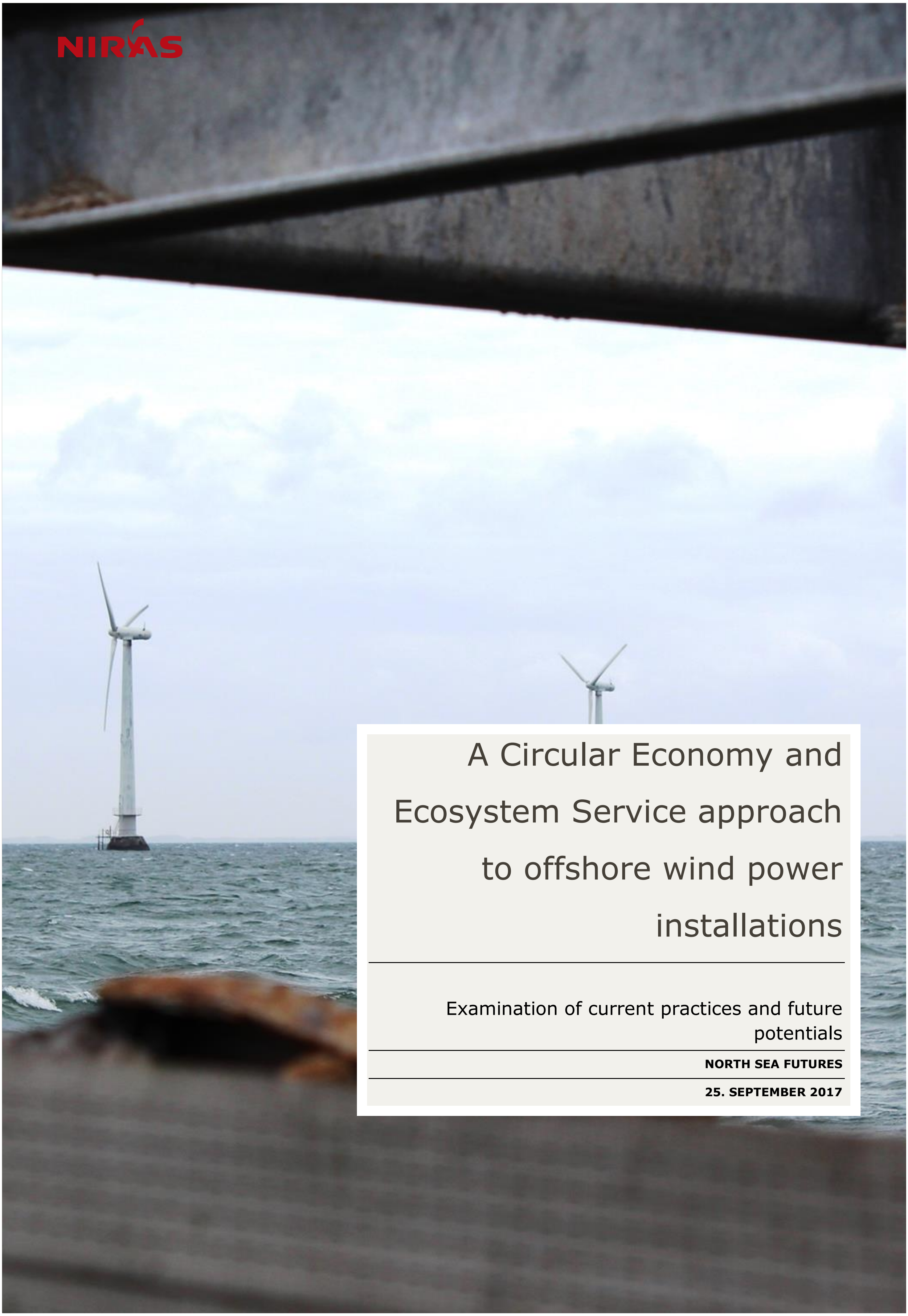

A Circular Economy and Ecosystem Service approach to offshore wind power installations

Examination of current practices and future potentials

NORTH SEA FUTURES

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Content

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List of abbreviations

- CBM: Circular Business Model
- CAPEX: CAPital EXpenditures
- CE: Circular Economy
- CS: Circular Supplies
- CLR: Closed Loop Recycling
- DK: Denmark
- EMF: Ellen MacArthur Foundation
- EoL: End-of-Life
- EIA: Environmental Impact Assessment
- ESS: Ecosystem Service
- FID: Final Investment Decision
- MP: Monopile
- NGO: Non-governmental Organisations
- NS: North Sea
- OEM: Original Equipment Manufacturer
- O&G: Oil & Gas
- O&M: Operation and Maintenance
- OHVS: High voltage substation
- OWE: Offshore Wind Energy
- OWF: Offshore Windfarm
- OPL: Open Loop Recycling
- OWF: Offshore Windfarm Installations
- PLE: Product Lifetime Extension
- PaaS: Product as a Service
- RR: Resource Recovery
- SE: Sweden
- SP: Sharing Platform
- TP: Transition Piece
- WTG: Wind Turbine Generator (including turbine, hub, blades and tower)

1 A circular economy and ecosystem service approach to offshore wind power installations – scope of the project

Offshore windfarms provide society with renewable energy. The cost of energy from wind is decreasing and traditional energy companies increasingly see a possibility for offshore wind energy in their energy portfolio. This development is supported by a societal development towards fossil free cities and electrical cars. Moreover, green demands from investors, are increasingly becoming a selling point, which implies transparency across value chains and incentives to further commercialize the wind energy sector. The concept of circular economy holds a promise that environmental and economic interests can be united. This through new business models and ownership structures that retains resources in a loop.

During the past years a new environmentally proactive approach towards offshore windfarms has developed, though not yet put into practise. Apart from seeking to mitigate environmental impacts through proper planning, a new paradigm of co-use, repowering and eco-design has emerged, aimed to enhance the economic value and ecosystem services delivered by offshore windfarms

This paper explores how a circular economy and ecosystem service approach might help to enhance environmental benefits from offshore wind power installations. Present and potential future practices around offshore installations are examined and we discuss how they would need to change in order to facilitate and enhance resource circularity and ecosystem services, including barriers to change.

One of the main purposes is to provide inspiration and guidance for future work on circular economy and ecosystem services for offshore windfarms in the North Sea. Therefore, the paper takes a holistic approach providing a broad and representative introduction to the offshore wind sector in the defined geographical area. We focus on monopile-based wind turbines, as this is the most common type of wind turbine in the North Sea. The provided examples are either representative of the case area as a whole or specific to the Danish part of the North Sea.

The paper provides a conceptual outline of circular economy and ecosystem services, followed by a thorough outline of prevalent resources, stakeholders, ownership structures etc. for the offshore wind industry in the North Sea. Thereby we seek to provide a solid foundation for future studies and projects.

2 Background and introduction

The flow of materials in a linear economy is traditionally summarised in a sequence of four stages:

1). Extraction of raw materials
2). Manufacturing of intermediate and final products
3). Product use
4). Waste disposal

This sequence implies that economic growth in a linear economy is inherently coupled to resource use. For traditional business models in the linear economy value is created as products change ownership throughout the value chain - from producers - to retailers - to consumers. In most cases products are discarded as waste once they no longer fulfil consumer-utility.

According to the Ellen MacArthur Foundation (EMF) more than 65 billion tonnes of raw material entered the worldwide economic system in 2010 - a number that is expected to increase to 82 billion tonnes in 2020[1]. Since the earth holds a finite stock of resources a linear economy cannot be sustained indefinitely. In addition to resource use, economic activities impose alterations to ecological systems and the services they provide, making life on planet Earth possible. Hence, new ways are needed for managing the flow of materials in the economy.

2.1 From a linear to a circular economy

As a contrast to a linear economy, the concept of Circular Economy (CE) suggests a potential to decouple economic growth from resource use and environmental impacts. In a CE products and materials are beneficially recirculated with minimal environmental impact. Prerequisites are careful management of material flows, product design, including the composition of materials in products. Moreover, energy use to power the economy should be renewable, such as wind energy.

The concept of CE is based on the study of biological systems, which are naturally sustained by circularity and closed loops. When organisms reach End-of-Life (EoL) they decompose and form important input of energy and nutrients for other organisms in the biological cycle. Hence, natural systems are organised in such a way that components are returned to and beneficially reused by the system without leaving behind waste. Imitating this cycle, production and consumption in a CE takes place within closed material loops (see Figure 2.1).

[1] EMF, 2013: "Towards the Circular Economy Vol. 1: an economic and business rationale for an accelerated transition": https://www.ellenmacarthurfoundation.org/publications/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an-accelerated-transition

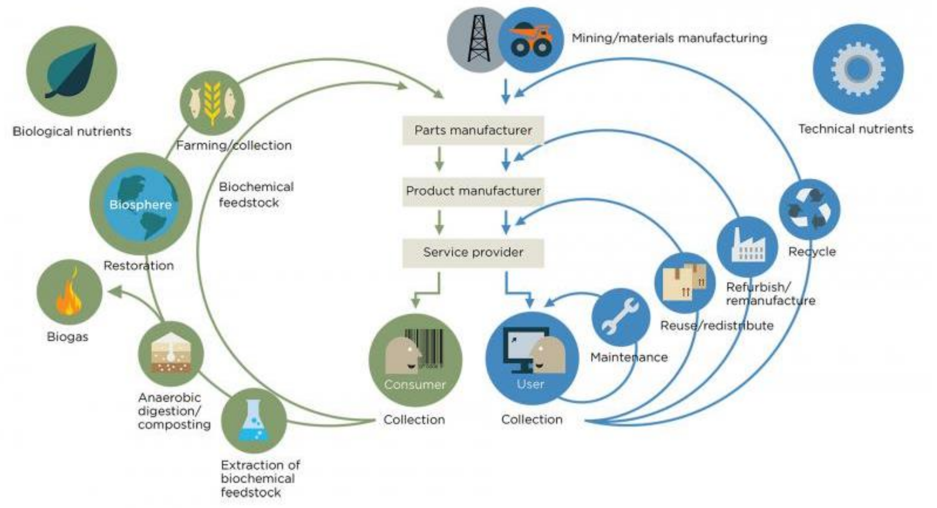

Figure 2.1: The circular economy framework illustrates how materials and products are circulated in a circular economy. Figure credit: EMF. https://www.ellenmacarthurfoundation.org

The right-hand side of the CE framework depicts the technological cycle of the CE, which is based on technical nutrients, e.g. plastics and metals. A number of strategies (maintenance, reuse, recycle etc.) support that products and materials are maintained at their highest possible value, considering entire life cycles, in order to reduce waste creation. The strategies are represented along a cascade of loops in which products and materials are guided. In the inner loops, products and materials are at their highest value. This is in accordance with the European Union (EU) waste hierarchy in which "waste prevention" is assigned the highest priority.

The left-hand side of the figure illustrates the biological cycle of the CE. Biological nutrients are non-toxic products and materials of natural origins (e.g. agricultural products including food, paper and textiles) that can safely be cascaded for succeeding use, and/or returned to the biosphere through composting or anaerobic digestion and rebuild natural capital.

