# Strategy for the decommissioning of concrete foundations for offshore wind

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# Summary

As offshore wind deployment accelerates, the industry faces an urgent challenge: preparing for the inevitable wave of decommissioning. By 2040, an estimated 26,000 turbines will be installed worldwide, making sustainable end-of-life strategies critical to the sector's long-term viability. Concrete structures, especially gravity-based structures (GBS), are often overlooked due to their misconceptions about removability. This paper demonstrates that offshore concrete structures can be decommissioned effectively and highlights viable pathways for re-powering, reuse, and recycling.

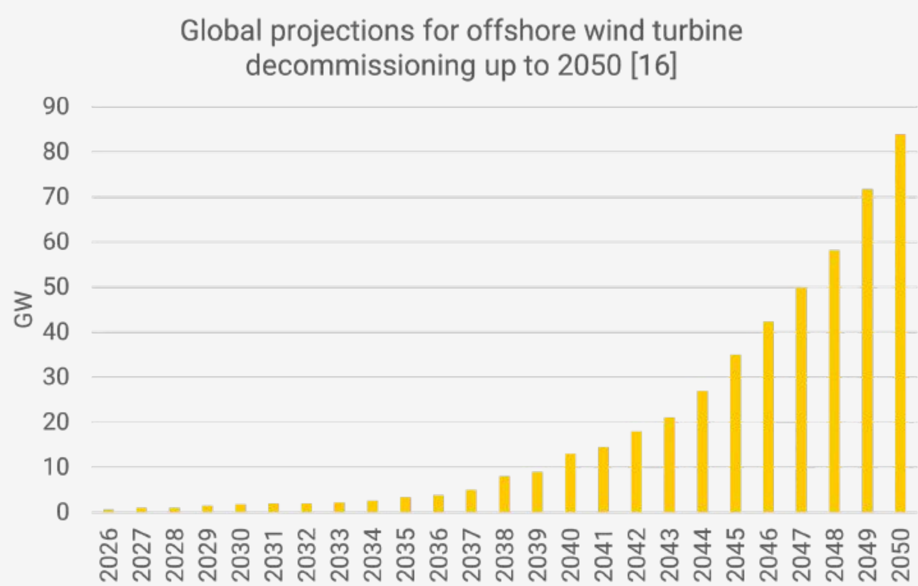
Concrete foundations can support multiple turbine lifecycles, be repurposed for coastal protection or harbour infrastructure, or be recycled into new construction materials. These strategies are already technically feasible and align with circular economy principles. Lessons from oil and gas decommissioning, combined with early offshore wind experiences, confirm the practicality of removing concrete structures when designed with end-of-life in mind.

Ultimately, integrating decommissioning considerations into early design phases will reduce lifecycle costs and environmental impact, supporting a more sustainable offshore wind industry.

# Introduction

As the move towards a circular economy and society is progressing, the need for an end-of-life strategy is becoming essential for all industries and construction sectors, including offshore wind. DNV predicts 350GW of offshore bottom fixed and 40GW of floating offshore wind to be commissioned by 2040[1]. Assuming an average turbine size of 15 MW, this corresponds to 26 000 units around the world. The decommissioning wave for offshore wind turbines is still in front of us, set to grow exponentially [16]. According to WindEurope the average fleet age for offshore wind in Europe is 9.7 years [6]. The main part of these foundations is monopiles and jacket structures.

