that offshore wind turbines are larger than onshore turbines in terms of e.g. height, and capacity. The coming years, offshore turbines may reach a capacity over 15 MW with blades over 100 meters long and a 250+ meters tall tower. Due to logistics, noise, and visual reasons most onshore turbines gap at around 5 MW, with blades of 75 meters and a tip height of 175 meters tall. On- and offshore turbines also differ on its foundation. Most onshore turbines have a concrete foundation. While offshore, several steel-based foundation types are mostly used.

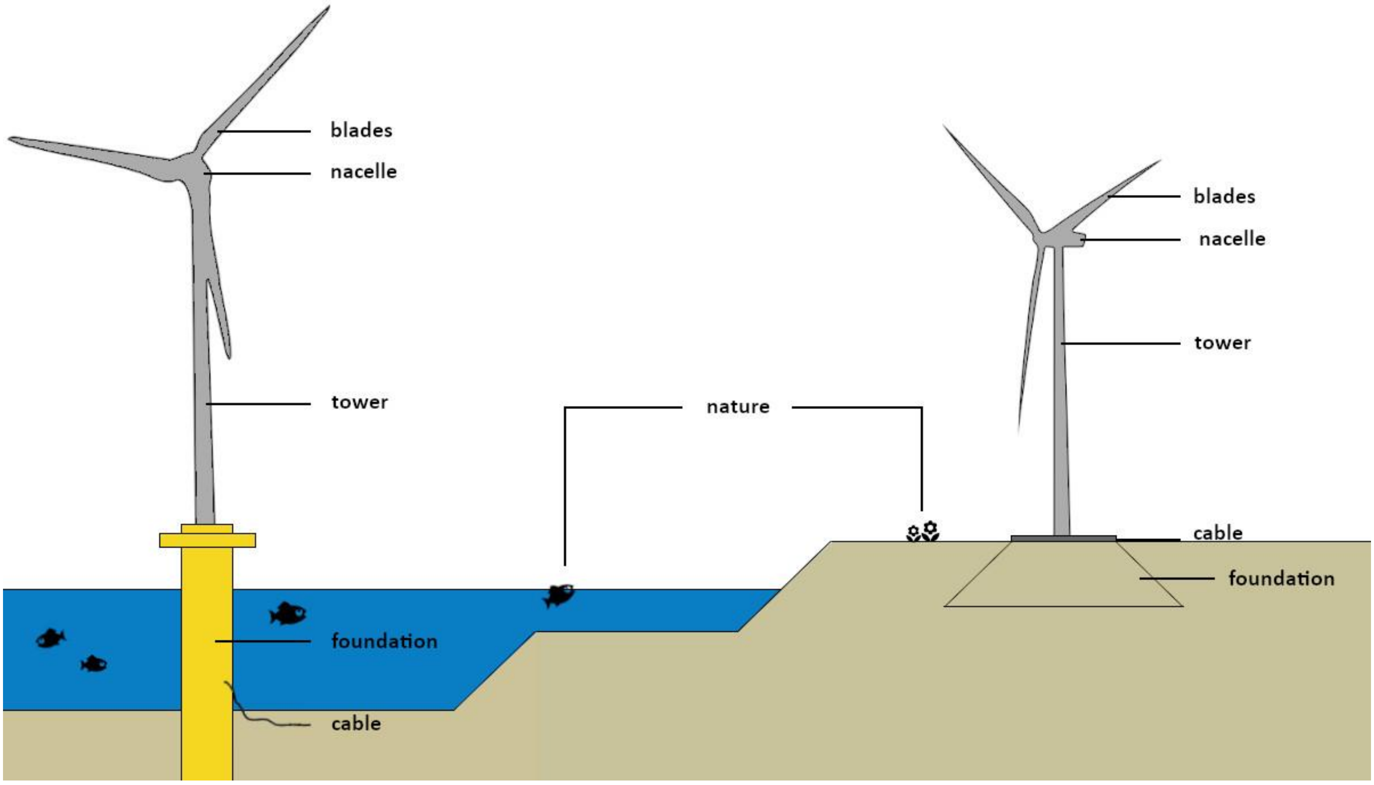

Figure 5: Schematic representation of structural elements of a wind turbine

Wind turbine blades are connected and directly bolted to the hub. The blades are made up of composite (lightweight) materials (ETIP, 2020) that allow efficiently generated wind energy to turn into a rotating motion.

The hub is connected to the nacelle, which houses a drive train and a generator, together with converting the kinetic energy into electricity. The housing of the nacelle is generally made of composites. The generator and the drivetrain are made of a variety of materials, from which rare earth elements (REEs) are the most critical.

The tower supports and gives the hight to the nacelle and is primarily manufactured of steel and stands on a foundation. The foundation of a wind turbine differs per location. Most of the onshore foundations are made of concrete (Carrara et al., 2020). Monopiles made of steel are by far the most used foundation type for offshore constructions in shallow waters (depth less than 40 m). Other important foundation types for offshore foundations are the gravity-based structure, tripod, jacket, and floating (Sánchez et al., 2019). These foundation types are also made of steel, although the gravity-based structure also contains concrete structures. Cables are used to transport power from the wind farm location to the grid infrastructure.

Current research on circularity in the wind industry mainly focuses on the turbine. For this report, the focus is on the whole wind farm. The ecological environment surrounding the wind farm is influenced by wind turbines. For instance, offshore wind turbines provide oysters with a surface where they attach themselves to and stay there for the rest of their life. Therefore, the element 'nature' is added to the structural elements in the framework. Thus, the six structural elements used in this research of a wind turbine are the blades, nacelle, tower, foundation, cable, and nature.

This report has set the scope on the wind farm level. However, in this report not all elements related to wind farms are included in the framework. Balance of Plant (BoP) is a term given to all the infrastructural components of a wind farm, except for the turbine and all its elements. Part of the BoP is e.g. the substation and the export cable. In onshore wind farms, the roads are also considered to be a part of the BoP. For future use of the framework in the identification of other circular strategies, it can be useful to include BoP in the framework.

3.5 Domain 'focus of the circular strategies'

The core of the framework created and used in this project consists of three groups of circular strategies:

1. Product design
2. Lifetime extension
3. Re-application of materials

To promote a transition to a circular economy for the wind industry, product and material chains need to be closed more effectively. Various approaches, known as R-strategies, have been developed to achieve less resource and material consumption in product chains and to make the economy more circular. To identify and classify these circular strategies, the framework contains a circular strategies domain with circular aspects related to the wind industry.

This domain is loosely based on the concept of a circular economy, according to PBL (2017) and the clustering of their concept in three segments based on e.g. PBL (2017) and PwC (2019). PBL (2017) state that a circular economy can be expressed in the 9R's: refuse, reduce, re-use, repair, refurbish, remanufacture, repurpose, recycle materials and recover (energy mostly via incineration). These R's present a range of strategies ordered from high levels of circularity (like refuse and reduce) to low levels circularity (like recycling and incineration) as shown in figure 6. In the framework used in this report, the R-strategies are clustered into three main circular strategies.

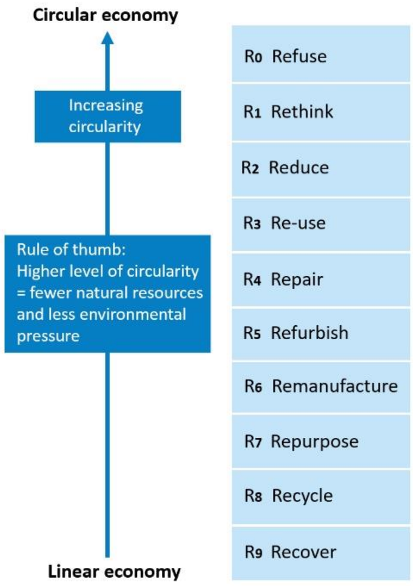

Figure 6: Levels of circularity (PBL, 2017)

Product design

Product designers can 'refuse' (R0) the use of specific materials or offer the same function with a different material. This can result in a different production process to avoid certain waste stream or fundamental less usage of virgin material. With the circular strategy 'rethink' (R1) or 'redesign', product use is made more intensive e.g., through sharing products, or by putting multi-functional products on the market. At the beginning of the design phase of a wind turbine, there is the possibility of eliminating certain materials and thereby to have an influence on the waste streams after the decommissioning of the wind turbine. The circular strategy ‘reduce’ (R2) focuses on the efficiency of manufacturing a wind turbine and the reduction of materials in their design, with the common goal of using fewer natural resources and materials.

Lifetime extension

When the wind turbine is built and operational, there are different circular design strategies applicable to extend the lifetime of a) the wind farm, b) structural elements (see paragraph 3.4) or c) parts of the wind turbine. When the life cycle of a wind turbine has come to an end, this does not mean the life span of a turbine (components) has come to an end. A circular strategy applicable is 're-use' or 'resell' (R3). With re-use, a wind turbine hardly needs any adaptation and provides the same functionality with the same purpose on a different location. Another strategy could be expanding the lifetime extension of a wind turbine. Repair (R4) and maintenance of defective products or components ensure they can be used with their original function. Refurbishment (R5) is most adequate in cases where the overall structure of a large multi-component product, like wind turbines, is used. This strategy focuses on restoring an 'old' turbine and brings it up to date.

A wind turbine, consisting of multi-components, is remanufactured (R6) when it is disassembled, checked, cleaned and when necessary replaced or repaired in a new product with the same function. This differs from refurbishment when discarded parts are remanufactured for a new product with the same function. When discarded parts are adapted for another function, the circular strategy 'repurposing' (R7) is in place. The discarded parts and materials get a distinct new life cycle. For instance, decommissioned wind turbine blades can be used in construction as the foundation of a bridge.

Re-application of materials

Recycling (R8) includes processing material to obtain the same (high grade) or lower (low grade) quality. This means that these materials can be used as a resource for new components within or outside of the wind sector. Materials can also be used to recover (R9) energy by incinerating the materials.

3.6 Domain 'time span regarding circular strategies'

The last domain of the framework is the time. This framework follows the differences in time of Billieu (2020) and makes a distinction on short-, mid and long-term actions.

- A short-term action is focused on the wind turbine generators (WTGs) that have already been installed. Finding solutions for the blades of turbines that are being decommissioned in the next few years is an example of a short-term solution.
- Mid-term solutions work on WTGs that are being installed in the coming years (0 – 5 years). A turbine designed with less material is an example of a mid-term circular strategy.
- Long-term actions focus on the decommissioning of WTGs that are to be installed in the coming years to decades (5 – 30 years). When making certain parts of the wind turbine, like blades, it will allow only decommissioning of parts resulting in life extension.

4 Findings phase 1

The ideation process focused on circular strategies in the wind industry

4. Findings phase 1: the ideation process focused on circular strategies in the wind industry

4.1 Overview of the executed ideation process methodology

The ideation process whereby ideas and solutions have been generated consisted of several activities like stakeholder sessions and workshops. Workshops, stakeholder sessions, interviews, and literature research have led to the definition of specific circular themes. These could be transformed into concrete circular action agendas to be picked up by wind energy industry stakeholders during phase 2 (see chapter 5). In this chapter, the commitment, challenges, and ideation process towards circular action agendas are described.

To get a clear overview of the stakeholders in the wind industry, the current value chain of the wind industry was simplified and visualised in Figure 7. Interviews with stakeholders in each area of the value chain, including NGOs (non-governmental organisations), research institutes, branch organisations, manufacturers, transportation and installation companies, decommissioning and waste treatment companies, were held to understand their motivation for and challenges of a circular wind energy industry. The framework as proposed in chapter 3, provided a guideline to identify and classify the circularity situation of the wind industry. Information gathered via interviews was used to optimize the stakeholder sessions.

Figure 7: Simplified value chain wind industry

The willingness of the industry to contribute to this transition became clear during the various stakeholder sessions. More than 100 participants from the whole value chain actively participated and shared their views and knowledge. At these stakeholder sessions, the goal was to understand the status of the industry, to enthuse the industry for circular transitions, and to explore vital action towards a circular industry. With contributions of among others from the CEO of WindEurope and the European Commissioner for Energy, the urgency of accelerating the circular transition has been reinforced.

The valuable input given by the stakeholders was gathered using among other online conversations and discussions, poll questions, and in-depth workshop sessions. For each stakeholder session different tools, themes, and models were used to give structure to the discussion with the involved stakeholders. An extensive overview of both the process and the content of the stakeholder sessions can be found in appendix A.

The next section provides an overview of the key findings of the information shared during the sessions by the participating stakeholders.

Giles Dickson, CEO of WindEurope
August 28th, 2020

"Circularity is at the heart of the European Green Deal. And a top priority for the wind industry as sustainability is at the core of our business.

The first generation of wind turbines are now starting to come to the end of their operational life. The fate of decommissioned wind turbines and in particular blades is subject to much media attention and stakeholder interest. 14,000 wind turbine blades will be decommissioned in Europe in the coming years. And this number will continue to grow. We need concrete and rapid action to move further towards zero-waste turbines. This will require collaboration from the whole value chain and across industry sectors.

We are delighted to see so many stakeholders gathered here today to participate in the 'Moonshot Project Circular Wind Farms'. We thank the Dutch government of Economic Affairs and Climate, the Dutch government of Infrastructure and Water Management, and ECHT for this initiative. Projects like these are key to enable the development of a fully circular wind industry."

Kadri Simson, European Commissioner for Energy
October 9th, 2020

"As you surely know the EU has set a sight on climate neutrality in 2050. This is the central goal of the European Green Deal. A few weeks ago, executive vice president Frans Timmermans and I had the great honour to propose a cut in greenhouse emissions by at least 55% by 2030. Renewable energy is at the core of our vision for 2030.

To reach our target we have to massively upscale both offshore and onshore wind energy, but we are focussing in particular on offshore where we see the greatest untouched potential. At the start of this year, when travelling and physical presence was still a normal part of our life, I had the pleasure of visiting Denmark and to see a wonderful offshore wind park. The first park was built in 1991, approximately 30 years ago. You can see there, with your own eyes, the progress made in turbine technology over the years.

New solutions are bigger and better and, of course producing more power. At the same time, constantly, evolving systems also have new questions that need answers. The first generation of wind turbines is quickly reaching the end of their operational life. In the coming years around 14,000, wind turbine blades will be decommissioned. That number is growing, meaning we need rapid action from you, the wind power energy sector. To move towards zero waste and make renewable energy fully circular.

The circular economy is a key element of the European Green Deal. If we don't change our habits, we will need three earths by the year 2050. Circularity is also important for how we generate wind power. While the energy is renewable, the wind turbines are not. Not yet. Working together across the entire value chain is crucial and I am glad there are so many different organisations represented today. We need collaboration between stakeholders, public and private sector. In Europe and beyond. Let us take the next steps together."

4.2 Key findings circularity in the wind energy sector

General opportunity

The main conclusion that can be drawn from the stakeholder sessions is that for the wind industry to accelerate the transition from a linear to a circular economy, the cost-driven focus should be shifted into a balanced focus between ecological and economical value. Currently, the entire process of a wind farm is designed around the lowest levelized cost of electricity (LCOE). This is reflected in every link in the value chain.

The stakeholders involved in the sessions indicated that the industry is aware of the challenges that it experiences concerning circularity. The wind industry value chain is very committed to making the transition towards a circular industry. However, the stakeholders involved in the sessions expressed that they are hesitant about incorporating circular business propositions in the current investment climate, because of a potential lack of business cases. Every stakeholder in the value chain has its expertise. For implementing a circular strategy, the value chain needs to collaborate. Even a slight modification in the design of a wind turbine could have a significant impact on the related processes further in the value chain. For instance, when wind turbines are designed to be taller, the transport and installation processes will most likely have to be adjusted to that size. Collaboration across the chain is needed when it comes to research, innovation, and implementation. The results of the stakeholder sessions show that this is most effective on a small scale with a good representation of the entire value chain preferably with relevant cross-chain and cross-sector representation. Different stakeholders have emphasised the critical role the government can, or even should play, to promote and to stimulate circular business propositions.

