Final report stakeholder process

October 2022 - June 2023

Vision paper
DECOMMISSIONING OFFSHORE WINDPARKS
in the Belgian part of the North Sea

federale overheidsdienst
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Royal Belgian Institute of Natural Sciences

Rue Vautier 29 | 1000 Brussels | Belgium

www.naturalsciences.be

mareco-odnature.naturalsciences.be

Marine Environment Department

Federal Public Service

Health, Food Chain Safety and Environment

Avenue Galilée 5/2 | 1210 Brussels | Belgium

https://www.health.belgium.be/en/our-north-sea

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FOREWORD

Developing a vision through stakeholder consultation offers several advantages. First, it provides an opportunity for stakeholders to come together and enter into dialogue. This leads to a better understanding of the views and concerns of all involved, and helps build consensus.

Another advantage is that by involving stakeholders in the process, the vision is more likely to correspond to the needs and expectations of the various parties. As a result, the vision can be more broadly supported, while potential obstacles and conflicting interests can be identified and addressed at an early stage.

Moreover, involving stakeholders in the process can lead to more involvement and ownership of the vision on the part of stakeholders. This can help in implementing the vision, and make it more successful.

In summary, developing a vision through stakeholder consultation can help create a more supported, feasible and effective policy vision.

~

This report presents the outcome of the stakeholder process regarding the various options for decommissioning offshore wind farms in the Belgian part of the North Sea, an initiative of Deputy Prime Minister and Minister of Justice and North Sea, Vincent Van Quickenborne.

The aim of this process was to gauge the opinions of stakeholders on the issue of decommissioning, to identify areas where the stakeholders agree and where they do not, and based on these findings, to advise the policy on the decommissioning of Belgian offshore wind farms. There are several options for decommissioning the infrastructure, whether for the foundations, the erosion protection layers or the cables. The foundations can either be completely or partially removed, or remain completely in place. The erosion protection layers and cables can be removed or remain in place. The advantages and disadvantages of the various options were discussed during an open and transparent consultation, with the goal of seeking consensus. Where consensus could not be found, the different views are presented.

There was broad public input to the consultation, with representation from industry, the academic world, policy and the public sector. Given the diversity of the profiles and competencies taking part, this analysis can by no means be viewed as a detailed ecological, technical, legal and/or socioeconomic analysis. This report presents information and inspiration to the federal government.

Tine Miet Van Maele & Steven Degraer

Royal Belgian Institute

for Natural Sciences (KBIN)

Nele Desplenter & Ingrid Van Aken

Marine Environment Department

FPS Health, Food Chain Safety & Environment

GLOSSARY

- **Waste** - legal definition from the Waste Directive (2008/98/EC), Art. 3(1):
  any substance or object which the holder discards or intends or is required to discard;

- **Monopile** - definition from Wiktionary:
  A foundation consisting of a single, generally large-diameter, structural element that supports the entire load of a large above-surface structure;

- **Dismantling** - actions taken at the end-of-life of infrastructure;

- **Recycling** - legal definition from the Waste Directive, Art. 3(17)":
  any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations;

- **Repowering** - reusing the zone to generate electricity from renewable sources;

- **Refurbishing** - (freely translated) definition from the Interreg NSR project DecomTools - Policy recommendations for the decommissioning of offshore and onshore wind turbines in Belgium:
  replacing certain parts of the wind turbine without, however, changing the external characteristics of the turbine. Extending the life of the wind turbine does not involve any works, except for the usual maintenance works;

- **Pollution** - definition from Art. 3.4° Marine Environment Act 2022 & the OSPAR Convention:
  The direct or indirect introduction into the seabed, water column and atmosphere of substances, materials, energy, including underwater noise, or non-native species, resulting from human activities, which causes or is likely to cause damage.
  e.g.
    - hazards to human health,
    - harm to living resources and marine ecosystems,
    - damage to amenities,
    - interference with other legitimate uses of the sea.

INTRODUCTION

Wind farms in the North Sea are important for our energy supply. The first zone for wind turbines in the Belgian part of the North Sea, developed between 2008 and 2020, accounts for an installed capacity of 2.2 gigawatts. Given the huge challenges in the area of global warming and the energy transition, energy sourced from the sea will continue to grow significantly.

By 2028-2029[1], the first wind turbines, including interconnectors to other countries, should be operational in a second renewable energy zone in the Belgian part of the North Sea, the Princess Elizabeth Zone, which is partly in a Natura 2000 area**.** The objective is that these will supply an additional peak capacity of minimum 3.15 and maximum 3.5 gigawatts. This objective makes it possible to achieve the peak offshore wind power capacity of 5.4 to 5.8 gigawatts proposed in the coalition agreement, by 2030 at the latest.

Concentrated in the port of Ostend, Belgium is among the world leaders when it comes to installing and operating offshore wind farms. It will also be the first country to install wind turbines in a protected marine area. Meanwhile, the first generation of wind turbines will soon be decommissioned. The importance of close consultation, both nationally and internationally, for the decommissioning offshore wind farms cannot be overemphasized.

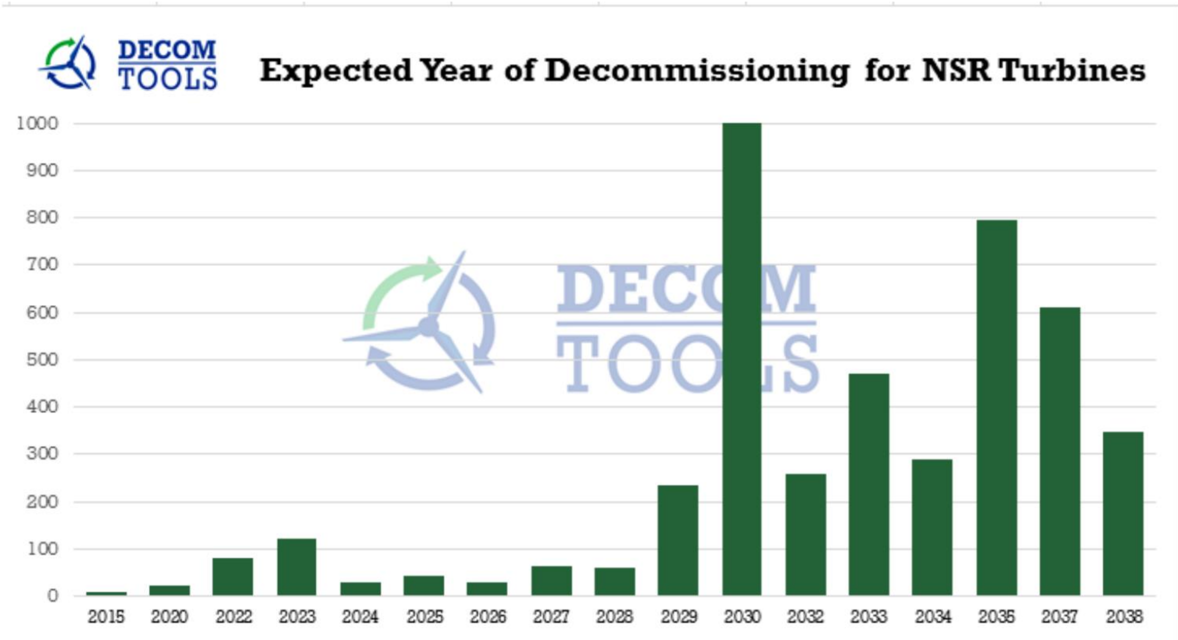


Figure 1 - Projected year of decommissioning of wind turbines in the North Sea area (DecomTools - Interreg project - 2019)

The domain concession of the very first Belgian offshore wind farm, C-Power, expires on 31 December 2034[2], but this can be extended once more subject to approval by the competent authorities. Within the current legislative framework, the decommissioning must be finalised by mid-2039 at the latest.

In the same way that the installation of the first offshore wind farms was pioneering, removing them will be too. Moreover, it has now been a long time since they were commissioned, and there are many

[1] From: Public consultation 2023-02-28 - see FPS Economy.

[2] From: Official Gazette 2014-01-27 - Environmental Permit - Extension - see BMM.

questions about this phased decommissioning process. On the one hand, new technologies are emerging at lightning speed and, on the other, the insights and knowledge on the interaction between wind farms and biodiversity are evolving.

Both in terms of technologies, the required materials, and cost, various new possibilities are being developed that could be applied to decommissioning a wind farm. Among other things, solutions are being explored for blades at their end-of-life stage, as well as ways to remove monopile foundations in their entirety from the seabed. A lot of research is also being conducted into the circular and nature-inclusive design of wind turbines.

Subject to changes in legislation, leaving parts of (some) wind turbines in place, and repurposing them, may also be envisaged. The structures left in place could be used, for example, for hydrogen extraction (in connection with new wind turbines), other energy technologies (floating solar panels, wave or tidal energy) or aquaculture. Questions regarding the desirability of this option and its impact on the marine ecosystem, safety and responsibility first need to be answered to this end.

As regards biodiversity, research[3] shows that additional underwater biodiversity has thrived in and around offshore wind farms, under the so-called artificial reef effect[4]. A wide variety of organisms grow on the new, hard substrates created by offshore wind farms. These artificial reefs form the basis of an abundant underwater fauna of invertebrates, which, being a growing food source, attract various species of fish. Several bird species, such as terns, and marine mammals, including seals, also benefit from the enriched food supply provided by the newly created artificial reef. The artificial reef effect entails a significant change in the original ecosystem.

For more background information and a concise contextual outline of policy, spatial use, environmental impact, sustainable use and the socioeconomic situation of the Belgian offshore wind sector, see the theme text Energy (including cables and pipelines) of the Compendium for Coast and Sea.

[3] Degraer, S., D.A. Carey, J.W.P. Coolen, Z.L. Hutchison, F. Kerckhof, B. Rumes & J. Vanaverbeke (2020). Offshore wind farm artificial reefs affect ecosystem structure and functioning: A synthesis. *Oceanography*, 33:48-57.