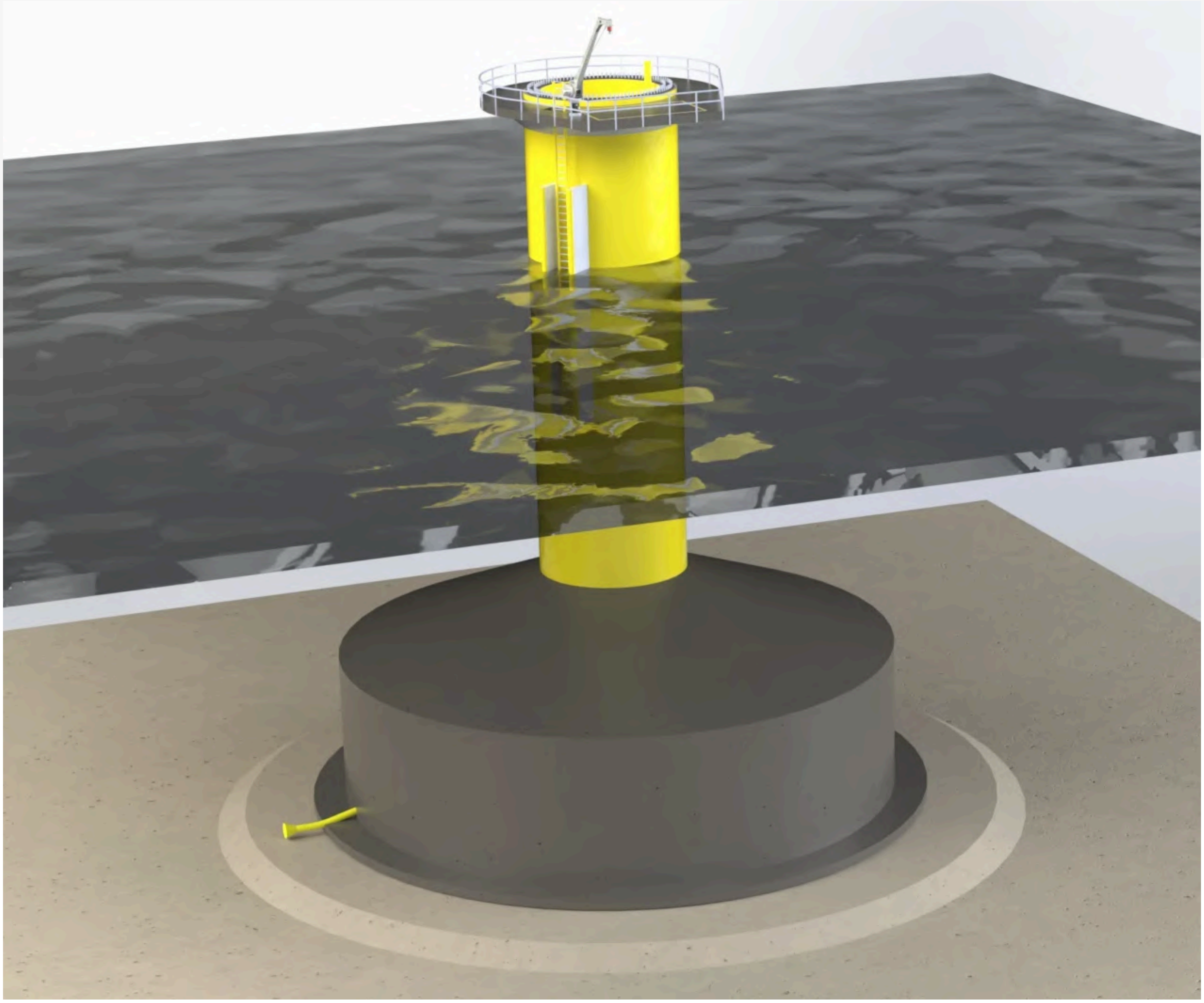
Concrete structures are becoming increasingly relevant due to larger turbines, challenging soil conditions, political pressure for local production, the need to cut $CO_2$ emissions, and a strong focus on cost competitiveness. Due to the fact that some gravity based structures are left in place for O&G, there is a common perception that GBS' cannot be removed at end of life. This paper argue that this is not the case and presents different decommissioning strategies and possibilities at end of life.



# Objective

The purpose of this paper is to highlight the possibilities for reuse and recycling of concrete foundations for offshore wind. It also aims to demonstrate the existing capabilities for managing these units at the end of their life. The paper focuses on the European market.

For the purpose of this paper a floating wind turbine of 20MW with a concrete substructure of 22 000 tonnes, and a bottom-fixed turbine of 15MW on a gravity-based structure of 9 000 tonnes has been assumed. Final weight and size of the structures will be project specific.



# End of life strategy

To reduce end-of-life costs, decommissioning should be integrated into the design phase. For floating wind units, offshore reverse installation is feasible: disconnect mooring lines and cables, tow the unit to port, remove ballast, and lift the structure ashore subject to port equipment and facilities.

Bottom-fixed structures should be designed for re-floating, enabling transport to shore. Local regulations vary by country and must be observed according to project location.

There are several end-of-life options for a concrete structure:

- **Re-powering**
  - New turbine and other components as needed
- **Reuse**
  - Harbour caissons
  - Coastal protection
  - Artificial reefs
- **Recycle**
  - Crush the concrete
  - Scour protection
  - Reuse in new concrete
  - Use as landfill for infrastructure projects
  - Recycle the rebars

These options are already technically feasible and require no additional research for offshore wind applications. However, further assessment is needed to identify the most environmentally and cost-effective solutions.