Many parties have their sustainability programme, but teamwork along the value chain is required to make a significant impact. Responsibility for circularity within the organisation, however, is often not well defined. Companies need to take initiative and clearly define the responsibility for circularity.

When looked at the framework, there are three main categories for circular strategies in the wind industry: ‘Product design’, ‘Lifetime extension’ and ‘Re-application of materials’. During the stakeholder sessions came to light that current initiatives are mainly focused on the material streams that become available after the decommissioning of wind turbines. Thus, current initiatives are mainly about the strategy 'Re-application of materials'. To preserve the quality of structural elements, the future focus on circularity should be broadened and include circular strategies focused on 'Product design' and 'Lifetime extension'.

Statements by stakeholders involved in one of the sessions in response to the question:
What is needed for a feasible business case for circular initiatives?

- *"Currently the focus lies on the competitiveness of price instead of sustainable or circular innovation. This price-driven focus already starts at the beginning of the value chain in the tender criteria. Awarding in selection criteria tenders will make a difference."*
- *"Collaboration in design will result in efficient material and component use."*
- *"Production waste and decommissioning of composite components are the most impactful sources of loss."*
- *"Modular wind turbines will at least contribute to transportation and logistics."*
- *"Gain consensus on the concept of leaving eco-friendly materials on the bedpost decommissioning where they show an eco-system net gain."*
- *"Keep in mind that circularity and sustainability will not always complement each other. Trade-offs have to be made between sustainability and circularity."*

Reflections per structural element

Appendix C gives more information on circularity options related to the structural elements of a wind turbine. Appendix D contains a case study based on the residual flow of offshore wind turbines and its materials in the southern North Sea by Hajonides et al. (2020). This case study provides a good indication of the size of future offshore annual material residual flows and the potential for circular business cases per structural element[9].

It is not the purpose of this report to give a complete overview of all the circularity options and barriers in the wind energy sector. However, the key findings for circular strategies on structural element levels are explained below.

Blades

When looked at the opportunities for the circularity of blades, a lot of projects have been initiated. Within these initiatives, a distinction can be made for short-term, focused on blades that are already installed, and mid-term initiatives, design of blades that will be installed in the future. For both short term, as midterm initiatives cross-sector collaboration is key.

As was stated by one of the participants involved in the stakeholder sessions "loss of materials occurs when choosing the wrong materials in product design. For instance, using composite fibres as a filler material for concrete". Currently, there are techniques to recycle the main material out of blades, composite. However, initially composite is high-quality material. When shredded and used as filler in concrete, it loses its high-quality characteristics.

For the redesign of blades, cross-sector collaboration is needed. The aim is that the materials used to produce a wind turbine blade can be recycled in a high-quality way at the end of life. A stakeholder participating in the session suggested building bridges, literally and figuratively. Current initiatives on mid-term circular strategies are among others about modular design and recyclable materials.

Nacelle

The nacelle of a wind turbine houses the generator. Offshore wind turbines currently mainly use a direct drive configuration, which has a simple and reliable design that is more efficient at low speeds and requires less maintenance by using permanent magnets (Carrara et al., 2020). The rare earth elements used in permanent magnets of wind turbines are neodymium, terbium, dysprosium, and praseodymium. In 2015, most offshore wind generators consist of 2-4% dysprosium and 29% neodymium (Smith Stegen, 2015). The materials in the nacelle are discussed in more detail in Appendix C. The stakeholders involved in the sessions suggested two circular strategies for the rare earth elements used in wind turbines. For the circular strategy 'Re-application of materials', the stakeholders involved in this session suggested developing commercially viable recycling methods. The second circular strategy focused on 'Product design', and aims to reduce the use of rare earth elements in the wind turbine.

The recycling rates of neodymium are below 1% (Crock et al., 2016). The distillation of REEs is difficult and most of the REEs are lost when the wind turbines are at the EoL. The price of REEs is relatively high and there is a large economic incentive to work on this potential business case. Mainly because Europe lacks large scale REE natural resources and mining facilities, which makes the EU dependent on countries outside of the EU.[10] With the run on renewable energy, these materials could become scarce and increase in their value. Many initiatives are working on recycling REEs, but the recycling methods are not yet commercially viable to be implemented on a large scale.

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[9] An outlook for the materials with the largest residual flows in the southern North Sea is given in appendix D. Below are the materials categorized per structural element:

- blades are mainly made from composite materials (figure 25)
- tower and foundation are mainly made from steel (figure 21) and cast iron (figure 22)
- the housing of a nacelle is mainly made from composites and in the generators NdFeB (neodymium) is used (figure 24)
- cables use copper (figure 23)

[10] China dominates the mining, processing, and manufacturing of REEs. For more information: see section 'Nacelle' in Appendix C.

Tower

Steel is the main material used in the tower. It offers considerable advantages for the construction of wind turbine construction element due to its strength and durability. Steel is fully recyclable, however, there are different levels in quality of steel. According to the stakeholders involved in the sessions, it regularly occurs that high-quality steel gets recycled into lower quality steel. When turbines are decommissioned, normally the parts of the same material are assembled and receive the same waste treatment. While some parts may still be relatively strong, and they might be directly re-used, they are still recycled and thereby reducing its value.

Suggested is to label decommissioned materials with the gathered data during the lifetime of a wind turbine, so that loss of material and component value can be prevented.

Foundation

Currently, several initiatives are researching the difference in impact on nature by either removing the foundation or keeping (some) sections in place after the EoL in offshore wind farms.

During the stakeholder sessions, it was indicated that the rock deposits in offshore wind farms form a shelter for marine life, and that removal of the rocks seriously damages the surrounding ecosystem. Not only NGOs, but also various other stakeholders oppose the removal of these rocks. Legislation can determine industry standards on whether the rocks can stay in place or if they need to be removed when the wind farm is decommissioned. Besides, the removal of the rocks entails extra costs. When the removal of rocks is not taken into account in the decommissioning of a wind farm, the profit can (partly) be used to invest in active nature enhancement, and thereby resulting in both ecological and economic value enhancement.

Another initiative suggested during the stakeholder session is to assess which technical requirements the offshore foundation must meet per location, to impact the ecological environment as little as possible. This could be a modular structure or for example, a structure made of biodegradable scour protection material.

Cables (array cables and export cables)

According to stakeholders involved in the sessions, large amounts of materials get lost at the end of life of a wind turbine. Although the materials used in (array and export) cables are relatively easy to recycle, these cables usually remain in place after decommissioning. Nature is disrupted in the commissioning of the cables. Therefore, normally the cables are left on-site when the wind farm is decommissioned, not to disrupt the surrounding nature again. However, copper is becoming more scarce in the coming years, and a lot of copper is being lost when the cables are left in situ. There is an economic incentive to consider removing the cables without further (excessive) harm to the surrounding nature.

4.3 Nine action agenda themes

The various stakeholder sessions have resulted in an extensive overview of possible circular strategies for product design, lifetime extension, and re-application of materials. Thereafter, the industry was asked which themes should have priority in the next years. Nine themes were distilled to form the basis for concrete circular action agendas (chapter 5) to accelerate the transition towards a circular wind industry. The nine themes are:

1. **Circular permit and tender criteria** regarding wind farm projects
2. **Modular design** of the structural elements
3. **Collaboration in design** with partners in- and outside the wind energy sector
4. **Environmental-specific foundation design and multi-use** of wind farms
5. **Retaining data** (e.g. on modules, components and material levels) **for optimal decommissioning and circular strategies**
6. **Responsibility of materials** to enhance circularity
7. **Refinery and recycling plant(s)** (e.g. rare earth elements (REE), steel and composites)
8. **Circular clusters** of companies **around ports**
9. **A platform for European wide circular collaboration**

4.4 Wrap-up

The circular strategies for the wind energy industry can be divided into short-term and mid-term strategies. Where short-term strategies focus on the WTGs that are already in use, the mid-term strategies focus on turbines that are to be built. The short-term strategies have to deal with the waste of turbines that are being decommissioned in the coming years and the concomitant environmental impact.

The mid-term strategies are focused on the large volumes of wind power that will be installed in the next decades (WindEurope, 2020b). The redesign and refusal of certain components and materials could have a great impact on the acceleration of the circular transition.

A focus point that was mentioned several times during the stakeholder sessions is that the industry should find a balance between the current cost-driven focus and the ecological impact it creates. Ideally, a balance is found between a cost-driven industry with high levels of circularity. This results in several challenges that should be tackled in several areas simultaneously. The urgency of this matter was reflected during the stakeholder sessions, with more than 100 professionals from the wind industry attending. The industry is committed to act now and tackle the first few steps towards a circular economy. Via workshops, polls, and interviews the first 9 circular action themes are chosen by the industry. These themes will not cover all actions that have to be conducted for a completely circular wind sector. However, these are the first realistic steps for product design, lifetime extension, and re-application of materials.

5 Forthcoming phase 2

Towards action agendas on circular strategies for the wind industry

5. Forthcoming phase 2: towards action agendas on circular strategies for the wind industry

5.1 Introduction Phase 2

The participants of this project have identified and expressed their commitment to act upon several themes in the first phase of the project. These themes form the foundation for the second phase of the project. This action agenda will be divided into several projects that deal with the aforementioned themes.

Achieving a climate-neutral and circular economy requires the full mobilisation of industry. It takes 25 years – a generation – to transform an industrial sector and all the value chain. To be ready in 2050, decisions and actions need to be taken in the next 5 years – (paragraph 2.1.3 of The European Green Deal, European Commission, 2019).

The goal of phase 2 (The Circular Wind Hub) is to set objectives, facilitate decisions, and take actions that will accelerate the road towards circularity. The stakeholders participating in the first phase of this project mentioned that decisions cannot be forced by a few industry actors and/or governmental organisations. Therefore, international collaboration and (cross)sector collaboration is needed to make progress towards impact. The action agendas and associated projects have a practical approach and aim to deliver tangible impact in the form of a new design, lifetime extension, or re-application of materials.

As a disclaimer, these action agendas do not cover all the necessary steps towards a circular industry. There are many ongoing projects with a focus on circularity. These action agendas are based on (cross)sector opportunities and collaborations in the value chain with themes that have not been at the centre of established projects. Collaboration within the value chain can start now and could have a substantial impact on the material streams. Phase 2 will therefore aim to align organisations, sectors and EU state members for actual implementation in phase 3 (see figure 3 in 3.2).

The road towards circularity is an incremental learning by doing process, that may change during its course. Therefore, the action agenda should be read as a guideline that is not set-in-stone and could change over time.

5.2 Introduction action agenda model

The projects associated with the action agendas are classified according to the framework portrayed in the table below. Each project is scored on its expected impact on circular strategies, structural elements, and time-span. Besides, the table provides an outline which can be used at the start of phase 2. The financial resources are noted in this framework but are more elaborately explained in appendix B, as well as potential funding for future pilot projects.

Action agenda theme / project						
Ambition	**Problem definition and goal of this project**					
Circular strategy	Product design	oooo	Lifetime extension	oooo	Re-application of materials	oooo
Structural element	Nature	oooo	Foundation	oooo	Nacelle	oooo
	Cable	oooo	Tower	oooo	Blades	oooo
Time-span	Short term	oooo	Mid term	oooo	Long term	oooo
Implementation readiness	Readiness for implementation of the project on several levels such as costs, technology, legal or social readiness.					
Challenges	What are the main challenges for this project?					
Required value chain partners	Who is required to apply for this project?					
Complementary initiatives	What initiatives cover (parts) of this project and can we learn from?					
Compatible industries	Other industries might have dealt with similar challenges that the wind industry is currently facing. What can be learned from other industries that have already dealt with this theme? Besides, other industries could have cross-sector collaboration opportunities.					
Governmental support/involvement	Is the support needed from certain authorities (EU, national, regional, local)?					
Arrangements for the working group	The practical plan per project.					
Financial resources for working group	Financial resources needed for the project.					

5.3 Presentation of the nine action agenda themes / projects

This paragraph elaborates further on the nine themes of the action agenda by using the action agenda model explained in paragraph 5.2.

1. Circular permit and tender criteria						
Ambition	**In general, it could be stated that current wind farm tenders are designed to select bids for the lowest levelized cost of Energy (LCOE). This can hinder the industry from the road to more circular business models and processes. Including circularity aspects and criteria in permits or tenders could stimulate companies to change their business processes and models towards circular strategies. However, new permit and tender policies should be workable and provide a level playing field for a European wide transition to circular wind farms. The desired outcome of this working group is that the wind industry and authorities come together and find new circular, cost-efficient and, workable permit and tender criteria.**					
"	Product design	●●●●	Lifetime extension	●●●●	Re-application of materials	●●●○
Structural element	Nature	●●●●	Foundation	●●●●	Nacelle	●●●●
	Cable	●●●●	Tower	●●●●	Blades	●●●●
Time-span	Short term	○○○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	Circular permit and tender criteria can be implemented after several consultation meetings between the industry and governments that lead to workable criteria.					
Challenges	- Determining permit and tender-related circular aspects and criteria that can be assessed on impact. - Search for workable criteria that comply with the circular ambitions of Europe while being workable for the industry. - Search for possible necessity of governmental intervention, e.g. government funding.					
Required value chain partners	National government, European Commission, wind farm developers, owners, and operators, turbine OEMs, suppliers, NGOs, industry associations and other value chain parties.					
Complementary initiatives	IEA Wind Task.					
Compatible industries	To be further considered during phase 2. Possibly relevant: Construction and infrastructure industry.					
Governmental support/involvement	Governmental involvement is essential as governments establish permits and tenders.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

2. Modular design						
Ambition	**The lifetime of components of WTGs differs. With a (more) modular design of (subsystems of) WTGs, the components that have reached EoL can be replaced (within the economic boundaries of the wind farm) while the components that are still intact can be left in place. A modular design of (subsystems of) WTGs is highly demanding, which is why this work package will deal with what is involved in designing (subsystems of) WTGs in a modular way.**					
Circular strategy	Product design	●●●●	Lifetime extension	●●●●	Re-application of materials	○○○○
Structural element	Nature	●○○○	Foundation	●●○○	Nacelle	●●●●
	Cable	●○○○	Tower	●●○○	Blades	●●●●
Time-span	Short term	○○○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	Technically, modular design is ready for implementation. However, cost-effectiveness should be researched.					
Challenges	- Determining the impact of a modular design on the current business model. - Determining the cost-effectiveness of replacing parts concerning excessive maintenance and transportation costs.					
Required value chain partners	Turbine OEMs, main suppliers of turbine OEMs (subsystems, modules), foundation and tower manufacturers and suppliers, O&M service providers, wind farm owners and operators.					
Complementary initiatives	EnVentus, Modvion, ECOBULK, European Raw Materials Alliance, Cluster Critical Raw Materials and Permanent Magnets.					
Compatible industries	To be further considered during phase 2. Possibly relevant: construction industry, electronics industry, truck manufacturing industry.					
Governmental support/involvement	No governmental involvement is needed. However, including modularity in permit and tender criteria will speed up the process.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources for working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