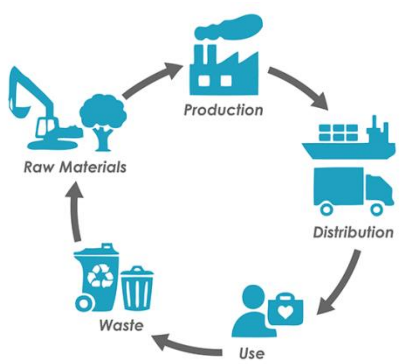

Figure 2.2: The figure illustrates a generic product life cycle from extraction of raw material to EoL. Figure credit: The LCA Centre. http://thelcacentre.com/en/what-is-lca/

Over the past decade, companies and governments around the world have gained interest in the concept of CE. In 2010 EMF was founded with the primary objective to promote and accelerate the transition towards a CE. A second example is the European Union CE-Package that holds a comprehensive action plan on how to foster a transition towards a CE in Europe. In an extensive publication by the knowledge partnership between EMF, the Environmental Economics Branch of the Deutsche Post Foundation, and the McKinsey Center for Business and Environment[2] it is estimated that a transition towards a CE could generate net economic benefits of €1.8 trillion by 2030 in Europe. Amongst other findings the partnership shows that current value creation in Europe is far more "waste full" than previously assumed. Of the total costs associated with resource use, actual resource costs only constitute 25 %, whereas the remainder are related to other cash-out costs and externalities. In addition, the publication shows a clear potential for new circular business models to underpin resource productivity and reduce total costs.

There is a widespread perception that CE has the potential to combine environmental considerations with business opportunities, which is why businesses and new business models are appointed a pivotal role in realizing a CE. Under the auspices of EMF the CE100 partnership is an innovation program with the purpose of enabling strategies for realizing a CE by facilitating networks across actors and stakeholders and to exchange knowledge and experience of developing a CE. The CE100 comprise a number of member groups including Governments & Cities, Pioneer Universities and Corporates. The CE100 members are all advocates of the CE being a strategy with the potential to decouple resource use from growth and the corporate members including Philips, Renault, Coca Cola & NIKE have made commitments to accelerate the transition towards a CE.

2.1.1 The role of businesses in a circular economy

Simply put, value creation for linear business models most often focuses on the sales situation as a product changes ownership from producer to consumer. In comparison, circular business models (CBM) may provide businesses with new opportunities for value creation throughout the entire product life cycle. In circular business models products and materials are retained in a loop within the economy through prolonged product use, reuse, recycling etc. Due to the fact that products are cascaded through consecutive use periods, consumers are said to be replaced by "users". EMF (2013) call attention to four interrelated principles of potential value creation for businesses in a circular economy:

Principle 1 – the power of the inner circle: The first circular principle focuses on prolonging the operating life of products. This preferably with the initial user in order to reduce resource use from redistribution etc. Hence, the first principle is associated with the "maintenance loop" of the CE framework and is said to be realised through non resource-intensive maintenance, repairs, upgrades etc. offered by manufactures. As emphasised by MST (2016) eco-design that allows for maintenance, upgrades etc. (see Table 2.1) and business models capable to operationalise maintenance schemes are crucial for the success of principle 1.

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[2] Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN), the new environmental economics branch of the Deutsche Post Foundation, and the McKinsey Center for Business and Environment, 2013: "GROWTH WITHIN: A CIRCULAR ECONOMY VISION FOR A COMPETITIVE EUROPE". The publication looks deeply into three key European sectors – food, mobility, and the built environment.

ECO-DESIGN AS AN INTEGRAL PART OF A CIRCULAR ECONOMY
According to the EU eco-design directive, eco-design is defined as "the integration of environmental aspects into product design with the aim of improving the environmental performance of the product throughout its whole life cycle" (EU, 2009)[3]. Hence, eco-design strategies may cover product design based on secondary raw materials; design for recycling without quality losses (downgrading); low-energy products in the use stage; non-hazardous content that challenges reuse and recycling; design for disassembly that allows for upgrades and for products to be used for spare parts etc. Based on the four circular principles (and the associated business models) it is evident that eco-design plays a crucial role in realising a circular economy.

Table 2.1. Eco-design cover design strategies that considers environmental impacts from products throughout the product life cycle.

Principle 2 – the power of circling longer: For the second principle focus is on maximising the number of consecutive product use periods and prolonging each use period. For durable goods (technical nutrients) the initial and second product use period may be prolonged through service and maintenance offered by the manufacturer, i.e. in line with the first principle. When the product no longer satisfy user needs, it may be used as spare parts to maintain similar products and/or as building blocks in the production of new similar products. Hence, principle 2 is related to the inner circle throughout to remanufacture if EoL products are reused as spare parts. In order to follow principle 2, products should be of high quality, repairable and easy to dismantle (MST, 2016).

Principle 3 – the power of cascaded use: The third principle is about diversified product and material use across value chains and sectors in order to substitute input of virgin raw material. As exemplified by EMF (2013) cotton garments may be cascaded through a number of use cycles, e.g. from first-hand use with the initial user, to second-hand use with a subsequent user. For both use periods the product fulfils the same functionality, which is in line with the first and second use period outlined in principle 2. Once the t-shirt becomes obsolete e.g. due to changing fashion or wear and tear (see Table 2.2) the fibres may be used as fill in upholstery and finally as insulation for construction before the fibres are returned to the biosphere to rebuild natural capital.

PLANNED, TECHNOLOGICAL AND PERCEIVED PRODUCT OBSOLESCENCE
There are a number of reasons why products reach EoL, including planned, technological and perceived obsolescence. Planned obsolescence may occur if products are designed to become functionally obsolete after a certain period of time. Technological obsolescence may occur when a product no longer supports the latest version of software, whereas altered user preferences may result in perceived obsolescence. Circular business models including product life extension offer a potential to extend product lifetime.

Table 2.2: There are a number of ways that products become obsolete, including planned, technological and perceived obsolescence.

Principle 4 - the power of pure circles: The fourth principle deals with retaining the purity of material streams and is a prerequisite for cascaded use.

[3] EU, 2009: *Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (recast).* Official Journal of the European Union, EN L 285/10, 31.10.2009.

If products/materials are contaminated the potential of reuse and/or for the materials (biological nutrients) to be returned to the biosphere decrease. Hence the power of pure circles increase the potential for material productivity throughout the circles of the circular economy.

As emphasised by MST (2016)[4] the four circular principles can be mixed in several ways in order to constitute a circular business model. Likewise several frameworks exist for capturing the potential value creation from combining the principles. As one example, Accenture (2014)[5] has defined five types of circular business models based on the four circular principles. These generic business models and how they relate to the circular principles are briefly explained below:

Circular business model 1: Circular Supplies (CS): The Circular Supplies business model provides fully renewable, recyclable or biodegradable resource input that underpin circular production and consumption systems, thereby substituting the extraction of virgin materials. Business models based on Circular Supplies in particular support value creation through the principles of circling materials longer (principle 2+3), which again depend on retained material purity (principle 4). The business models especially suits businesses that have large environmental footprints or deal with scarce commodities (Accenture, 2014 and MST, 2016).

One example of Circular Supplies is the Adidas Parley shoe, which is made from recycled plastic from the ocean. The long-term goal is to collect the plastic before it enters the ocean, and ultimately Adidas has an ambition to completely eliminate virgin plastic from the supply chain[6].

Circular business model 2: Resource Recovery (RR): Business models based on Resource Recovery enables a company to eliminate material leakage and maximize the economic value of product return flows, waste and by-products. This through reverse logistics, innovative recycling technologies, industrial symbiosis etc. Business models based on Resource Recovery are especially linked to value creation through pure circles (principles 4), circling longer (principle 2) and cascaded use (principle 3). The business models is in particular suitable for businesses that generate large by-product streams from production or businesses that can cost-effectively reclaim waste streams (Accenture, 2014 and MST, 2016).

One example of Resource Recovery is the Kalundborg Symbiosis (in Kalundborg Industrial Park) in Denmark. The municipality and local factories collaborate on sharing resources, waste streams and by-products from production. E.g. bio solids from a fish farm are processed and sold as fertilizers, whereas waste heat from a nearby coal fired power plant delivers energy to the fish farm. The factories have created a web of recycling in which waste streams from one factory becomes material input for another factory[7]

Circular business model 3: Product Life Extension (PLE): Product Life Extension allows companies to extend the life cycle of products and assets. Value that would otherwise be lost through wasted materials are instead maintained or even improved by repairing, upgrading, remanufacturing or remarketing products.

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[4] MST, 2016: "Best Practice Examples of Circular Business Models", ISBN no. 978-87-93435-86-5
[5] Accenture, 2014: "Circular Advantage. Innovative Business Models and Technologies to Create Value in a World without Limits to Growth".
[6] Adidas, 2016: http://www.businessinsider.com/adidas-shoe-from-plastic-ocean-waste-2016-11?r=US&IR=T&IR=T/#-1
[7] Kalundborg Symbiosis, 2017: http://www.symbiosis.dk/

The value creating potential for business models based on Product Life Extension is based on the power of the inner circle (principle 1) and of circling longer (principle 2). The business model especially suits capital-intensive B2B companies (e.g. industrial equipment manufactures) and B2C companies for which new products only bring marginal added performance-value (Accenture, 2014 and MST, 2016).

One example of Product Life Extension is the Danish company Refurb.dk, which has set up a system for take-back of high value electronics including computers and smartphones (B2C and B2B). The company repairs and upgrades the product with the latest software and the products are re-sold with a guarantee through the company's online shop and via B2B supply agreements[8].

Circular business model 4: Sharing Platforms (SP): Business models based on Sharing Platforms enables collaboration among product users, either individuals or organizations. Sharing Platforms in particular support value creation through the power of the inner circle (principle 1) and the power of circling longer (principle 2) as value is created from more intensive use of products and assets. The business models is especially relevant for businesses with over- or under capacity and for businesses that have low utilization rate of products/assets (Accenture, 2014 and MST, 2016).

One example on Sharing Platforms is car-sharing systems in a number of European cities. BMW has develop a concept in which environmentally-friendly cars are leased out on short term basis to city commuters, locals and tourists. The users locate the cars and pay for the use through an app. The cars are powered by electricity and are partly manufactured from recycled materials.

Circular business model 5: Product as a Service (PaaS): As opposed to product sale, focus in Product as a Service is on selling product function, access, service and performance e.g. through a lease or pay-for-use arrangement. For producers who extend value proposition to operation and maintenance there is a potential to obtain valuable knowledge on product performance for future product development. For business models based on Product as a Service the producer has an incentive to prolong the durable life of a product through eco-design strategies due to the fact that he retains ownership of the product. Product as a Service is especially linked to the power of the inner circle (principle 1) and the power of circling longer (principle 2). The business model is especially advantageous for products that are expensive to operate and for manufacturers who have an advantage in performing maintenance and upgrade.

One example of a business model based on Product as a Service is "Power by the hour" by Rolls Royce. On a "fixed-cost-per-flying" the company offers a full product and service package covering both the aircraft engine and the associated accessory replacement. As emphasised by Rolls Royce9, the offer aligns the interests of both the producer and the operator, who only pays for well-performing engines and ensures that maintenance costs become predictable. Due to the fact that Rolls Royce retains ownership of the engines the company gains valuable knowledge for future product development.

From the description of the five business models defined by Accenture (2014) it is evident that the four circular principles can be combined in a number of ways in

[8] Refurb (2017): https://www.refurb.dk/

[9] Rolls Royce (2012): "Rolls-Royce celebrates 50th anniversary of Power-by-the-Hour": http://www.rolls-royce.com/media/press-releases/yr-2012/121030-the-hour.aspx

order to create value and constitute a given circular business model. In reality the distinction between the types of circular business models is far from clear cut. A given business model may entail value creation through a mix of tangible products and intangible services and be determined on whether user are private or other businesses.