Existing research on removing oil and gas gravity-based structures ([4], [5]) primarily addresses much larger units—typically 10–100 times bigger than those used in offshore wind. Although offshore wind structures are smaller, the number of units to be removed is much greater.

Rakon, an AF Gruppen company, has maintained concrete structures offshore in the North Sea since 1990.

# Re-power

According to the waste hierarchy, prioritizing options that deliver the greatest value and minimize environmental impact is essential. Wind farms typically have a design life of 20 to 30 years, whereas concrete foundations can remain functional for at least 80 years requiring minimal maintenance. Consequently, extending the operational lifespan of windfarms through re-powering presents a viable and sustainable opportunity.

Re-powering refers to replacing the old turbines with new, more efficient models, while keeping the infrastructure such as foundations and cables. Re-powering has not been widely implemented for offshore wind farms yet, and in onshore wind, it has been common to increase turbine size while reducing unit numbers. This improves the utilization of existing sites.

Since the turbine sizes are still increasing in capacity and size [15], it is not obvious how the re-power market potential for offshore wind will be in the future. Assuming the concrete foundations can stand for almost a century, it is not guaranteed that there will be turbines in the market for the given design size. In that case, reuse or recycling shall be considered.

# Reuse

If the design life of a concrete foundation has expired, an operational licence is not renewed, or re-powering is not a viable option, alternative uses of the structures may be considered. Potential reuse includes deployment as harbour caissons, land reclamation, coastal protection, or offshore artificial reefs. The feasibility and practicality of reusing a GBS depends on its design, the intended location and purpose of re-use, as well as relevant local regulations and requirements.

The demand for effective coastal protection has grown in response to climate change and rising sea levels. According to a JRC technical report from the European Commission [3], costs associated with coastal damage may rise substantially, from EUR 1.4 billion in 2020 to EUR 240 billion by 2100 due to increased flooding resulting from extreme weather events and higher sea levels. Notably, sufficient coastal protection measures could mitigate up to 95% of these damages, utilising natural dunes and engineered structures such as dykes. These dykes and other manmade installations frequently incorporate concrete blocks and gravel. Gravity-based structures (GBS) offer additional opportunities for reuse in coastal defence applications.

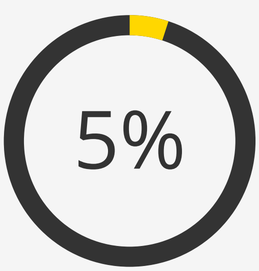
Another re-use case is artificial reefs. Numerous initiatives are underway to create artificial reefs using concrete structures in various configurations—examples include Boskalis [10] and the European Commission [11], both noting favourable impacts on marine habitats.

There is continued market interest in harbours and land reclamation projects along coastal areas. Bygge Uddemann has constructed over 3,600 harbour caissons to date [12]. Furthermore, energy islands, such as Princess Elisabeth Island in Belgium, employ caissons for their outer boundaries [13]. These projects showcase both serial production potential for large concrete structures, in addition to re-use potential of offshore wind substructures.

# Recycle

The final option for end-of-life management is the recycling of concrete. Following decommissioning, the structure can either be crushed at the site (especially for smaller units and windfarms) or transported ashore and crushed. The resulting concrete and reinforcing steel (rebars) will then be separated. The steel can be fully recycled using established processes, while the concrete may serve as aggregate in new concrete mixtures or as landfill. However, there are specific quality requirements for utilizing crushed concrete as aggregate, including sufficient strength, stiffness, and acceptable water absorption levels [2]. Offshore structures are typically constructed with high-quality concrete that possesses high strength, stiffness, and water absorption, making it particularly suitable for use as recycled aggregate compared to conventional onshore concrete.

According to the European Commission [2], construction and demolition waste (CDW) in Europe amounted to 840 million tonnes in 2021, of which concrete comprised 56.2%, or approximately 472 million tonnes annually. Assuming a scenario where 40 GW of floating wind and 300 GW of bottom-fixed wind capacity are constructed entirely from concrete, this would result in an estimated 224 million tonnes of CDW upon decommissioning. If assuming the structures will be decommissioned over a ten-year period, and the amount of CDW stays constant, CDW from offshore wind projects would represent less than 5% of Europe's annual CDW production. Consequently, the volume of materials arising from decommissioned offshore wind structures will constitute only a minor fraction of the overall construction and demolition waste requiring management in the coming years.




