Fact sheet 2: **Anchors and moorings**

What are anchors and moorings?

Anchor and mooring systems are used to secure floating offshore wind turbines to the seafloor, ensuring that they remain in the desired location. Mooring systems connect the anchor to the turbine and consist of sections of chain and synthetic rope.

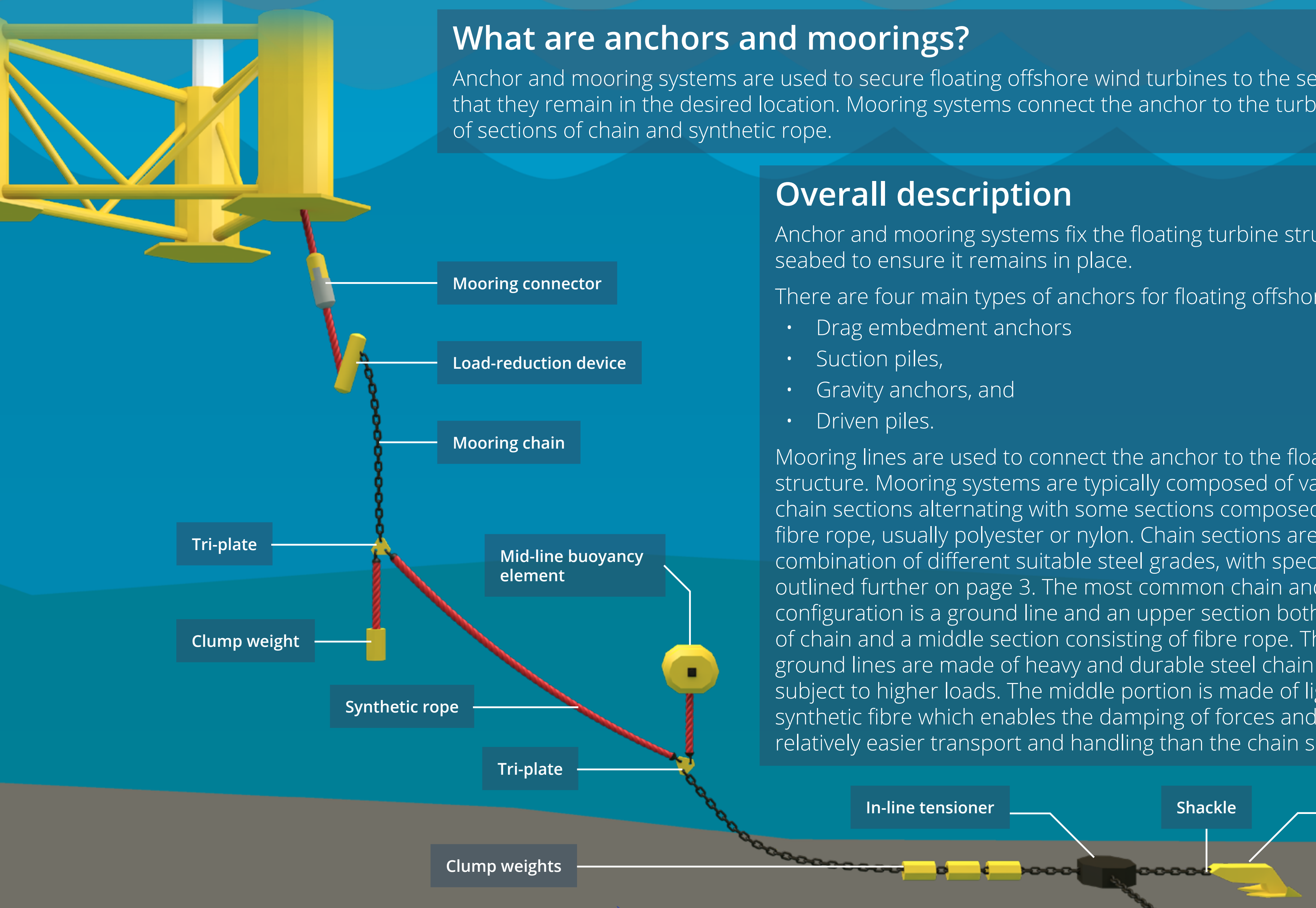
Overall description

Anchor and mooring systems fix the floating turbine structure to the seabed to ensure it remains in place.

