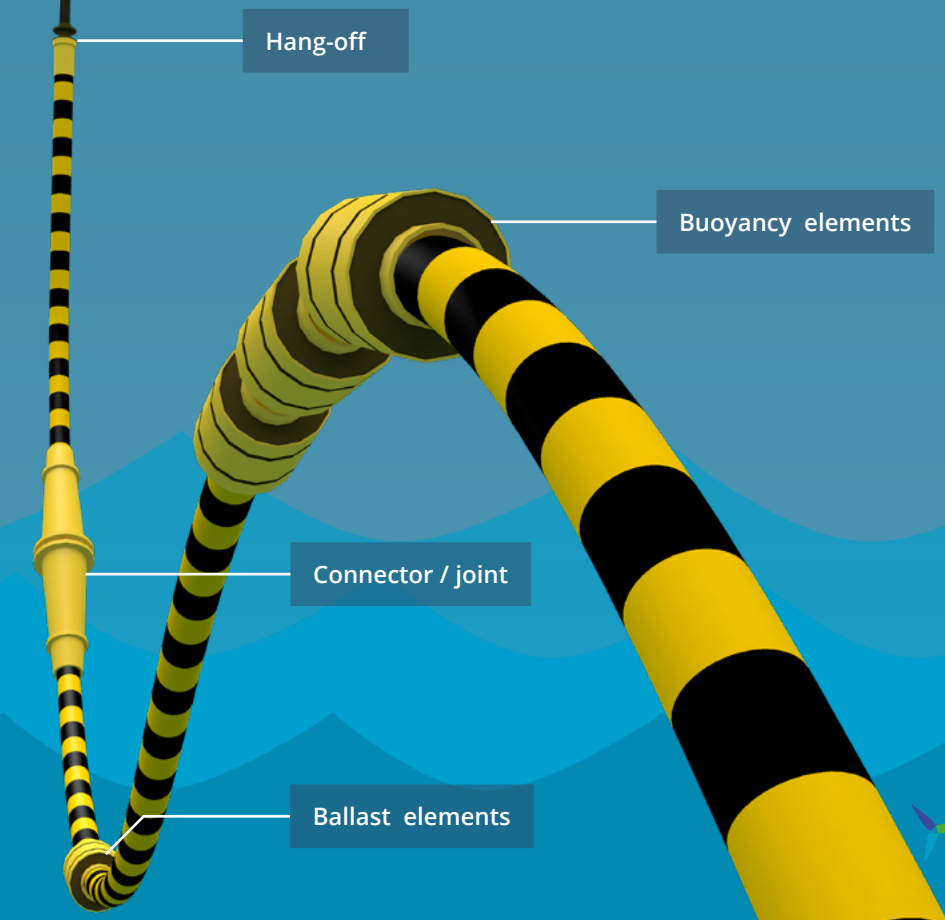
Fact sheet 4: **Cables and accessories**

What are cables and accessories?

There are two types of cable used in offshore wind, array cables and export cables. Array cables transmit power from wind turbines in a string to an offshore substation. Array cables are typically rated at 66 kV, this is expected to increase to 132 kV in the future. Higher capacity export cables, typically rated at 220 kV, deliver power from the offshore substation to the onshore substation for further distribution into the grid. Future wind farms may use export cables with higher ratings, up to 275 kV. Sometimes for smaller wind farms an offshore substation is not required, and the array cables connect to the onshore substation. Cable accessories terminate the cable and provide mechanical support during installation and over the cable's lifetime.



Overall description

Offshore wind farms are generally composed of two types of cables. Array cables connect the turbines in a farm and deliver the power generated to an offshore substation. Export cables connect the offshore substation to the onshore substation.

Floating wind turbines will use dynamic array cables as a minimum for the section near the turbine, while static cables are used for fixed turbines. Dynamic cables are more durable and flexible than static cables, to withstand the loads and movement experienced during floating turbine operation. Whether a mix of static and dynamic cables with joints are used depends on availability and a cost benefit analysis of cable supply and installation.

Cable accessories include:

- Buoyancy elements
- Cable protection (covered in *Fact Sheet 3: Cable protection systems*)
- Connectors and joints, and
- Hang-offs.

Cables are composed of a conductive metal core, surrounded by insulation and armouring material and bound by a sheath or polymer rope. Fibre optic cables can be incorporated into the cable to facilitate communications and data transfer between the shore and the wind farm and cable condition monitoring. Cable accessories are made of a variety of materials, mainly fabricated metal and polymers.

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Cables and accessories: Subcomponents

Array cables: Static

Description: Static cables are used as inter-array cables for fixed-bottom wind turbines. Static cable cores tend to be made of aluminium.

Sub-components: Aluminium core, insulation material – commonly cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR), armouring material (steel or lead wire), polypropylene binding ropes.

Applicable standards: DNV – ST – 0359, IEC 60840

Typical weights: Approximately 60 kg/m or more (for a typical 66kV cable).