2.2 Ecosystem services

Ecosystem Services (ESS) are defined as contributions from ecosystems to human wellbeing. Several classification schemes for ESS exist and this paper follows the CICES classification[10] with ESS grouped into three[11] main categories:

1). Provisioning Services
2). Regulating Services
3). Cultural Services

"Supporting Services" which for some ESS classification schemes constitute a main category on its own, is by CICES perceived as "the underpinning structures and processes that ultimately give rise to ecosystem services"[12]. Supporting services include primary production and nutrient recycling. Supporting Services are thus the necessary prerequisites for both Provisioning, Regulating and Cultural services.

In the CICES classification the main categories are further divided into "Divisions", "Groups", "Classes" etc. However, such level of detail is beyond the scope of this paper.

Figure 2.3: Ecosystem Services – what do we get from nature? Figure credit: https://www.linkedin.com/pulse/biomimicry-using-nature-design-inspiration-amber-kartalyan

[10] CICES: Common International Classification of Ecosystem Services
[11] "Supporting Services" are not always listed as a separate ESS category, but rather as a subcategory acting as basic pre-conditions for ecosystems to provide Provisioning, Regulating and Cultural services respectively.
[12] CICES, 2012: https://cices.eu/

Provisioning services are services that humans can harvest from nature, including crops, fish, fresh water, wood etc., i.e. the materials and energy produced by ecosystems.

Regulating services contribute to human wellbeing by regulating natural processes, e.g. groundwater recharge through vegetation or climate regulation through carbon stocks in forest.

Cultural services are ecosystem services that provide cultural and recreational value to humans, e.g. for aesthetic or educational reasons.

As ESS are the services provided by ecosystems, it is evident that changes to ecosystems will impact the ESS provided from a specific system. Changes to ESS are inherently connected to human activities, including activities that alter natural habitats. As explained in the previous section, the concept of CE aims to minimise negative impacts on the environment from economic activities. At the same time, taking a CE approach also holds a potential for obtaining positive and/or stabilising impacts on ecosystems and on ESS, e.g. through eco-design (sometimes also referred to as 'building with nature' or bio-optimisation). The remainder of the paper focuses on the potential for reducing negative impacts and increasing positive impacts of offshore windfarms (OWF's) by means of applying the CE and ESS approaches.

3 Offshore Windfarms

The map below (Figure 3.1) indicates the propagation of offshore installations (including ship wrecks) in the North Sea (NS). These man-made structures - oil and gas installations, offshore wind turbines and ship wrecks including surrounding safety zones – cover an area of ±1,000 km^2 or 0.13 % of the total surface of the NS. In the coming decades, the number of operational oil and gas installations will rapidly decline, while the number of wind turbines is expected to increase dramatically reflecting the transition from fossil to renewable energy sources. With the expected growth in offshore wind turbines, the propagation of offshore installations may increase to some 7.5 % of the NS surface (±57,000 km^2)[13].

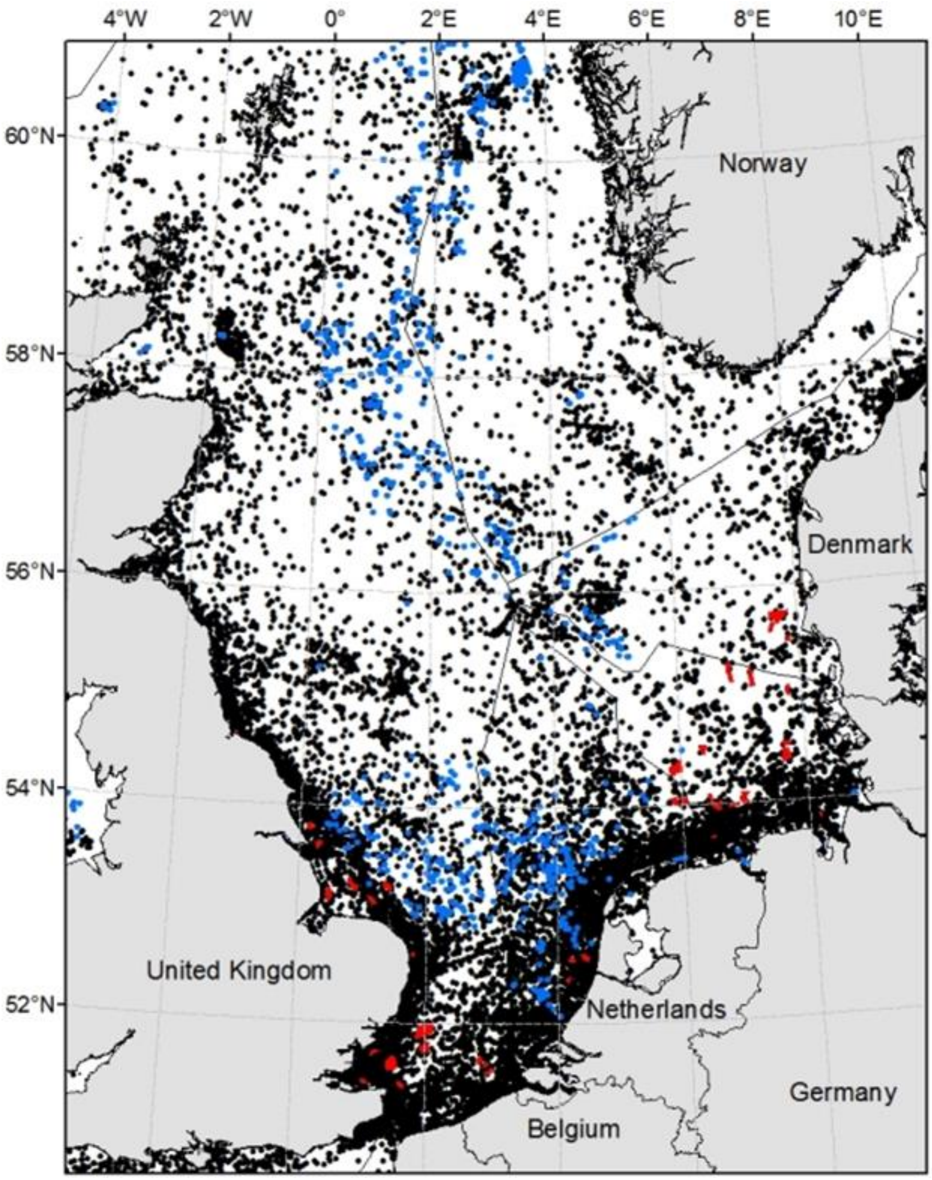


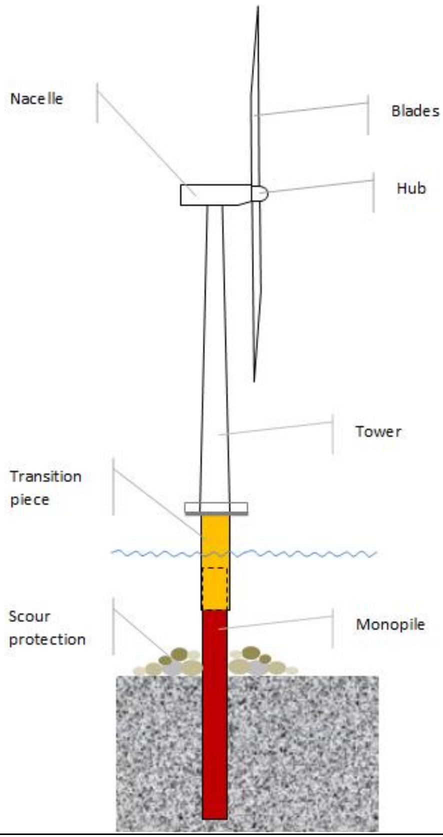
Figure 3.1: Map from Coolen JWP (2017) North Sea Reefs: Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD-thesis Wageningen University & Research, 203p.
***Black** dots = ship wrecks; **Blue** dots = oil & gas installations; **Red** dots = windfarms*

[13] This calculation is based on the following assumptions: 591 O&G structures each with a safety zone of 500 m = 464 km2; 30,000 ship wrecks with a mean surface of 1,200 m2 = 36 km2; 2,400 wind turbines with an average safety zone of 0.22 km2 = 550 km2.

As implicated above offshore wind energy (OWE) plays an increasingly important role in the Nordic energy system. However, apart from providing society with renewable energy, the production of offshore windfarm's (OWF's) requires large quantities of a number of resources, as well as imposing potential negative impacts to ESS. This calls for ways of ensuring that both decommissioning of existing OWF's and the design, construction and decommissioning of future OWF's account for CE and ESS principles.

The subsequent sections outline the most common resources from wind turbines and the general ownership structures associated with offshore wind installations in the North Sea. Moreover, the terminology associated with circular resource use found in the CE framework is adjusted to reflect offshore wind installations. Finally, known impacts on ecosystems from offshore windfarms are outlined via generic examples. The focus of this report is offshore wind installations in the North Sea, in particular monopile-based offshore wind turbines, as this is the most common type in the North Sea (Table 3.1).

MONOPILE-BASED WINDTURBINES IN THE NORTH SEA



The figure illustrates a typical monopile-based wind turbine.

Overall an offshore monopile-based wind turbine consists of the wind turbine generator (WTG) defined as turbine, nacelle, blades and tower. The WTG is placed upon a foundation which in this case is a monopile (MP) that includes a transition piece. The monopile is rammed 35-45 m into the seabed.

Waves and currents can cause "scour" (seabed erosion). In order to prevent this, scour protection (most often layers of rock) is placed on the seabed surrounding the monopile.

The generated wind energy is gathered by a system of inter array cables in between the WTG's in the OWF and in many cases joined in the offshore high voltage substation (OHVS), which delivers the generated electricity to the super grid[14].

Table 3.1: Illustration of a monopile-based wind turbine

3.1 Prevalent resources

Table 3.2 outlines the prevalent resources in monopile-based wind turbines. The resources are grouped between the three main parts of the installation: WTG,

[14] The super grid is a great transmission network making it possible to trade large quantities of electricity across large geographical distances.

Monopile, Scour protection, OHVS and inter array cables (Conductors), and column three indicates in which sub-part of the installation the resources are found.

The table presents the resource use in a ranked order. I.e. the quantity decreases with the rows. It should however be emphasised that the importance of resource use is not solely expressed by quantity. Other considerations should additionally be considered. E.g. a given resource may be used in only small quantities but be scarce in nature, and/or a given resource may be extremely energy demanding to extract and thereby result in a large carbon footprint[15].

PART OF THE INSTALLATION	PREVALENT RESOURCES	FOUND IN
WTG	Steel	Tower and nacelle
	Cast iron	Nacelle and hub
	Glass fibre	Blades, nacelle and hub
	Copper	Nacelle and hub
	Electronic equipment (incl. metals and plastics)	switchboards
	Rubber	Nacelle and hub
	Composites	Coupling and more
	Oil	Hydraulics and gear
	Neodymium magnets	Generator
	Insulation	Miscellaneous
	Copper	Cables
	PVC	Blades, nacelle and hub
	Batteries	Lamps etc.
Monopile & Transition piece	Steel	Monopile, TP and secondary structures
	Grout	Grouted connection between monopile and transition piece
	Zink	Anodes
	Marine growth	On monopile
Scour protection	Smaller stones	Scour protection filter material layer on the seabed
	Larger rocks	Above the filter layer
OHVS	Steel	Substructure and top side
	Cast iron	Topside
	Al and Cu	Transformers (topside)
	Zink	Transformers (topside)
	Mineral Oil	Transformers (topside)
	Motor oil	Transformers (topside)

[15] A carbon footprint is the quantity of greenhouse gases emitted (directly or indirectly) to produce a given product or activity. Carbon footprint mays additionally be measured on company or organization-basis. A carbon footprint is expressed in equivalent tons of carbon dioxide (CO2e).