3. Collaboration in design						
Ambition	**The design of a WTG does not always facilitate efficient processes of the other partners in the value chain. Slight modifications in the design of a WTG could on occasion significantly impact the related processes down the value chain. This project will deal with the collaboration possibilities in WTG design.**					
Circular strategy	Product design	●●●○	Lifetime extension	●●○○	Re-application of materials	●●○○
Structural element	Nature	●●●●	Foundation	●●○○	Nacelle	●●○○
	Cable	●●○○	Tower	●●○○	Blades	●●○○
Time-span	Short term	○○○○	Mid term	●●●●	Long term	●●○○
Implementation readiness	Ready for implementation					
Challenges	- The supply chain has to make agreements on revenues and risks related to collaboration in design to facilitate supply chain integration and circularity. - Determining a standard set of criteria for companies involved in the same step of the value chain. An example: different transport companies have different sizes of ships. Which size will be the standard?					
Required value chain partners	All value chain parties could be involved. The most important parties are the turbine OEMs.					
Complementary initiatives	SUSWIND, GenVind, Dreamwind, ECOBULK, FiberEUse, ZEBRA, NEOHIRE, ECOSWING, Susmagpro, Dementer, and Amphibian.					
Compatible industries	To be further considered during phase 2.					
Governmental support/involvement	No governmental involvement is needed.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources for working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

4. Environmental-specific foundation design and multi-use of wind farms						
Ambition	**There is much uncertainty on the ecological integration of offshore wind farms with marine nature. Removing monopiles during the decommissioning favours the recycling of materials. However, nature flourishes around foundations, so some voices claim that part of the foundation could be left in place. Cables are left in the ground after EoL because decommissioning is (still) costly and disrupts the surrounding nature severely. A substantial amount of copper and other materials are lost. This working group will focus on performing research on design standards for ecological integration with marine nature that favours both cost-effectiveness and the enhancement of the environment. Besides, multi-use of the wind farm area may increase ecological, economical, and social values of a farm. This workgroup aims to integrate ecology in the wind industry for environmentally friendly wind farms.**					
Circular strategy	Product design	●●●●	Lifetime extension	●○○○	Re-application of materials	●○○○
Structural element	Nature	●●●●	Foundation	●●●●	Nacelle	○○○○
	Cable	●●●●	Tower	○○○○	Blades	○○○○
Time-span	Short term	●○○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	The development of nature standards requires expertise in the ecological integration of foundation and cables.					
Challenges	- Ecological integration with nature should be cost-effective or included in regulations. - Multi-use options that are workable for operators and NGO's - Determining whether the standards for foundation designs are transferable throughout the industry, as foundation designs differ per company. - Harmful, but more cost-effective designs are preferred over designs that are more suitable for integration with nature. - Cable decommissioning related business cases with respect for the environment.					
Required value chain partners	The government, offshore wind farm owners, NGOs in nature preservation, installation/decommissioning and transport companies.					
Complementary initiatives	E.g. Rigstoreefs, and DeRijkeNoordzee.					
Compatible industries	To be further considered during phase 2. Possibly relevant: offshore and onshore oil and gas industries, relevant mining industries.					
Governmental support/involvement	If cost-effective, (a part of) the offshore wind industry will most likely want to implement the standards. However, governmental involvement is needed, as this will require adjusting the regulations or tender criteria.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources for working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

5. Retaining data (e.g. on modules, components and material levels) for optimal decommissioning and circular strategies

Ambition	**The component and/or material quality of WTGs is well-monitored during the lifetime (operations phase), but this is primarily used to determine the technical or economic status during the lifetime. At the EoL, most (sub)components are combined and processed using the same strategy. This working group will focus on gathering information during the lifetime, which can be used to determine the technical quality of EoL (sub)components regarding recycling or re-use potentials.**					
Circular strategy	Product design	○○○○	Lifetime extension	●●○○	Re-application of materials	●●●●
Structural element	Nature	○○○○	Foundation	●●●●	Nacelle	●●●●
	Cable	●●●●	Tower	●●●●	Blades	●●●●
Time-span	Short term	●●○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	Ready to implement					
Challenges	- Possible (business) sensitivity of information, meaning that a limited amount of parties should have access to the information. However, it must be considered that it is more useful if many EoL parties can access the information so that they can express their interest in the components/materials. - Instant measuring of component quality and providing an industry-supported standard on how to measure and define the quality of components and materials in operational WTGs.					
Required value chain partners	Wind farm owners and operators, OEM turbine companies, O&M service providers (repair and maintenance), EoL companies (recycling and waste treatment), transport and decommissioning companies.					
Complementary initiatives	Circularise.					
Compatible industries	To be further considered during phase 2. Possibly relevant: aerospace and space industries, oil and gas industries, certain industrial sectors (e.g. advanced machines for semicon). E.g. developments in material passports, predictive maintenance, aerospace material standards.					
Governmental support/involvement	Governmental involvement could be relevant for providing regulations on EoL measures. Governments could also facilitate, for example, quality standards.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources for working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

6. Responsibility of materials						
Ambition	**Every partner loses ownership after their product is passed on in the value chain, which leads to loss of material (quality) at the EoL. This working group will work on the goal of re-using materials or components with minimal loss of quality. To achieve this goal, a party must have responsibility for the materials. Possibilities contain material passports, leasing of materials or setting up a material market place. Responsibility of material also should not end at the decommissioning phase of a wind farm. Ideally, materials loop back to the raw material phase.**					
Circular strategy	Product design	●●○○	Lifetime extension	●●○○	Re-application of materials	●●●●
Structural element	Nature Cable	○○○○ ●●●●	Foundation Tower	●●●● ●●●●	Nacelle Blades	●●●● ●●●●
Time-span	Short term	●●○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	To be further considered during phase 2. Knowledge of material passports or leasing of materials is required.					
Challenges	- The requirement of a broad range of expertise, as WTGs contain a variety of materials. - Cooperation of every partner in the value chain concerning material passports. - The need to make agreements by the industry on incentives for responsibility regarding materials. - Determining where to make a distinction between components and materials.					
Required value chain partners	All parties in the value chain, but specifically: manufacturers of components, EoL parties like waste treatment and recycling.					
Complementary initiatives	E.g. Stichting C2C Bouwgroep, Madaster Services, and European Dataspace for Smart Circular Applications					
Compatible industries	To be further considered during phase 2. Possibly relevant: the construction sector.					
Governmental support/involvement	No governmental involvement is needed. However, including modularity in permit and tender criteria will speed up the process.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources for working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

7. Refinery and recycling plant(s) (e.g. rare earth elements (REE), steel and composites)						
Ambition	**Nowadays, Rare Earth Elements (REEs) are essential for most wind turbine productions. However, the REE demand for the energy transition will surpass the total critical metal production[11]. Currently, both the Netherlands and Europe are highly dependent on countries outside of Europe for their critical metals. The current recycling rate of Neodymium and other REEs is below 1%. New recycling techniques need to be developed and implemented to keep the scare metals in the value chain. In addition to REEs, Composites and other materials in the wind farms need optimal recycling techniques that retain as much material value. The goal of this project is to identify potential refinery and recycling plants for e.g. REEs, composites and other materials. The ambition is to retain as much material value as possible when materials are being recycled.**					
Circular strategy	Product design	●○○○	Lifetime extension	●○○○	Re-application of materials	●●●●
Structural element	Nature	○○○○	Foundation	●●●●	Nacelle	●●●●
	Cable	●●●●	Tower	●●●●	Blades	●●●●
Time-span	Short term	●●○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	Depends on the recycling techniques.					
Challenges	- Finding workable business cases and technology. - Practically executing business cases.					
Required value chain partners	Recyclers, Ports, Operators, Logistic companies, OEM turbine companies (and/or their suppliers of generators or generator components).					
Complementary initiatives	Interreg DecomTools, CircularIndustries, Susmagpro, Amphibian, Tarantula, REE4U, Dementer European Battery Alliance, European Raw Materials Alliance (ERMA), SER-IMVO covenant etc.					
Compatible industries	To be further considered during phase 2. Possibly relevant: battery industry, aviation industry, recycling industry, solar industry.					
Governmental support/involvement	Both national and European governmental support can be useful in research and technological development. Local and regional authorities' involvement is essential for the practical recovery part.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

[11] Neodymium, dysprosium, and praseodymium are not only used in generators of wind turbines but also in e.g. electric vehicles (magnets and batteries).

8. Circular clusters around ports

Ambition	**Every offshore wind project utilises ports, during the installation phase (pre-assembly and vessel loading), the O&M phase (warehousing, hub for transport of maintenance teams and ('circular') parts), and the decommissioning and end of life phase (transport hub for decommissioning and/or repowering activities, hub for inland logistics regarding 'circular' parts and (raw) materials). From a collection and treatment perspective, the scale is paramount to close a recycling business case. Larger ecosystems of companies around ports, which facilitate information sharing, could search for optimization in the application of material strategies, especially there where (sub)components have different EoL purposes. The desired outcome of this project is to assess and design potential hubs that could be developed around ports to deal with material return streams when wind farms come to their end of life.**
Circular strategy	Product design ●○○○ · Lifetime extension ●●●○ · Re-application of materials ●●●●
Structural element	Nature ○○○○ · Foundation ●●●● · Nacelle ●●●● Cable ●●●● · Tower ●●●● · Blades ●●●●
Time-span	Short term ●●●○ · Mid term ●●●● · Long term ●●●●
Implementation readiness	The identification of return volumes, hubs and EoL strategies can start right away. The construction of actual hubs and their timespan shall be further considered during phase 2.
Challenges	- Identifying hub locations and business cases. - Developing lifetime extension and EoL strategies with valuable business cases. - Relocating companies or setting up specific business units around ports. - Facilities for recycling components (like blades)
Required value chain partners	Ports, wind farm operators, decommissioning and EoL companies.
Complementary initiatives	Interreg DecomTools, CircularIndustries, SURFACE, FIBROUS etc.
Compatible industries	To be further considered during phase 2. Possibly relevant: oil and gas industries; shipping industry; onshore wind industry.
Governmental support/involvement	Both local and regional governmental involvement is essential.
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.
Financial resources working group	National government and/or membership funding. Other options are to be further considered during phase 2.

9. Platform for European wide circular collaboration						
Ambition	**Industry partners mentioned the urgency to handle this transition on a European level. Circular strategies make the most impact when they are ensured and implemented European wide. Currently, there are many ongoing circular initiatives (e.g. over 25 for blade recycling) that contain similarities. A European wide circular wind alliance, that collects ideas and searches for connections could create more stability and an overview of the next steps towards a circular wind industry. The desired outcome of this project is to connect circular initiatives, find complementing areas and give input for a European Circular Wind Action Agenda.**					
Circular strategy	Product design	●●●●	Lifetime extension	●●●●	Re-application of materials	●●●●
Structural element	Nature	●●●●	Foundation	●●●●	Nacelle	●●●●
	Cable	●●●●	Tower	●●●●	Blades	●●●●
Time-span	Short term	●●○○	Mid term	●●●●	Long term	●●●●
Implementation readiness	This work package can be implemented right away.					
Challenges	- Gaining funds and support from the European Commission. - Establishing the right mix between governmental and industrial input. - Search for possible sea basin collaboration across national borders.					
Required value chain partners	R&D/universities/institutes, industry associations.					
Complementary initiatives	European Battery Alliance, European Raw Materials Alliance (ERMA),Catapult, and SusWind.					
Compatible industries	To be further considered during phase 2. Possibly relevant: battery industry					
Governmental support/involvement	European governmental involvement is essential.					
Arrangements for work package	In spring 2021, the first kick-off meeting will be held with the participants. Before this meeting, participants will be consulted to elaborate on their ambition and practical arrangement preference. After the kick-off, a select group of parties will further collaborate in recurring meetings aiming for the practical implementation of projects starting in 2022. Additional practical arrangements are to be further discussed during phase 2.					
Financial resources working group	National government and/or membership funding. Other options are to be further considered during phase 2.					

5.4 Wrap-up

Phase 1 was instrumental to bring together stakeholders from the wind industry together to elaborate on circularity in the wind energy sector, and to indicate specific themes that lead to a set of concrete circular action agendas, driven by the industry and with (potential) support from governments.

The various sessions and workshop of phase 1, including input from desk research, have resulted in a diverse set of themes regarding circularity in the wind energy sector for this moment. The themes cover all three circular strategies domains (product design, lifetime extension and re-application of materials). It should be noted that these circular action agenda themes deserve more reflection during phase 2 (The Circular Wind Hub), e.g. regarding impact and business case potentials.

It is positive that at least 4 themes have strong connections with the challenge of design for circularity. It could be stated that smart product design (including the smart design on the level of subsystems, module, components, and subcomponents), taking into account design for circularity, is essential to make fundamental progress in higher levels of circularity in the wind energy sector (onshore and offshore). Design for circularity is also valuable for the strong drive of the wind industry sector and government to 1) reduce the cost of electricity as much as possible (low LCOE) and 2) integrate large amounts of renewable electricity into the energy system.

From a practical point of view – also looking at the degree of overlap between certain themes – it is suggested to during the start phase of phase 2 look if certain themes could be clustered

The framework introduced in this chapter could help to make – during phase 2 - swift progress in converting the themes into concrete circular action agenda plans (ambition, stakeholders, complementary initiatives, action plans and milestones, funding for working groups etc.).

6 Conclusions

6. Conclusions

The conclusions of this report are a reflection on the current state of circularity in the wind energy industry and the perspective of this project's participants on the most viable next steps towards a circular wind energy industry. The conclusions are derived from the first phase of this project and are essential input for phase 2 (planning of circular initiatives in the circular wind hub) that will further elaborate on the action agendas. Besides, some conclusions may already affect long term solutions or challenges that could occur in phase 3 (implementation of circular initiatives) of this project.

Conclusion 1: The wind energy industry is very committed to making the transition towards a circular industry.

With the Green Deal, the EU has set its direction towards a carbon-neutral society that is less dependent on the use of virgin materials. The combination of this factor with the large residual flow of wind turbines the coming years has created an urgency to move towards a circular industry. The wind energy industry has shown its commitment to the transition towards a circular industry by its participation in the first phase of this project and the number of registrations for the second phase.

Conclusion 2: The cost-driven focus hinders the transition to a circular industry.

The wind energy industry has a strong focus on cost-efficiency, which is fundamental for the contribution of wind energy for the energy transition and economic development within the sector but can hinder the transition to a circular industry. The wind energy industry is committed to accelerating the transition towards a circular industry, but the actual implementation of circular business processes remains a complex challenge. Many industry stakeholders have emphasized the critical role the government can play to promote and stimulate circular business propositions.

Conclusion 3: Current circular projects tend to focus merely on the recycling of materials.

Currently, circularity in the wind industry is strongly focused on challenges and opportunities related to the recycling of materials. However, more attention is coming for complementary circular strategies related to smart product design (e.g. design for circularity) and lifetime extension (e.g. related to modules and components).

Conclusion 4: The quality of material must be better conserved.

Within the circular recycling strategy, a distinction can be made between high quality, mid quality, and low quality recycling. Even though 85-90% of a wind turbine can be recycled with currently available technologies, reality shows that materials regardless of their quality receive the same waste treatment. This results in high quality materials being recycled and processed into low quality raw materials. This can be prevented when decommissioned components and materials are labelled and the gathered data during the wind turbine lifespan is used as input for the recycling process.

Conclusion 5: Collaboration between partners in the wind industry value chains and outside of the sector is required to implement circular strategies, and most efficiently pursued by having a joint (digital) discussion.

Often, changes from linear to circular business processes not only affect the processes of one company but will also affect other sections of the value chain. The value chain of the wind energy sector is large and very diverse, so it is important to utilise the expertise of every party. Discussion groups (including online sessions) with stakeholders from different sections in the value chain led by a discussion leader, have proved to be very effective in phase 1 of this project.

Conclusion 6: The participants of this project mainly want to pursue circular strategies in the domains of product design and re-application of materials.

The circular strategies in this project are categorized according to three domains: product design, lifetime extension and re-application of materials. The result of the elaboration on circular action agenda themes with the project's participants in the following: 9 themes were distilled that are relevant for phase 2 of the project. Each theme has been assessed on its relevance for the domains (themes can be relevant for multiple domains).