There are four main types of anchors for floating offshore wind:

- Drag embedment anchors
- Suction piles,
- Gravity anchors, and
- Driven piles.

Mooring lines are used to connect the anchor to the floating turbine structure. Mooring systems are typically composed of various steel chain sections alternating with some sections composed of synthetic fibre rope, usually polyester or nylon. Chain sections are often a combination of different suitable steel grades, with specific grades outlined further on page 3. The most common chain and rope configuration is a ground line and an upper section both consisting of chain and a middle section consisting of fibre rope. The upper and ground lines are made of heavy and durable steel chain as they are subject to higher loads. The middle portion is made of lighter, elastic synthetic fibre which enables the damping of forces and allows for relatively easier transport and handling than the chain sections.



Anchors and moorings: Main subcomponents

Anchors: Drag embedment

Description: Drag embedment anchors consist of various steel plates welded together. They secure the floating turbine to the seabed by embedding themselves into the seafloor through drag forces. They are the cheapest anchor solution for floating offshore wind and the anchors are easily recoverable. Drag embedment anchors are most suited where the seabed consists of cohesive sediment that will allow for anchor embedment.

Sub-components: Steel plate, shackle.

Applicable standards: DNV – RP – E302, DNV – ST – 0119.

Typical weights: Current designs are in the range of 30 – 40 tonnes. The expectation is that future designs will be in the range of 24 – 30 tonnes, with more mooring lines used. This is to increase the handleability of the anchors.

Typical dimensions: Typically drag embedment anchors will be in the range of 6 m x 6 m x 6 m.

Anchors: Suction pile

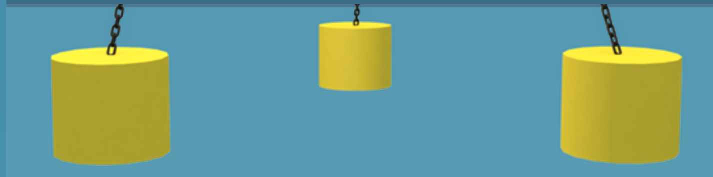
Description: Suction pile anchors consist of a tubular steel component which is capped at the top. The cap contains a valve that assists with embedment. Most of the anchor's penetration occurs under its own weight, after which a remotely operated vehicle (ROV) can be used to pump water out of the pile through the valve, causing greater suction and completing the embedment. Recovery of suction piles is simple, being the reverse of installation. They are best suited for ground that is solid enough to maintain suction but not hard enough to impede embedment.

Sub-components: Steel tubular, cap with valve, shackle.

Applicable standards: DNV – RP – E303, DNV – ST – 0119.

Typical weights: 60 – 100 tonnes.

Typical dimensions: Approximate outer diameter (OD) of 10 m, height of 35 m.



Anchors: Driven pile

Description: Driven pile anchors for floating offshore wind are typically tubular piles that are driven into the seabed using an impact or vibro-hammer, similar to fixed offshore wind piles. Driven piles are difficult to recover as they are securely embedded and grouted into the sea floor. Driven piles can be used over a range of seabed conditions including rocky or hard ground.

Sub-components: Steel tubular, pile cap, shackle.

Applicable standards: DDNV – ST – 0126, DNV – ST – 0119.

Typical weights: 40 – 100 tonnes.

Typical dimensions: Approximate OD of 5 m, height of 40 m.

Anchors: Installation

Lighter weight anchors can be installed by Anchor Handling Vessels (AHVs) and have deck space to carry four to six anchors per trip. Heavier anchors will require a Heavy Lift Vessel (HLV). AHVs are equipped with winches, stern rollers and cranes.