	Insulation	Topside
	Electronic equipment	Topside
	Diesel	Transformers (topside)
	Batteries	Topside
	Gas	Topside
	Grout	Transition piece between topside and substructure
	Marine growth	
Inter array and export cables (conductors)	Copper or Aluminium	Cables
	Insulation	Cables

Table 3.2: Prevalent resources from offshore installations. Source: NIRAS Innovation Project, ODIN WIND.

Materials from OWF's primarily form part of the right-hand side of the CE framework as presented in section 2.1, i.e. they constitute technical nutrients that have the potential to be circulated in the economy through strategies such as reuse, refurbishing and recycling.

3.2 Project-life cycle, ownership structures and stakeholders

The project-life cycle of OWF's consists of a number of stages from idea through to EoL with a number of different actors involved. In the subsequent sections the project-life cycle is presented and the associated ownership structures and relevant stakeholders are outlined.

3.2.1 The project-life cycle

Before the OWF project-life cycle is initiated the authorities designate a location of the OWF based on wind conditions, environmental considerations, potential interplay with nearby industries (including harbours) etc. The figure below illustrates a generic project-life cycle once the authorities have designated a site for the OWF.

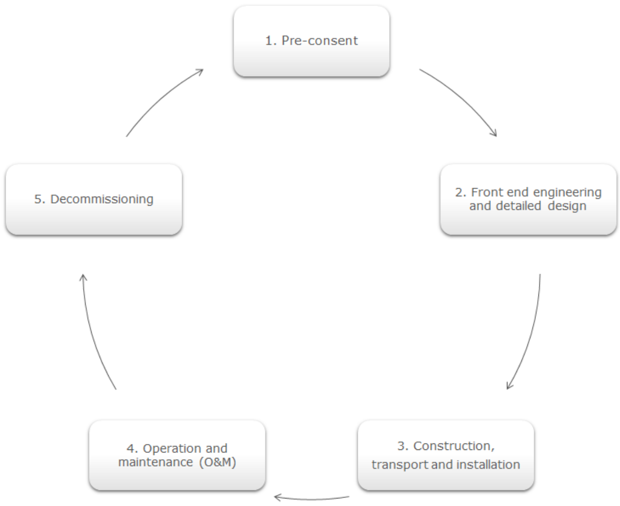


Figure 3.2: Generic project-life cycle for an OWF. The project-life cycle is created based on the Danish code of practice, and variations may occur across countries in the NS.

Pre-consent phase
The phase starts with participating in the tendering process and winning the right to develop the project. The tendering party (the authorities) determines the award criteria for which cost of energy is provided the greatest importance. In this phase, there are studies that connect to the de-risking of and refining the technical solution. All of which will be necessary to be included in the consent file e.g. the Environmental Impact Assessment (EIA) etc. The developer's project organization will conduct all pre-studies necessary to confirm the bid assumptions.

Front end engineering and detailed design
This phase is typically initiated when the authorities have consented the project, which means that developer now has acquired the right to build - conditioned by available equity. The studies in this phase will aim at refining and detailing the project to the degree where the lenders are comfortable with the overall business plan. This is perhaps the most important milestone, the final investment decision (FID), beyond which the project has acquired the equity necessary to contract the project deliverables - construction, transport and installation of the project as a whole.

Construction, transport and installation
This is the actual fabrication, component transportation and installation at the OWF. This phase additionally covers onshore elements including establishing operational ports, onshore substations, export cables, onshore routing etc. This phase usually ends up with energizing and commissioning the assets entirely ready for operations.

Operation and maintenance (O&M)
As the construction phase is being completed the operator takes over the asset for operation and maintenance (O&M) in order to exploit the capacity of the assets according to the business plan. This phase is typically 20 to 25 years and the focus is on executing the strategic directions laid out in the project development phase. This phase normally ends up with the owner's decision to decommission, partially or entirely, or alternatively to repower the asset.

Decommissioning
This is the final phase where the OWF is shut down partially or entirely and the parts are dismantled and re-used/recycled in the most environmental friendly and cost-efficient manner. So far Yttre Stengrund (SE) and Vindeby (DK) are the only two wind farms in the world that have been decommissioned.

Yttre Stengrund was in operation from 2001 and decommissioned by 2016. Vattenfall, who owned the windfarm from 2006, stated that the considerations leading to decommissioning rather than replacement of the turbines with new ones, included difficulties in acquiring spare parts as well as substantial costs associated with upgrading the turbines and gearboxes[16]. At Yttre Stengrund, the piles were cut several centimetres above the seabed in order to protect the surrounding ecosystem from trawling.

As the worlds' first offshore windfarm, Vindeby was put in operation in 1991 and is being decommissioned in 2017. The windfarm (owned by DONG Energy) was initially erected as an experimental project, and has provided valuable knowledge and experience for the offshore wind energy sector. The decommissioning decision

[16] 4coffshore, 2016: http://www.4coffshore.com/windfarms/yttre-stengrund-completely-decommissioned-nid3199.html

was based on the fact that the turbines were gradually becoming functionally obsolete and that they could no longer fulfil the demanded production capacity. At Vindeby, everything, incl. the concrete foundations, has been removed and transported to shore in order to restore the seabed to its original situation. Components from Vindeby will either be recycled or used for scientific purposes at the Technical University of Denmark[17].

3.2.2 Business constellations and stakeholders

The integrated organisation
Some organisations are able to manage the full project-life cycle of an OWF on their own – i.e. as an integrated organisation. This implies that they have the knowledge to control and in some cases fund the OWF from the initial idea through development into operation and onwards until closure and decommissioning (i.e. the entire OWF project-life cycle). This either by use of their own capacities or by having experience in hiring and managing a range of consultants, operators and contractors. Equally they are able to find the required funding for development inside their own organisation.

It is not uncommon that offshore windfarm owners call for tenders, which include both purchase of equipment, installation and maintenance of the WTG while at the same time including maintenance of the rest of the installations. This is however usually limited to the initial 5 years, which follows the standard warranty period. The integrated organisation has a focus on understanding the maintenance process as fast as possible to ensure independence from the manufacturer. Alternatively the manufacturer might gain monopoly during the many years of operation.

The developer
Some organisations focus on OWF development only. These own or strongly support the project from idea on through the development phase. When the installation phase is over, they hand over the finished OWF partly or fully to new owner/operator.

Organisations such as Copenhagen Infrastructure Partners (CIP) are experts in developing and installing OWF for customers. CIP have had success in attracting external funding, controlling experts and contractors during development and finally handing over the developed OWF to its operator.

DONG also acts as a developer where they establish the OWF, followed by a split ownership with local operators such as for instance traditional energy companies or cooperatives.

Other traditional energy organizations like Vattenfall, EON, EOLFI, EDPR, etc. also fill this role already or are trying to place themselves in this position. This also in cases where they partly own the OWF after development.

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[17] DONG Energy, 2016:
http://www.dongenergy.com/da/presse/nyhedsrum/nyheder/articles/worlds-first-offshore-wind-farm-on-its-last-turn and
Danish Wind Energy Association, 2017:
http://www.windpower.org/da/aktuelt/aktuelt_i_vindmoelleindustrien/news_q1_2017/verdens_foerste_havvindmoellepark_tages_ud_af_drift.html

The operator
The operator is responsible for management and operations of the OWF during its lifetime. During this time they ensure that the OWF is operated and maintained in such a way that the energy production is as efficient as possible. Some of the larger organisations are able to lift the O&M themselves, while others outsource the work to sub-contractors fully or partly.

The operator can either be the owner of the OWF or a service provider. In recent years almost all the larger international oil & gas (O&G), nuclear and hydro energy companies are making strategic investments to enable themselves to be in this position.

In some countries the onshore tradition of cooperative ownership of windfarms has been copied on to offshore windfarms. This meaning that cooperatives of individuals or smaller companies and organisations own, run and maintain the windfarms (partly or entirely). Due to the high costs and liabilities associated with offshore activities, ownership is often shared with larger organisations such as DONG or Vattenfall.

The grid owner
In several countries the OHVS and the grid are owned by semi-governmental organisations. In Denmark energinet.dk owns most of the OHVS, export cables and the super grid. In France it seems like the plan is to let RTE (French transmission system operator) own the export cable equal to the present ownership structure of the super grid, while the OHVS is owned by the operator. In the UK NGET partly owns the OHVS namely the transformer as well as the export cable and the super grid other countries have similar structures.

3.2.3 Other stakeholders
There are other stakeholders that are important for the success during development and operation of an OWF. Some of the most important are listed below

Investors
Apart from energy companies and operators, which have already participated and invested in the sector investment funds, superannuation funds and institutional funds are increasingly funding development of OWF. Their role will further increase as developments increasingly become subsidy-free.

Original equipment manufacturer (OEM)
The original equipment manufacturers (OEM) are also to a large extent the innovators that fostered the wind energy sector. Several of them are still active either independently or as part of more traditional international manufacturers and organisations, who have bought themselves a position and knowledge in the market. Large, multi-national cooperation’s have brought capital and volume to the sector as well as experience and knowledge making the wind energy sector more business orientated. The most obvious OEMs are manufacturers of turbines, cables and main components. Second-degree suppliers to these is a large number of sub-contractors who are equally dependent and important for the supply chain.

Contractors and service providers
Contractors and marine service providers are key during development and also provide assistance during the O&M phase and finally during the decommissioning phase.

The service providers are needed on the project from a very early start. They provide assistance during the development. During the O&M phase the service providers remain important as inspection, repairs, operation etc. becomes increasingly relevant. This of course depends on how much the owners/operator uphold the O&M themselves.

Several layers of sub-contractors deliver into the contractors and service providers. The supply chain is vast and contains both traditional sectors and more specialised companies.

NGO's and trade associations
NGO's and other organisations which have an interest in an OWF project such as for instance fishermen or trade associations are very important to consider both in regards to the initial investigations, development, operation and during the final decommissioning. Both parties are attached to OWF projects and consulted through hearings. Moreover, they play a major role in the preparatory phase preceding the actual project cycle.

Authorities
These are the bodies that give the permissions and hence determine the criteria that determine who will be the developer and how the windfarm will be located, designed and to some extent managed. They also are the owners/administrators of their respective continental shelfs and therefore sells the concessions to make use of the part of the sea in question for the OWF. Eventually, authorities have a major say in when and how an OWF is decommissioned.

The authorities include all the different authorities whose jurisdiction and field of responsibility is affected by the specific project; government, state, police, navy, local government, international bodies etc. Most countries have appointed one of the most affected authorities to handle the contact to the offshore project as a "one-stop-shop".

3.3 Terminology for circular use of resources

In section 2 we outlined how products and materials are guided along cascades of consecutive uses within the CE: maintenance; reuse; refurbish/remanufacture and recycling. In Table 3.3 this terminology is adjusted to reflect offshore installations.