- 4 out of 9 themes are fully focused on product design.
- 2 out of 9 themes are fully focused on lifetime extension.
- 5 out of 9 themes are fully focused on the re-application of materials.

Conclusion 7: The use of a circular framework operationalised for the wind industry helps to structure the exploration towards and findings of circular strategies.

The framework specifically operationalised for the wind industry and used in this report - and the frameworks on which this framework is based - provided the tools to identify loss of quality on a component or material level. The framework was used as a reference to elaborate on circularity strategies for the wind industry, and to define relevant action agenda topics. It shows what aspects of circular strategies differ from each other and how they can be compared or clustered.

7 Recommendations

7. Recommendations

The recommendations of this report aim to inform and highlight steps that would support the transition towards a circular industry. This section covers recommendations on various themes like action agendas, value chain, circular strategies, and the European dimension.

7.1 Recommendations related to the circular action agendas

Recommendation 1: Pursue the action agendas as identified in phase 1 of this project, because the industry participants have indicated the importance of and commitment for phase 2.

During phase 1 of this project, multiple action agendas were identified from various interviews and stakeholder sessions. These action agendas contain themes that the industry participants have identified as vital for the transition towards a circular industry, in addition to the initiatives that already make progress. The participants have also committed themselves to work on these action agendas in the second phase of this project. It is recommended to maintain the momentum and use the commitment of the industry. The following concrete agendas have been proposed for the second phase of this project:

1. Circular permit and tender criteria regarding wind farm projects
2. Modular design of the structural elements
3. Collaboration in design with partners in- and outside the wind energy sector
4. Environmental-specific foundation design and multi-use of wind farms
5. Retaining data (e.g. on modules, components and material levels) for optimal decommissioning and circular strategies
6. Responsibility of materials to enhance circularity
7. Refinery and recycling plant(s) (e.g. rare earth elements (REE), Steel and composites)
8. Circular clusters of companies around ports
9. A platform for European wide circular collaboration

Recommendation 2: Organise large involvement of industry partners for the action agenda projects.

One of the goals of the second phase of this project is to establish, implement and execute industry standards like modular design. Joining project(s) working on the action agendas provides participants the opportunity to collectively shape and accelerate the circular transition. Additionally, including a large and diverse number of participants will most likely result in a higher acceptance of industry standards and regulations.

Recommendation 3: Keep the action agendas up to date, as it is a continuous road towards a circular wind industry.

Action agendas have been identified for the second phase of this project, but these may change over time. Future commitment might change, the themes of the action agenda might overlap when started working on them, or they might not lead to the desired results. It is therefore recommended to keep an open mind and adjust the (focus of the) themes of the action agendas whenever necessary.

7.2 Recommendations related to the value chain

Recommendation 4: Create collaborations (like consortia) within the wind industry for proper alignment of circular businesses.

Implementing circular strategies as a company influences the business of related stakeholders in the value chain. It is therefore recommended to align related stakeholders for optimal integration of circular strategies. For instance, using alternative metals in the gearbox will influence the material supply chain before installation and will influence the maintenance and decommissioning after installation.

Recommendation 5: Create synergies with related sectors for a smoother transition towards circularity.

Industries like oil & gas (decommissioning), aviation (composite EoL strategies) or infrastructure (quality-based tenders) might have undertaken the same circular challenges as the wind energy sector is confronted with. Therefore, it is valuable to learn from these industries. Besides, these industries may be confronted with similar challenges that can be more easily tackled through cross-sector collaboration (an example is the collaboration of WindEurope, Cefic, and EUCiA regarding composite recycling).

7.3 Recommendations related to circular strategies

Recommendation 6: Implement circular strategies in the order from R0 ’refuse’ to R9 ’recover’ to retain as much component and material value as possible.

In the transition towards a circular industry, companies – also in the wind energy industry - tend to search for recycling solutions while this is one of the lowest value-retaining circular strategies. Circular strategies are ordered from high levels of circularity (like refuse and reduce) to low levels of circularity (like recycling and incineration). It is therefore recommended for companies active in or for the wind energy sector to focus on circularity opportunities starting with refuse (R0) and reduce (R1) to retain the highest component and material value and make the highest impact.

It is also important to note that accelerating the circular transition does not automatically mean the industry is more sustainable. A balanced decision has to be made about the sustainability impact with every circular strategy implemented.

Some circular strategies (in particular recycling) may require a substantial amount of energy. Sometimes, using virgin materials or using another circular strategy may be more energy efficient. The trade-off between material use and energy use is a complicated matter that should be considered when developing circular strategies. This trade-off may change by technology development and will therefore change over time.

Recommendation 7: For the exploration and impact assessment of circular strategies in the wind industry, use the methodologies and the framework as presented in this report.

The framework has proven to be very useful in gaining insight into circular strategies. When other topics are added to the circular action agenda, the framework can be used as a tool to quickly and effectively understand the potential impact of these topics can make and the practical arrangements that need to be made. This also applies to the framework used to categorise and classify circular strategies.

7.4 Recommendations related to European dimensions of the wind industry

Recommendation 8: Elaborate on the added value of an EU-wide collaboration platform in the wind industry that is focused on the transition towards a circular wind industry.

EU-wide collaboration in the wind industry is key for companies in the wind industry to change to more circular value chains on a European level. It is recommended to start an EU-wide platform that aims at increasing transparency between projects. The EU Battery Alliance is an excellent example of EU-member states working together with companies to make large scale progress on complex transitions. A Circular Wind Energy Alliance may be the answer for the wind industry in its road towards circularity.

Recommendation 9: It is recommended to keep the momentum and enthusiasm in this transition through among others, stakeholder sessions and webinars.

During the first phase of this project, the enthusiasm and input from the industry made the insights of this report possible. A committed industry in the complex road towards circularity is important to accelerate this transition. Therefore, it is recommended to continue organising sessions to keep the momentum and enthusiasm in this transition. This results in higher levels of awareness on circularity challenges and opportunities across the wind industry. Besides, these sessions could lead to additional circular action agenda projects that can be further developed and tackled by the industry.

Recommendation 10: Create national focal points for European financing, legislation, and collaboration to support sustainable and circular development.

The European Commission and its member states have been (and are) creating financing platforms[12] for circular economy and wind energy projects, offering major opportunities to develop projects on a European scale. In some cases, EU legislation, member state legislation, and several EU collaborations, project, alliances make it challenging to find the appropriate building blocks for sustainable and circular development. Therefore, it is recommended for member states to have a focal point that could help companies with EU legislation, finance, and collaborations, while helping EU collaborations with finding relevant national stakeholders.

[12] Through instruments such as IPCEIs, North Sea Wind Power Hub, Connecting Europe Facility, and the Industrial Forum.

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Appendix A: overview of sessions and workshops in phase 1

This appendix is an extension to chapter 4 (phase 1). The content of the stakeholder sessions (also known as Value Chain Meetings) and workshops (given during value chain meeting 2 and, the CIRCO Track) is shared. This appendix aims to show the results of these activities. This will give you a better understanding of the commitment of the industry. Besides, it will contain the workshop material that is used to conclude the main report.

Session 1 was an introduction to this ideation process, session 2 contained 7 workshops to define circular building blocks and session 3 addressed cross-sector collaboration and an outline of phase 2. Thereafter, a 3-day long workshop was performed with help of CIRCO to create a better understanding of the circular strategies that could be used in phase 2.

Stakeholder Session 1

August 28th 2020	
Goal	At the first online stakeholder session more than 100 participants where present. The goal of the first stakeholder session was to enthuse and excite the different stakeholders from throughout the whole value chain. Besides, the session contained many polls and open questions, to gather insight on dilemmas that the wind industry experiences. The stakeholders expressed their ambitions and projects, and the reactions afterwards were overwhelmingly positive.
Agenda	The following speakers cast their light on the current processes from their company's point of view and their goals for a circular and sustainable future: 1. Firstly, Giles Dickson, CEO of WindEurope, presented a video message in which he stressed the importance of the circular wind industry. 2. Erwin Coolen, CEO of ECHT, continued by explaining the goal of the Moonshot Project Circular Wind Farms and hosted the rest of the meeting. 3. Subsequently, Marylise Schmid, Analyst Environment & Planning of WindEurope, presented the topic of blade waste, the current status and the market outlook of future blade waste. 4. Afterwards, Thomas Wegman of EuCIA presented the recycling techniques of composite materials. 5. This was followed by a presentation from Kristen Skelton from Siemens Gamesa. She presented the market position of Siemens Gamesa and their work on their sustainability commitments and turbine circularity. 6. Ilse van Andel, Sustainability officer procurement of Eneco, presented next. She discussed a producer responsibility, modular design and collaboration between the entire value chain. 7. Lastly, Joost Eenhuizen, Business manager offshore industry from the Port of Rotterdam, presented their current operations in the wind industry. Furthermore, the cast light on their goal to move towards climate neutrality by 2050 and the circular strategy that is incorporated in that plan.
Method	During this online stakeholder session, it was actively encouraged to share information and discuss certain topics. This information was gathered through polls, open questions and general statements. The polls are visualised in graphs. The participants answered the open questions and general statements by answering in the chat of the Zoom meeting.
Results	The industry shows that they use many different circular strategies. The most commonly used circular strategy is to recycle, reduce, repair, re-use and refurbish as can be seen in figure 8. The responsibility

	for circularity remains an ambiguous topic. When asked who is responsible for circularity within their company, the most replied answer was: no one specified (figure 9). This confirms the general impression that companies are willing to change, but that they are still at the beginning of this process. This reflected in many invitations and reactions of companies that would like to learn more about circularity and that would like to join and speak during the second and third stakeholder sessions.
Key takeaways	The wind industry is aware of the challenges that it experiences concerning circularity. Many parties have their sustainability programme, but teamwork is required to make a significant impact. Responsibility for circularity within the organisation, however, is often not well defined.

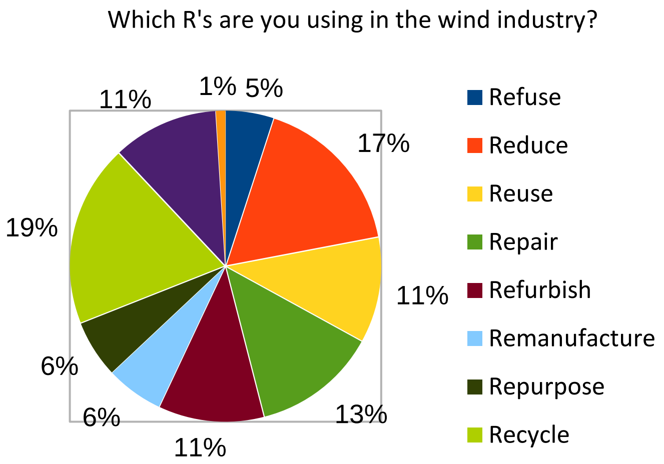

Figure 8: Inventory of the EoL strategies during the first stakeholder session

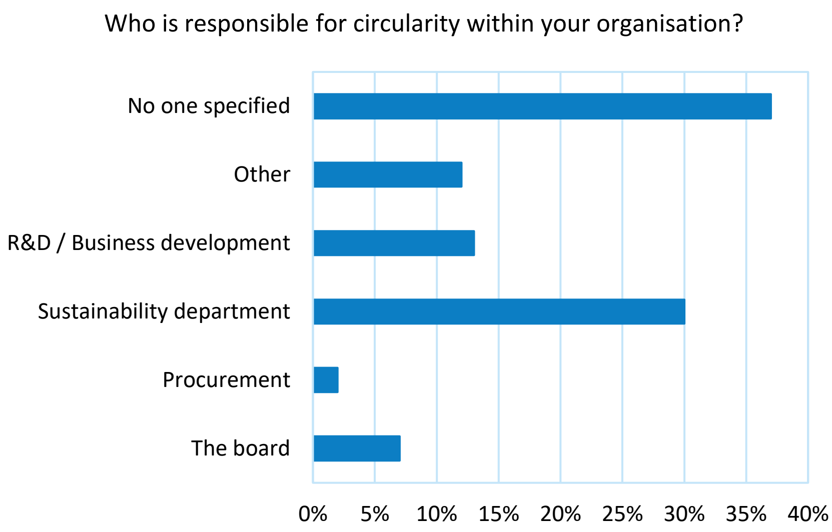

Figure 9: Responsibility for circularity

Stakeholder Session 2

September 18th 2020	
Goal	The main concern after the first stakeholder session was that some participants only joined to retrieve information. Therefore, the second stakeholder session had a slightly higher barrier to join. The aim of the second stakeholder session was for the participants to get to know each other and to gain in-depth knowledge of the current linear business processes and circular strategies. Participants were asked to collaborate within workshops and to actively share their thoughts in this session. Within this session, 7 workshops led by NWEA, Port of Amsterdam, AYOP, Groningen Seaports, DeRijkeNoordzee and ECHT took place. More than 75 professionals actively shared their thoughts to change the current linear value chain towards a circular value chain. The results of this workshop confirmed the willingness of the industry to cooperate in the transition to circular wind farms.
Agenda	This meeting comprised two main parts. Firstly, speed dates were held in small groups for the participants to get to know each other. Subsequently, discussions were held in breakout rooms. The topics that were identified in the first value chain meetings were used as discussion topics.
Method	Each participant had subscribed themselves to a breakout room before the meeting. The focus of each breakout room was one of the four topics; Nature, Rare earth elements, Composites, and Transport & Installation. In each breakout room, a discussion was held between 8-15 participants with a discussion leader that is an expert in the breakout room's topic and a moderator by ECHT. The Ellen MacArthur Foundation is a commonly used model to work on a circular business proposition. It is commonly known as the butterfly model. A circular economy seeks to rebuild capital, whether this is financial, manufactured, human, social or natural. This ensures enhanced flows of goods and services. The butterfly model illustrates the continuous flow of technical and biological materials through the 'value circle', as can be seen in figure 10: Therefore, to structure the discussion, this model was used. The discussion was held for an hour, with each building block of the model taking 15 minutes. The model's building blocks; product design, business models, reverse cycle skills and cross cycle and cross-sector collaboration, were used to trigger the participants to give thought to every aspect of a transition towards a circular industry.
Results	The moderator of the sub-tracks gathered the results and added them to the model. Each section of the results contains a figure with the logos of the participants in the sub-track and a figure with the findings.
Key takeaways	*Key takeaways:* Moving towards a circular economy is a complex process which requires cooperation between all partners. Small discussion groups are the most effective way of gaining insights and sheds light on shared problems.