Drag embedment anchors are launched from the vessel using winches and a stern roller.

Suction and driven piles are placed onto the seabed using cranes. Driven piles are embedded into the seabed using an impact or vibro-hammer. Suction piles embed themselves onto the seafloor with an ROV then pumping water out of the pile to generate greater suction. AHV capacity is a key factor in maximum anchor mass and therefore the number of mooring lines specified.

Anchors: Gravity

Description: Gravity anchors use their mass to secure an object to the seabed, rather than embedding themselves in the seafloor. They therefore tend to be much heavier than other anchor types. This makes them harder to transport and manoeuvre than other anchor types, so are generally not preferable. Gravity anchors are suited for all soil conditions except very loose soils.

Sub-components: Concrete mass, shackle.

Applicable standards: DNV-OS-E301, DNVOS-C101, DNV – ST – 0126.

Typical weights: 600 – 1000 tonnes.

Typical dimensions: 10 – 20 m diameter.

Anchors and moorings: Main subcomponents

Moorings: Chain

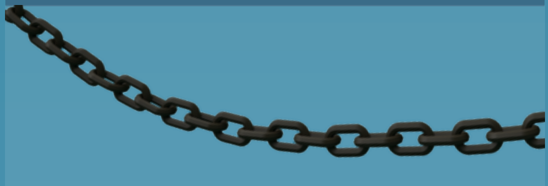
Description: Chain sections normally comprise the upper and ground lines of the mooring system. The upper chain section should be larger than the ground line due to being subject to the greatest loads. Chains are manufactured in stud-link and stud-less varieties. Stud-link is better at preventing knot formation but is more expensive than stud-less links, which are less sensitive to fatigue loading.

Sub-components: H-link shackle.

Applicable standards: DNV – OS – E302.

Typical weights: 500 – 700 kg per link.

Typical dimensions: OD approximately 160 – 220 mm, length approximately 1,100 – 1,500 mm and width approximately 550 – 740 mm.



Moorings: Synthetic rope

Description: Synthetic rope typically comprises the middle section of the mooring system, which experiences the least amount of load. Synthetic rope is light and dynamic, enabling flex. An eyelet must be placed at each end of the fibre rope to allow connection with the chain sections.

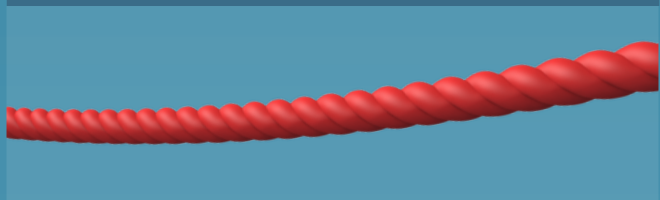
Fibre ropes are typically made from polyester or nylon. Polyester is used due to its strength and durability. Nylon is lighter and more flexible than polyester while providing similar durability, however it is significantly more expensive than polyester.

Sub-components: Rope, eye loop.

Applicable standards: DNV-OS-E303, DNV – RP – E305.

Typical weights: Up to approximately 50 kg per meter.

Typical dimensions: OD from 100-300 mm, lengths from 200 – 1,600 m.



Moorings: Jewellery

Description: A range of items that are attached to mooring lines either to connect sections of a line or items that may be connected along the length of the line. See page 6 for a detailed description of each component. Jewellery includes:

