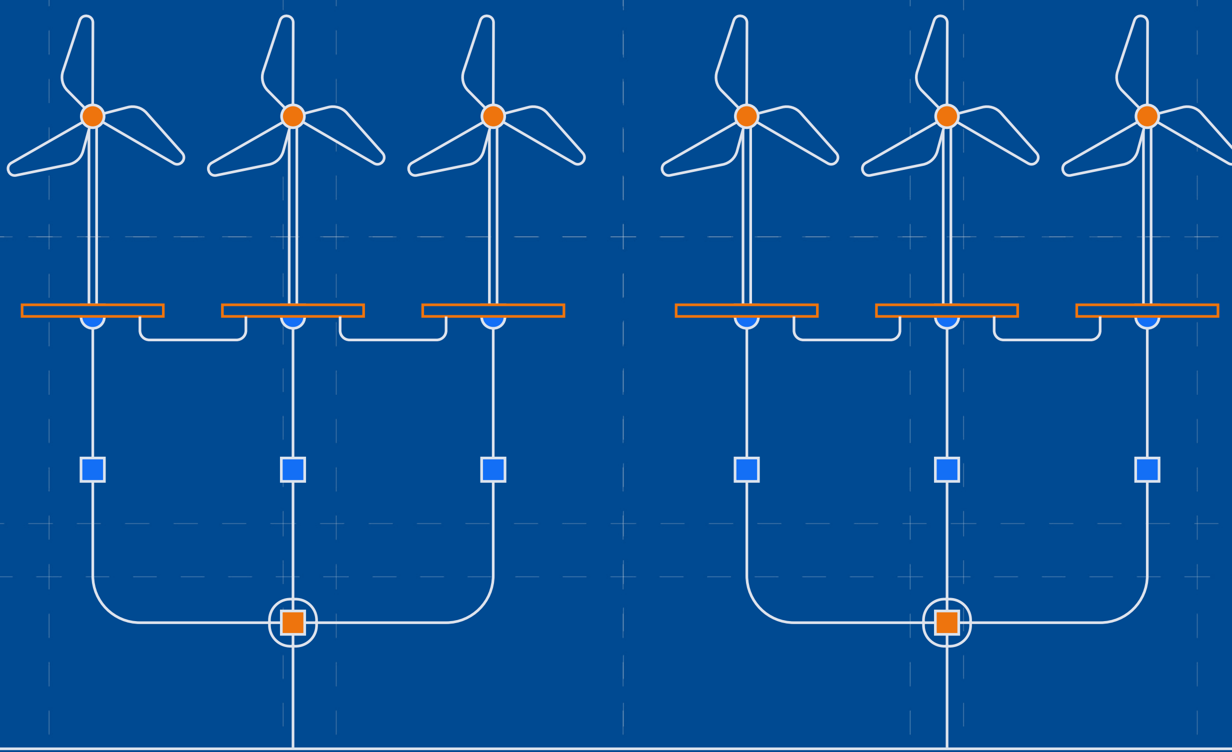
TAILWIND

KEEPING FLOATING WIND AT THE FOREFRONT

TAILWIND insights on sustainable anchor concepts and fibre rope recyclability



Floating offshore wind is moving towards larger farms, new waters and more demanding station-keeping systems. TAILWIND is addressing this challenge by advancing key technologies for anchors and mooring lines, with the aim of reducing costs, improving sustainability and supporting the scalability of next-generation floating offshore wind farms.

This infopack presents findings from TAILWIND's work on sustainable anchor concepts and fibre ropes recyclability to offshore wind stakeholders, technology developers, and industry actors.

KEY POINTS

→ Anchor selection depends on soil type, mooring configuration and load magnitude: there is no one-size-fits-all solution.

→ Pre-treatment of fibre ropes is identified as a dominant bottleneck for technical and economic feasibility of recycling.

→ Floating wind scale-up requires station-keeping systems that are reliable, cost-effective and sustainable.

→ Recyclability and environmental performance are becoming central criteria for both anchors and mooring lines.

→ Maturity of recycling processes depend heavily on material and recycling type, ranging from industry to laboratory scale.

PROJECT CONTEXT AND OBJECTIVE

Floating offshore wind farms rely on station-keeping systems to maintain the position and stability of floating turbines through their lifetime. As the sector moves towards commercial-scale deployment, anchors and mooring lines become decisive components for reliability, installation efficiency, environmental performance and overall cost reduction.

TAILWIND investigates sustainable station-keeping solutions for floating offshore wind, focusing on technologies that can reduce the cost of floater and mooring systems while supporting deployment at scale.