Building blocks of a circular economy—what's needed to win

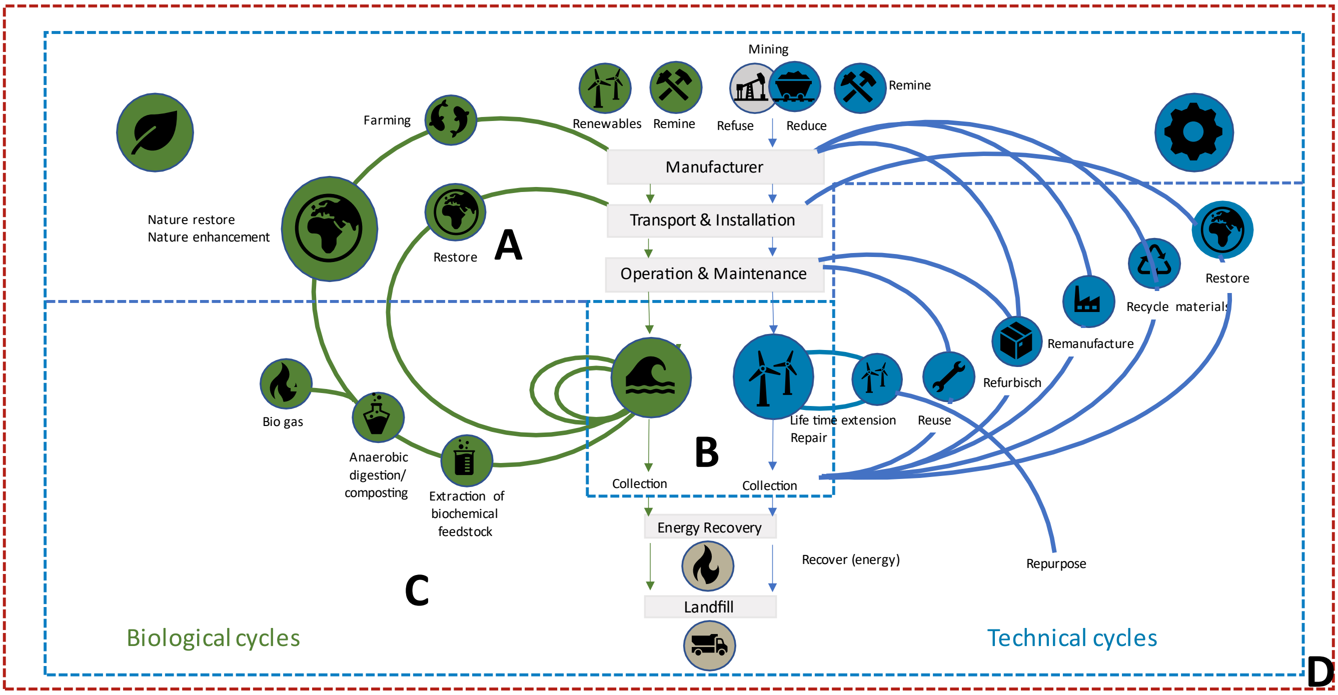

Figure 10: The butterfly model of the Ellen MacArthur Foundation modified by ECHT.

Composite workshop

	Building blocks to transition from a linear to a circular economy	
Product design	• Linear process of building, using and destroying. • Blades are not interchangeable. Blades are made out of carbon, glass fibres and thermosets, which are difficult to recycle. • Cost driven focus makes the design focus on larger blades and therefor larger turbines.	• Expending lifetime by modular blades. Root section, mid-section and tip-section. • More standardization for easier reuse • Synthetic fibres (and resins) that are fully recyclable (for instance FILAVA). Or biobased composites (resins) that are easy to remelt • Wood and other natural fibres. • Designing easier dismantlable blades (for reuse or recycle) • Multilayer plastics containing recycled components. • Thermoplastics (Elium for example)
Business Models	• Stakeholders are only responsible for the product at a certain moment in the value chain.	• Sharing responsibility starting at the manufacturing of parts part instead of product level. • WTG could be used for the second-hand market is not used in its full potential • With a closed-loop, the raw material provider is the recycler. • Leasing as a business model
Reverse cycle skills	• Currently, the decommissioning process is not structured. There is no clear understanding of this process.	• Arrange to decommission like the aviation sector. Certify materials after decommissioning so they can be reused. • Keep control of raw materials like a warehouse or material passport.

Cross cycle and cross-sector collaboration	• **Currently, most of the composite is being landfilled in Europe.**	• **The decommissioned composite could be used in other industries (with shorter fibres). For instance, making bicycles.** • **Building bridges! Literally and figuratively. The recycled composite could be the raw material of other industries, for example, infrastructure or construction.**

Rare Earth Elements workshop

	Building blocks to transition from a linear to a circular economy	
Product design	• Currently, the rare earth elements are not recovered from the decommissioned wind turbines. • The virgin raw materials price of Neodymium is €40.000 / ton. This all goes to waste after the life cycle of a wind turbine.	• Reduce, reuse, recycle and substitution should be the main focus of the science projects, research and funding needed to turn it into a circular process. Two tracks: 1. New design: reduce as much as possible of the rare material use 2. Design with current materials: trying to find a way to recycle the rare earth elements out of the wind turbine.
Business models	• Rare earth elements are considered scrap after decommissioning. There is no current business case for recovering rare earth elements.	• There is an economic incentive because of the virgin material price of Neodymium starts at 40.000 euro/ton. • Refurbishment or reuse of the magnets in its whole or as raw material. • Feasible business cases can also be built around Boron and Copper. • Looking at who possesses a material at a certain point. • Leasing as a possible business model for the materials of a wind turbine. • Currently, Neodymium can only be refined in China, there is an opportunity here. • Renting a wind turbine
Reverse cycle skills	• The current options are limited.	• Collaboration across the chain is needed when it comes to innovation, research and how to extract raw materials. Collaboration with parties who have the expertise of extracting certain materials. • A lot of the materials get lost at the end of life, there are refinery opportunities in the EU if we work together and create scale. From a technical perspective, everything is possible.
Cross cycle and cross-sector collaboration		• Collaboration with metal associations. • Mass-based recycling regulation for the wind industry.

Nature workshop

	Building blocks to transition from a linear to a circular economy	
Product design	• Instal and decommission wind turbines, thereby destroying nature that has developed during wind farm lifetime. • In situ, raw materials are lost, and area can't be used by other industries. • There is no business case to remove the foundation. • 5D or 8D distance between wind farms • Packing material plastic	• Packing as fertiliser • Leave turbines in situ, thereby skipping the waste phase. • Optimizing the design for better integration of scour protection to fit the kind of nature and do long-term monitoring. • Moving to other foundation types that are easier to decommission. Jacked-up foundations could be a solution for easy decommissioning in a shallow environment (high-risk). Asses which foundation type is best suited per kind of nature and asses which technical requirements the foundation must meet per location, to incorporate that into the design. • Build a business case for using the foundation. Implement regulatory measures. • Design wind farms so that you can leave nature in between. Utilise the space in between for farming. • Design biodegradable scour protection • Build windfarms at less ecological areas to restore • Modular structures, less impact on ecology • May benefit for rock environment, but not from other types of environment (sand).
Business models	• Install and decommission. Parts are bought for single-use • Invest in recovering nature • There is no incentive for parties to monitor the state of nature • The owner owns the WTG • Do not want to buy refurbished parts • Bigger and Bigger	• Invest in a decommissioning bond before installation. The money of the bonds can be used to invest in other sustainable initiatives or nature (if there is no need for decommissioning) • Leasing parts will improve the quality and duration of parts • Prevent damage to nature. CO_2 capture, (plant seaweed or a tree when you build a wind turbine) • Long term monitoring of the problem. Responsibility could lie with designers of scour protection/foundation if their objective is to make it sustainable (they are not the owner, so they must be hired as subcontractors) • Nature area (tourism) or diving • What is important on NIMBY and translate into business cases. • Involve fishery in the business model for more plant-based food, turn fishermen in seaweed farmers. • Share ownership also with private people • The substation can be used for floating solar.

Reverse cycle skills	• Take out most of the wind turbine • Look at the quality of the parts that are being decommissioned. • WTG decommissioned, scrap value, leave behind concrete foundation left. • Part of foundation left maybe cables and scour • The temporary hood of an offshore monopile is scrapped	• A clear assessment of the distinction between waste and useful components. It might be useful on other sites or for coastal defence. • Move it to the designated space of end-of-life scour protection. Then it is not occupying seabed which might be useful for other industries. • Assess the quality before decommissioning. • Looking at CO_2 leave the structures where they are. Make a new reef out of it. Leaving parts behind offshore when nature is created • Use biodegradable products • Monopile reuse as an eco-tunnel under the highway • Use to temp hood for monopile as an artificial reef • Biobased blades
Cross cycle and cross-sector collaborati on	• There is mistrust between aquaculture/fishing industry and offshore. • Coastal infrastructure and offshore wind work on their project, but offshore wind farms modify the conditions at the coast. • Wind turbine engineers only work on technical designs. • Many interesting events are happening, but they are not always picked up by the media • Recycled is more expensive than new products, fact of life.	• More collaboration between aquaculture and offshore for reuse of scour protection • Form a collaboration between coastal defence/infrastructure and offshore wind • Form a collaboration between engineers, natu re/ conservation parties and government • Wind turbine farms and media about good news stories • Government legislation needed offshore to leave certain structures behind • Tender criteria • Partnerships e.g. with chemical recycling companies concerning decommissioning. • Ownership of the material stays with the prod ucing company and taking responsibility.

Transportation and installation workshop

	Building blocks to transition from a linear to a circular economy	
Product design	• Cables remain in the ground after the wind farm is decommissioned, thereby losing all materials. • It's underneath the seabed and can even stimulate the environment by the emitted heat. • A trench is built to bury the cables underneath the seabed • Materials and design are fit-for-purpose. • Wind turbines and transportation process are designed separately. Therefore, ships often must be modified, leaving little space to innovate in other sustainable options like hydrogen.	• Cables must be redesigned. • Drill the trench in a way that the cables can easily be installed and decommissioned without (excessive) harm to the nature around it. • Use hydrogen nearby the wind farm, so there is no need for cables to the shore • Design with end-of-life strategy in mind. • Design wind turbines and transportation processes to be complementary E.g., wind turbines should be designed to fit on a ship or other way around • Provide insight into the total value chain to seek opportunities for standardization.

	• Companies do not provide insights into the value chain because of intellectual property	
Business models	• In tenders, the main point is being as cost-effective • Project is managed on risks. Implementing a new business model for optimization and collaboration is high-risk. • Keep processes as they are. Why change a winning team? • Responsibility for decommissioning and waste treatment is solely for wind farm	• Tenders should incorporate circularity. Advice to government: What would the tender look like if you incorporate circularity? No subsidy in general, but a subsidy for circular wind farm • Services are shared and new companies step up as universal. Decommissioning is less time-sensitive than installation. • Innovations that come available should be taken into consideration. Try to widen your scope to optimize the logistics process. • Decommissioning and waste treatment are a shared responsibility. The producer should have responsibility for product/component to last. If their product lasts or if it is re-/upcycled better, they should receive compensation.
Reverse cycle skills	• There are companies located near the port that can reuse materials, but there is not a structural plan to make this happen. • Responsibility for recycling or decommissioning is in the hands of the party that might not be an expert in this.	• Keep the supply chain in the port. Team up with companies that are located near the port, keeping down the transportation costs. • Shared responsibility of recycling in a consortium, e.g., asset owner and producer should take the lead.
Cross cycle and cross-sector collaboration	• There is little cooperation, there are even different nationalities of the same companies at the same port that does not fully cooperate amongst themselves. • Ports are only responsible for the transportation part of the value chain. • No or little communication between party's design, project, and decommissioning phases. Short term-planning and one hurdle at a time. Therefore, the last phases must adapt to choices made earlier in the process. • Transport is carried out by their own company, services are not shared, partly because of i.p.	• Team up and make plans about what is coming next • For ports: recycling the steel from the tower and selling it to German and Austrian steel producers • Communication between these parties and include them in their process design. • Share transportation vehicles and processes

Stakeholder Session 3

October 9th 2020	
Goal	The goal of the third stakeholder session was to inspire the industry with successful cross-sector collaborations and to discuss the next steps for Moonshot phase 2. Several projects like ZEBRA, SURFACE, FIBROUS and ECOBULK presented the content of their cross-sector projects in circularity. During the first 2 stakeholder sessions, the participants often pointed to tender criteria. Therefore, RVO presented the current tender situation in the Netherlands. They confirmed that new tender criteria are on the horizon.
Agenda	The following speakers presented during the third stakeholder session: 1. Kadri Simson, European Commissioner for Energy inspired the participants with a motivating video message to take action. 2. Ruud de Bruijne from RVO spoke about the current tender process, the market outlook of offshore wind in the Netherlands, and the importance to include circular criteria in tenders. 3. This presentation was followed by Jelle Joustra, a researcher from the TU Delft and ECOBULK, on the design strategies for composites in a circular economy. He illustrated general circular strategies and he showed various practical examples of the reuse and recycling of blades. 4. Next, Martijn Koelers and Nicolas Quievy from the ZEBRA project held a presentation. They provided valuable insight into the process of forming a consortium. They clarified the importance of mutual trust in the partner's expertise and the key aspects of successful project execution. 5. The final external presentation was held by Harald van der Mijle Meijer. Firstly, he explained the SURFACE project. The project will research the capability of processing large blade sections and longer fibre lengths (> 2m). Afterwards, he explained the FIBROUS project. This project focuses on the reuse of fibres from composites of wind turbine blades. He also showed the importance of cross-sector collaboration between multiple partners. 6. Ultimately, Erwin Coolen illustrated the next phase of the Moonshot Project Circular Wind Farms. He explained the timeline, the workgroups, and he introduced the subscription to these groups.
Method	Knowledge and information were shared during this last session using presentations by representatives of initiatives and consortia of practical examples. In response to these presentations, the involved stakeholders were asked to comment, either through poll questions or starting discussions in the chat function of Zoom.
Results	In the different sessions, the industry has mentioned multiple times that it is difficult to move forward to a circular industry because they might lose their market position in the short term. Therefore, government action is required. This view is confirmed in figure 11. To gain insights about the topic circularity within the organisation of the different stakeholders involved in the sessions, the question of how circular is your organisation was presented to the stakeholders involved in this session. Once more, this confirms the commitment of the industry towards a circular transition, but it also shows the progress that is yet to be made. In response to the presentation given by Jelle Joustra of the TU Delft about design strategies for composite, the stakeholders involved during the session were asked what the greatest opportunity is in a circular design. Figure 13 reveals widespread reactions with recycling as the frontrunner at the moment. When asked which area the stakeholders found most important composites is the frontrunner closely followed by rare earth elements, transport and nature inclusive life cycle as shown in figure 14.
Key takeaways	This meeting provided valuable insights in cross-sector collaboration and showed the commitment of the industry towards a circular economy. Many parties have already subscribed for the second phase of the Moonshot Project Circular Wind Farms.