[4] The artificial reef effect refers to the ecological effect as a direct and indirect result of the introduction of infrastructure, i.e. the foundations and erosion protection layers.

PROCESS

"What was the process?"

Kick-off

To formulate a vision on the decommissioning of offshore wind farms in the Belgian North Sea which enjoyed the broadest possible support, we invited stakeholders from the academic world, policy, industry and the public sector. Around 120 stakeholders signed up, around 70 of whom were present on 18 October 2022 for at the kick-off meeting in Bruges for the stakeholder process for the decommissioning of wind farms. During the kick-off, the thoughts of stakeholders were gauged for the first time, with questions about the opportunities and concerns surrounding the decommissioning of wind farms. The plan of action and timing of this process was explained and updated at the meeting (Figure 1).

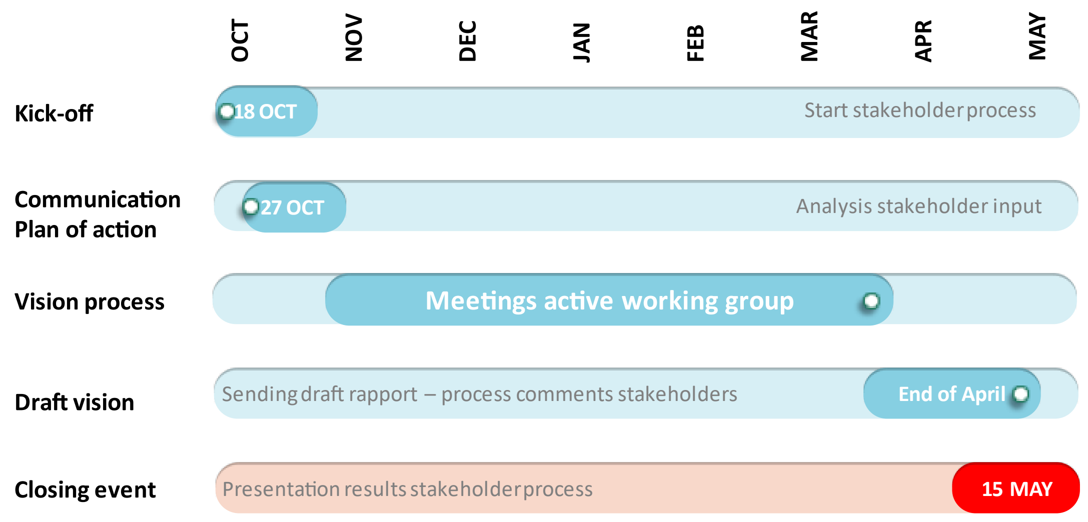
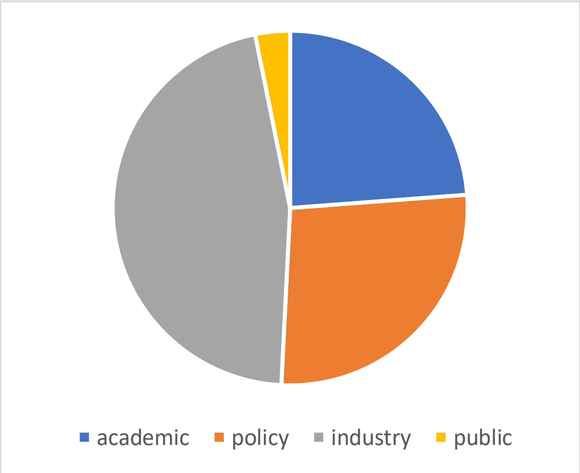


Figure 2 - Plan of action & timing of the stakeholder process

Meetings of the active working group



In the four subsequent meetings, a smaller active working group of about 40 people continued the work.

The participants of this working group are roughly equally divided between academia, policy and industry (Figure 2).

A total of 39 different organisations were involved (Annex 1). The public sector is (only) represented by 4Sea, a coalition of five Flemish nature associations.

Figure 3 - Distribution of participants in the active working group on the decommissioning of offshore wind farms

Each meeting first reflected on the results of the previous consultation, and the next steps were then debated in small groups before the new findings were discussed in plenary at the end. The results were presented in a text or table, and were circulated within the working group for review and adjustment.

The various topics addressed during the meetings were:

- Listing (past and ongoing) decommissioning projects
- Finetuning the objective of the stakeholder process
- Deciding on whether repowering and/or recycling were also relevant
- Defining what the short term and long term are for this vision paper
- Assessing the different decommissioning options for monopile foundations
- Identifying the opportunities and concerns, and organising them according to theme
- Evaluating the options by theme
- Identifying the knowledge gaps identified among stakeholders
- Weighing the importance of the opportunities and concerns within the themes. Assessing other repurposing options if repowering is not chosen
- Ascertaining whether there are any differences when decommissioning GBF[5] and jacket foundations
- Formulating opinions for the government
- Establishing a long-term vision for the wind farms that still need to be (re)built in the Eastern Zone (if repowering is chosen) and for the future wind farms in the Princess Elizabeth Zone.

It quickly became apparent during the discussions at the kick-off meeting that decommissioning and repowering go hand in hand. Repowering was defined here as reusing the zone for electricity from renewable energy sources, and therefore not refurbishing or reusing the foundations by installing new poles (or masts) with nacelles and blades into them. Other repurposing options, such as designating the zones as fishing grounds, nature reserves, sand extraction zones, etc. were also discussed.

Two distinct time frames were identified: the near future and the more distant future. In the near future, a vision needs to be formulated on decommissioning the current wind farms in the Eastern Zone. On the other hand, the new insights may lead to suggestions for the wind farms which still need to be (re)built, and therefore have an impact on decommissioning in the more distant future.

[5] Gravity-based foundations

"What are we discussing?"

1° Overview of wind farms in the Belgian part of the North Sea

Three types of foundations were used for the current 399 wind turbines in the Eastern Zone of the Belgian North Sea (Table 1): six gravity-based foundations (concrete cones filled with sand), 49 jacket foundations (metal lattice structure on pin-piles anchored into the seabed) and the 344 monopile foundations (steel cylinders anchored directly into the seabed; referred to hereinafter as monopiles).

Table 1 - Overview of wind farms; information from the report WinMon.BE 2022 & website of the Belgian Offshore Platform

Project		#	Capacity (MW)	Type of foundation	Rotor diameter in m	Hub height in m LAT[6]	Total capacity in MW	Operational since	Depth LAT[7] in m	Dia-meter	Distance from coast
Norther		44	8.4	monopile	164	107	370	2019	20-35	8-9 m	23
C-Power	phase 1	6	5	gravity-based	126	94	325	2009	14-18	N/A	30
	phase 2 & 3	48	6.2	jacket	126	94		2013		N/A	
Rentel		42	7.4	monopile	154	106	309	2019	22-36	8 m	34
Northwind		72	3	monopile	90	72	216	2014	16-29	6-7 m	37
SeaMade = Mermaid + Seastar		58	8.4	monopile	167	109	487	2020	24.4 - 39.5 22-38	8.3	54 40
Belwind	phase 1	55	3.1	monopile	90	72	171	2011	15-37	4.3	49
	Alstom Demo	1	6	jacket	150	100		2013		N/A	
Nobelwind		50	3.3	monopile	90	72	165	2017	26-38	6-7	47
Northwester 2		23	9.5	monopile	164	106	219	2020	25-40	8-9	51

2° Previous initiatives that are relevant to offshore decommissioning

The interdisciplinary research project SeeOff (01/11/2018 - 30/04/2022), led by Bremen University of Applied Sciences, resulted in a handbook on the framework conditions, technology, logistics, processes, scenarios and sustainability of the decommissioning of offshore wind farms.

In November 2020, WindEurope published a guidance document for the onshore industry *Decommissioning of Onshore Wind Turbines - Industry Guidance Document* with information of interest to the offshore industry as well.

[6] LAT = lowest astronomical tide.
[7] depth LAT is the minimum vertical distance between the sea surface and the seabed at the lowest point of the tide.

"DecomTools" (*Interreg North Sea Region* project)" (01/08/2018-31/01/2023) in which both POM West Flanders and the Port of Ostend are partners, explored new processes and tools in the area of logistics, ship design, safety, and upcycling and recycling. This resulted in a first draft, both in terms of policy recommendations and the development of concepts and tools for the sector.

As regards the impact of offshore wind farms on biodiversity in Belgian waters, the WinMon.BE reports and the accompanying website on the monitoring of wind farms contain a lot of information, which is also relevant for the decommissioning stage. In addition, the EDEN2000 study, "Exploring options for a nature-proof development of offshore wind farms inside a Natura 2000 area," made an important contribution, through 25 studies, to filling various gaps in the scientific knowledge in terms of the impact of offshore wind farms on biodiversity, some of which may be relevant for the decommissioning stage.

In February 2023, it was announced that the company VESTAS had found a solution to the currently non-recyclable 10-15% of existing wind turbines, thanks to the CETEC (Circular Economy for Thermosets Epoxy Composites) project. According to this pilot project, it will be possible within 3 years to upgrade the composites to reusable fibres and recycled epoxy with the same quality as new composites, including by thermal solvolysis.

Below is a list of several studies looking into developing techniques to remove monopiles in their entirety. Even if these are not quite ready to address the larger and deeper offshore wind turbines on a large scale, it is evident that the first steps have already been taken.

- Cape Holland vibrohammer
    - Tested on a smaller monopile from Amalia Wind Farm in the Netherlands, which had already endured the harsh conditions of the North Sea for three years.
- Dieseko vibrohammer
    - This reference concerns relatively small piles with a "small" vibrohammer.
    - A new installation four times larger has since been built by the company De Meyer in Belgium.
- IQIP Blue Hammer
    - Blue Hammer is a small startup that developed this unique pile driver concept. When the pile driver was tested, a pile was installed several times and then removed. A new technique was developed for removing the pile: the pile is hermetically sealed at the top, filled with water and then forced out of the ground by applying additional pressure to the water.