Offshore concrete structure will contribute with less than 5% to the annual CDW in Europe if **all foundations** are assumed to be built using concrete designs.


AF Gruppen alone handles 500,000 tonnes of construction waste per year at its two facilities, Rimol and Nes Miljøpark, in Norway. Cleaning contaminated soil and managing waste are standard practice and proven methods.

# Decom experience GBS

Decommissioning gravity-based structures presents technical challenges; however, precedents from the oil and gas industry demonstrate that such activities are achievable. Multiple studies have affirmed the feasibility of removing gravity-based structures [7]. To date, only one wind farm utilizing gravity-based structures—the Vindeby Offshore Wind Farm in Denmark—has undergone decommissioning, which occurred in 2017. The gravity-based structures at this site were dismantled using hydraulic demolition shears on location and subsequently collected. The 500-ton structure [14], originally constructed in 1990, supported a 0.45MW turbine [8].

In contrast, the Maureen gravity-based platform—a 110,000-ton installation with a gravity base—was successfully refloated in 2001 [9].

Gravity-based structures for a 15MW offshore wind turbine are typically designed to weigh approximately 10,000 tonnes, considerably less than those historically developed for oil and gas applications. Experiences from the Vindeby and Maureen projects reinforce the viability of gravity-based structure removal, while underscoring the importance of incorporating future decommissioning considerations into current design practices.

**Integrating decommissioning into the design phase is essential; if this is not done, a structured end-of-life plan for operational windfarms is strongly recommended.**

AF construction and decommissioning yard in Vats has recived and dismantled more than 500 000 tonnes of offshore structures.

# Ongoing research initiatives

Research efforts are accelerating to improve the reuse and recyclability of concrete, a material responsible for 5–7% of global emissions. Increasing the proportion of reused aggregates helps conserve finite resources like sand and gravel, while advancing circularity in concrete production—a development that will directly benefit offshore wind projects.

Several EU-funded projects are leading the way in developing low-carbon, circular solutions that will directly impact offshore wind infrastructure. MADE4WIND is creating durable concrete formulations for floating wind foundations, combining structural performance with reduced emissions to support Europe's carbon-neutral ambitions. C2CA introduces an upcycling process that transforms concrete waste into high-quality cement substitutes, avoiding the downgrading typical of conventional recycling and preparing for industrial-scale deployment. Similarly, CEMCON is developing methods to convert recycled concrete fines into supplementary cementitious materials, turning waste into a valuable resource while reducing carbon footprints through life cycle assessments.

Building on these advances, AF Gruppen drives innovation through BetongHUB, an initiative led by AF Decom and Betong Øst. BetongHUB focuses on integrating construction and demolition waste into new concrete mixes, testing alternative binders, and exploring additives to enhance performance. By challenging current standards and promoting circular practices, the project aims to set a benchmark for sustainable concrete solutions and accelerate the transition to climate-friendly construction.

Research into low-carbon and circular concrete is delivering solutions that reduce emissions, conserve resources, and enable reuse of construction waste. Advances in material formulations and upcycling processes are making concrete more durable, sustainable, and suitable for future offshore wind applications. These developments will increase the value of decommissioned foundations and support the transition to climate-friendly infrastructure.

# Conclusion

The transition to a circular offshore wind industry hinge on integrating end-of-life strategies into the earliest design phases. Concrete gravity-based structures, often perceived as immovable, can in fact be dismantled, repurposed, and recycled using proven methods. By planning for decommissioning from the outset, operators can unlock significant environmental and economic benefits.

Re-powering offers the highest value by extending the operational life of existing assets, while re-use and recycling provide robust alternatives when re-powering is not feasible. These pathways align with the waste hierarchy and support global sustainability goals, reducing lifecycle emissions and conserving resources. Lessons learned from oil and gas decommissioning, combined with emerging offshore wind experience, confirm that technical feasibility is not a barrier.

As offshore wind scales to meet climate targets, the industry must embrace circularity as a core principle. Designing for removal, reuse, and recycling will not only mitigate future liabilities but also strengthen the sector's contribution to a low-carbon economy.

**Gravity-based structures can be dismantled, repurposed, and recycled using proven methods.**

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# About the authors

Feel free to contact the authors with your questions or thoughts.

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