Typical dimensions: 120mm OD to 200mm OD. Length is project dependent, typically 1.5 km or more.

Array cables: Dynamic

Description: Dynamic cables are used as inter-array cables for floating wind turbines. For dynamic cable cores, copper is the preferred material. Dynamic cable sections can be connected to static cable sections using cable joints. This is typically done if the cable section is 5 km or longer. Dynamic cables typically have two armour layers, differentiating them from static cables.

Sub-components: Copper core, insulation material – commonly XLPE or EPR, armouring material (steel or lead wire), polyethylene sheathing.

Applicable standards: DNV – ST – 0359, IEC 60840, DNV – ST - 0119

Typical weights: Approximately 70 kg/m or more (for a typical 66kV cable).

Typical dimensions: Dynamic cables tend to be larger than static cables. OD typically 140 mm or more. Length is project dependent, typically 1.5 km or more.

Export cables

Description: Export cables are high voltage cables linking wind farms to shore and the grid. They can be HVAC or HVDC and range in voltage from 120kV to 400kV.

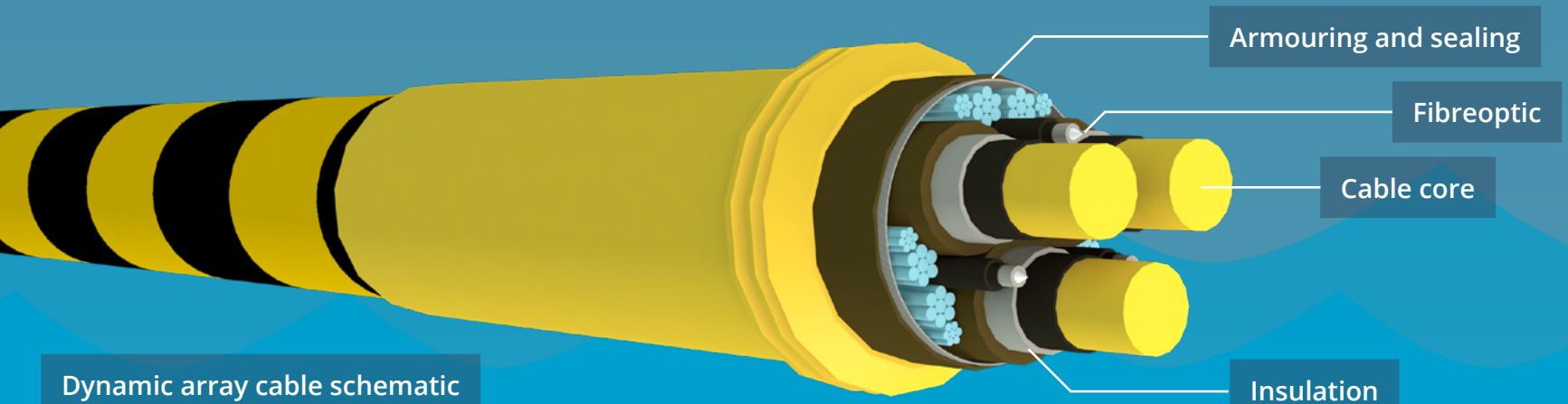
Sub-components: Copper (or aluminium) core, insulation material – commonly XLPE or EPR, armouring material (steel wire), sealing material (lead) and polyethylene sheathing.

Applicable standards: DNV – ST – 0359, IEC 60840

Typical weights: approximately 70 kg/m

-150 kg/m

Typical dimensions: 200mm - 300 mm outer diameter.



Dynamic array cable schematic

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Cables and accessories: Subcomponents

Hang-offs

Description: Cable hang-offs support and secure the termination points of subsea cables. They provide support and protection to the cable at the transition point between the wind turbine and ocean.

Sub-components: Metal plate, seal, clamp, hang off casing, armouring wires, steel bolts.

Applicable standards: DNV – ST – 0359, IEC 60840, DNV – ST - 0119

Typical weights: 250 kg – 500 kg

Typical dimensions: OD of approximately 500 mm. Length 0.5 m – 1 m.

Connectors and joints

Description: Connectors are pluggable connections between two portions of cable or between the cable and floating substructure. They allow cables to be disconnected and reconnected. The decision to use connectors in a floating wind farm is based on the chosen maintenance strategy. For example, a tow-to-port strategy would need to use connectors for easy disconnection.

Joints connect segments of cable into a single continuous length. They can be used to connect static and dynamic array cable sections.

Sub-components: Housing, seal, bolts

Applicable standards: DNV – ST – 0359, IEC 60840

Typical weights: 500 kg – 1 tonne

Typical dimensions: OD of approximately 500 mm, length of approximately 2 m.

Buoyancy and ballast elements

Description: It is preferable to hold dynamic cables in a "lazy wave" configuration, to reduce cable fatigue caused by movement of the substructure. Buoyancy modules are used to maintain the shape of the cable, lifting the top of the curve. Ballast modules perform the opposite function, weighing the cable down at the bottom of the curve.