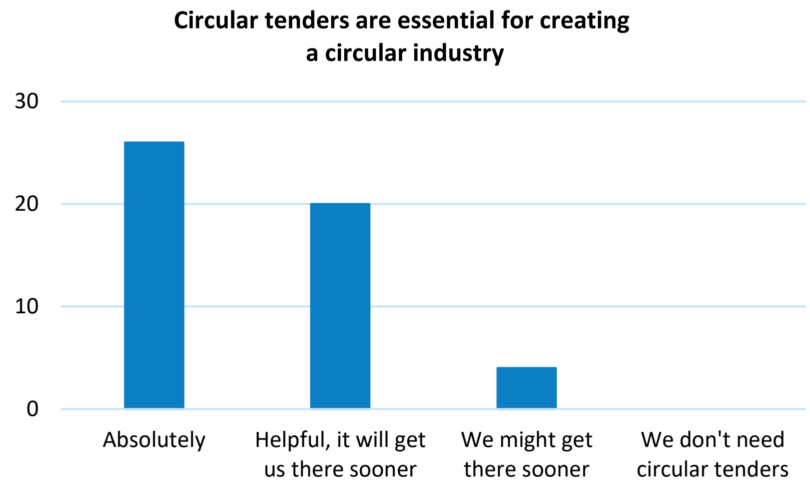

Figure 11: Poll question during the third stakeholder session

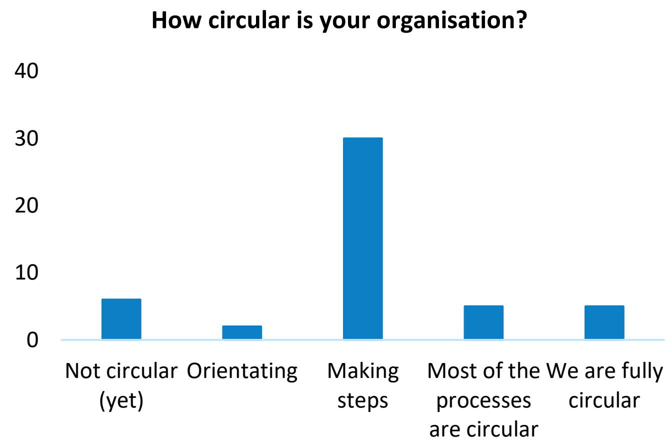

Figure 12: Poll question during the third stakeholder session

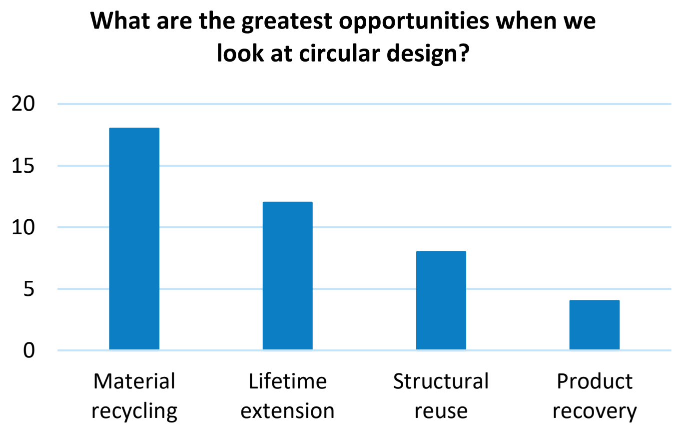

Figure 13: Opportunities for circular design

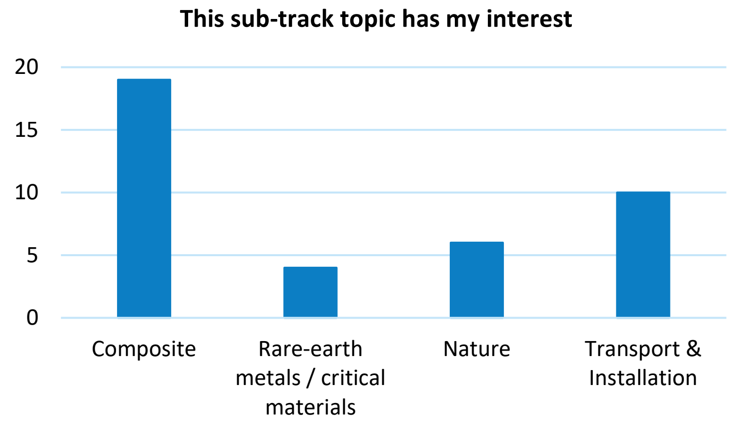

Figure 14: Question during the third stakeholder session

Workshop

The CIRCO track was a three-day workshop that provides the tools to identify and work on circular business propositions. CIRCO has developed a methodology that activates production companies and creative professionals to get started with circular design. By (re)designing products, services and business models, circular entrepreneurship they support and teach companies towards circular business processes.

Compared to the stakeholder sessions, this track had a more in-depth focus with a smaller group of participants. The track consisted of 12 participating companies.

During these three days, the participating companies worked together to identify value loss in the linear business model, to then see it as a circular business opportunity. The value losses were ranked on influence and impact. Various design strategies have been thought through, to see which one has the most potential. The most potential business case was further developed and presented to the other participants during a pitch.

Appendix B: financial resources

This appendix covers the financial resources that are needed for the second and third phase of this project. Firstly, possible financial resources and funding will be identified for the action agenda and related workgroups of phase 2. Section 2 covers the financial resources for (pilot) projects that follow the circular strategies have been established in the work packages.

Workgroups subsidies
The move towards a circular industry poses complex challenges that require identification and solving of general problems first before being able to advance to a viable business case. In the first phase of the Moonshot project, workgroups have proven to be the most efficient method of working on these general roadblocks/strategies.

Membership funding
The workgroups could be funded by a membership. An example of membership funding is used by the RDRWind consortium. This consortium contains 25 companies in the wind industry and has become the German Trade Association of recycling wind turbines. RDRWind works with a membership through which the companies that become a member pay their share depending on their amount of employees (RDR Wind E.v., 2019).

National government funding
The Moonshot Project Circular Wind Farms is a prime example of a government-funded project that stimulates cross-sector collaboration for a circular industry. Another example of successful consortium forming is the Genvind project (reusing and recycling composites from wind turbine blades), which is funded by The Innovation Fund Denmark. This fund is paid for by multiple scientific institutes and the Danish Agency for Science, Technology and Innovation (Genvind, sd).

Pilot project subsidies
This section contains a selection of subsidies that can be used for technological innovations. Other subsidies might be applicable, depending on the kind of technology and the location of the companies.

Horizon 2020 / Horizon Europe
Multiple innovation projects circular initiatives that are mentioned in this report have used the Horizon 2020 subsidy. Horizon 2020 is the EU's largest-ever research and innovation program with nearly € 80 billion in funding. After 2020, the program will change and it will become Horizon Europe. The total budget for Horizon Europe will contain € 97.6 billion. The project contains three pillars: Excellent Science (€ 25.8 bln), Global Challenges & European Industrial Competitiveness (€ 52.7 bln) and Innovative Europe (€ 1.5 bln). The first pillar supports researchers. The second pillar (Global Challenges and European Industrial Competitiveness) will focus on cross-sector collaboration. The third pillar (Innovative Europe) will focus on high potential breakthrough technologies and innovative companies that are trying to scale up.

Eurostars
Eurostars is a collaboration between EUREKA and the European Union, with some countries that are located outside Europe. EUREKA is an intergovernmental innovation network. Eurostars offers to finance for R&D-driven SMEs. Eurostars is interesting if another company owns a technology that will benefit your company. A Netherlands-based company shall receive the subsidy from RVO. A Germany-based company will receive a subsidy from the German government (RVO, sd).

Innovatiekrediet (Dutch instrument example)

Innovatiekrediet is a loan from the Dutch Ministry of Economic Affairs and Climate Policy for a new product. Its purpose is for the development of promising and challenging innovations (RVO, 2020). The budget for 2020 is € 40 million. The maximum amount per project is € 10 million.

The subsidy contains two pillars:

1. Technical innovations - For technical innovations, the maximum amount is € 10 million.
2. Clinical innovations - For clinical innovations, the maximum amount is € 5 million.

When requesting Innovatiekrediet, the entrepreneur is not making revenue and the company must be working hard on developing the project. Innovatiekrediet is mainly focused on improving the Dutch economic position, so the project must be very promising and must surely make it to the development phase. The subsidy can only be applicable if the technology that is being developed is completely new.

Missie Onderzoek, Ontwikkeling en Innovatie (MOOI) (Dutch instrument example)

The Dutch MOOI subsidy supports parties that work in a consortium on an integrated solution that contribute to the climates (RVO, 2020). The *Topconsortia voor Kennis en Innovatie* (TKIs) and *Rijksdienst voor Ondernemend Nederland* (RVO) support the application process. Furthermore, these parties offer advice and help in finding appropriate partners in their network.

The subsidy contains four pillars, for which Moonshot pilot projects are eligible for the pillar Wind op zee. This pillar had a budget of € 10.1 million in 2020, for which the maximum amount for a single project is € 4 million. A project can only apply for this subsidy if it is a partnership of at least 3 companies and if it works on an integral approach for concrete challenges from the climate agreement. The subsidy contains more conditions.

Appendix C: report on options and aspects related to circularity in wind

The goal of this appendix is to give insight and inspire the stakeholders to accelerate the transition into a circular wind economy. Therefore, this chapter is not exhaustive but tries to give an overview of the current possibilities in the field of circular strategies.

Circularity domains in wind / technical overview

This report views circularity on the material level of the wind farm. All parts of the structural element domain are covered and the most promising circular material strategies are identified.

This chapter covers the components and materials and what properties the components contain. Thereafter, the chapter identifies the current waste treatments of each wind turbine component. As explained in chapter 3, the commonly used distribution of structural elements is accordingly:

1. Blades
2. Nacelle
3. Tower
4. Foundation
5. Cables

Blades	
Material	Blades consist for the largest part of reinforcement fibres. Most reinforcement fibres are made of glass or carbon or a mix of these two materials (Cefic, WindEurope & EuCIA, 2020). Glass fibre has been the industry standard and is currently the most used material. Carbon fibre is stronger and has a higher stiffness, but its higher cost per volume is a barrier to further deployment. Another substantial part of the blades is the polymer matrix. The polymer matrix is made of thermosets or thermoplastics. These polymers are cross-linked in an irreversible process. This is a key property to reach its desired strength and resistance against material fatigue. Unlike thermosets, thermoplastics do not become cross-linked. This simplifies the recycling process, but thermoplastics incomparable price ranges are limited in their applications compared to thermosets. Therefore, currently, thermosets polymer make up most of the industry (Cefic, WindEurope & EuCIA, 2020). The combination of the reinforcement fibres and the polymer matrix, also known as composites, make up the largest part of the blade (60-70% fibres, 30-40% polymer matrix by weight) (Cefic, WindEurope & EuCIA, 2020). Composites are excellent materials to use for blades, because of their properties: • They provide resistance to fatigue and corrosion for the expected lifetime (20 to 30 years). • Composites are flexible and can be used to incorporate very specific forms. This enables manufacturers to design blades in the most aerodynamically efficient way. • Composites have a high strength-to-weight ratio. • It generates high yields that result in a low Levelized cost of energy.

Current EoL

Wind turbines blades are challenging to recycle. This issue increases over time, as it is estimated that 14,000 blades could be decommissioned by 2023 (Cefic, WindEurope & EuCIA, 2020). Landfilling of blades is prohibited in the Netherlands, Germany, Finland and Austria (WindEurope). This means that in all other European countries landfilling of composite materials is still possible.

Although in the Netherlands landfilling composite waste is banned, there is an exemption from which wind farm operators can benefit. If in principle the cost of alternative treatment is higher than 200 EUR/t, landfilling is still an option. Mechanical grinding, a recycling solution for composite, is offered in the Netherlands by recycling companies. The ground short fibres and powder are recycled and used as raw materials for riverbank support, furniture and bridges (WindEurope). Currently, this is only viable for glass fibre composites. Although cost-effective, this method also produces a low quality of recyclates and up to 40% turns into waste (ETIPWind, 2019). Presently, the cost of mechanical grinding is between 150 and 300 EUR/t, meaning that landfilling is still practised (WindEurope). This shows that although regulation is in place, it is not fully effective due to the exemption.

Figure 15: Landfill ban for composite (WindEurope, 2020)

In Germany, where the landfill ban came into effect in 2005, there is no exemption. In response to this regulatory constraint, a technical solution was developed for handling bigger amounts of glass fibre reinforced polymers: cement co-processing (WindEurope).

The glass fibres from the composite through cement co-processing are recycled as cement clinker, while the thermal energy is recovered, thus substituting fuel in cement production (WindEurope). The process can reduce the CO_2 emissions of cement manufacturing by up to 16% and is more resource-efficient. Furthermore, it is relatively affordable and easily scalable. Currently, composite materials from wind turbine blades are commercially recycled through cement co-processing (ETIPWind, 2019). This process is in operation at Neowa (Bremen) and LafargeHolcim (Lägersdorf) (EuCIA presentation stakeholder session 1). According to EuCIA, early LCA studies show a positive effect with a reduction in the CO_2 footprint.

One of the key downsides to cement co-processing and mechanical grinding is that the value of the recycled material is significantly reduced (WindEurope, 2020). Although this is a more sustainable solution than landfill or incineration, the properties of the composites are lost when they are recycled in this manner. During the first stakeholder session, the view of the industry on the topic of cement co-processing was divided.

The other technologies, explained further in this chapter, are more promising but they are not economically viable yet. It can therefore be said that the industry should exploit the option of cement co-processing while there is no other technique commercially available. The stakeholders involved in the sessions agree with this statement, they agree that the acceptance of cement co-processing should increase as a necessary first step towards circular composite, shown in figure 16.

The data gathered through the stakeholders involved in the first session shows, as can be seen in figure 17, there is a need for incentives to use recycled composite materials in new products, increasing the attractiveness of the recycling industry.

Circular Initiatives

Blades can be re-purposed on a small scale for architectural purposes like bridges and playgrounds (Speksnijder, 2019) (The Plaid Zebra, 2017). Although these initiatives show excellent use of the blades and keep the material property of the blades high, these solutions are not scalable.

The stakeholders involved in the sessions expect expects that fully recyclable blades will be the industry standard around 2030, as can be seen in figure 18.
Currently, there are different techniques for recycling composite as shown in the table below. Only the technologies with a readiness level of 9 are possible on large scale.

Technology	TRL
Cement kiln route (or cement co-processing)	9
Mechanical Grinding	9
Pyrolysis	9
High Voltage Pulse Fragmentation	6
Solvolysis	5/6
Fluidised bed	5/6
Microwave pyrolysis	4/5

Figure 16: Technology Readiness Levels of the different recycling technologies for composite (ETIP Wind, 2020)

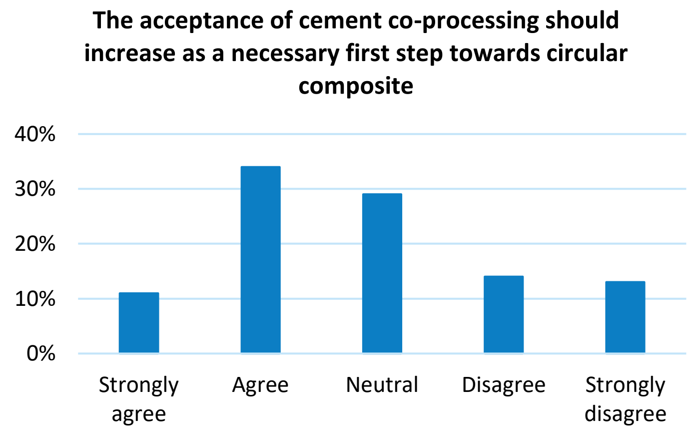

Figure 17: Poll result cement co-processing first stakeholder session

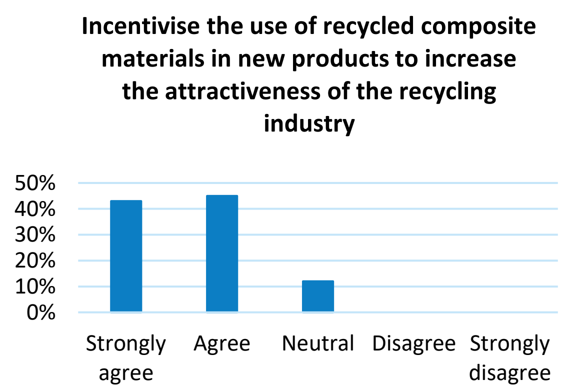

Figure 18: Poll result incentives the use of recycled composite during the first stakeholder session

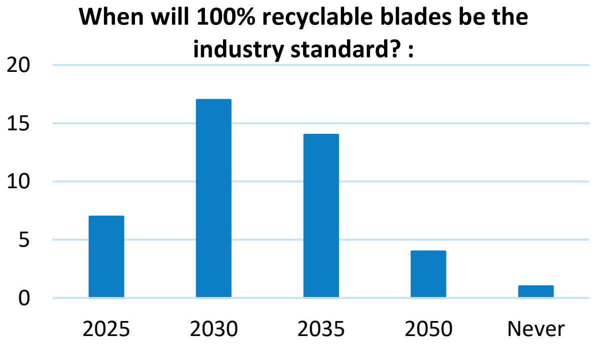

Figure 19: Poll result recyclability of blades during the second stakeholder session