CE USE (CE framework)	**CE USE** (Terminology adjusted to reflect offshore installations)
Maintenance	In the offshore wind sector the term "Maintenance" is used for planned repairs and upgrades for the initially planned lifetime of the OWF, for which it is designed. Maintenance ensures that the planned lifetime of OWF's (and the associated resource use) is fully exploited. However, maintenance might be extended after the initial designed life – cf. experiences from O&G where offshore installations have been maintained beyond their initial planned lifetime.
Reuse	**Repurposing:** When OWF's reach EoL (e.g. due to functional obsolescence or when the owner's/operator's permission expire), they are provided a second life with new functions in the same location. E.g. installations for aquaculture. If new functions substitute the construction of new installations (e.g. for aquaculture) there is a potential to reduce overall resource use. If new functions are not substituting new installations, but in fact create a demand for new products, there is a potential to increase overall resource use from repurposing.

	Repowering 1: New OWF's are erected in the same place as previous installations. Parts of the initial installation (e.g. cables) are reused. Repowering 1 offers a potential to reduce resource use by substituting the production of new products (e.g. cables).
	Repowering 2: New OWF's are erected in the same location as previous. Repowering 2 has the potential to prevent environmental impacts (positively/negatively) in new marine areas. Here it is the location, as opposed to products and materials, that is reused.
Refurbishment/ remanufacture	**Product lifetime extension (PLE):** Refurbishment/remanufacture of e.g. wind turbines and spare parts in preparation for resale to other wind energy markets. Refurbishment and resale offer a potential to reduce resource use from the production of new installations in other wind markets. In addition, resale of wind turbines may offer a potential to develop new wind-based energy sectors in countries without a tradition for wind energy, i.e. in countries without the required knowledge and experience within this field. Hence, resale and the required knowledge-transfer may prove as a means to mature new wind energy markets through cheaper, refurbished wind installations and thereby substitute fossil based energy sources in these locations.
Recycling	**Closed loop recycling (CLR):** Resources are recycled into similar products. E.g. recovery of copper from cables in order to produce new copper cables. Closed loop recycling offers a potential to substitute the extraction of new virgin resources.
	Open loop recycling (OLR): Resources are recycled into new product systems. E.g. if metals are not sorted properly prior to recycling, certain metals cannot be recovered and used as secondary raw material. Secondary raw material from OLR has the potential to reduce the extraction of new resources if other raw materials are substituted. On the other hand OLR may result in increased resource extraction if the recovered materials are downgraded (cannot be used for the same purpose) and/or if the secondary use creates an demand for new products. It may prove challenging and/or non-cost-effective to recycle certain materials into secondary raw material of a similar quality, which implies that new raw material needs to be extracted. As emphasised in Table 2.1 on eco-design, product design should integrate environmental aspects throughout the product life cycle including design for recycling. Hence, if the recycled material is being downgraded other materials could be considered in the production of future similar products.

Table 3.3: Potential for circular use of materials from offshore installations.

3.4 Potential impacts on ecosystems

Offshore wind installations provide society with renewable energy and the potential to mitigate indirect impacts on ecosystems, due to avoided energy production from fossil fuels with known impact on climate change. On the other hand, OWF's may also directly affect natural habitats, hydrology etc. with potential negative (and positive) impacts on ecosystems. Based on a publication on 'Europe's onshore and offshore wind energy potential´(EEA, 2009)[18] Table 3.4 outlines a

[18] EEA (2009): "Europe's onshore and offshore wind energy potential. An assessment of environmental and economic constraints": https://www.eea.europa.eu/publications/europes-onshore-and-offshore-wind-energy-potential

number of potential impacts on ecosystems associated with the placement of OWF's. In addition the impacts are illustrated with *non-exhaustive examples* for the three groups of ESS. The section primarily focuses on potential *negative* impacts, whereas section 4.1.2 broadens the scope to potential positive impacts from OWF's. Firstly, the three groups of ESS for marine environments are briefly outlined below.

Marine Cultural Ecosystem Services: The cultural opportunities for marine environments depend on the specific state of the ecosystem including aesthetic appearance, the emotional response experienced by the individual observer, opportunities for leisure activities (fishing, bird watching etc.), educational purposes etc. (Hattam et al., 2014).

Marine Provisioning Ecosystem Services: Provisioning services from marine environments include the provision of food and non-food. Food includes wild or farmed fish and shellfish, whereas non-food includes biotic raw materials extracted for medicinal, non-medicinal, energy, decoration purposes etc. (Hattam et al., 2014).

Marine Regulating Ecosystem Services: Regulating services from marine environments include coastal erosion regulation, regulation of water flows, waste treatment & assimilation, purification of water, sequestration of carbon (= climate regulation) and biological control (e.g. disease and pest control) (Hattam et al., 2014).

POTENTIAL IMPACTS ON ECOSYSTEMS (EXAMPLES)	**TRANSFERRED TO IMPACTS ON ESS** (EXAMPLES)
Collision risk: There is a chance that birds and bats collide with offshore structures, including rotors, towers and nacelles or supporting structure (e.g. cables and meteorological masts).	***Cultural Service:*** *In the event of collision between birds and offshore structures the opportunity for bird watching may decrease and thereby impact recreational and leisure value from the site.*
Barrier effect: Offshore installations may impact birds flight direction, which may impact the animals energy use and/or disrupt the linkage between feeding and roosting sites.	***Provision:*** *If birds are displaced and relocate to adjacent areas they may compete for fish with commercial fisheries and impact food provision in adjacent areas.*
Displacement: Noise, visual alterations and/or vibration from the installation during use and/or the construction phase may displace marine mammals.	***Cultural:*** *The educational and/or educational value from a site may decrease from displacement of marine mammals and/or impact food chains.*

Habitat loss or degradation: Depending on the scale of the installation smaller habitat loss may occur from the construction phase. From large installations there is a potential to interfere with hydrological patterns and geomorphological processes, which increase the chance of habitat loss/degradation.	***Regulation:*** *Increased suspension of sediments or release of contaminants may exceed the systems' capacity to mediate waste, toxics and other nuisances, and/or cause changes to water flows (Hattam et al., 2014).* ***Provisioning:*** *Habitat loss or degradation may impact the types and amount of fish that humans can harvest from a site. (Impacts on the types of species could be positive or negative, depending on which species are preferable from a human perspective).* ***Cultural:*** *Decrease the opportunities for leisure fishing including the recreational value of an area.*

Table 3.4: Potential impacts on ecosystems and ESS from offshore installations. Left-hand side of the table is based on EEA (2009). Based on the Marine ESS by Hattam et al., 2014, the potential impacts are "translated" into impacts on ESS (right-hand side of the table).

As outlined in Table 3.4 there are a number of potential impacts on ecosystems from OWF's above and below sea level. Prior to obtaining OWF permits, comprehensive EIA's are usually conducted in order to establish potential impacts on ecosystems during the construction stage, the use stage and from decommissioning as installations reach EoL.

The magnitude of environmental impacts from OWF's are widely discussed and impacts are continuously examined and monitored. When the Danish OWF's Horns Rev I (2002) and Nysted (2003) were erected, the operators were obliged to launch extensive environmental monitoring programmes in order to provide thorough measurements of the environmental conditions prior, during and after erecting the installations. As a follow-up on the results, additional monitoring programmes focussing on porpoises, aquatic birds and fish were initiated (ENS, 2017[19]). Based on the programme results it is generally concluded that with appropriate planning it is possible to construct environmentally sustainable OWF's without causing significant damage to ecosystems (ENS et al., 2013[20]).

[19] Danish Energy Agency, 2017: "Vindmøllers miljøpåvirkning». Available at: https://ens.dk/ansvarsomraader/vindenergi/vindmoellers-miljoepaavirkning
[20] Danish Energy Agency, Danish Nature Energy, DONG Energy and Vattenfall, 2013: Danish Offshore Wind. Key Environmental Issues – a Follow-up. Available at: https://ens.dk/ansvarsomraader/vindenergi/vindmoellers-miljoepaavirkning

4 Current practices and potentials for OWF's in a CE and ESS perspective

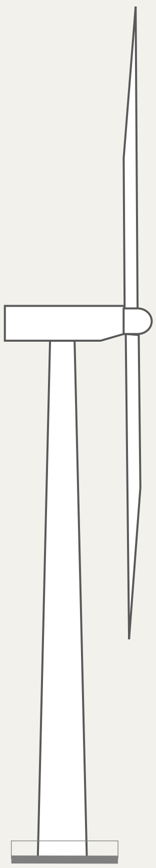
This section examines how current practices around OWF's match with a circular economy and ecosystem service approach. Due to the fact that decommissioning of OWF's is in its modest beginnings "current practices" cover the real situation as well as tendencies and intentions. Potential improvements of current practices are outlined and the focus is extended to cover future installations.

4.1.1 Current practices and potential improvements for circular material use

The offshore oil and gas sector has for decades erected installations without considering the EoL scenario, which has led to unnecessary high costs during the decommissioning stage. In the North Sea alone it is estimated that total costs associated with decommissioning of offshore installations are as high as USD 76 billion over the next 30 years (Deloitte, 2011)[21]. To prevent a repetition for the OW sector experts including NIRAS recommend that thorough considerations with regards to decommissioning are included already during the de-risking and design phase. For new OWF's the CE approach should be incorporated once the project-life cycle is initiated, including in the selection of materials. Obviously, no contractor deliberately introduces hazardous or environmentally harmful materials, but as it is materials which are suspected of such are currently used for OWFs and will most likely prove to be difficult (impossible) to reuse or recycle in a proper way after 25 years of operation. Moreover, composite materials can be challenging and energy demanding to separate and recycle to secondary raw material. Composites are used in large scale for present OWF's, namely to produce the blades. For the same reason blades constitute the largest waste fraction from OWF's. Blades are currently being landfilled or incinerated at EoL.

In this section current practices around OWF's are placed in a CE context. The "circular temperature", i.e. how current practices around OWF's match with a circular economy is outlined for the different parts of the monopile-based wind turbine and potential improvements are suggested.

[21]Deloitte & Douglas-Westwood, 2011: Decommissioning report.

WTG: TURBINE, BLADES & TOWER	
CURRENT SITUATION 	**WTG’ as a whole** are maintained until they reach the planned decommissioning stage. It is part of the standard maintenance scheme to ensure that WTG’s reach the planned lifetime. (Maintenance may be extended after the initial planned lifetime). **The turbines** are regularly maintained. In some cases refurbishment of the turbines occurs where they are reused on other onshore or OWF’s similar purposes (PLE). The same can be expected for spare parts. NIRAS has previously examined the resale market for onshore turbines. The market situation was assessed through interviews with major Danish installation and decommissioning contractors with experience from on- and offshore windfarms. The conclusion[22] hereof was that up to 50 % of the turbines are reused after EoL - often to countries/regions which are one or more step(s) behind the Danish and Northern European region in regards to wind energy development. The resale is both as whole turbines and as spare parts. The prediction and common understanding of resale of offshore windfarm components is in continuation to the onshore experience, i.e. that OW is expected to experience a similar scenario for resale of turbines at their EoL. The potential resale market for offshore turbines and spare parts is also expected to be larger as it contains of both the off- and onshore market. Furthermore the requirements for offshore farms and the turbines are tighter than for onshore ditto, therefore offshore turbines and spare parts should be easier to sell than onshore turbines and spare parts. If the above is not possible the main parts are suitable for recycling and in most cases a valuable asset for other productions. **The blades** are maintained for as long as possible to reach the planned lifetime. When the OWF reach the planned EoL (or if the blades fail prior to this) there is presently no other large scheme solution than landfill or incineration. Although not presently equipped for future scale of blades, smaller start-ups and research solutions seek to find new ways to exploit the composite material for similar or new purposes. Recycling of the blades for similar purposes (CLR) upholds the material quality, i.e. no “downgrading” from a prime to a lower quality material, whereas recycling for other purposes (OLR) may lead to downgrading of materials. See recycling examples in Table 4.2 and Table 4.3. **The tower** is not reused for other purposes in its existing form at EoL. The main component of the tower is steel, a material, which easily can be recycled. Furthermore the tower contains valuable materials which in large can be circulated in the economy for other purposes.