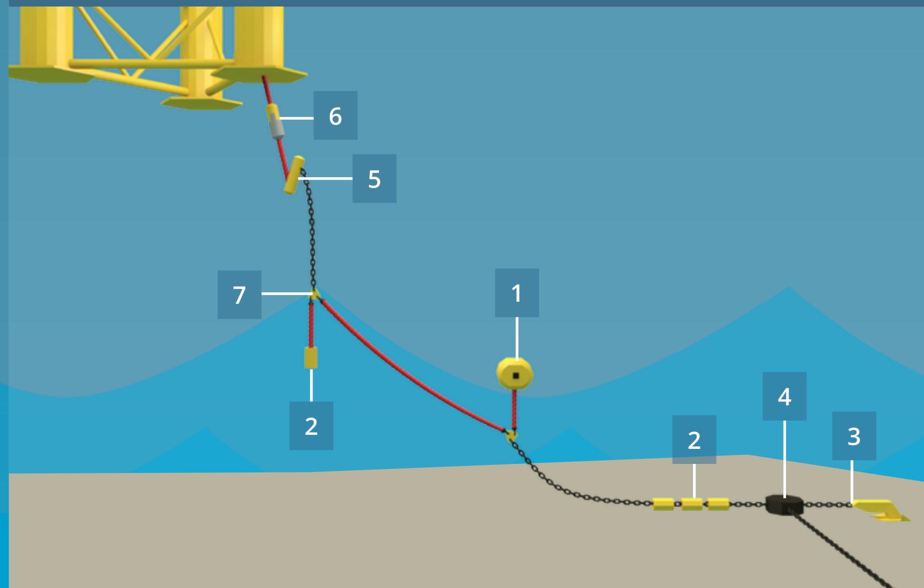
1. Buoyancy elements
2. Clump weights
3. Shackles
4. In-line tensioners
5. Load reduction devices
6. Mooring connectors, and
7. Tri-plates

Further details on these components are found on page 6.

Applicable standards: DNVGL-RU-OU-0512, DNV-OS-E301

Typical weights: Weights and sizes vary between elements and designs, but can range from 250 kg to 10 tonnes

Typical dimensions: Weights and sizes vary between elements and designs. See page 6 for more detail.



Moorings: Installation

AHVs are used to support mooring hook-up. The lower section of the mooring line, often chain, is connected to the anchor during installation:

- For drag embedment anchors it is attached before the anchor is embedded, as the attachment point is below the sea bed once it is embedded.
- For suction and piled anchors, it is attached after the anchor is installed.

If there is a section of synthetic fibre rope in the mooring line, this section would not be connected at this time.

A submersible marker buoy is connected to the end of the mooring line to support retrieval for later hook-up operations.

Anchors and moorings: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Mooring lines					
Chain	Approx. £2,000 to £5,000 per tonne	R3, R3S, R4, R4S or R5 steel bar	500 – 700 kg per link depending on link diameter	Exact dimensions will depend on link diameter used OD approximately 160 – 220 mm Length approximately 1,100 – 1,500 mm Width approximately 550 – 740 mm Full chain section lengths depend on water depth, but are typically in the range of 30 – 150 m	Class societies are starting to market their own grades of steel that require specific mills that are certified to the required specifications Different chain sections will typically require different steel grades
Synthetic rope	Approx. £800 to £3,000 per meter	Polyester or nylon	Approximately 4 – 40 tonnes depending on rope length	OD approximately 170 mm Length will depend on water depth, however manufacturers can typically expect requirements of approximately 200 – 1,600 m	Ropes typically consist of 8 – 12 strands of material
Anchors					
Drag embedment	Approx. £4,000 to £5,000 per tonne	Welded S355 steel plate	24 – 40 tonnes	6 m x 6 m x 6 m	Must be designed to meet the requirements of DNV-RP-E301 and DNV-RP-E302, or other applicable standards. This will vary based on ground conditions at sites
Suction pile	Approx. £3,000 to £4,000 per tonne	Rolled and seam welded S355 steel plate	60 – 100 tonnes	Up to approximately 10 m OD by 35 m length	Must be designed to meet the requirements of DNV-RP-E303, or other applicable standards. This will vary based on ground conditions at sites
Driven pile	Approx. £3,000 to £4,000 per tonne	Rolled and seam welded S355 steel plate	40 – 100 tonnes	Up to approximately 5 m OD by 40 m length	A specific design requirement standard is not available for driven piles, but the overall structure must meet the requirements of DNVGL-ST-0119
Gravity anchor	Approx. £1,000 to £2,000 per tonne	Concrete and rebar	600 – 1,000 tonnes	10-20 m diameter	As above