An overview of the ongoing and planned initiatives relating to offshore decommissioning is provided in Annex 2.

3° Decommissioning options

There are several options for decommissioning the infrastructure of offshore wind farms, whether for the foundations, the erosion protection layers or the cables. The foundations can either be completely or partially removed, or remain completely in place. The erosion protection layers and cables can be removed or remain in place.

Since the majority of wind turbines in the Belgian part of the North Sea are on monopiles, decommissioning the monopiles was first discussed in more detail, and after that it was explored whether this is different for the other types of foundations, and if so how different.

The options for decommissioning the monopiles, the erosion protection[8] and the cables were deliberately evaluated separately. This offers maximum flexibility in opting for a decommissioning scenario, by combining the different options.

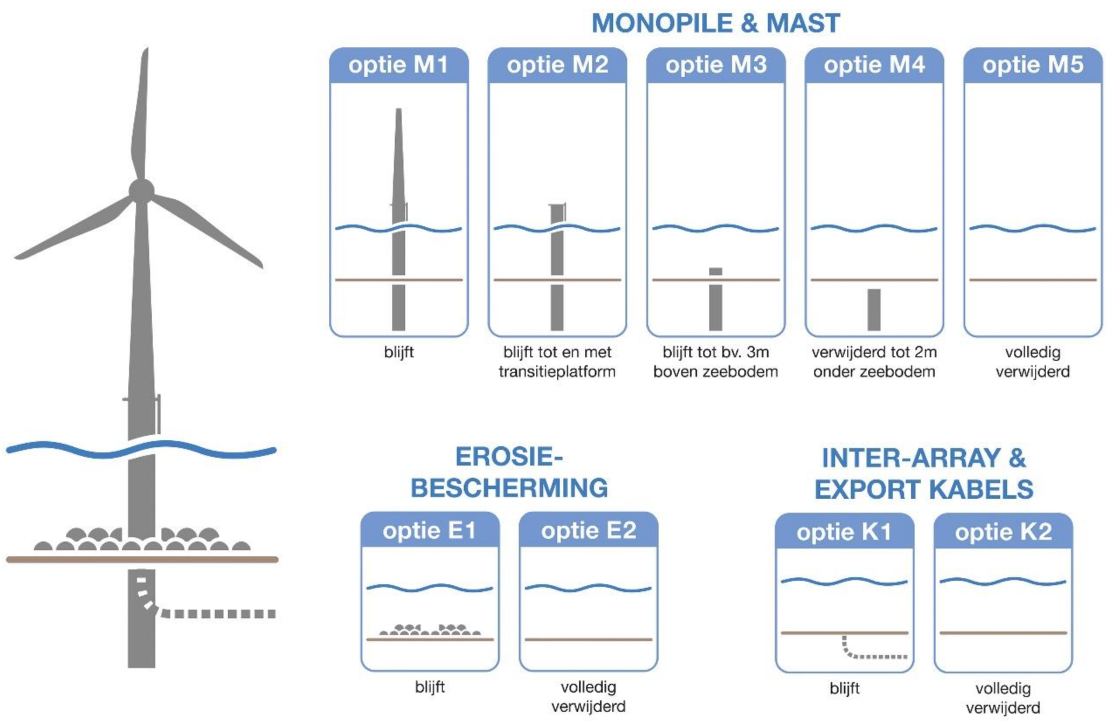


Figure 4 - Options for decommissioning monopiles

[8] Also called scour protection; this consists of dumping stones in the Belgian North Sea.

What options are listed in the environmental permit as regards decommissioning?

In every environmental permit, also called a "ministerial order authorising construction and a license to operate", the following provisions are stated on the subject of decommissioning (in roughly the same terms for the different wind farms) (freely translated):

"The holder is obliged to restore the site to its original condition, in accordance with Article 30 of the RD VEMA (procedure for the authorisation and licensing of certain activities in sea areas) unless, after consultation between the competent administrations and the holder on the advice of the board, it is decided otherwise by the minister. At least one year before the anticipated decommissioning, the recovery plan must be submitted to the board."

"The holder is obliged to comply with the conditions of use as listed in Annex I of this decree, in accordance with Article 26 of the RD VEMA."

Article 26 of the RD VEMA (Royal Decree of 7 September 2003 on the procedure for the authorisation and licensing of certain activities in sea areas under the jurisdiction of Belgium) states (freely translated) "*The Minister may impose any conditions of use to the permit or authorisation that he deems useful to protect the marine environment.*"

Article 30 of the RD VEMA states (freely translated), "*The Minister may impose conditions to be fulfilled at the end of the activity.*"

As regards the conditions of use, every environmental permit states, in roughly the same terms:

"…

Upon expiry of the permit/and or authorisation or cessation of activity, the competent administrations must be informed by the holder of their intentions and proposals. The holder must envisage the necessary financial resources to remove the cables after the operation phase and restore the site (including any removal of the metering mast and transformer platforms and erosion protection) back to its original state to the extent possible.

…

The masts must be cut down to 2 metres below the seabed. Nevertheless, erosion in the area must be taken into account. If the board deems that the piles must be cut to a greater distance than stated herein to account for any occurring erosion, the board reserves the right to propose other standards to the Minister in this regard.

The cables must be completely excavated/removed. If the use of the cables is extended, by the holder or any other user, this extension must be the subject of a new application in accordance with the law and its implementing decrees.

…"

4° Possibilities and concerns

The possibilities and concerns that were identified in terms of decommissioning wind farms in the Belgian part of the North Sea were brought together under several themes:

- Nature conservation and restoration
- Pollution
- Circularity (reduce, reuse, recycle)
- Financial aspect
- Safety
- Future use
  (repowering, aquaculture, fisheries, tourism, research and test site, sand extraction, marine reserve)
- Administrative/legal aspect

The themes of nature conservation and restoration, pollution, circularity, the financial aspect and safety were taken as the starting point for evaluating the various decommissioning options. Each theme includes several elements, which guided the assessment of different decommissioning options one by one. The result of this exercise formed the basis for formulating the proposed preferred scenario.

ASSESSMENT

"Which scenario of decommissioning the current wind farms in the Belgian part of the North Sea is the preferred one?"

ASSESSMENT OF DECOMMISSIONING MONOPILE FOUNDATIONS

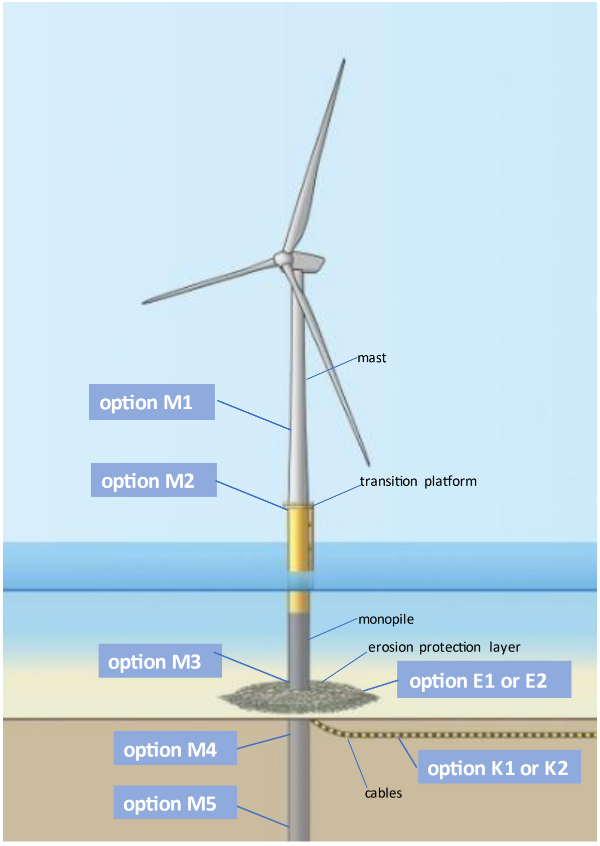


Figure 5 - Monopile parts and options for decommissioning

NATURE CONSERVATION AND RESTORATION

Original nature

The original nature in the Eastern wind farm zone includes an ecosystem essentially linked to dynamic sandbanks. The benthic biodiversity is adapted to living in, on and over permeable, medium- to coarse-grained sediments structured by sand dunes and sand ridges (Van Hoey *et al.*, 2004[9]; Breine *et al.*, 2018[10]).

Offshore wind farms give rise to habitat loss and habitat disturbance of the original nature. Habitat loss is connected to the area taken up by the infrastructure and is limited to the footprint and

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[9] Van Hoey, G., Degraer, S. & Vincx, (2004). Macrobenthic communities of soft-bottom sediments at the Belgian Continental Shelf. *Estuarine, Coastal and Shelf Science*, 59: p. 601-615.
[10] Breine, N. T., De Backer, A., Van Colen, C., Moens, T., Hostens, K. & Van Hoey, G. (2018). Structural and functional diversity of soft-bottom macrobenthic communities in the Southern North Sea, *Estuarine Coastal and Shelf Science*, 214: p. 173-184.

immediate (metre scale) surroundings of this infrastructure. Habitat disturbance is connected to the physical and biological changes resulting from the artificial reef effect.

The artificial structures introduced by the wind farms on the seabed and throughout the water column change the hydrodynamic climate within the wind farm. As a result, changes - coarsening and refinement - occur in the sediment composition. These changes are particularly visible in the immediate vicinity (tens of metres scale) of the foundations and erosion protection layers.

The sediment composition is further altered due to the activity of fauna living on the foundations and the erosion protection. This fauna filters nutrients from the water column and uses them for growth and reproduction. Waste is excreted as faecal pellets that sink to the seabed, refining and enriching the original sediments with organic matter. This refinement and organic enrichment are observed up to tens of metres away from the turbines and erosion protection layers (Coates *et al.*, 2014[11]) and there is evidence to suggest that they extend throughout the entire wind farms and several kilometres beyond (Ivanov *et al.*, 2021[12]). These changes in habitat are reflected in changing benthic fauna. For more information: see FaCE-It, PERSUADE.