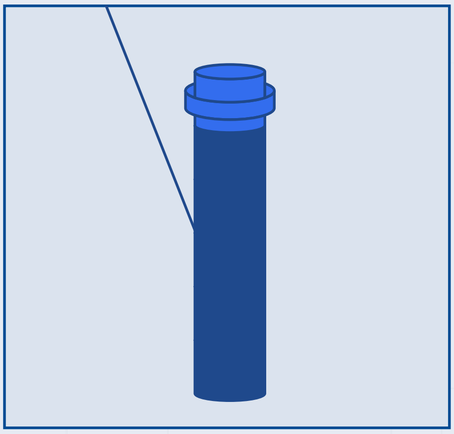
WHY STATION-KEEPING MATTERS FOR FLOATING WIND SCALE-UP

The upscaling of floating offshore wind creates new requirements for station-keeping systems.

Future farms will require a much higher number of anchors and mooring lines than traditional oil and gas applications, while also demanding reduced material use, increased recyclability, lower carbon footprint and competitive European supply chains. These systems will also need to withstand challenging loading conditions generated by the offshore environment. This means that anchor and mooring technologies cannot be assessed only in terms of technical capacity. They also need to be evaluated against economic, environmental, social and technological sustainability criteria, including fabrication, logistics, installation, site investigation effort, material sustainability, impact on the marine environment, decommissioning and recyclability.

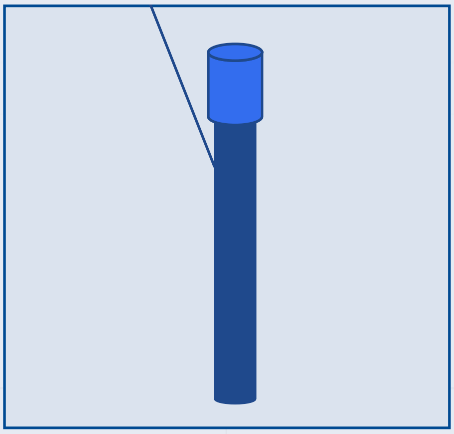
ANCHOR CONCEPTS

TAILWIND's first assessment focused on five commercially available and certifiable anchor technologies: suction anchors, pile anchors, gravity anchors, plate anchors and fluke anchors. These concepts were analysed across selected floating offshore wind scenarios, considering different floater types, soil conditions, mooring configurations and load magnitudes. The assessment used mooring loads provided by TECNALIA and state-of-the-art design methods aligned with industry guidelines and DNV standards. The results were then compared through evaluation matrices designed to support the selection of anchor concepts for further development in the project.



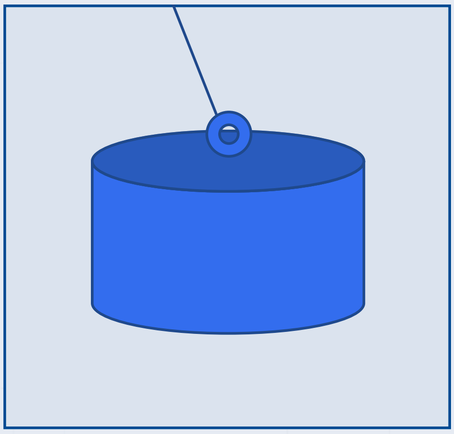
Suction Anchor

Installed through pump-induced under-pressure.



Pile Anchor

Driven or vibro-driven into the seabed.



Gravity Anchor

Relies on weight and sliding resistance.

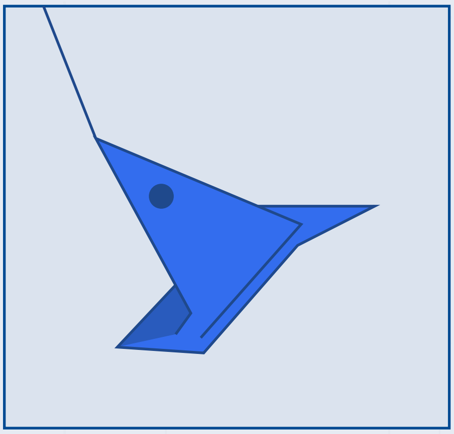
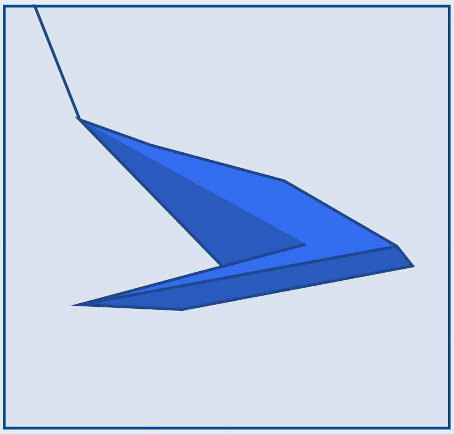


Plate Anchor

Buried anchor mobilising soil bearing resistance.