Anchors and moorings: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Mooring jewellery					
Buoyancy elements	Large range depending on size. £500 per unit to £5,000 per unit	Polyurethane foam core and polyethylene coating	Large range, typically from hundreds of kilograms to many tonnes	Large range, typically 1 cubic metre to 4 cubic metres	Flotation devices, which can provide several tonnes of uplift each, and are attached to mooring lines. Their function is either to lift the lower section of the mooring line above the sea bed to prevent damage or to fine tune the compliant response by forming a multi-catenary shape
Clump weights	Large range depending on size. Approximately £1,000 to £3,000 per tonne	Cast iron or carbon steel	In the range of 250 kg to 10 tonnes per weight	There is no standard design configuration for clump weights. They are generally barrel shaped	Masses, which can be several tonnes each, and are attached to mooring lines to tune the compliant response
In-line tensioner	Large range depending on size and application. Approximately £2,000 to £10,000 per tonne	Welded steel plate	Large range, typically from many tonnes	Large range, typically 1 cubic metre to 4 cubic metres	A simpler alternative to a powered winch to adjust the tension in a mooring system which would sit on the sea bed for the life of the project
Load reduction devices	Large range depending on size and application. £2,000 per tonne to £10,000 per tonne	Cast and fabricated steel, concrete ballast, polyurethane foam	Hundreds of kilos to several tonnes	Usually tubular design, approximately 3 to 7 m long with OD of 3 to 5 m	These devices modify the mooring stiffness response to reduce mooring dynamic loads. They come in many forms, including gravitational, elastomeric and compressive devices
Mooring connector	Large range depending on size and application. £1,000 per unit to £25,000 per unit	R3, R3S, R4, R4S, R5 steel	Approximately 2.5 – 7 tonnes	Approximately 500 – 750 mm in width, 1,300 – 1,800 mm in length and 500 – 700 mm in depth	The simplest mooring connector design is simply a shackle. Traditional designs tend to bolt the mooring lines to pad eyes on the foundation. Mooring connectors must be able to withstand the fatigue and ultimate mooring loads
Shackles	Large range depending on size. Approximately £3,000 per tonne	R3, R3S, R4, R4S, R5 steel	Approximately 2.5 – 7 tonnes	Approximately 500 – 750 mm in width, 1,300 – 1,800 mm in length and 500 – 700 mm in depth	Used to attach the mooring line to the anchor, different sections of mooring together, or the mooring line to the floating substructure. The shackle should be designed to withstand at least 120 tonnes of load. H-link shackles are preferred, but other types (like swivel shackles) can be used
Tri-plate	Large range depending on size. Approximately £3,000 per tonne	R3, R3S, R4, R4S, R5 steel	Approximately 1 – 2 tonnes	Triangular plate with sides of approximately 550 – 600 mm and thickness 200 – 250 mm	Flat plates with three holes, used to allow connection of two sections of mooring line with a clump weight or buoyancy element

Anchors and moorings: Manufacture

Typical manufacturing process

Anchors

- To manufacture a drag embedment anchor, steel plates are cut into desired profiles and welded together for the final profile. Most drag embedment anchors will consist of flat plate, but depending on design, rolled steel may be required.
- Gravity anchors are constructed by forming concrete around steel rebar framework.
- Driven piles are made from seam welded rolled steel plate, with sections welded together to make a full length.
- Suction piles are made in a similar way to driven piles but tend to be shorter and larger diameters.

Moorings

- Chains are manufactured from individual lengths of bar stock. Bar stock is heated, formed, welded, shaped, heat treated and coated. Chain accessories are quenched and tempered to match the same mechanical properties as the chain. Thicker chains require more energy to manufacture
- Synthetic ropes are formed by intertwining synthetic strands. The thicker the rope, the more energy is required in its production.
- Jewellery manufacture varies based on the component type, but are generally steel components made through forging, or plate welding.