> SO, for the original nature, complete decommissioning is the best option because a restoration of the original hydrodynamic conditions and the originally present sediment with its associated fauna are then expected.
>
> If repowering is opted for, whereby the zone is occupied again by various structures, long-term hydrodynamic change and habitat loss and disturbance will occur again. This is another reason to ideally remove as many structures as possible, so that there is minimal negative impact on the original, aimed-for nature.

However, when the infrastructure is completely removed, the natural soft substrate will be disturbed in places. Nevertheless, the fauna which is characteristic of these dynamic ecosystems will rapidly recover. As a result, the impact is expected to be undetectable as early as the short term (scale of several years). Carbon storage in the sediments will also be reversed in places in this scenario.

> SO, the original fauna quickly recovers following a brief, local disturbance during the decommissioning that only occurs once every 25-30 years.

In turn, the indirect effects created by preventing certain shared uses could be a reason to preserve parts of structures above ground. Indeed, the presence of the structures, subject to several restrictive preconditions (such as the distance between the turbines and the locations of the wind turbines, erosion protection layers and cables), will rule out some other activities, such as sand extraction and

[11] Coates, D. A., Deschutter, Y., Vincx, M., Vanaverbeke, J. (2014). Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea, *Marine Environmental Research*, Volume 95, 2014, p. 1-12,

[12] Ivanov, E., Capet, A., De Borger, E., Degraer, S., Delhez, E.J.M., Soetaert, K., Vanaverbeke, J., Grégoire, M. (2021). Offshore wind farm footprint on organic and mineral particle flux to the bottom. *Frontiers in Marine Science*.

bottom fishing. Excluding bottom-disturbing activities offers opportunities to preserve, protect and restore the original biodiversity of dynamic sandbanks, where the habitat has not been lost or disturbed. Permanently excluding bottom-disturbing activities will also ensure that the carbon storage linked, inter alia, to organic enrichment due to the artificial reef effect (Heinatz & Scheffold, 2023[13]) is maintained. But authorising activities or not is more a policy choice which is contained in regulations, and cannot be a reason in itself for installing and/or leaving structures behind.

> However, if the zone is repowered, the restrictions regarding bottom-disturbing activities will continue to apply (immediately or later), so the positive impact of this exclusion on wildlife and carbon storage throughout the entire wind farms will be visible even then.

New nature

Biodiversity created by the presence of the wind farms is regarded as new nature and is essentially directly or indirectly linked to the artificial reef effect.

The new nature found on the wind turbines and the erosion protection layer around them are mostly very common species, such as mussel *Mytilus edulis*, frilled anemone *Metridium senile* and amphipod *Jassa herdmani* (Degraer *et al.*, 2020). These species do not contribute much to the intrinsic nature value, as laid down in international and European conventions and directives (Habitat and Birds Directives, European Nature Restoration Law 'being drafted', protection status, etc.) and as pursued in the current federal policy vision on conservation, protection and restoration of marine nature.

These very common species are an important food source for higher trophic levels, including (commercially important) species such as cod *Gadus morhua* and plaice *Pleuronectes platessa*, which appear to be in higher numbers around wind turbines (Mavraki, 2020; Buyse, 2023). The fact that there are more sheltering opportunities in the wind farms clearly also accounts for these higher numbers. Moreover, it is not yet proven whether these local positive effects are also reflected in the population dynamics of these species at a larger geographic scale and over a longer time period.

Wind farms are also often thought of breeding grounds. Small cod (less than a year old) have been observed near the wind turbines (unpublished data, Jan Reubens), but the relative value as a breeding ground cannot yet be estimated. It may just be a few individual fish finding habitat in the wind farms while the vast majority of juvenile cod are outside them.

These added values are linked to the ecosystem services 'food supply' and 'water quality', rather than to the intrinsic added value for nature and biodiversity.

There is very high connectivity in the southern North Sea, characterised by strong currents. All studies already carried out on e.g. mussels *Mytilus edulis* and limpets *Patella vulgata* (De Mesel *et al.*, unpublished data, Coolen *et al.*, 2020) clearly indicate that the southern North Sea is well-connected given that the larvae of these species can travel long distances (more than 100 kilometres). Consequently, the chosen option for the decommissioning will have a negligible effect on the so-called stepping stone effect.

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[13] Heinatz, K. & Scheffold, M. I. E. (2023). A first estimate of the effect of offshore wind farms on sedimentary organic carbon stocks in the Southern North Sea. *Frontiers in Marine Science*, 16 January 2023, Sec. Global Change and the Future Ocean, Volume 9 - 2022 | https://doi.org/10.3389/fmars.2022.1068967,

The effects linked to increased food supply and additional habitat, shelter and resting opportunities in certain places can be observed as early as several months, to years after the construction of the wind farm (Degraer *et al.*, 2020). In the case of decommissioning in the context of repowering, the hard substrate will be re-installed, meaning that the additional habitat, shelter and resting possibilities will recover quickly. Moreover, not all wind farms are decommissioned and repowered at the same time, meaning that the artificial substrate installed in the area will be replaced each time.

> If a long-term effect on a larger geographic scale does prove necessary for the new nature in terms of food supply, it seems to be best to leave as many structures as possible in place during decommissioning.
>
> The only drawback is that the added value of the new nature is not the added value pursued in the context of nature conservation. Moreover, not everything will be dismantled at once, and in the case of repowering, new nature will rapidly redevelop given its high connectivity.
>
> SO, as regards new nature, the positive effect of leaving the hard substrate in place is barely different when subsequently repowering with wind turbines. In any case, this possible advantage does not outweigh the many disadvantages in other areas, which are described in the following chapters.

Besides facilitating new nature, wind farms also facilitate unwanted non-native species. These non-native species primarily occur on hard substrates in the intertidal zone (Kerckhof et al., 2016[14]). Since there are no natural intertidal hard substrates habitats in the offshore area of the Belgian part of the North Sea, and by extension in the southern North Sea, the risk of these species disturbing natural processes is negligible. Many of these species are also found near stone harbour walls, beachheads and offshore platforms, among other places.

A number of non-native species also occur in the subtidal zone of the offshore area, but in limited numbers. They are found on shipwrecks, gravel beds and other natural and non-natural hard substrates. Given that these species are already widespread, wind farms do not add much to the risk of invasiveness.

> SO, the risk of adding to the further proliferation of invasiveness by non-native species when the artificial hard substrates are left in place is assessed as low. However, for absolute zero risk, the structures must be removed.

Note that this assessment is very specific for the current wind farms in the Belgian part of the North Sea (= Eastern zone), which were mainly (90-95%) built on dynamic sandy areas. Consequently, this assessment does not correspond entirely to the Princess Elizabeth Zone, which is partly located in a valuable Natura 2000 Habitat Directive area and where hard substrates naturally occur (see below).

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[14] Kerckhof, F., De Mesel, I., Degraer, S. (2016). Do wind farms favour introduced hard substrata species?, in: Degraer, S. et al. (Ed.) *Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Environmental impact monitoring reloaded*. pp. 61-75

MISSING KNOWLEDGE - BIODIVERSITY

- Added value of new nature for biodiversity and fish stocks on a large spatial scale and in the long term
- Breeding ground function of wind farms for fish
- Stepping stone function for native and non-native species
- Impact on ecosystem functioning and ecosystem services provided, including possible carbon storage
- Counteracting eutrophication due to suspension feeders on piles
- Exact duration of environmental impacts of decommissioning

POLLUTION

While at first glance it may seem possible to avoid certain forms of pollution in the short term by leaving the wind turbines in place, in the long term the result could potentially be more pollution. However, immediately removing the infrastructure will generate additional physical pollution in the short term, but this ensures that pollution can be avoided in the long term.

Leaching

Preventing or limiting leaching must be a priority. This concerns metals from the cables or from the piles themselves, from the paints, etc., and once the decision is made to leave (parts of) the foundations in place and/or cables in place. It is important to avoid situations where any pollution requires permanent monitoring, and there are no obvious structural solutions to the problem.

Paint flakes

Weathering on the coating of the foundations results in paint flakes breaking off, with possible adverse impacts in the marine ecosystem. This is currently being investigated in the ANEMOI project. Leaving the foundations in place will mean more paint flakes breaking off than if the foundations are removed. Furthermore, if part of the foundation is cut away, polluting paint flakes will break off into the ecosystem. As a result, the option of removing the monopile in its entirety seems preferable to sectioning it above or below the seabed.

Disasters

If the structures remain in place, whether above the water surface or above the seabed, there will be a higher risk of a disaster. Especially with the additional vessels involved in the decommissioning and repowering, the risk of collision is higher. Depending on the type of disaster, the associated pollution can range from negligible to severe.

Material left in place

Apart from the leaching and other disturbances, leaving cables and parts of monopiles where they are is not an option in any case. Once material is no longer in use, it is legally regarded as 'leaving waste behind' and must be treated as such.

Cables are usually underground and are therefore not really 'seen'. Ultimately, they are structures put there by humans that sooner or later will have to be removed, e.g. because they are in the way of new infrastructure works, sand extraction, or because the components can be reused in the near or more distant future.

Noise

When infrastructure is demolished, the volume and total duration of underwater noise is a concern. Impulsive noise in particular has negative effects, e.g. on marine mammals such as porpoises commonly found in Belgian waters (Haelters *et al.*, 2011). In contrast to the construction of wind farms, removing infrastructure - as far as is currently known - does not produce impulsive noise. Nevertheless, a negative effect of non-impulsive noise cannot be ruled out.

The noise does not stop after the decommissioning, as noise is also subsequently produced during repowering. The decommissioning phase and a new installation phase therefore form one long period of noise.