Nacelle	
Material	The outer shell of the nacelle housing is, like the blades, made from composite (Carrara et al., 2020), offering a significant weight reduction. The nacelle houses the generator. Generators use either electromagnets or permanent magnets. Electromagnets do not require rare earths and they need some electricity to start operating. Permanent magnets use rare earths and do not require electricity because of the magnetic properties of the rare earths. Permanent magnet generators have a higher energy density, which increases its efficiency and reduces the weight of the generator. It works highly efficient, even with low wind speeds. There are two main drive train configurations: Geared Drive Train and Direct Drive. The drive train connects the hub to the generator and different configurations are required for different rotational blade speeds. The Geared Drive Train is heavy and requires maintenance, therefore, it is less competitive in larger plants and offshore solutions (Carrara, Alves Dias, Plazzota, & Pavel, 2020). In Direct Drive Trains, the blades are directly connected to the generator. Direct Drive benefits from not having a gearbox, which makes them significantly lighter. Direct drive has a simpler and more reliable design that is more efficient at low speeds and requires less maintenance. This makes them more suitable for offshore purposes because the high wind speeds put more pressure on the gearbox and they are more difficult to reach for maintenance (ActionAid, 2018). The use of high-temperature superconductors in a Direct Drive is an upcoming technology having another decrease in weight and increase in performance, whilst using less rare earths like neodymium and dysprosium (Carrara et al. 2020). This requires technological progress and reductions in costs (Månberger & Stenqvist, 2018). In 2018, wind turbines with permanent magnets accounted for 100% of the offshore market. The Direct-Drive low-speed PMSG configuration was most widely adopted. Onshore wind turbines mostly adopted DFIG drive trains. Permanent magnets have been increasing its onshore market share, but are still not as widely adopted, constituting only 30% of the European market (Carrara, Alves Dias, Plazzota, & Pavel, 2020). The rare earths used in the production of permanent magnets are neodymium, terbium, dysprosium, and praseodymium. In 2015, most of the magnets contained 2-4% of dysprosium and 29% of neodymium (Smith Stegen, 2015). There are concerns that the supply of REEs might not be sufficient to fulfil (future) supply. China dominates the mining, processing and manufacturing of REEs. Although its earth mine production has fallen from 95% in 2010 (USGS, 2011) to 62% in 2019 (USGS, 2020), its supply monopoly for heavy rare earths remains largely intact (Carrara, Alves Dias, Plazzota, & Pavel, 2020). This shows the urgency of the problem of the supply of rare earths. Rare earths are used in various industries, and the wind industry alone is expected to use a large part of the currently available rare earths for Europe.

Current EoL	Although the nacelle contains many materials, this report focuses on the housing and generator. As mentioned in section 2.2, the housing is made of composites. The waste treatment, therefore, resembles that of the blades. Currently, there are no recycling techniques for rare earth elements used in permanent magnets. It is cheaper to buy virgin materials than to reprocess the complex scrap material from recycled resources (Schüler, Buchert, Liu, Dittrich, & Merz, 2011). This means that the REE are currently treated the same as other metals.
Circular Initiatives	There are different metallurgical processes to recover REEs from magnet scrap from various technology readiness levels (TRLs). However, these techniques were developed to recover the REEs from pre-consumer scrap that is relatively clean and homogenous (Yang, et al., 2017). Most of the recycling methods are still at early TRLs. REEs are used in other industries like electronics and household appliances, but those products contain very small quantities of REEs, which makes manual separation of the magnet challenge. It is estimated that in the coming 10-15 years, the recycled REEs from end-of-life permanent magnets will play a significant role in the total REE supply if technologies will be developed and implemented in practice. The results of the estimation of substitution impact showed that refusing or substituting REEs plays an enormous role in reducing future demand for rare earths in the wind power sector. Even though the total annual demand for rare earths in the global wind sector is expected to increase about 1.7 times between 2015 and 2020, a strong component substitution could bring it to a lower level than that of 2015 (Pavel, et al., 2017). There are three general refusing/substitution strategies: 1. Rare earth-free generators, such as DFIG, SCIG or EESG, were already developed and offer good levels of efficiency. High-temperature superconductors (HTS) could potentially be a new generator for wind turbines, with capacities of more than 10 MW, possibly being a relevant solution. This technology can generate magnetic fields 100 times stronger than copper windings for the same dimension, allowing higher electrical currents in the same ratio. Consequently, HTS wind turbines could even become superior to high-performance PMSG technology. Some design studies and investigations have been initiated, but the prototype stage has not been reached yet. In terms of the demand for rare earths for HTS wind turbines, first estimations indicate a very low quantity of about 2 kg REEs/MW. 2. Progress has recently been made on magnet manufacturing techniques and wind generator design, allowing a reduction of the number of rare earths used in a wind turbine. A wide variety of alternative technologies to PMSG, either requiring smaller amounts of rare earths or being rare earth-free, exist today. For instance, there are mid-speed turbines that can operate with gears and a much smaller PMSG generator (with significantly lower rare earth content) as well as high-speed turbines that may include a conventional generator (e.g. DFIG or squirrel-cage) without permanent magnets. These different turbine designs, already available on the market, have also shown good performance and are considered as feasible 'component substitution' for the permanent magnet generator (PMSG). With their strengths and weaknesses, these alternative turbines can be used in both onshore and offshore applications. 3. The direct substitution of rare earths in permanent magnets or the development of new materials with similar functionality to the NdFeB magnet is still at the research stage.

Tower	
Material	The tower is primarily manufactured of plate steel (World Steel Association, 2012). Steel is the most vital material of wind turbines, accounting for 80% on average of all materials used to construct a wind turbine. It offers considerable advantages for the construction of wind turbine due to its strength and durability.
Current EoL	Currently, all steel can be recycled. Recycled steel is 90% less energy-intensive than primary steel production (EIA, 2014), hence a significant reduction in environmental impacts is achieved. Collection rates of steel in wind turbines are expected to be very high due to high concentration and legislation, with exception of monopiles. Monopiles are currently cut 1-2 m below the seafloor (Topham, McMillan, Bradley, & Hart, 2019), leaving roughly 57% on-site (depending heavily on seafloor depth and soil conditions).
Circular Initiatives	As mentioned in the previous section, monopiles are currently not fully decommissioned. The submarine life adapts to the subsea construction during the lifetime of the wind turbine. Taking mono-piles out of the ground is a difficult process which causes a lot of harm to the environment. Decommissioning the mono-pile fully will increase the recovered material, but this is not preferred. There are alternatives to mono-piles like the jacket or a floating construction which are easier to remove at the end-of-life. This topic was discussed during the second value chain meeting, where it was recommended to incorporate an environmental-specific foundation design. This circular strategy is further explained in section 4.1.4. Although the recycling rate for steel is high, CO_2 is produced in the process. Some steel components might have maintained their material strength during their lifetime. Structural reuse of these components reduces the impact of the material throughout its lifetime. With good monitoring of quality, it can be determined which parts can be used for structural reuse. This idea was discussed in the second value chain meeting and is further explained in section 4.3.1. Heerema Marine Constructors has developed an internal steel scrap marketplace which contains the steel parts that are decommissioned from the sea (Heerema Marine Constructors, 2020). Engineers can use these parts to include in their design.

Foundation	
Material	The materials used for the foundation of a wind turbine differ in their location. On average, 93-95% of the onshore foundations are made from concrete (Carrara et al., 2020). Mono-piles, made from steel, are by far the most used foundation type for offshore constructions. Other important foundation types for offshore foundations are gravity-based structure, mono-pile, tripod, jacket and floating (Sánchez, López-Gutiérrez, Negro, & Esteban, 2019). These foundation types are also made of steel.
Current EoL	Presently, concrete is mainly landfilled or recycled into a road-based aggregate (RBA). In the Netherlands, in 2014 nearly 100% of the current end-of-life concrete is used in the road building sector (Lofti, et al., 2014). However, this number is predicted to have dropped below 40% by 2025. Another problem is that the production of cement from primary materials is responsible for about 10% of the word's CO_2 emissions (Lotfi, et al., 2013).
Circular Initiatives	The central government, Directorate-General for Public Works and Water Management, Government real estate, ProRail and the province of South-Holland have committed to the requirement that newly made concrete will contain at least 5% recycled materials. The industry has agreed with the government that in 2030 all concrete that is released during renovation or demolition will be reused in high-quality new concrete (BRBS Recycling, 2018). Several municipalities have already demanded that every new project uses 30% recycled granulate in concrete, and this has proven to not pose any problems. The demolition and recycling industry has shown that all demolished concrete can be reused in new concrete. In Oss, the concrete from a demolished hospital is 100% reused in the build of a new neighbourhood (BRBS Recycling, 2018).

Cables	
Material	A subsea power cable has a multi-layered structure consisting of a conductor, insulation, sheath, armour and a jacket (Chien & Bucknall, 2007). The multi-layered structured cables use a wide range of materials. For the conductor, typically small wires of copper are tightly wound into a larger conductor core, forming the central section of the cable. The XLPE insulation, a cross-linked polyethene, which is paper-impregnated insulation is mostly used because of its ability to withstand high-voltage stress. Another material that can be used for the insulation is EPR (ethylene propylene rubber) (Dinmohammadi, et al., 2019). For the armour, steel wires are used (Chien & Bucknall, 2007).
Current EoL	Although the cables contain many materials, stakeholders from the industry emphasized the importance of copper. Therefore, this section will cover the general end-of-life strategy of the power cables and the waste treatment of copper. Subsea cables are generally buried more than a meter below the seabed (Topham & Mcmillan, Sustainable Decommissioning of an Offshore Wind Farm, 2016). This poses very few risks for marine life and has limited environmental or pollution impact. At the EoL, cables can be partially or wholly removed, but this depends on whether the cable is buried, as the removal costs will significantly increase when the cables are buried. Furthermore, significant damage and disruption are caused to the seabed with the complete removal of the cables. Leaving the cables in situ at EoL is currently considered to be the best method (Topham & Mcmillan, Sustainable Decommissioning of an Offshore Wind Farm, 2016). Any onshore cables that are buried can be left in site where appropriate, as the potential environmental impacts will be similar to the impact during installation. The onshore converter substations and any other structures must be decommissioned, restoring the land to its original state (Topham & Mcmillan, Sustainable Decommissioning of an Offshore Wind Farm, 2016). In principle, copper can be recycled with zero material loss. The increased amount of more complex scrap poses challenges to the recycling process. The recycling of copper, however, is well established in Europe. A large share of the copper is produced from secondary sources (Samuelsson & Björkman, 2014).
Circular Initiatives	The recycling process of copper has a high yield. Improving the circular strategy can best focus on t removal of copper, which stimulates the use of recycled copper instead of virgin copper needs to be an incentive.

Inventory of Dutch and European circularity initiatives

The wind industry transcends the borders and is a perfect example of European collaboration. The Dutch excel in transport and installation while the German and the Danish are excellent manufacturers. Countries like Germany, Spain and France are already large consumers of wind electricity and time will tell which countries will excel in end-of-life strategies.

Tender requirements or regulations by municipalities or provinces (local authorities) are just for Dutch areas. However, this research is focused on the initiatives by the industry and therefore extensive research towards local authorities is not performed. Nevertheless, local authorities could enhance circularity within wind farms by local regulations and requirement. Currently, it is uncertain if and which local authorities are already obliging certain forms of circularity.

In this section, an overview is given of European circular initiatives. Input for this list is retrieved by WindEurope, ETIPWind, Catapult, ORE, NWEA and by several entities in the wind industry. The list covers many projects and is drafted in November 2020. However, the completeness of this list cannot be guaranteed. Therefore, Catapult and ECHT aim to keep this list up to date in the future.

Catapult is an organisation from the United Kingdom that aims to accelerate the development and adaption of among others circular design thinking by bringing together different technology centres and invest in terms of economic capability.

Circular initiatives around blades
SusWind, GenVind, IEA Wind Task, Steam to Value Stream, HiPerDiF, ReRoBalsa, DecomTools, Sparta, ELIOT, Dreamwind, ECOBULK, Re-Wind, EURECOMP, FiberEUse, LIFE-BRIO, RECCOMP, Recy-Composite, RAAK-project, ZEBRA, SURFACE, Holcim cement, SER, Fibrous.

Circular initiatives around REE
NEOHIRE, ECOSWING, SusMagPro, Demeter, ReProMag, REE4EU, Tarantula, Amphibian.

The above-mentioned initiatives where actively brought up during the stakeholder sessions or interviews with organisations. However, there are certainly several initiatives that are under the radar. A few examples of which are: HYBRIT (CO_2 neutral steel), Self-climbing Crane (Transport & Installation, Enercon) and Nature Inclusive Design (DeRijkeNoordzee).

Appendix D: outlook residual flow of wind turbines (Including Southern North Sea case study)

With a lifetime expectancy of a few decades[13] and a large increase in installed capacity, the residual flow of decommissioned wind turbines is set to drastically increase. This appendix briefly elaborates on the outlook of the European wind energy sector as discussed in chapter 2 and the materials mentioned in chapter 4. Firstly, this appendix will describe the European outlook for installed wind capacity is introduced with a distinction between on- and offshore wind energy. This is followed by a case study from Hajonides et al. (2020) commissioned by Smartport[14] that provides an exemplary outlook on the residual flows of offshore installed turbines and its materials until 2050 for the southern North Sea.

European context

European policy documents outline an increase in the offshore wind power generation capacity in Europe ranging from 230 GW to 450 GW in 2050 (Wind Europe, 2019; European Commission, 2020). Simultaneously onshore wind capacity in Europe is estimated to grow towards a range of 400 GW to 750 GW in 2050 (IRENA, 2019; WindEurope 2019; European Commission, 2020).

Onshore versus offshore wind energy

Onshore wind energy started developing at a quicker pace than offshore wind energy, therefore the installed capacity of wind turbines is predominantly onshore. In 2019, the onshore installed capacity was around 205 GW against approx. 22 GW offshore (WindEurope, 2020). Onshore wind's capacity will still account for 80% of all wind energy installations in 2030 and could grow to 750 GW in 2050 (WindEurope, 2019).

Today around 34,000 onshore wind turbines are 15 years or older. The residual flow from onshore wind turbines is already ongoing and will grow substantially in the next 5 years. Currently, this residual flow is already creating challenges in e.g., Germany, because of its recycling capacity of composite materials (Zotz, Kling, Langner, Hohrath, Born & Feil, 2019).

The European Offshore Strategy proposes to increase the capacity of offshore wind energy to 60 GW by 2030 and 300 GW by 2050 (European Commission, 2020). The residual flow of offshore wind has been very minimal up to now. Besides, the bigger offshore turbines and working in rough environmental conditions make the residual flow of offshore a big challenge.

Case study: residual material flows in the Southern North Sea

In the report of Hajonides et al. (2020), the residual wind turbine material flow is estimated for the southern North Sea[15]. The report provides an important and unique outlook on the residual flows of offshore turbines and its materials. All undermentioned data in this appendix is extracted from this report. The total material flow

[13] These days the operational life expectancy of wind farms is 20-30 years. It is imaginable that the operational life expectancy of wind farms will be extended (due to extended licensing period) – especially for offshore wind farms – to keep wind energy attractive and affordable for developers and investing stakeholders.

[14] SmartPort is a joint venture between the Port of Rotterdam Authority, Deltalinks, the Municipality of Rotterdam, TNO, Deltares, Marin, Erasmus University, and Delft University of Technology.

[15] The southern North Sea in the report by Smartport & TNO (2020) contains the following areas: UK03, UK04, BEG01, NL01 and DE01.

determined by Hajonides et al. (2020) is based on the annual installed wind energy capacity[16], the operational life of wind farms, and the system and material compositions[17]. Figure 20 visualises the future annual decommissioning of turbines in the Southern North Sea. The largest annual material residual flows are shown in Figures 21 to 26 to give more understanding about the implications of wind farm decommissioning for circular strategies. The data points show the range of possible outcomes.