[22] *Source: NIRAS Innovation Project, ODIN WIND.*

RECOMMENDATIONS: IMPROVEMENTS TO FOSTER CIRCULAR USE OF PRODUCTS AND MATERIALS?	• *Authorities and other stakeholders should support resale of turbines and components in order to support the 2nd circular principle "The power of circling longer". Authorities could furthermore lower restrictions and laws and regulations for resale and cross border sales.* • *Resale can also be assisted by harmonising categorization and certification of resalable components.* • *Support design for disassembly and reuse/recycling of all parts, e.g. through tendering criteria.* • *The OW sector and specifically OEM should consider alternative materials for the blades in order to ensure recycling of the material without loss of quality. This in line with the 4th circular principle "The power of pure circles".* • *It is important to support research in alternative solutions for the vast amount of waste, which otherwise will be produced by the present materials used in blades – this either by introducing blades produced by other (non-composite) materials and recycled into new blades (close loop recycling) (Table 4.2), or blades being recycled into new products (open loop recycling) (Table 4.3).*

Table 4.1: The circular temperature for offshore installations: WTG (turbines, blades and tower)

DREAMWIND: CLOSED LOOP RECYCLING OF WIND TURBINE BLADES
DREAMWIND is a Danish research project (University of Aarhus, Vestas and Danish Institute of Technology) that seeks to develop new materials for wind turbine blades that can be separated and recycled into new blades. Repowering of blades offers a potential to substitute raw material production with secondary raw material through close loop recycling. Note that energy use from recycling (and implicitly the carbon footprint) should be accounted for in order to determine the environmental benefits from recycling.

Table 4.2: Close loop recycling of blades. The Danish Research Project DREAMWIND seeks to develop new sustainable blades made from composites that can be separated and recycled. Source and picture credit: http://www.dreamwind.dk/en/

MILJOSKARM®: OPEN LOOP RECYCLING OF FIBERGLASS FROM WIND TURBINE BLADES

As an example on an alternative to landfilling/incineration, Miljoskarm® develops products for acoustic and thermal insulation from composite materials including blades from OWF's. Composite materials (e.g. fiberglass from blades) are not easily separated and individually recovered, however, for acoustic and thermal applications of fiberglass separation is not required. The picture shows a noise barrier in Copenhagen made from recycled composite and polymer materials.

Secondary raw material from open loop recycling has the potential to reduce the extraction of new resources if other raw materials are substituted. It should always be considered which materials are being substituted, and whether or not the substituted material is better or worse from an environmental perspective.

Table 4.3: Open loop recycling of blades as an alternative to landfilling/incineration. The Danish company MILJOSKARM® develops products for acoustic and thermal purposes, e.g. from blades from OWF's. Source and picture credit: http://miljoskarm.dk/english/

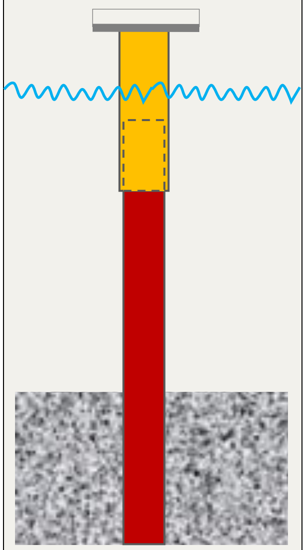
MONOPILE AND TRANSITION PIECE	
CURRENT SITUATION 	**Monopiles** do not uphold the basic CE ideology of circular material use, as a large part of the monopile is unlikely to re-enter the system. This is because 35 to 40 m of the monopile is rammed into the seabed, where removal of the sub-seabed part is almost impossible without the use of a great amount of energy, which would counteract the full environmental benefits from recycling. Therefore it can be argued that this type of substructure is not the most sustainable substructure in a long term perspective as it continuously leaves enormous amounts of steel in the seabed. Although international bodies and agreements such as IMO and OSPAR directs complete removal, the scenario of leaving the rammed part of the monopile beneath the seabed is the common perception of how it will work in the future. The two main material components in the monopile and the transition piece is steel and in some cases grout (concrete) in the transition piece. The steel is easily recyclable and the concrete can equally fit a recyclable purpose. The main challenge is the explained scenario with a large part of the monopile, which is expected to be left in the seabed as it is very difficult if not impossible to remove once it has been rammed. At present, there are no known schemes or examples for reuse of monopiles.
RECOMMENDATIONS: IMPROVEMENTS TO FOSTER CIRCULAR USE OF PRODUCTS AND MATERIALS?	• *For the next generation of monopiles the key challenge is to solve how to prevent that vast amounts of resources are left in the ground when the OWF reach EoL. This argument is in line with a CE line of thought, whereas leaving a large part of the monopile in the seabed may prove beneficial from a ESS perspective.*

Table 4.4: The circular temperature for offshore installations: WTG (Monopile and transition piece)

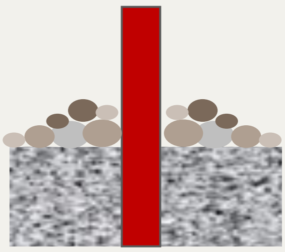
Scour protection	
CURRENT SITUATION 	**Scour protection** most commonly consists of smaller stones and larger rocks. Within current regulation, it is unclear whether it has to be removed or may be left in place after decommissioning. In line with the circular principle 4 (the power of pure circles) the scour protection material retains its purity as it is applied in its natural form and not mixed with other materials. This allows for reuse in the same location (Repowering 1), or relocation and reuse of the stone and rock material for other purposes.
RECOMMENDATIONS: IMPROVEMENTS TO FOSTER CIRCULAR USE OF PRODUCTS AND MATERIALS?	• *Should re-powering become a possibility for a specific windfarm the scour protection should be reused, supporting the 2nd circular principle (the power of circling longer). The most obvious way for reuse occurs if the turbines are replaced with new ones on existing monopiles. If the WTG's are replaced with more powerful ones on new foundations the scour protection would most likely have to be separated prior to reuse, which may counteract enhanced ESS from scour protection.*

Table 4.5: The circular temperature for offshore installations: Scour protection

Inter array and export cables	
CURRENT SITUATION	**Inter array cables and export cables** are at the present intended to be removed completely. Not for reuse but rather with a recycling agenda. This as the existing cables include copper, which is, and increasingly will be, of value for recycling. A material which, after removing the surrounding insolation (plastic), is easy to recycle. However it is also the case that several old cables have been left at sea (when replaced) e.g. intercontinental telephone cables. It could also end up being the case for cables from OWF. Furthermore it is the tendency that developers move towards aluminium cables, which are cheaper to install. These however do not have the same value after EoL as aluminium is much harder to recycle.
RECOMMENDATIONS: IMPROVEMENTS TO FOSTER CIRCULAR USE OF PRODUCTS AND MATERIALS?	• *In terms of re-powering, cables are one of the items that could be reused in new OWF's, supporting the 2nd circular principle (the power of circling longer). This both if turbines are replaced on the existing towers, but also if existing WTGs are replaced with fewer and more powerful ones.*

Table 4.6: The circular temperature for offshore installations: WTG (Inter array and export cables)

CRS Holland: Reuse, refurbishment and recycling of marine cables

According to CRS Holland[23] cables on the seabed represent a potential value of several billon USD in metals and plastics. In order to promote circular business models for marine cables CRS Holland has teamed up with cable owners to recover cables from the seabed. Three main circular strategies for recovered cables have been identified:

Refurbish (Repowering 1):

Existing cables are refurbished and reused in the same location.

Reallocate and reuse (Product life extension):

Collected cables are reused in new locations, providing a cheaper alternative compared to producing and installing new cables.

Recycling (CLR):

Metals and plastics are recycled into secondary raw material. In line with a growing demand for metals and plastics, scarcity for these materials will increase. Hence, CLR is regarded with great potential for a business model based on Circular Supplies.

Table 4.7: CRS Holland has teamed up with cable owners to recover cables from the seabed. Three circular strategies have been identified: Refurbishment; Reallocate & reuse and Recycling. Source and picture credit: https://www.circle-economy.com/case/crsholland/#.WcOFn01MrDD

[23] CRS Holland, 2017: https://www.circle-economy.com/about/#.Wce_w01Mqpo

OHVS: Transformers, Structure and Foundation	
CURRENT SITUATION	**The OHVS** is in principle easy to recycle as the far dominant materials are metals. The metals are more or less valuable and have always had a recycling market. This goes for topside as well as foundation.
RECOMMENDATIONS: IMPROVEMENTS TO FOSTER CIRCULAR USE OF PRODUCTS AND MATERIALS?	• *Similar to the cables there is a large potential in the OHVS as it could be maintained and eventually upgraded to service a new farm after re-powering.* • *If the OHVS is recycled it is crucial to ensure that it is dismantled and metals sorted prior to recycling. If metals are not sorted properly prior to recycling certain metals cannot not be recovered and will be lost forever.* • *This understood as a scheme where turbines are replaced on the existing towers but also if the existing WTGs are replaced with fewer and more powerful WTG's i.e. the sum of the power is the same or less.*

Table 4.8: The circular temperature for offshore installations: WTG (Transformers, Structure and Foundation)

4.1.2 Current practices and potential improvements in terms of ESS

As established in section 3.4 OWF's may impose negative impacts on ESS. Apart from seeking to mitigate environmental impacts through proper planning, a new paradigm of enhancing ESS through OWF's has gained footing during the previous years. This creative and proactive approach not only seeks to mitigate environmental impacts from OWF's, it aims to create supplementary positive impacts in ESS from offshore installations through strategies including repurposing, repowering and by adding new functions and value propositions to the OWF apart from energy production. This section outlines a number of non-exhaustive examples of potential positive impacts on ESS as a result of OWF's.

ESS During the functional lifetime of the OWF

There are a number of examples of potential positive effects on ecosystems from offshore installations during the functional lifetime of the OWF, including:

Refuges for fish: If fisheries are prohibited, offshore installations may function as refuges for fish and foster increased fish population and/or species diversity in a certain area (EEA, 2009). E.g. for Horns Rev windfarm (DK) a long-term study reveals a higher number of fish species inside the windfarm compared to an adjacent reference area (Danish Energy Agency et al., 2013)[24].

Species diversity and breeding opportunities: Offshore installations may act as artificial reefs. The installations, especially scour protection and concrete foundations, create structures, which can increase organic growth in terms of species diversity as well as create new breeding opportunities for marine mammals and seabirds (EEA, 2009).E.g. the Horns Rev windfarm study shows that the fish around artificial reefs from substructures exhibit similar behaviour as fish in natural reefs, thereby resulting in new species to establish.