Sediment plume

Removing infrastructure situated in the seabed inevitably creates a sediment plume, as the bed is stirred. The size of the sediment plume will depend on when it occurs. The level of the impact of bottom disturbance when e.g. a complete monopile is removed, depends on the technique used. Despite the fact that techniques for complete removal are still under development, the impact is expected to be temporary in general, and primarily at the local level. Given the dynamic nature of the sandbank ecosystem in the current wind farms in the Eastern Zone, the impact will be acceptable. In the future wind farm zone, the Princess Elizabeth zone, where hard substrates is naturally present, a sediment plume will have much more impact and is best avoided.

Corrosion

(The remaining part of) the monopile will continue to corrode, and the corrosion will be mixed with the sediment. Although corrosion of metals is known to have ecological effects similar to those of shipwrecks, the exact impact is not known.

Carbon footprint

The carbon footprint during the decommissioning should be kept as low as possible, but can be offset if necessary. It is possible that at the time of the decommissioning, ships will be running on renewable energy, which could significantly reduce the footprint. This makes it difficult to compare the impact of different options.

Visual pollution

Assessing visual pollution is irrelevant, as there is a good chance that there will be repowering with new wind turbines. In that case, the view will remain pretty much the same.

MISSING KNOWLEDGE - POLLUTION

- Harmful paint flakes breaking off during (partial) sectioning
  > currently being investigated in ANEMOI project.
- Applicability of techniques for removing monopiles in their entirety, on larger monopiles that have been in place for some time.
- Noise pollution from the removal technique; total noise pollution.
- Negative effect of non-impulsive noise on marine organisms.
- Exhaustive reduction in noise production when foundations are removed.
- Precise level and impact of corrosion when a part of the monopile is left behind, both above water and in the sediment. Note: is information on corrosion of shipwrecks applicable to monopile part?
- Striving for the lowest possible carbon footprint

- CO_2 impact of various operations; total life cycle analysis.
- Dredging volume inside and outside the pile, and before removing the erosion protection and cables.
- Whether or not to use geotextiles (e.g., at landfall of cables on shore and/or at crossing of cables) to estimate risk of release of microplastics when infrastructure is removed.
- Degree and speed of leaching metals from cables.
- Amount of grouting released during removal (as well as during the entire operational phase).

  Grouting is the injected cement layer at the transition piece to transfer the loads from the turbine tower to the more stable monopile foundation of the turbine.

CIRCULARITY

Geopolitics

There are increasing signals from the European Commission that Europe needs to become self-sufficient, including in raw materials and other supplies. This can only be achieved by continuing to use and reuse the materials we already have for as long as possible, and therefore definitely not leaving materials unused at sea.

Pressure on local waste management

For 90% of the more recyclable materials, including metal, strong but manageable pressure on local waste management is to be expected, given that the capacities are not always available locally, and there may be related logistical problems (see also "Processing capacity"). For the 10% of more difficult to recycle materials, primarily the blades but also cables, batteries and permanent magnets, there is significant pressure due to uncertainties regarding the technology to be used, available capacity and possible outlets for the recycled material, on top of the pressure related to logistical issues.

The pressures on local waste management (and current processing capacity) were clearly identified in the DecomTools project.

Processing capacity

Metals and concrete

For metals and concrete, the primary material streams when monopiles and gravity-based foundations, respectively, are decommissioned in offshore wind farms, there are sufficient processing facilities available in Belgium. Although smaller local companies can sometimes temporarily face an accumulation of material, the larger players, such as scrap metal companies in the seaports of Ostend and Ghent, and crushers that process concrete rubble from large construction sites, have sufficient processing capacity. To ensure that these materials are efficiently forwarded to recycling companies, the right preconditions (such as location, maritime access, quay and site strength, surface area and accessibility) for potential port sites and an efficient logistics organisation are necessary. However, it may be interesting to envisage more processing capacity near the decommissioning port, to reduce logistics costs.

Concrete recyclates from offshore wind farms may have to be used with caution in new applications. The long-term effect of salty seawater on the material will potentially make it unsuitable for reinforced concrete applications.

Offshore cables

Recycling capacity is available in Belgium to recycle ground cables, but for now it is not entirely clear whether these facilities are also all technically capable of handling offshore cables and/or whether the licensed capacity will be adequate to handle this additional volume. As is the case with the other material streams, it will have to be examined whether more local recycling capacity is needed for logistical reasons.

Permanent magnets

There is still a lot of uncertainty regarding the processing of permanent magnets, which contain REE[15]. This material could in principle be processed in the metallurgy sector, but it is not known whether companies in the EU are already doing this. In Belgium, at least one metallurgical company (Umicore) is already licensed to recover REE from magnets, but it is unclear for now whether the company already actually does it, and whether on a large scale.

Blades

Until now, the processing of blades has consisted mainly of grinding and further use as filler in building products, or in the cement industry for energy recovery and as a source of mineral material for cement; not very appealing reuses in general. Moreover, precautions definitely must be taken when using the filler in building materials, in view of potential problems later on when these materials are recycled, such as microplastics and fine fibres released during crushing. Similarly to the problem of fine mineral fibres with asbestos, safety is also an extremely important consideration.

[15] *REE* = Rare Earth Elements = used in various industrial applications because of their unique magnetic, optical and chemical properties.

Small-scale initiatives reuse the blades in bridges, for bike shelters, benches, climbing equipment for playgrounds and noise barriers next to motorways.

For the large volumes that will be generated from the offshore decommissioning, there is a need for readily scalable recycling methods that produce materials for which outlets can be found. Various research and pilot projects are underway in this context, and a distinction can be made between, on the one hand, developments toward easily recyclable blades for future wind farms and, on the other hand, developments toward recycling the blades for the current wind farms to be decommissioned. Through its CETEC project, the company VESTAS recently came up with a solution to reprocess the composites into reusable fibres and recycled epoxy with the same quality as new material, among other things by thermo solvolysis.

As regards the blades of the current wind farms in the Eastern Zone, decisions will have to be made in the relatively near future regarding the recycling techniques and the related logistical requirements. Finding suitable sites, going through licensing procedures and building facilities and/or scaling up capacities takes time.

It may be possible to rely on recycling possibilities in other member states, but even then there will be logistical requirements that will have to be met locally.

Another consideration when looking for outlets for recycled material from the blades is that the presence of any substances of concern clearly has to be ascertained. Among other things, if these substances are present, restrictions may be imposed on applications where it is still possible to use the material.

Erosion protection rocks

In principle, the rocks of the erosion protection layer are eligible for reuse, even for their original purpose. That way, they don't have to be brought on land first. The rocks in themselves do not pose any direct risk if left at sea, but according to the waste hierarchy, reuse is preferable to leaving behind unused. Moreover, if removed or reused, the rocks will no longer obstruct any repurposing of the zone. Nevertheless, it is unlikely that the rocks of the current erosion protection layers will be spontaneously reused as erosion protection in the event of repowering.

Completely removing the erosion protection layer is also envisaged in current environmental permits, which state that (freely translated) "the holder shall envisage the necessary financial resources to restore the site (including the erosion protection layer) to its original condition to the maximum extent possible after the operation phase." However, the wind farm owners request that the erosion protection layer be left (partially) unused or not, as removing it is not very interesting financially, and time-consuming, and the erosion protection layer is not an obstacle for the repowering. But marine contractors contradict this claim.

MISSING KNOWLEDGE - CIRCULARITY

- Long-term effect of salty seawater on concrete recyclates from offshore wind farms; material possibly unsuitable for reinforced applications.
- Further research into alternative/better decommissioning techniques for gravity-based foundations.
- Is the technology to recycle onshore cables the same for processing offshore cables as well?
  And if so, is the technical capacity of these facilities for handling onshore cables sufficient?
  Is the licensed capacity sufficient to handle this additional volume of offshore cables in addition to onshore cables?
    - AZ Kabel (Tielt); Dockx Recycling (Arendonk)
- Many uncertainties as regards processing permanent magnets; one company in Belgium is definitely licensed to recover REE[1] from magnets, still unclear if they do so on a large scale.
- Results of ongoing research and pilot projects on the one hand, including developments towards easily recyclable blades for future wind farms and developments towards recycling blades of current wind farms on the other.
- Presence of substances of concern in the blades
- Current available capacities
- Ecodesign - design with the lowest possible environmental impact
- Legally possible to extend the life of wind farms?
    - Is keeping them operational for an additional 10 years an option?
    - EU policy decisions desirable; federal government (based on technical limits of materials --> maintenance companies of current wind farms)
- Which parts typically qualify as spare parts already? Perhaps gearbox and generator. To be explored further.

FINANCIAL ASPECT

Total financial cost

The financial total cost is very important in any scenario, but difficult to assess without knowing the actual cost. Nevertheless, it seems plausible that delaying the removal of the infrastructure is only a short-term cost saving. The cost of removal will come at some point anyway, and in all likelihood will even be higher.

In the long run, it may just become more difficult and expensive to demolish, dispose of and recycle the older structures. The scale of the future costs is more uncertain as a result. There are no longer any uncertain costs for everything that gets removed.

It is therefore advisable to remove everything 'in one go', and this is an elastic concept. This means that structures must be removed in a continuous and logical sequence, taking into account available capacity (people and resources) and according to weather conditions (including seasons). Possible limited breaks, e.g. to group things together depending on efficiency (scale effect) or to give time to develop the appropriate technology, may be considered.

Cost savings for future reuse

It is crucial to decommission the wind farms in a way that leaves as many options as possible open for future reuse of the zone, both for repowering and for other current or future uses. Financially, this has the advantage that no further unforeseen costs can be expected, nor are there additional long-term insurance costs to cover the risk of left behind, dangerous or invisible obstacles to navigation and other functions.

Cost savings by reusing materials

When conducting a cost-benefit analysis, there may be potential cost savings from reusing materials in other locations or through recycling. However, this aspect will never be decisive in the financial consideration of the chosen scenario.

Making financial savings by reusing materials, such as rocks from the erosion protection layers in place, is considered highly unlikely. On the contrary, both reusing the erosion protection layer where it is, and completely removing it, are deemed to be very costly.