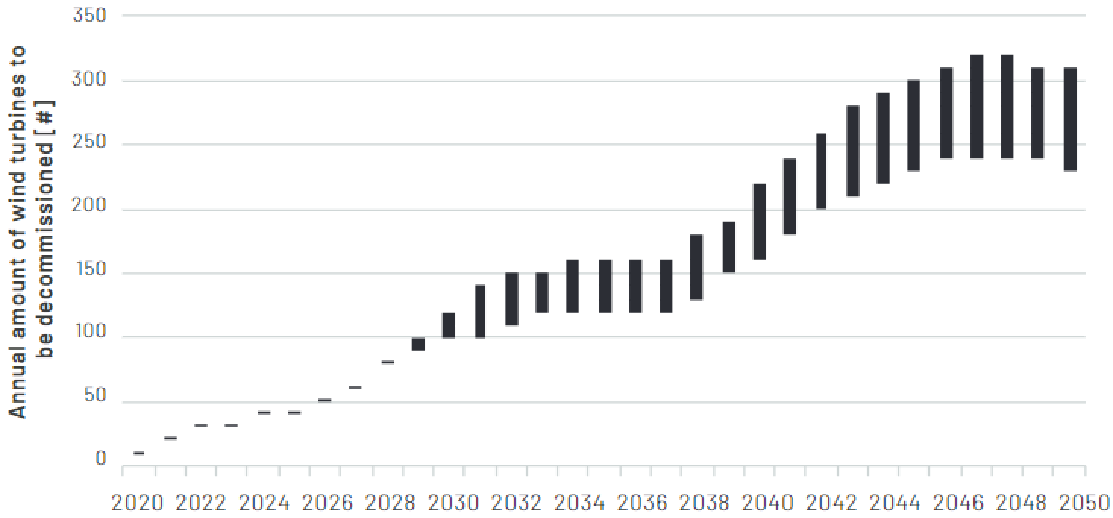

Figure 20: Annual amount of wind turbines to be decommissioned (#) (Hajonides et al., 2020)

The figures below representing material residual flows generally show an increase of residual flows from offshore wind turbines from 2026 onwards. Only the neodymium (NdFeB) magnets start to significantly increase around 2036, because of the expected increase of turbines that use direct-drive[18] generators in offshore wind turbines. Also, offshore wind turbines are expected to grow in size, and the use of REEs grows exponentially with a linear increase in turbine size.

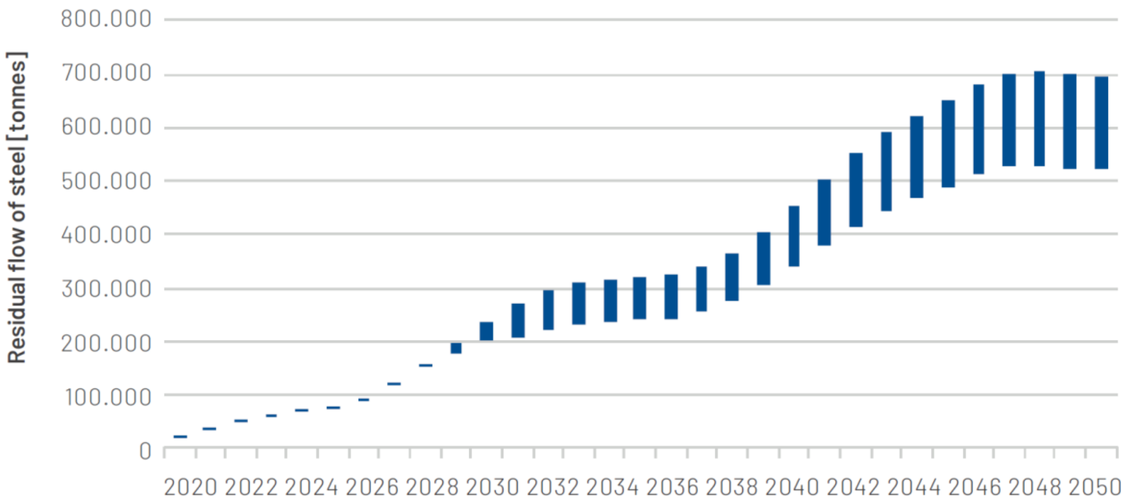

Figure 21: Residual flow of steel [tonnes] resulting from offshore wind farm decommissioning in the southern North Sea (Hajonides et al., 2020).

[16] The estimations are based on an expected installed wind energy capacity of 174 GW in the southern North Sea in 2050 (WindEurope, 2019).
[17] It is recommended to read the publicly available report of Smartport & TNO (2020) for more information on their assumptions, calculations, methods, conclusions, and recommendations.
[18] The two main configurations for wind turbine drivetrains are geared and direct-drive.

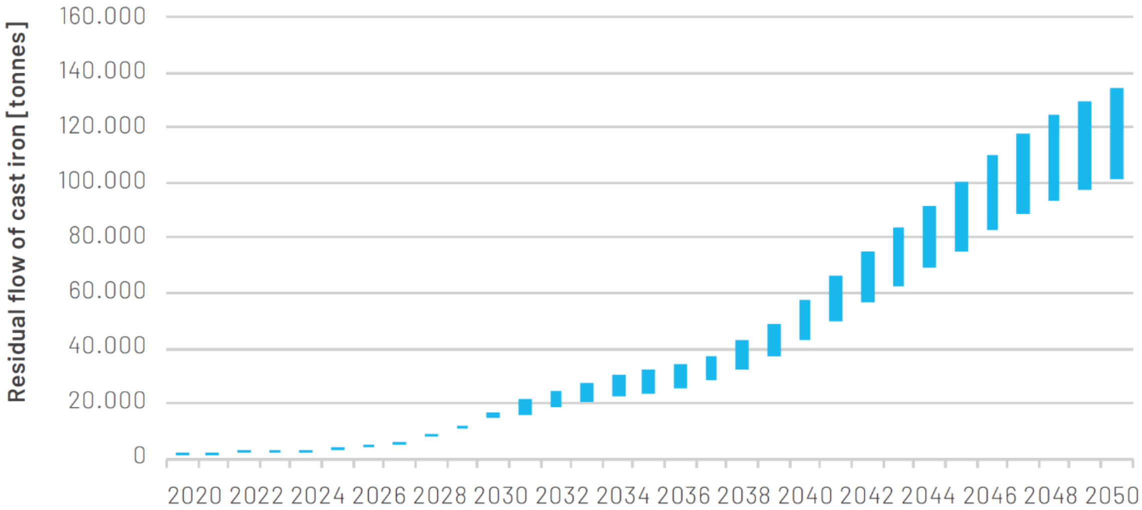

Figure 22: Residual flow of cast iron [tonnes] resulting from offshore wind farm decommissioning in the southern North Sea (Hajonides et al., 2020).

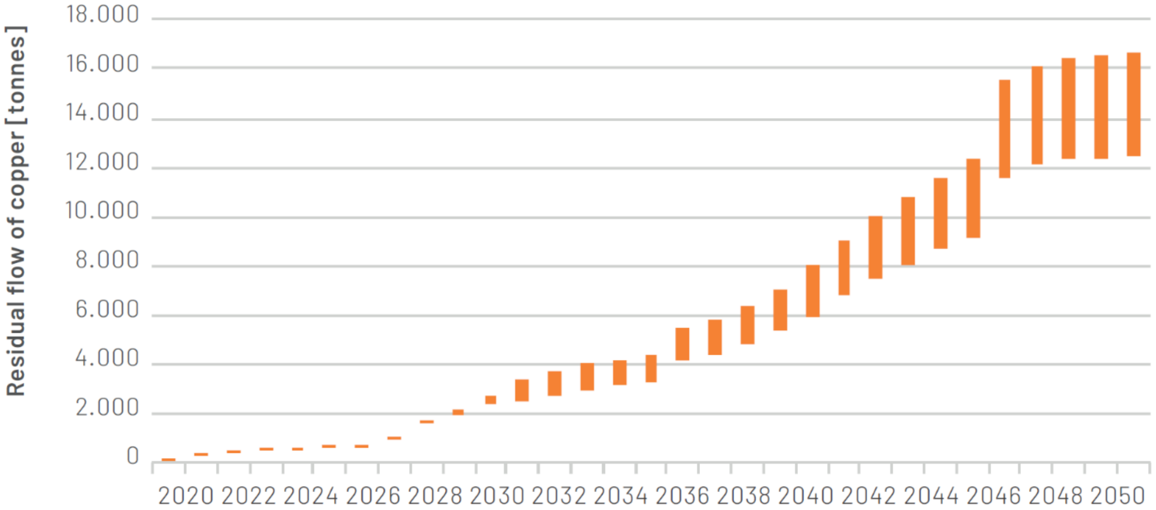

Figure 23: Residual flow of copper [tonnes] resulting from offshore wind farm decommissioning in the southern North Sea (Hajonides et al., 2020).

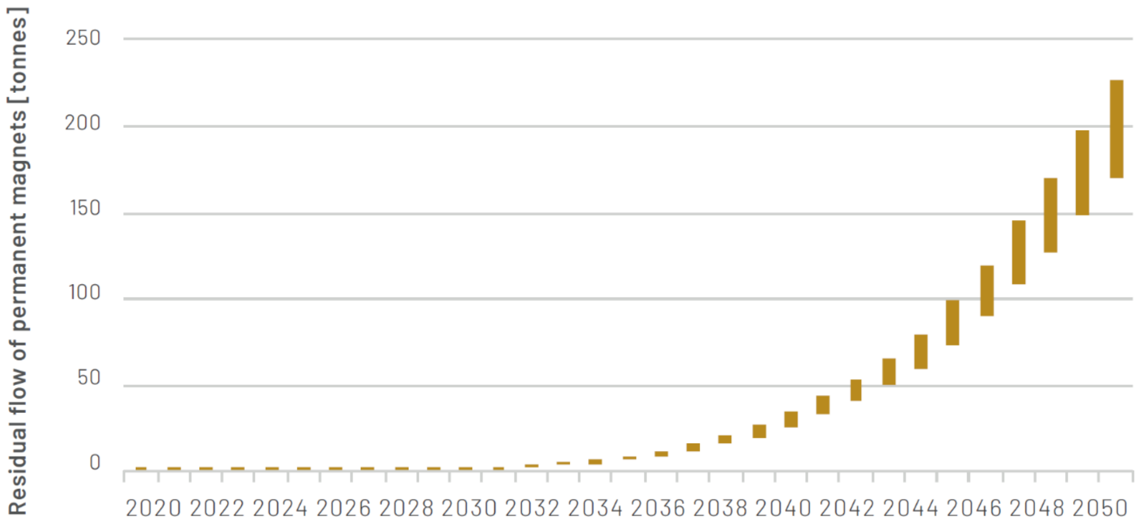

Figure 24: Residual flow of neodymium alloy permanent magnets [tonnes] (NdFeB) resulting from offshore wind farms decommissioning in the Southern North Sea (Hajonides et al., 2020).

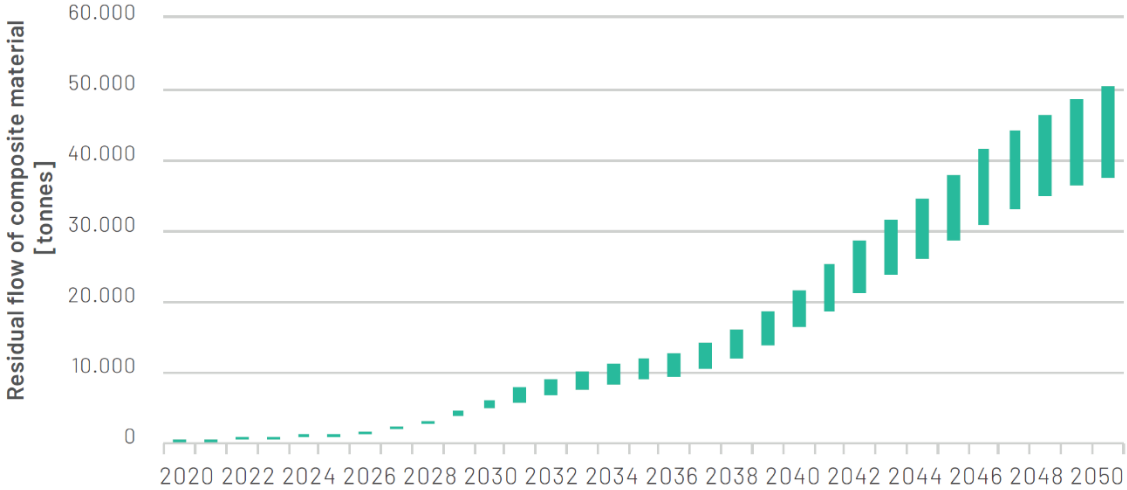

Figure 25: Residual flow of composite material [tonnes] resulting from offshore wind farm decommissioning in the southern North Sea (Hajonides et al., 2020).

Urgency

Now that the EU is making the transition towards a sustainable society with a circular economy, it becomes more important to make the switch towards a circular industry. Because of the growth of the wind energy industry overall, materials used in this industry may become scarce. Besides, mining new materials contradict with the sustainable purpose of renewable energy when materials can be recovered or reused. Both arguments underpin the urgency for more circular use of materials. With the growth in the number of wind turbines to be decommissioned specifically in the next few years, the decommissioning of wind turbines poses to be an opportunity with a highly urgent character.

Onshore has experienced a small residual flow till today, but the first large batches are about to be decommissioned across Europe between 2020 and 2025. Besides, the first big batch of offshore wind turbines will be decommissioned from 2030 (figure 25).

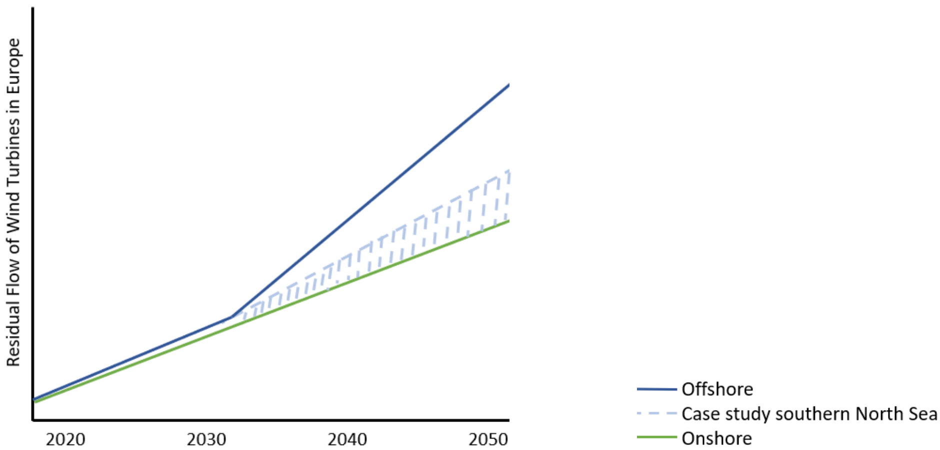

Figure 26: Schematic visualization of the residual flow of wind turbines in Europe.

The data of SmartPort & TNO outlines just a small part of the total residual flow of wind turbines in Europe. Besides, there is only very limited experience in the decommissioning of offshore wind farms. Optimising the decommissioning process (in the future) is a highly urgent matter when taking into account the increase in residual flows and the potential business cases that the materials contain when reclaimed with high quality. The outlook of the increase in installed wind capacity has set the Moonshot project Circular Wind Farms in motion (see this report). These data further substantiate the call to start collaborating with urgency on industry standards for circularity and new circularity strategies regarding wind energy farms.

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