Drag embedment anchor after flat plate welding and weld finishing.
Image courtesy of Bruce Anchor. All rights reserved.

Mooring quick connector assembly.
Image courtesy of First Subsea. All rights reserved.

Component materials

- For drag embedment, suction and driven pile anchors: plates of S355 grade steel.
- Concrete and rebar for gravity anchors.
- For chains: R3, R3S, R4, R4S and R5 grade steel bar stock.
- Polyester or nylon fibre rope for mooring lines.

Manufacture facility requirements

Anchor manufacture facilities require the typical equipment needed for steel fabrication:

- CAD and CNC software
- CNC cutters and machining equipment
- Press brakes
- Roll forming machines
- Lifting equipment
- Induction pipe bending machines
- Various drills, grinders and saws
- Surfacing equipment
- Welding equipment, and
- If in-house coating is desired, coating equipment.

Mooring chain requires the above as well as heat treatment equipment.

Slip forming, or concrete casting equipment is needed for gravity anchors.

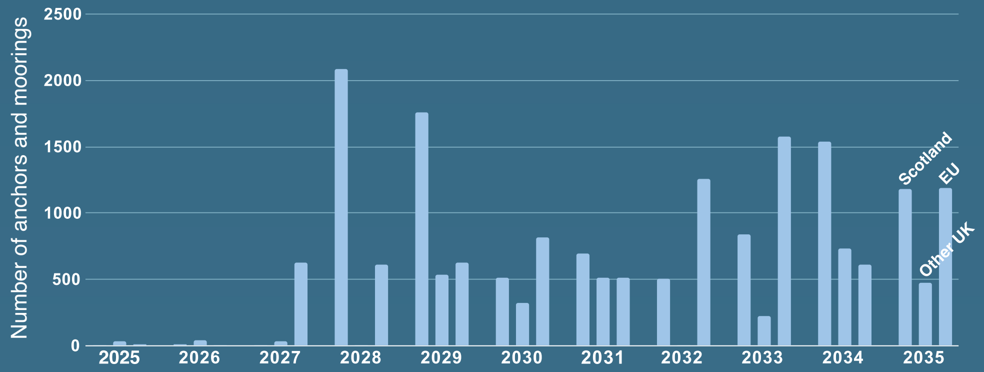
Fibre rope manufacture requires:

- Extrusion machines
- Twisting or braiding equipment
- Tensioning and spooling equipment
- Cutting and splicing equipment, and
- Oven for curing/heat setting.
- Mooring and anchor systems consist of very heavy components, suitable lifting and handling equipment will be required.

Anchors and moorings: Market

Available market

Anchors and moorings will be required on all floating foundations. The number of mooring lines/anchors will depend on foundation design, but three to five is typical. The forecasts below are based on BVGA's predictions, accounting for project pipeline, national targets, and expected growth in wind turbine rating. In 2035 the combined Scotland, UK and EU market accounts for 57% of the global floating market.



The table below shows forecast values for ScotWind and INTOG projects based on an 18 MW turbine capacity. Designs of mooring systems for these projects are not confirmed, therefore a typical 5 mooring line semi-sub design has been used as a representative case study design. The arrangement of subcomponents is as shown on page 1.

Component	Assumption	Forecast for ScotWind / INTOG*	
		ScotWind	INTOG
Anchors	5 per floating turbine	5,355 units	1,530 units
Chain	Used for 50% of the mooring line	803,250 m	344,250 m
Synthetic rope	Used for 50% of the mooring line	803,250 m	344,250 m
Jewellery systems	5 per floating turbine, containing the below components	5,355 systems	1,530 systems
Shackles	1 per mooring line	5,355 units	1,530 units
Tri-plates	2 per mooring line	10,710 units	3,060 units
Clump weights	2 per mooring line	10,710 units	3,060 units
In-line tensioners	1 per mooring line	5,355 units	1,530 units
Mooring connectors	1 per mooring line	5,355 units	1,530 units
Buoyancy elements	1 per mooring line	5,355 units	1,530 units