Envisaged financial resources

Whether or not the costs are within the envisaged financial resources[16], to restore the area to its original state as much as possible, is especially important for both the operators of the wind farm and society at large. The conditions of use of the environmental permit state that these resources must be envisaged by the operators of the wind farm. In the end, it will be society (i.e. us) who will bear the costs, either because they will be passed on by the operators of the wind farm, or because costs were not envisaged and the government will be responsible for the clean-up.

[16] Depending on the permit, this is a provision or a bank guarantee; the latter is not held by the government. Action would therefore still need to be taken here.

Until now, the decommissioning procedure was assumed to be the installation procedure reversed. This assumption is now being questioned more and more, for the following reasons:

1. Studies conducted on removing existing monopiles highlight the fact it was more complex than expected (SeeOff studies, Dillinger Offshore Wind conference, Passat Trials Project, etc.)
2. Decommissioning the foundations involves more, and more complex, steps than installation (preparatory work offshore rather than on land, removing rocks, dredging, sectioning, etc.)
3. Lessons from decommissioning oil and gas facilities suggest that it is more complex than originally expected in execution and preparation
4. The technical condition of an offshore structure after several decades is significantly different from the time of installation (corrosion, leaching, loss of grout, weakened lifting points, etc.)

However, what may have a positive effect is the fact that today's installation vessels are evolving at such a pace that decommissioning can potentially be carried out using vessels that are much larger and more efficient than those used when the wind farm was installed.

In summary, there are currently many uncertainties regarding the decommissioning scenarios from a financial perspective!

MISSING KNOWLEDGE - FINANCIAL ASPECT

- Actual costs unknown

  - Additional or lower costs of completely removing the monopile

  - Possible additional cost of demolishing it in two times

  - Additional cost due to degradation over time; cf. chance of them falling or breaking, and then clean-up is even more difficult (or impossible)

  - Additional cost and obstruction for new activities in that zone in the future

  - Additional risk (and therefore cost) due to poor or invisible obstacles to navigation

  - The impact on the cost of energy of the different scenarios.

- Who is liable for materials left behind (monopile/cable spaghetti)?

- Full cost-benefit analysis, including long-term impact on ecosystem services (ESS) and life cycle analysis (LCA) of all options needs to be carried out.

  Important point: what indicators will then be decisive in choosing a method? Where most importance is attached: impact on ecosystem services, climate change, resource depletion, etc.

- Consult maritime/offshore project developers, but definitely also companies that are already active in decommissioning in other industries: Saipem (IT), Heerema (NL), Boskalis (NL), Scaldis (BE), DEME, Van Oord (dismantled at Robin Rigg, among others).

SAFETY

Incidents at sea, whether involving persons, vessels or environmental in nature, must be avoided to the maximum extent possible. In this risk analysis of the various strategies for people and equipment, only the offshore context was looked at, in other words, onshore security risks were not considered.

Risk management during decommissioning

Risk management during decommissioning is essential. The decommissioning itself is a temporary but highly intensive process. Operations at sea always involve significant risks. The operation at sea creates an obstacle at that spot, similar to road works. This can lead to dangerous situations as surrounding traffic continues while an operation is in progress.

The risks of the decommissioning activities increase as more is dismantled, due to the increasing complexity of the tasks. These risks are known and under control at the companies in question, just as they were when the wind farms were built. Examples can be found at Boskalis|Decommissioning, DECOM|North Sea, etc.

Risk management after decommissioning

Once the decommissioning process leaves infrastructure (partially) in place, risk management after the decommissioning is essential. This is a long-term process and consequently entails known and unknown long-term risks. This can be dangerous for reuse of the zone for the same activities or is occupied by new users, as well as for the environment. As such, it remains uncertain how much erosion will occur in this zone which could cause any structures left behind to rise above the seabed surface.

Navigation risks

Navigation risks must be avoided to the maximum extent possible, for both large and small vessels. This includes preventing collisions (including when large ships drift in heavy storms), as well as maintaining safety during anchoring. Every additional structure in the sea, especially one without a function, is one too many. Cables and left-behind parts of the monopiles, when they are no longer in use or monitored, can become exposed in the long term. Besides economic motives, removing the entire erosion protection layer and monopile, and to a lesser extent the cables, is therefore also necessary for the safety of navigation.

Contractual and insurance risks

The additional risks of leaving structures behind is also reflected in contractual risks and insurance risks. Clarity as regards liability is essential, as is adequate protection for the people involved.

Utilisation of the sea

It is essential to consider the level of utilisation of the sea. This is currently visually represented in regularly updated heat maps and used by agencies such as pilot stations. The lower the utilisation rate, the safer it is. This suggests that it is better to leave as few structures as possible. The decommissioning phase itself, like the construction phase, is itself a feat in terms of ensuring safety for all involved.

Improper use

Structures that are left in place naturally attract improper use: mooring at the foundations (yachts, divers, fishermen, migrants), catching lobsters on and around the erosion protection layer, theft of cables due to the value of copper, etc. This entails additional risk and danger which is eliminated if all infrastructure is completely removed.

Tourism function/overnight stay

It was briefly suggested using parts of the foundation for economic activities, such as a hotel or casino. This scenario seems highly unlikely since the foundations were originally designed with a limited lifespan in mind and never for permanent use. Different design criteria apply to manned platforms. Moreover, a monopile only offers limited space, so other uses are far from straightforward. Perhaps it could just about be envisaged as a workers' hub, where it is possible to stay overnight occasionally and only if necessary e.g. in bad weather conditions. A thorough risk analysis must first be carried out in this regard.

MISSING KNOWLEDGE - SAFETY

- The domain concession and the environmental permit stipulate that the installations must be decommissioned. But who remains liable if more material is left behind than originally anticipated? Who will take care of signage? Who bears the responsibility, management and cost in this regard?
  - This requires a more thorough legal examination. At first glance, permit holders, new and old, appear to be responsible. As soon as the government gives permission to leave material behind after the permits expire, this will probably fall on the shoulders of the State.
- Who remains responsible for maintenance and stability of the structures so that safety is not compromised?
- There are methods to completely dismantle installations. How safe are they?
  - Check with maritime/offshore project developers
- Who can estimate risk management after decommissioning - service life depends on type of use (fatigue, corrosion, etc.)
  - Check with maritime/offshore project developers

ASSESSMENT OF DECOMMISSIONING NON-MONOPILE FOUNDATIONS

For the assessment of the different decommissioning options for the other (non-monopile) foundation types, virtually no differences emerged.

However, the method of bringing a gravity-based foundation ashore is different from that for monopiles in technical terms. This foundation may first be broken into smaller pieces using specialised equipment such as breakers or hydraulic demolition hammers. The broken pieces are then removed from the site and disposed of. This will create significant additional local disruption. Further investigation may well identify alternative and perhaps better decommissioning techniques for the six gravity-based foundations.

Conversely, the four legs of the jacket foundation can be cut more easily than a monopile. There is also no erosion protection layer around wind turbines with jacket foundations.

Apart from that, the same observations apply as for dismantling the monopile foundations.

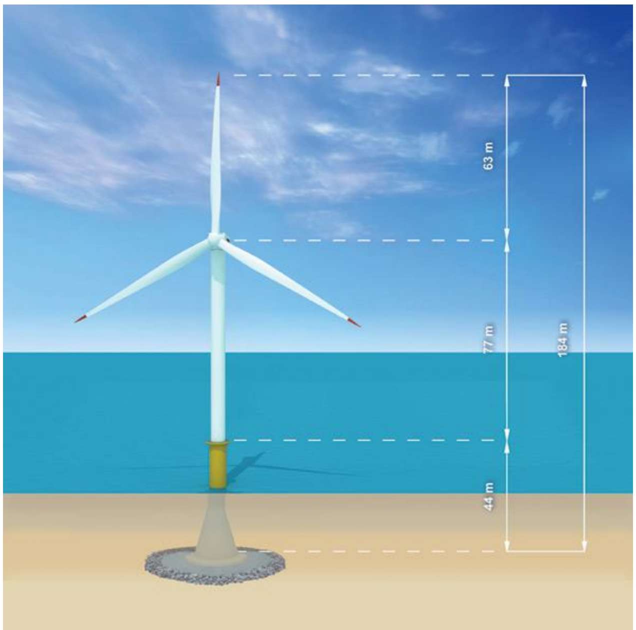

Figure 6 - Gravity-based foundations

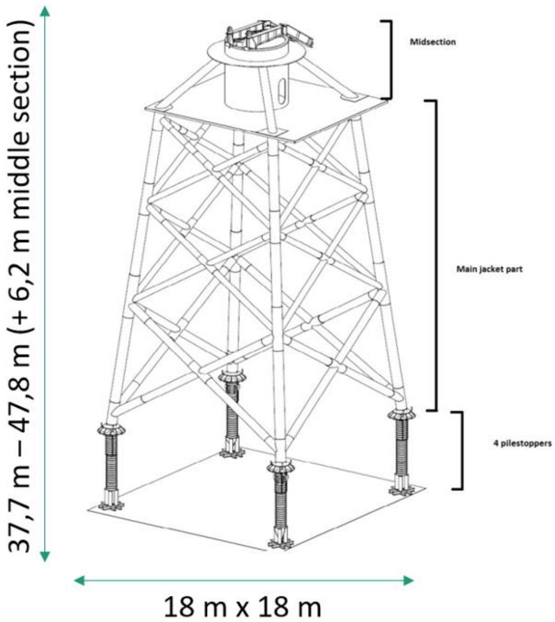

Figure 7 - Jacket foundations

VISION

VISION in the event of REPOWERING

Several wind farms are currently operational in the Belgian part of the North Sea. When these wind turbines reach the end of their working life, the question arises whether or not they should be completely removed.