[24] Danish Energy Agency, Danish Nature Energy, DONG Energy and Vattenfall, 2013: Danish Offshore Wind. Key Environmental Issues – a Follow-up. Available at: https://ens.dk/ansvarsomraader/vindenergi/vindmoellers-miljoepaavirkning

Stepping stone for threatened or 'lost' species and for non-native species: It is a known fact that offshore installation substructures can function as stepping stones and refuge for flora and fauna which is under severe pressure or even was thought to have disappeared from the area. On the other hand, studies also show that substructures may in some cases serve as potential stepping stones for non-native species. In the North Sea, non-native species have been found only in the intertidal zone and primarily on relatively near-shore locations[25].

Aquaculture during the OWF operational lifetime: A Belgian consortium "Noordzee Aquacultuur" of research institutions and companies are presently investigating the potential for mussel farming on OWF's. The perspectives of this new type of aquaculture offers "innovative farming techniques and efficient use of space" to increase sustainability[26]. Apart from the Belgian project, the Danish National Institute of Aquatic Resources has for several years investigated the potentials for shellfish production on OWF's in Danish waters. The Danish studies show potentials and typically barriers specific to wind/wave conditions and OWF designs (Stenberg et al., 2012[27]). Aquaculture expands the ESS that humans can harvest from the same geographical area without imposing additional pressure to the area in terms of installations and constructions and thereby accounting for marine "space" as a valuable resource.

As emphasised by the Danish Energy Agency (2013) positive implications on ecosystems (populations, diversity etc.) should be regarded in a long-term perspective. E.g. management actions should ensure that the area becomes an important fish habitat and not a temporary "fish trap".

Some of the potential positive impacts on ESS occur during the operational life of the OWF, whereas others are regarded in a temporal perspective. Provisioning services including commercial aquaculture and increased fish populations outside the aquaculture cages occur during the operational life of the OWF. However, it should be considered if these services could be extended beyond the functional life of the OWF.

ESS After the functional lifetime of the OWF

As explained in Table 4.4 (section 4.1.1) international bodies and agreements such as IMO and OSPAR directs complete removal of OWF's. However, the common expectation of operators and authorities is that the rammed monopile will remain in the seabed, as removal currently isn't feasible without causing damage to the sub seabed. To the extent that the rammed part of the monopile is left in the seabed, the negative impact might be partially compensated by ensuring that it remains surrounded by scour protection that could help create a more diverse habitat and support biomass production.

Another recourse, which holds similar complications, are the cables, for which it is argued that removal will interrupt the marine environment that has been

[25] Coolen JWP, 2017: North Sea Reefs: Benthic biodiversity of artificial and rocky reefs in the southern North Sea. PhD-thesis Wageningen University & Research
[26] Offshore wind biz, 2017:
http://www.offshorewind.biz/2017/06/02/belgians-start-growing-mussels-on-offshore-wind-farms/
and
Flanders Investment and trade, 2017:
https://www.flandersinvestmentandtrade.com/invest/en/news/shore-aquaculture-in-flanders-flying-start
[27] Stenberg et al., 2012: Offshore windfarms and their potentials for shellfish aquaculture and restocking. DTU Aqua. National institute of Aquatic Resources. ICES CM 2010/O:12.

introduced. This reasoning has been used several times as an argument for leaving cables on the seabed. Hence, from an ecosystem perspective there may be a rationale in leaving behind cables.

Apart from "passive" potential environmental benefits from leaving behind cables and substructures, a more proactive approach based on strategies such as repurposing and repowering to enhance ESS from EoL OWF's has emerged, which is exemplified below:

Aquaculture post OWF operational lifetime: Apart from prospective commercial aquaculture during the OWF operational lifetime, it is suggested that installations should remain in the sea after the functional lifetime in order to host (passive) aqua farming e.g. of lobsters, crab, oysters or mussels, and thereby enhance provisioning services from the area post energy production. This type of repurposing has the potential to substitute other farming installations or reduce the need for wild fishing.

Barriers to such initiatives are currently formed by among others the international agreements and general practise of total removal of installations and strict requirements to O&M that increases the annual running prices and thereby profitability. Moreover, stakeholders such as trade organisations and fisheries may oppose if leaving sub-structures in the sea negatively interferes with trawling and complicates sea transport for fishing boats.

Bird protection areas post OWF operational lifetime: It can be argued that installations (post functional lifetime) may form part of natural protection schemes such as bird protection areas. Installations may be used for bird breeding areas and repurposing may become part of proactive natural protection. E.g. a Dutch research project "Platforms Naturally" is currently applying for permission to explore the effects on marine life by leaving substructures from gas rigs (platform steel jackets) in the North Sea. Apart from exploring the development of biological life subsea (fish, shellfish etc.) a breeding area for sea birds may be established on top of the jackets supported by the enhanced feeding opportunities[28]. In a similar scenario for offshore monopile-based wind turbines breeding areas for sea birds could be established on top of the OHVS with feeding opportunities created from leaving substructures (e.g. scour protection) below sea level.

Designed artificial reefs: As explained above, offshore structures may act as artificial reefs during and after the functional lifetime of the OWF. Under the assumption that the rammed monopiles (and the scour protection) remain in the seabed it would be rational to consider – already in the design stage – how to develop structures that create optimal reefs in terms of organic growth. This ensures that space as a resource is used to the optimum effect. Again, leaving installations in the sea may enhance ESS, whereas recirculation of resources from a CE-perspective is not considered.

4.2 Future potentials in terms of CE and ESS

Generally speaking OWF projects are continuously becoming more and more profitable. The cost of energy (per kWh) from wind decreases and the traditional energy companies are increasingly becoming interested in wind energy. From a societal perspective there is a broad interest in lowering the price on wind energy.

[28] Engie, 2017: http://www.engie-ep.com/en/technologies-and-innovations/restore-nature/platforms-naturally.aspx

By 2025 (BBC, 2016[29]), several European capitals have banned the use of diesel vehicles and Volvo has announced that from 2019 all new produced cars will be electric or hybrids (Information, 2017[30]).

All of this has fostered a clear tendency that operators from the traditional energy sectors (O&G, nuclear, hydro etc.) see a possibility to include offshore wind in their energy portfolio. Often these traditional organisations buy themselves in to the sector by purchasing experienced players. It is very likely that future funding and business structures will not only count traditional energy companies but also new innovative structures of funding, ownership and business models. In the subsequent section this is discussed in order to highlight the future potentials for increased circular resource use for OWF's and how this may benefit different stakeholders. Furthermore, potentials for enhancing ESS potentials are outlined.

As described in section 3.2.2 **"the developers"** generally take part of the project-life cycle stages *pre-consent* and *front end engineering & detailed design.* These stages form the key foundation of the future OWF including decisions regarding choice of materials and design strategies. The developers raise capital through investors such as pension funds. During the past years there has been an increased focus on the type of investments that the pension funds take part of, and the policyholders increasingly demand that pension funds integrate climate considerations and other sustainability criteria in investment policies. In fact there are a number of examples of pension funds that blacklist mining and energy companies rooted in fossil energy sources. As an example, the Danish pension fund PKA has excluded more than 30 coal producers and initiated a dialogue with a number of other producers in order to demand that they cut down on mining and coal use (Politiken, 2015)[31].

Hence, as the developers are trusted with investments they are obliged to obtain knowledge on the entire project-life cycle and the associated value chain in order to report to the investor. Once the developer/investor gains transparency he is able to make "green demands" to suppliers and critically assess "what comes in and what goes out".

Increased green demands from investors may foster circular strategies in terms of resource use for future OWF's. If circular use of resources becomes a selling point, suppliers are incentivized to develop new strategies that remain resources in a loop, e.g. in collaboration with other suppliers in the value chain. Collaboration across the value chain may include reverse logistical systems that allow for resources to return to the OEM. If circular use of resources increasingly becomes a green demand, a snowball effect may create momentum for research and development within resource optimization, all of which may foster commercialisation of certain technologies and design strategies.

Likewise, green demands may enhance ESS and thus incentivize long-term management actions in order to ensure that negative effects are mitigated and positive implications on eco-systems retained (e.g. avoid "fish traps" as mentioned in section 4.1.2) and/or create supplementary positive impacts from OWF's (e.g.

[29] BBC, 2016: Four major cities move to ban diesel vehicles by 2025. Available at: http://www.bbc.com/news/science-environment-38170794
[30] Information, 2017 : Volvo vil satse fuldt ud på el- og hybridbiler fra 2019. Available at: https://www.information.dk/telegram/2017/07/volvo-satse-fuldt-paa-el-hybridbiler-2019
[31] Politiken, 2015: Pensionsselskaber investerer 42 milliarder i vindmøller og solceller. Available at : http://politiken.dk/oekonomi/art5575573/Pensionsselskaber-investerer-42-milliarder-i-vindm%C3%B8ller-og-solceller

through eco-design of scouring protection or combinations with aquaculture during the operational life of the OWF thereby accounting for marine "space" as a valuable resource, see section 4.1.2).

For the time being cost of energy is considered the most important criterion in the tendering process. Within the current framework of single-use business models and full removal of installations at EoL, this emphasis does not create clear incentives for CE and ESS. In order to incentivise CE and ESS in future OWF's, the authorities should place greater importance to CE and ESS considerations for the described project-life cycle, which would put the bidding parties on equal terms.

Potential barriers:

- *Developers/suppliers might be burdened with additional documentation requirements.*
- *Global markets may complicate cooperation across the value chain.*
- *In order to ensure net environmental benefits, it is important to consider the carbon footprint from reverse logistical systems.*
- *Especially in the beginning, CE and ESS measures may increase costs rather than reduce them. Decommissioning is far away, whereas construction costs are up-front. Hence, authorities (the tendering party) should place greater importance to CE and ESS in order to "mature" a market for CE and ESS solutions.*

As described **"integrated organisations"** are able to lift the full OWF project-life cycle, which provides the integrated organisation with a top-level control and insight into all the different project-life cycle stages. Although the integrated organisation teams up with consultants, operators, contractors etc. it is in top-level control from the initial idea through to termination. This is possible due to the fact that the integrated organisation possess the required knowledge, experience and competences to lift the full project–life cycle.

The potentials for the integrated organisation can be compared to those of PaaS-providers that retain ownership of products throughout the product life cycle (c.f. the concept of PaaS as described in section 2.1.1.) E.g.: Presently EoL handling of WTG blades imposes expenses for the integrated organisation (for owners in general) due to landfill or incineration. In order to keep costs down in a long-term perspective there may be an incentive for the integrated organisation to develop and include design strategies that "design out waste", including blades and other components that can be dismantled and reused at EoL. In addition, in order to keep raw material costs down and avoid fees for landfilling/incineration after the blades have been recirculated, blades could be designed from materials that ultimately allows for recycling into secondary raw material. Waste prevention, i.e. maintaining the highest possible value of products for as long as possible corresponds to the inner loops of the CE framework.

As the integrated organisation (as opposed to the developer) is in top-level control throughout the entire project (and ultimately responsible for termination and decommissioning) the potentials for maintaining resources in a loop are present, including setting up systems for reverse logistics and repowering – e.g. reusing parts of initial installations for future installations. This type of repowering may foster design development towards increasingly hardwearing installations, and "design for durability" (that is another strategy for maintaining the highest possible value of resources for as long as possible), which may become a selling point for suppliers and ultimately foster research and development within this field.

Other potential benefits from this type of repowering applies to ESS. Repowering could preserve the organic growth that may have developed during the functional lifetime of the installation (refugees for fish, species diversity and re-introduction of fish) as presented in section 0.