**this forecast is based on the entire ScotWind/INTOG capacity being installed. This number may decrease if projects are not taken forwards, or increase if projects increase their capacity.*

Route to market

- Anchor and mooring systems make up a portion of the balance of plant costs of a development.
- Anchor and mooring system manufacturers will need to source standard steel forms and synthetic fibre ropes to assemble components.
- Anchors can be fabricated anywhere in the world quayside, which can then be used as a marshalling facility for other turbine components to provide flexibility to the project.
- As floating offshore wind is not yet as developed as fixed offshore wind, there is not yet a typical buyer of anchor and mooring systems. Most floating wind developers are consortiums that have yet to settle on purchasing responsibilities.
- Incumbent suppliers of anchors include Delmar Vryhof, Bruce Anchor, Swift Anchors and Subsea Micropiles.
- Incumbent suppliers of mooring solutions include Bridon Bekaert, InterMoor and Mooreast.

Accreditation / regulatory landscape

Mooring chain and accessories are subject to visual and non-destructive testing (NDT). Suppliers must prepare written procedures for NDT, and all NDT personnel must be qualified and certified according to ISO 9712.

Anchors must be subjected to proof-load testing on-site.

Fibres ropes must satisfy breaking loads as per DNVGL-OS-E303.

There are many DNVGL standards which apply to anchor design, including but not limited to:

- DNVGL-ST-0119
- DNV-ST-0126
- DNV-RP-E301
- DNV-RP-E302
- DNV-RP-E303
- DNV-OS-E301
- DNV-OS-C101
- DNV-RP-C205

For a product to be used on an offshore wind farm (particularly one as critical as the mooring system) it is likely developers will require independent verification.

Anchors and moorings: Costs

Typical costs / CAPEX requirements

- Mooring systems cost approximately £50 million for a 450 MW floating offshore wind farm.
- Anchors cost approximately £17 million for a 450 MW floating offshore wind farm.
- This equates to 110,000 £/MW for moorings and 38,000 £/MW for anchors or approximately £1.65 million for mooring lines and £0.57 million for anchors for a 15 MW turbine's substructure.
- This is approximately 1.9 % of the total project cost for mooring lines and 0.7% for anchors
- This cost is for the mooring line and anchor work packages for a typical floating offshore windfarm as outlined in the cost assumptions. This includes lines and anchors only, excluding accessories.
- This cost will vary significantly depending on what is included in the mooring/ anchor package, and the foundation design used.
- Costs are sourced from **The Guide to a Floating Offshore Wind Farm**. See for more information and detail of all cost assumptions.