If the government opts for repowering the area, completely removing all structures (= reset scenario) seems the most appropriate solution for decommissioning the current wind farms in the Eastern Zone. This means restoring the site to its original condition to the extent possible, by actually removing everything, unless this proves infeasible for the monopile foundation, from a technical perspective. In the latter case, everything must be removed as deep as possible, and at least to two metres below the stable seabed.

The only opposition to removing all structures is from wind farm owners, who prefer the option of removing the structures up to two metres[17] below the stable seabed unless there are no obstacles to deeper removal. Furthermore, for the erosion protection layer, we prefer to keep the possibility open of leaving it (partially) in place, or not. Both proposals are based primarily on short-term financial arguments and technical uncertainties.

Why choose the 'reset scenario'?

Nature conservation and restoration

A distinction must be made between biodiversity which is typical of the original habitat of dynamic sandbanks, and the new biodiversity, which is typical of hard substrates and created by artificially introducing a hard habitat.

The naturally occurring and preferred fauna of dynamic sandy substrates is adapted to high dynamics, so it can withstand temporary disturbance caused by the decommissioning activities relatively well.

For the new biodiversity created from the artificial reef effect, completely removing the structures is not considered problematic. Indeed, this biodiversity is not considered of such interest in a naturally dynamic sandbank ecosystem that it has to be left untouched, given that such habitat do not naturally occur in this location. Moreover, decommissioning in the context of repowering will mean that the hard substrate reappears in the form of a new wind farm, so these additional habitat, shelter and resting opportunities will recover in the short term and in phases.

[17] Concern of the group: if it is financially/technically feasible to remove the structures up to two metres deep, the question is whether the same technique could also be applied three, four, five, ... metres deep.

Safety

The structures left behind create more problems than benefits. For example, the parts left behind can be an obstacle to shipping, and may be dangerous to other users of the sea. It is critical to minimise the safety risks as much as possible.

Waste hierarchy

Whatever the case, it is advisable to reuse or recycle unused valuable materials rather than leaving them unused in the sea.

Various functions can be considered if part of the foundation is preserved for reuse (aquaculture, passive fishing, research, etc.). Assuming the area is redeveloped for renewable energy generation in any case, these functions can just as well (or better) envisaged on or adjacent to the new structures. In this respect, it is unnecessary to incur financial and security risk by leaving parts in place. For example, the design of the new wind turbines can take into account the needs of aquaculture or research, and provide additional space for sensors and monitoring.

Furthermore, any structures left behind will also have a negative impact on the marine ecosystem and biodiversity. Various pollutants will leach out, including copper and other metals, zinc anodes and flaking paint, plastics and concrete (including the grouting) for a long period of time.

Legislation

The scenario in which the foundation, erosion protection layers and cables are completely removed is in line with prevailing regulations and agreements, including the domain concession and associated environmental permit(s)[18], the 'polluter pays' principle from the Marine Environment Act and the OSPAR convention that complete decommissioning should always be the rule.

Moreover, when everything is removed, the uncertainty in terms of liability for the remaining structures is also eliminated.

Technology

Technologies in the field of decommissioning are developing rapidly due to strong market demand. Among other things, this can be seen in the efforts to find solutions for completely removing monopiles. Various solutions are currently being tested to apply the complete removal of monopile foundation on a larger scale, even for larger monopiles that have been in the water for a long time. In addition, there is also a growing focus on reducing the environmental impact of the decommissioning process itself.

It is important that this aspect be considered as much as possible for wind farms that still need to be built or repowered, as early as the design phase.

[18] Besides the stipulation in the environmental permit that the holder must restore the site to its original condition unless otherwise decided by the minister, the terms of use of the same permit require the masts to be cut down to 2 metres below the seabed. Legal clearance is therefore called for.

VISION in the event of other repurposings

If the area were to be fully or partially repurposed other than repowering, this could affect the assessment in some areas. Nevertheless, in most cases even the reset scenario, with the complete removal of all structures, remains the most logical choice for the same reasons as mentioned above. For example, if (part of) the area is freed up to allow functions such as active fishing, sand extraction or the development of MPAs[19], removing all structures is also *de facto* the best conceivable preparation of the site for this future use.

If there is no repowering in the area, and no new structures will be built, a number of activities call for retaining a limited number of foundations, whereby the piece above the transition platform is removed[20].

Some of these reasons include:

- providing structures that can be attached to, which are useful for aquaculture and passive fishing
  (e.g., longlines, baskets, etc.);
- providing a research base for monitoring the sea and climate (e.g., for sensors, testing, etc.);
- providing a test site for new technologies in offshore wind and other forms of renewable energy (e.g., floating solar panels, hydrogen generation, etc.);
- use as a unique attraction for tourists, especially people interested in the sea and adventure (e.g., use as an observation deck or 'adventure park', a jetty for recreational divers and snorkelling enthusiasts).

For aquaculture, it may be important in that case to retain the erosion protection, as the increased presence of European oysters would lead to more splash catch. Moreover, leaving the erosion protection is place has a positive impact on (new) biodiversity, which provides opportunities for passive fishing and recreational diving, although there are related safety risks (see 'Safety' above).

The MultiUse Purpose (ETF) project plans to further research the potential of this form of reuse (Annex 2).

[19] *MPA = Marine Protected Area*

[20] The transition platform is the wide platform located between the mast of the wind turbine and the tower. This is yellow, and has a safety railing.

Opinion on future wind farms

Advice for both the Princess Elizabeth Zone and the Eastern Zone

The findings also offer insights into how the design of future wind farms can be optimised, taking into account the decommissioning phase. In the Belgian part of the North Sea, new wind turbines are planned to be installed in two locations. Firstly, the repowering of the Eastern Zone will (most likely) go ahead, and secondly, a new wind park zone, the Princess Elizabeth Zone, will also go ahead.

Regarding the opinions for both zones, the main points raised related to the principle of circularity, taking into account the waste hierarchy. The various elements of a wind turbine (including the foundation) must be developed in such a way that simplifies decommissioning. Before new wind farms are built, consideration should be given to how the wind turbines will be decommissioned, and the design should be adapted accordingly.

AVOID WASTE

For the current wind farms in the Eastern Zone, avoiding waste is no longer possible because it is already there. This makes it all the more important to focus on this as much as possible in the event of repowering, and in wind farms that still need to be built. One way to do this is to take a more modular approach, so that certain components and structures can be replaced or reused more easily and more effectively.

If waste really cannot be avoided, it is crucial for future wind farms to further optimise the designs so that the same (or higher) efficiencies can be achieved with fewer materials.

MAXIMIZE REUSE

Spare parts are already reused wherever possible, to a limited extent, and that is very valuable. For other parts, reuse should be examined according to technological advances, as this is not currently possible. Taking a more modular approach in future wind farms should make it easier to reuse more components (as spare parts or as parts for a new turbine).

In principle, the rocks used for erosion protection can be reused again and again. If the zone is repowered, it makes sense not to bring the rocks back onshore first, but to immediately reuse them as much as possible in the same zone.

RESTORE MATERIAL

Repairs and maintenance are already frequently organised, to optimise the working life and efficiency of the turbines. For future wind farms, the turbine design, including the foundation, should be further optimised to ensure that all components can be repaired/replaced. If this makes it possible to significantly extend the working life of the turbines compared to the current 20 to 25 years, then longer-term concessions can also be considered, to avoid having to decommission high-performing units early.

RECYCLE

Recycling is the treatment and processing of waste materials so that they can be made into new products. It is important that the elements from future wind farms, that cannot be reused, can be recycled as much as possible.

ENERGY RECOVERY

Energy recovery is one of the current options for processing the blades, but this is generally considered low-grade due to the material loss. Developments are underway that will enable higher-quality recycling, so it makes little sense from a circular materials viewpoint to focus on further expanding this processing avenue.

LANDFILL DISPOSAL

Various materials are already subject to a landfill ban. Focusing on more landfill capacity is not at all desirable from a circular materials policy standpoint.

Opinion for the Princess Elizabeth Zone

Unlike in the Eastern wind farm zone, there are extensive geogenic reefs in the Princess Elizabeth Zone, i.c. gravel beds (Habitat Type 1170). This means that a hard substrate is naturally present. As a result, e.g., a sediment plume created by the operations of the decommissioning will have much more impact than in dynamic sandy soils, and is best avoided. On the other hand, various win-wins can be achieved in the gravel bed areas by introducing artificial hard substrate habitats such as foundations and erosion protection layers. Whereas, due to the natural value in the first zone, it is recommended that everything be removed during decommissioning, the situation is different in the Princess Elizabeth zone.

Over the last 20 years, both technological know-how and the way biodiversity (disruption) is viewed have evolved significantly. Precisely for that reason, that discussion around decommissioning offshore infrastructure, even at the OSPAR level, has been revived.

The gravel beds currently have limited wildlife value because they are still intensively stirred and fished with trawls. If bottom fishing is excluded here for 20-30 years due to the presence of a wind farm, a rich ecosystem will develop (see EDEN2000 studies). Consequently, taking into account all the considerations in this report, we can consider (partially, or not) leaving the cables and/or erosion protection layers in place in the Princess Elizabeth zone, and more specifically in or near gravel beds.

With the current knowledge and techniques, it is best not to remove cables in or near gravel beds during the decommissioning, so as not to disturb the rich habitat. This will not occur in the dynamic sandbanks of the current Eastern Zone, as there are no gravel beds naturally present. Another example involves designing erosion protection layers in a way so that they closely resemble natural gravel beds. When an erosion protection layer is constructed in this way in or near a gravel bed area, after 20-30 years it also creates biodiversity which occurs naturally in that area. Subsequently removing this erosion protection during decommissioning, and compromising the area again for the next 20-30 years, should be avoided.

The new wind farm zone (Princess Elizabeth Zone) will partially straddle a Natura 2000 area (Figure 6). This means that, unlike the first wind farm zone, the local natural value takes priority.