Fluke Anchor

Drag-embedded anchor with high holding capacity under suitable conditions.

KEY FINDING 1

NO UNIVERSAL ANCHOR SOLUTION

A central finding of the assessment is that there is no one-size-fits-all anchor type for floating offshore wind. The suitability of each solution depends mainly on the combination of soil type, mooring configuration and load magnitude. This is particularly important for early-stage project design, where anchor screening can support better decisions before moving into more detailed engineering. In this context, KPIs can help compare different technologies not only from a technical perspective, but also in terms of cost, environmental impact, social sustainability and technological maturity.

KEY FINDING 2

SHARED ANCHORS OPPORTUNITIES

Shared anchors are one of the most relevant innovation pathways for large floating wind farms, as they could reduce the total number of anchors required across a farm layout. This may bring advantages in terms of installation effort, site investigation needs, material use and overall environmental performance. However, TAILWIND's analysis also shows that loads on shared anchors are not always smaller than those on single anchors. Their performance depends on the specific farm layout, mooring concept and ocean conditions. This means that shared-anchor systems require dedicated design procedures and further investigation, particularly regarding multidirectional and cyclic loading.

KEY FINDING 3

PLATE AND SUCTION ANCHORS POTENTIAL

Plate anchors emerge as a promising option due to their high geotechnical efficiency and their potential suitability across different mooring concepts. At the same time, further evidence is needed on installation methods, installation feasibility, keying behaviour and proof loading, especially in clay. Additional experience with suction anchors in coarse-grained and layered soils could help extend their use beyond typical clay sites and increase confidence in their application for floating offshore wind.

While anchor concepts define how floating wind turbines are secured to the seabed, mooring lines play an equally important role in the performance, cost and sustainability of station-keeping systems. For this reason, TAILWIND also looks at fibre rope solutions, with particular attention to their recyclability and end-of-life potential.

FIBRE ROPES AND RECYCLABILITY

TAILWIND's evaluation of the recyclability feasibility for fibre-based offshore mooring lines has assessed recycling potential for four fibre ropes: PET and PA6 for buoyancy stabilized units, and HMPE and aramid for mooring stabilized units. Existing recyclability technology and pathways were identified, as well as emerging technologies. Further, bottlenecks for fibre rope recycling have been identified, and the legislative framework was analysed to identify requirements and obstacles for recycling.

KEY FINDING 1

RECYCLING PATHWAYS

Four dominant pathways for recyclability are identified: Mechanical recycling produces flakes, granulates, or pellets that can be re-used for secondary applications, although polymer quality is typically reduced. Well-defined value chains exist for PET and PA6, although purity requirements limit the current applicability for marine mooring lines. Chemical recycling breaks down the plastic fibres into monomers, which can be used to produce new fibre material with comparable properties as the original material.

Technologies are established for PET and PA6, while emerging recycling methods are showing promising potential for aramid and HMPE. Recycling via dissolution has the potential to produce high-quality recycled materials maintaining polymer structure while removing contaminants, but technologies for this is currently at low TRL.

The final recyclability path is repurposing, where mooring ropes are re-used for applications with lower requirements such as temporary moorings. However, traceability of the ropes' history remains a challenge for this route.

KEY FINDING 2

PRE-TREATMENT BOTTLENECK

Permanent mooring ropes are complex structures from a recycling perspective.

The ropes are multilayered, with different materials in the load-bearing core, and the protective filter and jacket layers. Additives from the production process and marine biofouling accumulating over the lifetime further contribute to in-pure fibre ropes entering the recycling stream. Combined with the purity requirements of many of the recycling alternatives and the modest amount of fibre ropes expected to enter the waste treatment stream from offshore mooring applications, pre-treatment, such as cutting, separation into components, washing, and drying, is emerging as the dominant bottleneck for recycling.

This applies to both the technical and economic feasibility, as well as heavily impacting the environmental footprint of the recycling.

KEY FINDING 3

RECYCLABILITY IMPROVEMENT

To enhance the recyclability of fibre rope mooring lines, four major steps have been identified. Firstly, incorporating recyclability in the rope design is essential. This includes steps as using mono-material structures and using compatible coatings to reduce pre-treatment barriers.

Secondly, increased traceability of rope history and standardizing material declarations can support sorting, quality control and allow increased use of decommissioned ropes.

Thirdly, dedicated collection and recycling value chains are required to increase the volume of recycled ropes and increase economic viability while reducing climate footprint.

Finally, enhanced legislative requirements and guidance specifically for fibre ropes will create stronger incentives for circular end-of-life management.