Potential user costs

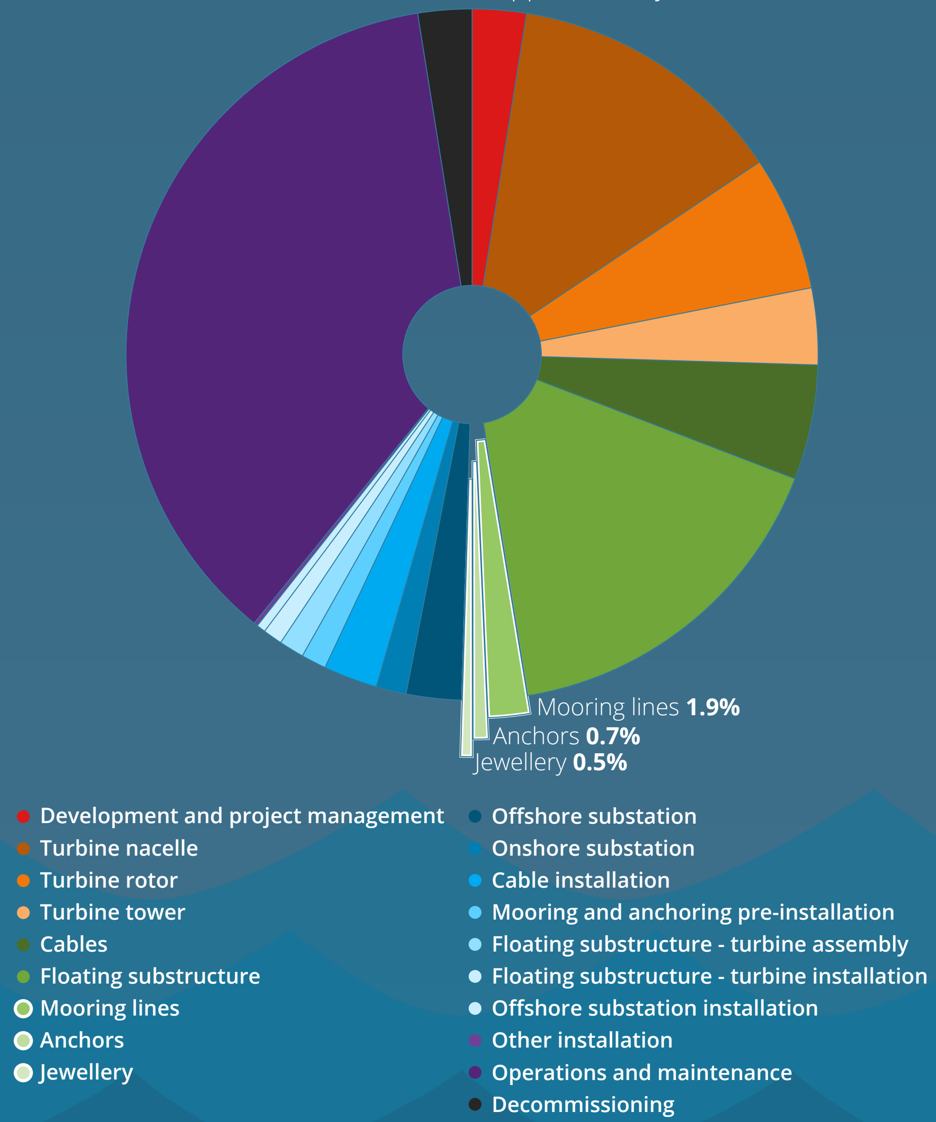
- The user will incur inspection, maintenance, transport, installation and decommissioning costs.
- ROVs undertake mooring line and anchor inspections on a 5-year interval.
- The connections between chains and terminations for buoyancy elements and weights are key inspections points.
- Transport costs for all anchor types is similar, with the exception of gravity anchors which are much more difficult to transport due to their size.

Support available

For further details on offshore wind supply chain assistance, information, and support programmes available, please contact Scottish Enterprise: **offshorewind@scotent.co.uk**

450 MW floating offshore wind farm lifetime costs

Lifetime 450 MW windfarm cost approximately £2,600 million.



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Acknowledgements

Scottish Enterprise, Highlands and Islands Enterprise and South of Scotland Enterprise commissioned BVG Associates to produce a number of fact sheets on different aspects of floating offshore wind projects. They are intended to provide background information for companies wishing to enter the offshore wind supply chain. Other fact sheets are available including:

Fact sheet 1: Secondary steel

Fact sheet 3: Cable protection systems

Fact sheet 4: Cables and accessories, and

Fact sheet 5: Corrosion protection

Thanks to Bruce Anchor, Delmar Systems, First Subsea and InterMoor for providing information used in this fact sheet.

Further reading:

Guide to a Floating Offshore Wind Farm

The Guide to a Floating Offshore Windfarm provides more information on supply element of floating offshore wind projects. It has an overview of the important physical elements, lifecycle processes and costs of a floating offshore wind farm.

guidetofloatingoffshorewind.com

guidetofloatingoffshorewind.com/b-3-1-anchors

guidetofloatingoffshorewind.com/b-3-mooring-system

guidetofloatingoffshorewind.com/b-3-3-jewellery

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