As the integrated organisation owns the OWF, there is a potential to create additional value for several stakeholders from the installations, e.g. by renting out space for aquaculture, through a sharing platform business model. If commercial aquaculture gains footing in OWF's it could be that commercial fishing operators become part of the *pre-consent* and *front end engineering & detailed design* stages in order to optimize the installation for aquaculture – i.e. ensuring that marine space as a resource is used to the optimum effect.

In terms of other ESS's additional stakeholders (NGO's, ornithologists etc.) could be invited for the initial project-life cycle stages in order to consider how installations may be used for nature conservation after the functional lifetime of the OWF, e.g. for bird breeding areas (as described in section 0) after the functional lifetime of the OWF. Such holistic strategies may additionally benefit the integrated organisation in terms of goodwill from a broader spectrum of stakeholders as ESS may be impacted positively as a result of the installation.

As described in section 3.2.2 the integrated organisation may call for tenders that include purchase of equipment, installation and a five year maintenance period. Presently the organisations typically focus on understanding the maintenance part to ensure future independence from manufacturers. However, it may show profitable for both the manufacturer and the integrated organisation if the manufacturer's responsibility is extended beyond the standard warranty period. The manufacturer could establish business models based on PaaS, in which the integrated organisation pays an annual fee for the "function of the WTG". I.e. implicitly the full organisation pays for the equipment, installation and maintenance, whereas it is up to the PaaS provider to decide how he delivers the functionality in the most profitable way. By extending responsibility beyond the initial five years, the manufacturer is provided with new areas of value proposition. This provides him with valuable knowledge on the installations, and most importantly creates incentives to design for disassembly, reuse and durability etc. Due to the fact that the manufacturer is in charge for a long time period, it may further become profitable to invest in new technology (e.g. long-lasting paint that requires less maintenance) and other eco-design strategies. As opposed to a traditional OEM that capitalises from producing and selling products, it may become profitable for the manufacturer to produce less and retain the lifetime of existing products for as long as possible. Today, there is a tendency that developers with less experience and technical knowledge - compared to the integrated organisation - increasingly begin to outsource both operation and maintenance.

Potential barriers:

- *Consider energy use (and implicitly the carbon footprint) from recycling into secondary raw material in order to obtain net environmental benefits from recycling.*
- *The price of raw materials has to remain below recycling of secondary raw materials.*
- *The wish of integrated organisations to get independent from the manufacturer ASAP may form a barrier to closer cooperation between the two on the longer term.*

The section on **"the operator"** outlines the tendency that OWF's are being partly owned by private cooperatives that typically consist of local stakeholders and other interested parties. It is NIRAS' experience that these private cooperatives are driven by strong environmental ideologists and it is likely that the cooperatives are inherently interested in supporting a CE or ESS development approach in terms of the OWF that they co-own.

As laid out in this paper, resource potentials and enhanced ESS is a complicated web that could include new business models, the properties of components and materials (composites vs. non-composites), reverse logistical systems etc. Based on a number of examples Figure 4.1 on the subsequent page seeks to illustrate how the use of materials corresponds to the hierarchy of uses in the CE, starting from *maintaining* resources in a loop all through to *recycling* (1). Moreover, the figure illustrates how ownership structures and business models may foster circular use of materials (2). Lastly a number of ESS are connected to the before-mentioned strategies.

The figure illustrates that leaving behind substructures in the seabed may enhance ESS. From a CE perspective this indicates that resources "leave" the economic system. On the other hand, the ESS provided by the substructure, may eventually contribute to the long-term continued availability of biological nutrients (i.e. the left side of the CE model). It may be that the design of future OWF's could incorporate a temporal perspective and a broader, integrated systems perspective on the total of technical and biological nutrients. The design may consider a post-functional life (e.g. as a reef, where protein production and harvesting can take place), and future design strategies may allow for complete removal without causing significant environmental impacts. The net result would indicate optimum utilisation of the OWF and the associated marine space from a life cycle perspective.

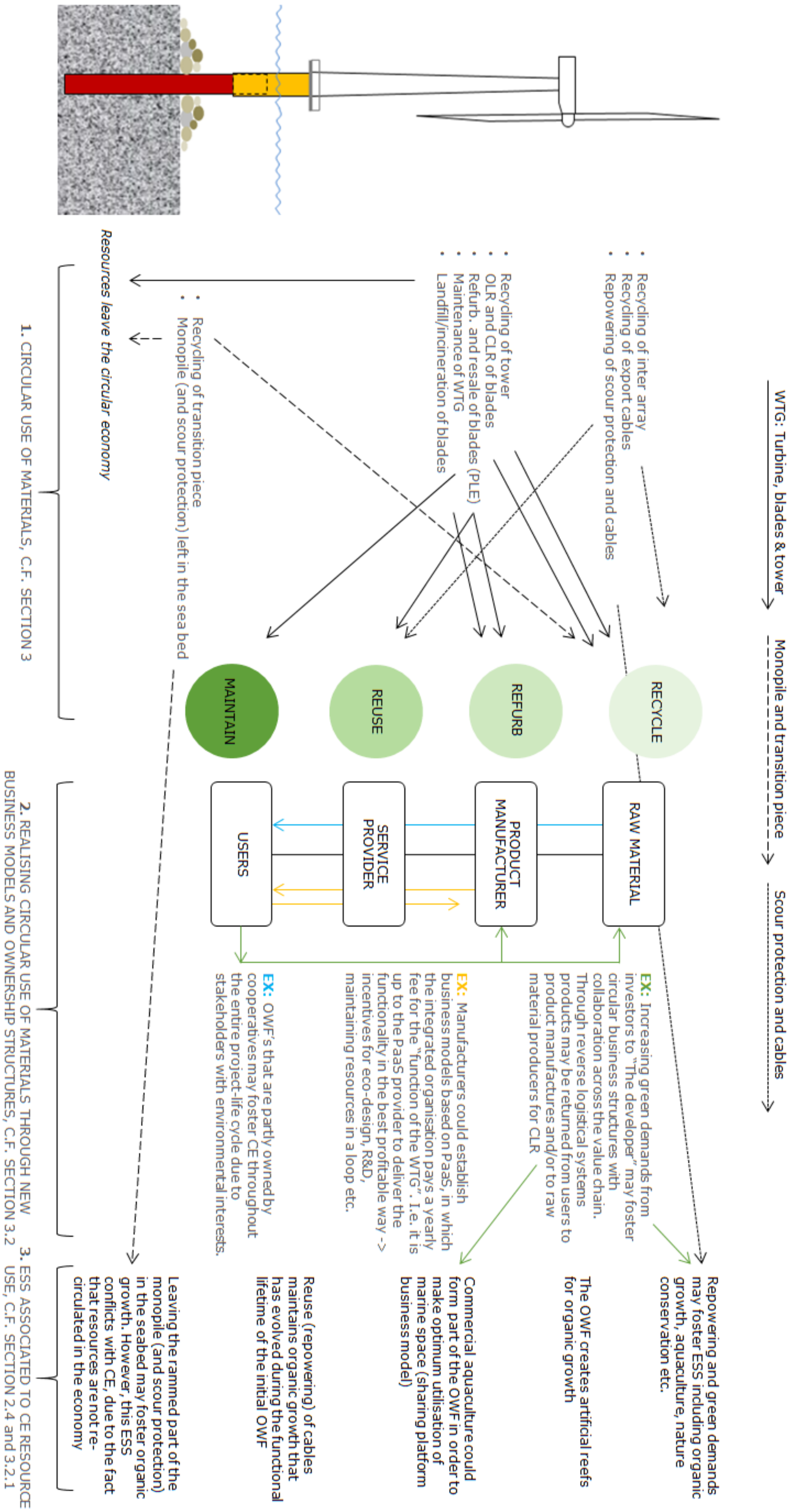


Figure 4.1: Examples on CE and ESS connected. Leaving installations in the subsea may foster ESS, however, this goes against the basic idea of the CE to maintain resources in a loop within the economy. As with all natural resource management, trade-offs are necessary.

5 Next steps

In this paper a number of potentials, barriers and recommendations have been listed in terms of enhancing CE and ESS from OWF's. This, together with a thorough outline of resource use and a description of business structures, ownership and stakeholders in relation to OWF's, has established a solid and necessary ground to conduct future studies. The subsequent bullets outline suggested future projects in relation to OWF's:

Quantification of resource potentials:
As established in section 3.1, the resources in OWF's consist of technical nutrients with inherent properties that allow for recirculation in the economy. The different materials and resources are outlined and the relative magnitude is indicated in Table 4.2. Based on this, it is interesting to further investigate and quantify the resource potentials from OWF's, including the subsequent research questions:

- Which resources used in OWF's are particular critical? (e.g. in terms of scarcity and energy use from extraction and processing).
- Can specific resources be substituted by other resources, and which are preferable from an environmental and economic perspective?

The project could be executed as a screening LCA study accompanied by an economic assessment of different resource scenarios.

New materials for blades:
As outlined in the paper composite materials can be challenging and energy demanding to separate and recycle to secondary raw material. Composites are however used in large scale for present OWF's, namely to produce the blades. For the same reason blades constitute the largest waste fraction from OWF's. Blades are currently being landfilled or incinerated at EoL. Based on this, it would be interesting and highly relevant to establish the potentials for developing blades of new materials. Research questions could include:

- Current status for developing new types of blades
- Screening of possibilities/materials
- Transfer of knowledge and experience from the onshore windfarm industry
- Barriers (including technical)

Reuse of materials and components:
As established in section 3 and Table 4.1 there is a potential to reuse turbines and components (PLE) from OWF's. Therefore, it would be relevant to do a feasibility study that investigates the potential for reuse (economically and environmentally), including the subsequent research questions:

- Potential markets and market size
- Reverse logistics across borders
- Legislative barriers (cross-borders)
- Barriers in terms of standardized/non-standardized product components

Wind turbine foundations:
For the next generation of monopiles the key challenge is to solve how to prevent that vast amounts of resources are left in the ground when the OWF reach EoL. A potential study would be to investigate other wind turbine foundations in terms of CE and ESS. E.g. in a comparative study with monopile-based foundations.

Legal barriers (and opportunities) for CE and ESS

In the current regulatory and business model system, there are significant barriers to CE and ESS thinking: many ideas and proposals have been launched, but hardly any are being implemented in practice. It would be useful to get to understand in depth what are the legal and business model barriers to change, in order to be able to create more incentives for experimenting with and implementing these practices. The study could be conducted through research of relevant regulatory frameworks and through interviews with businesses in the OWF industry.

- Screening of barriers for circular business models for OWF’s
- Screening of barriers for linking ESS to OWF’s
- Potential initiatives to enhance CE and ESS practices – e.g. as award criteria in the tendering process
- Potential incentives for CE and ESS practices from a business point of view

Inventorize opportunities for and potential gains from ESS

Across Europe (and elsewhere), research institutes and consultants have developed a range of ideas and concepts for ESS initiatives that might potentially be combined with OWF (or other offshore installations). Gathering these ideas in a ‘catalogue’, with a proper description of potential gains (ecologic and economic), conditions for implementations, etc. would be helpful for developers and investors to find their way towards new opportunities.

- Outline and description of potential impacts on ESS from OWF’s
- Ideas for ESS initiatives (from a OWF project-life cycle perspective)
- Economic and ecologic gains from ESS initiatives