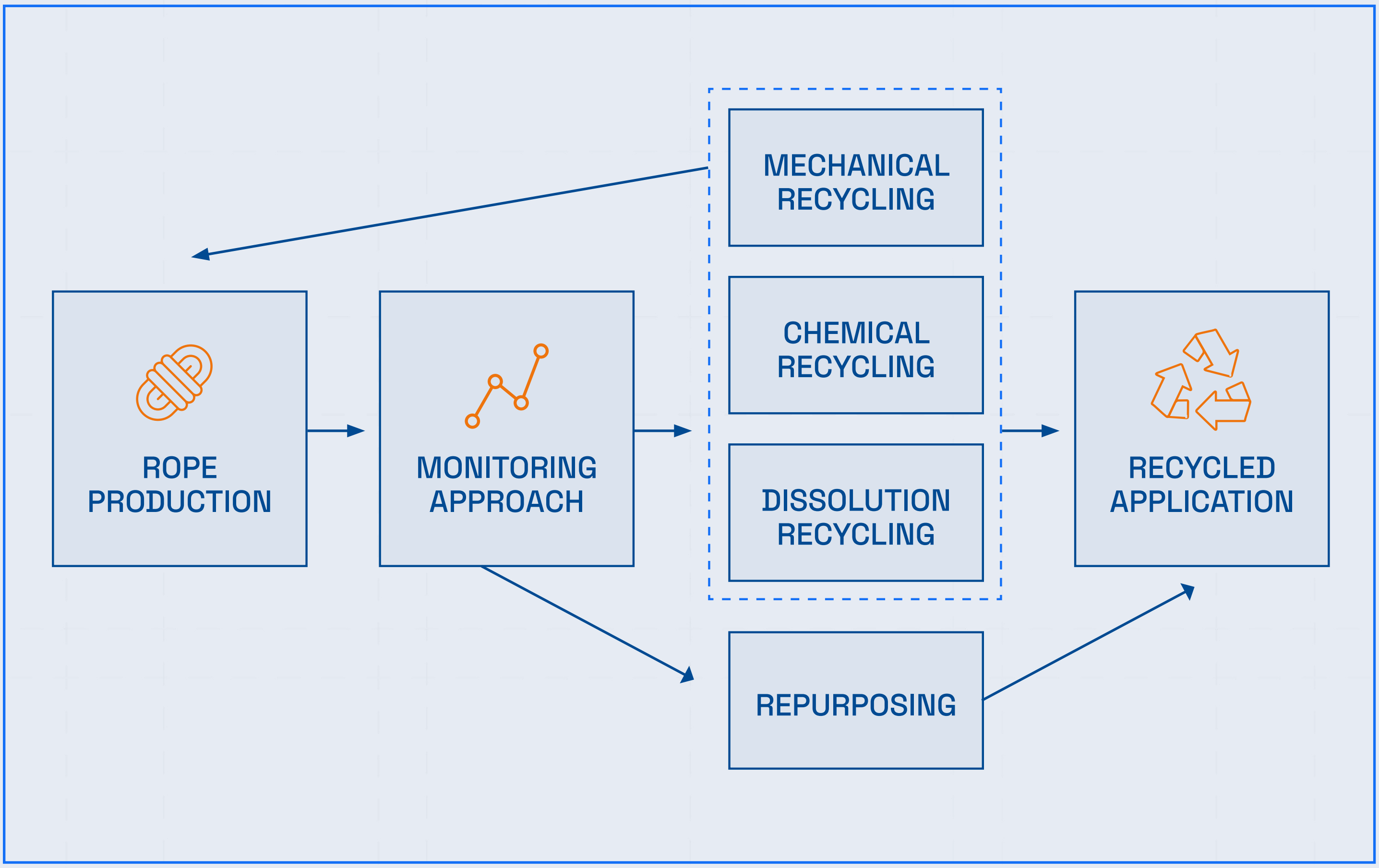


Fig. 1 - Circularity pathways for fibre rope mooring lines

CONCLUSIONS

TAILWIND's preliminary findings show that scalable floating offshore wind deployment will depend on station-keeping systems designed around specific site, soil, mooring and sustainability conditions. The assessment confirms the importance of environmental and circularity-related indicators, but also shows that these are among the most difficult aspects to evaluate objectively. Quantitative environmental studies on common anchor types would therefore be valuable to support stronger comparisons and more transparent decision-making. Recyclability of fibre ropes should be considered already from the mooring design and rope production phase, to ensure proper end-of-life management.

References:
TAILWIND. D3.1 Sustainable anchor concepts
TAILWIND D2.4 Recyclability of fibre ropes

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