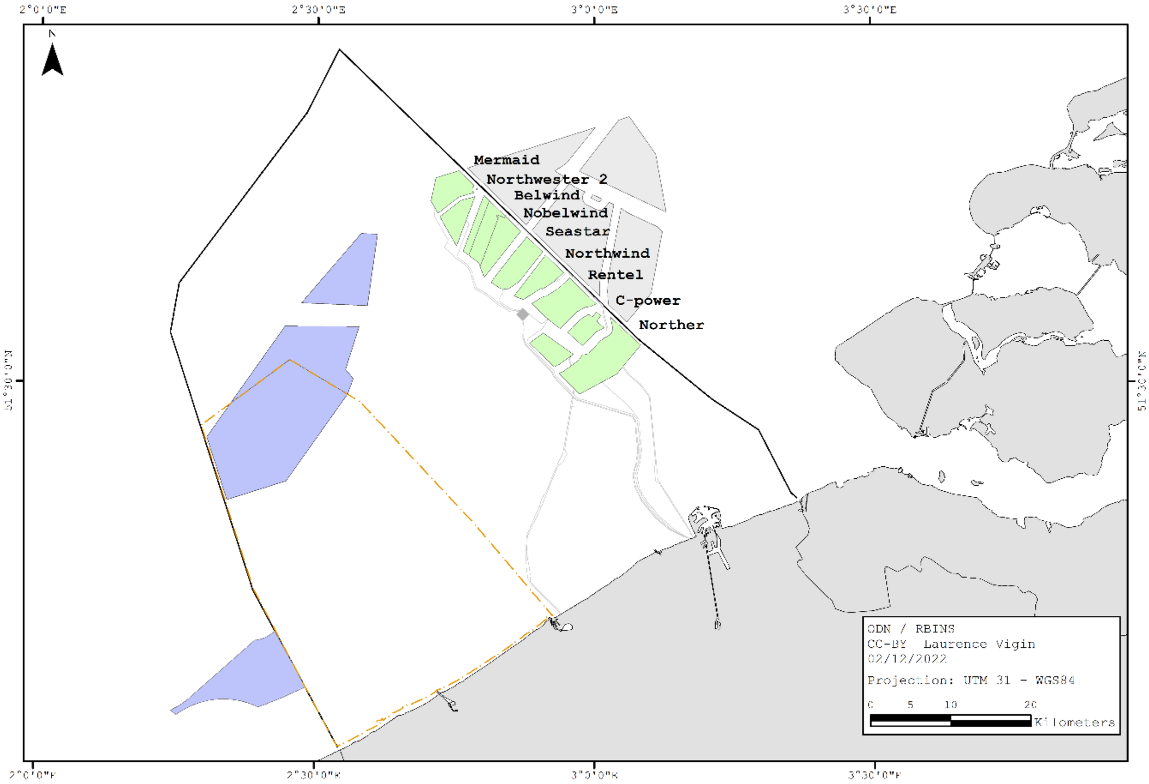

Figure 8 - Current and planned renewable energy zones in and around the Belgian part of the North Sea (in orange dotted line Natura 2000 area).

The Natura 2000 site, more specifically the 'Flemish Banks'[21] habitat directive area, is demarcated on account of very specific natural value. This means that the renewable energy extraction function can be expanded if it does not adversely affect the local natural value. If significant adverse effects cannot be ruled out, expanding the Princess Elizabeth Zone will entail an obligation to compensate the damage to the natural environment. This compensation will have to be discussed and agreed upon with the European Commission, as was previously the case when a soil protection area was established to compensate for the damage to a Natura 2000 area during the Maasvlakte 2 development at the Port of Rotterdam.

Belgium is one of the first countries in the world to build a wind farm in Natura 2000 territory. The country is therefore playing a pioneering role, which creates a pressure that should not be underestimated. The implications of this are being considered, and more specifically, how any adverse effects can be avoided and any positive effects enhanced. The scientific basis for this analysis was recently boosted by the EDEN2000 studies.

[21] Natura 2000 areas can be both habitat directive areas and bird directive areas; no wind farms are currently located in bird directive areas.

List of figures and tables

ANNEXES

ANNEX 1 - Organisations in the active working group for the vision process DECOMMISSIONING OFFSHORE WINDPARKS in the Belgian part of the North Sea

1	Antea Group
2	Arcadis
3	Belgian Offshore Platform
4	Boskalis
5	De Blauwe Cluster
6	DECO Subsea NV
7	Department of Agriculture and Fisheries
8	DG Maritime Affairs
9	ENECO
10	ESM bv
11	FPS Economy - Continental Shelf service
12	FPS Health, Food Chain Safety and Environment (HFCSE) - DG Environment - Marine Environment Unit
13	GEOxyz
14	Port of Ostend
15	Research Institute for Agriculture, Fisheries and Food
16	International Marine and Dredging Consultants
17	Jan De Nul Group
18	Catholic University of Leuven
19	Royal Belgian Institute of Natural Sciences
20	Luminus
21	Natuurpunt NPO
22	Nieuwpoort
23	OTARY NV
24	OVAM (Public Waste Agency of Flanders)
25	Parkwind
26	POM West Flanders
27	Private
28	Province of West Flanders
29	Rederscentrale
30	Rederij De Smit
31	FPS Economy, DG Energy
32	City of Ostend / Port of Ostend
33	Strategy and Development|Province of West Flanders
34	University of Antwerp
35	University of Ghent
36	Virya Energy
37	Flanders Marine Institute
38	WWF Belgium
39	Zeegra NPO

ANNEX 2 - ongoing and planned initiatives around offshore decommissioning

Ongoing projects

The project "Circular Transition in Offshore Wind - CTO - (VLAIO project)" - (01/01/2022-31/12/2024), is looking into how the end-of-life phase of offshore wind turbines in the Belgian part of the North Sea can be addressed in a sustainable way and how industry can prepare.

Various projects are also underway that focus on recycling and reusing the blades, and making them circular:

- "Blades2Build (EU Horizon project)" (01/01/2023 - 31/12/2025) - Research and industry are jointly developing circular solutions for wind turbine blades;

- "EoLO-HUBs (EU Horizon project)" (01/01/2023 - 31/12/2026) - Wind turbine blades **E**nd **o**f **L**ife through **O**pen **HUBs** for circular materials in sustainable business models;

  EoLO-HUBs will set up long-term collaboration to ensure that nearly 90% of wind turbine materials are recycled, thereby creating a circular economy that generates jobs and reduces greenhouse gas emissions by 2030;

- "REFRESH (EU Horizon project)" (01/01/2023 - 31/12/2026) - Smart dismantling, sorting and **RE**cycling of glass **F**ibre **RE**inforced composite from wind power **S**ector through **H**olistic approach;

  REFRESH aims to develop and demonstrate a new circular, smart system for enhanced recycling (>90%) of glass fibre reinforced composites derived from wind turbine dismantling or rewashing, with high purity.

- The Dutch company Blade Made is committed to recycling composite materials; with applications in playgrounds and noise-protection walls;

- The RECYPALE project by Centre Terre et Pierre (CTP) recycles wind turbine blades.

For wind farms that still need to be built, the results of the LICHEN BLADES project, from Delft University of Technology, will be important, as this project is working to design blades that last longer and contain more components that can be recovered and used in high-value applications over multiple life cycles.

Another project to keep an eye on for wind farms still to be built is the European MAREWIND project, **MA**terials solutions for cost **R**eduction and **E**xtended service life on **WIND** offshore facilities, which will look at solutions for cost reduction and extended service life of offshore wind facilities in general.

A new Interreg North Sea Region project was recently launched on chemical emissions: **ANEMOI** (Chemical emissions from offshore wind farms: assessing impacts, gaps and opportunities) with partners ILVO, KBIN, POM West Flanders, UAntwerpen.

The Provincial Development Agency West Flanders (POM West Flanders) submitted the "**Ready4Decom**" project under the "Belgium Builds Back" call (WINDENERGY theme). This project aims to further identify legal, logistical, processing technical as well as societal issues in the field of decommissioning of onshore and offshore wind turbines. The kick-off took place on 31 May 2023.

Planned projects

POM West Flanders will establish an offshore wind decommissioning expertise centre through the submitted ETF project "**OWiDEx**[22] (planned for 01/09/2023 - 31/08/2025). Among other things, the goal is to bring together the fragmented know-how in offshore wind turbine decommissioning into a single centre of expertise, to support a balanced decision-making approach. This would also include KBIN, UGent, VUB, SIRRIS, OVAM and Parkwind.

A tender procedure was launched at FPS Economy, namely 'Drafting of a desktop study related to the repowering of the eastern wind farm zone, incorporating a comprehensive, integrated legal, economic and technical analysis" (Special Specifications No. 2022/77268/E2/REPOWERING). This repowering study will soon be completed. A presentation in a public workshop is planned in late 2023.

Another tendering procedure has also been launched at FPS Economy, namely "Special Specifications No. 2022/78497/E2/Offshore Study Decommissioning Provision", involving an assessment of the costs and existing provision for decommissioning the existing offshore wind farms of the Eastern Zone, in Belgium. This decommissioning provision study is still in the procurement phase, and is still being evaluated.

Projects awaiting approval

VUB/OwiLab (lead partner) together with, IMDC, UGent, KULeuven and Sirris, has submitted an ETF (**MultiUse Purpose**) project proposal. The project will study the feasibility of (re)using existing infrastructure for hybrid power generation and/or repurposing it for wave/tidal power, or to house storage technologies. It therefore aims to improve yield and reduce the Levelized Cost of Energy[23] of the Belgian offshore zone and provide an alternative to completely decommissioning existing infrastructure. As part of the project, the experienced consortium partners will conduct a conceptual, economic, legal and structural reliability study of the multi-(re)use of existing infrastructure and the combined use of the maritime space.

[22] Project now approved - start date 1 September 2023
[23] Or LCOE, a measure of the total financial cost of producing electricity over the life of a project, including all capital and operating costs, and divided by the total amount of electricity produced. It is often used to compare the costs of different types of energy projects, such as wind, solar and natural gas.