Sub-components: Polyurethane core, polyurethane coating, steel bolts.

Applicable standards: DNV – ST - 0119

Typical weights: Large range, from hundreds of kilograms to many tonnes.

Typical dimensions: Typically 1 cubic meter to 4 cubic metres. Generally barrel-shaped.

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Cables and accessories: Manufacture

Typical manufacturing process

Cables (all types follow a similar process):

- A catenary continuous vulcanisation (CCV) line extrudes insulation material over the conductive core.
- Once insulation has been applied to the core, a vertical layup machine is used to twist three cores together along with a length of fibre optic cable to form a twisted helix.
- A horizontal armouring machine is then used to twist the armouring material around the helix.
- Ropes consisting of the container material are then twisted around the armoured core using a horizontal armouring machine to bind the entire package together.

Hang offs:

- Hang offs are made from steel plate and large diameter tube welded together.
- Welded sections are then bolted together in final assembly.
- In some cases, subcomponents could also be cast.

Buoyancy elements: Cast and assembled onto the cable typically in two parts.

Cables being spooled for Moray East offshore wind farm.
Image courtesy of JDR, all rights reserved.

JDR array cable at port
Image courtesy of JDR, all rights reserved.

Component materials

- The cable core is manufactured from either aluminium or copper. Aluminium or copper can be used for static cables, while copper only is preferred for dynamic cables.
- Cross-linked polyethylene or ethylene propylene rubber are commonly used for cable insulation.
- Cable wrapping and filler is commonly made of polypropylene.
- Cable armouring is made of steel wire. Lead is also used to seal export cables.
- Fibre optic cables are made of silica glass.

Manufacture facility requirements

Cable manufacture facilities require the following equipment:

- Plastic extruders
- Vertical layup machines
- Horizontal armouring machines
- Cable spooling equipment
- Type testing equipment, and
- Lifting and handling equipment

Cable accessory manufacture facilities require the following equipment:

- Plate steel cutting and welding equipment
- Type testing equipment, and
- Lifting and handling equipment.

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Cables and accessories: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Dynamic array cables	**Approximately £70 million per GW**	**See below**	**-**	**-**	**Must be able to transmit required power without overheating and survive the fatigue and ultimate loads applied at installation and over lifetime**
Cores	Approximately £150 per m. Highly dependent on commodity pricing	Copper	Approximately 10 kg/m	OD approximately 40 mm, length as required, but typically at least 1.5 km	Typically, there will be three cores per cable
Insulation	Approximately £2 per m	XLPE or EPR	1 kg per m – 1.5 kg per m	Wall thickness between 8 to 12 mm OD and lengths depending on cable requirements	Insulation prevents electrical leakage from the conductive core into the surrounding water
Armouring	Approximately £1 per m	Steel wire	4 g per m per strand – 60 g per m per strand	Typical OD of 0.8 mm– 3 mm	Zinc wire can be used if greater corrosion protection is desired. Bitumen can be layered over the armouring to provide additional corrosion resistance and adhesion
Static array cables	**Approximately £50 million per GW**	**See below**	**-**	**-**	**Must be able to transmit required power without overheating and survive the fatigue and ultimate loads applied at installation and over lifetime**
Cores	Approximately £15 per m. Highly dependent on commodity pricing	Aluminium	Approximately 3 kg/m	OD approximately 40 mm, length as required, but typically at least 1.5 km	Typically, there will be three cores per cable
Insulation	-	-	-	-	*See dynamic array cable entry above*
Armouring	-	-	-	-	*See dynamic array cable entry above.* Static cables typically have a single layer or armouring.
Export cables	**Approximately £200 million per GW**	**See below**	**-**	**-**	**Must be able to transmit required power without overheating and survive the fatigue and ultimate loads applied at installation and over lifetime**
Cores	Approximately £30 per m. Highly dependent on commodity pricing	Aluminium	Approximately 3 kg/m	OD approximately 40 mm, length of several km	Typically, there will be three cores per cable
Insulation	Approximately £1.5 per m	-	-	-	*See dynamic array cable entry above*
Armouring	Approximately £1.5 per m	Steel and/ or lead wire	Steel: 4 g – 60 g per metre per strand Lead: 6g – 80 g per metre per strand	Typical OD of 0.8 mm– 3 mm	*See dynamic array cable entry above* Lead wire is used as a sealing material if dry cable design is chosen, and cable capacity is 150 kV or greater

Cables and accessories: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Fibre optic cables	**Approximately £50 per m**	**See below**	**-**	**-**	**Must be able to transmit data requirements**
Core	Approximately £6 - £12 per m	Glass fibre	2 g per m – 30 g per m	OD 1 mm – 4 mm	Fibre core typically comprised of 48 individual fibre strands but can contain up to 96 strands
Steel tube	Approximately £10 - £50 per m	304 or 316L stainless steel	10 g per m.– 40 g per m	OD typically 2 to 5 mm Wall thickness 0.2 mm – 0.3 mm	Houses the glass fibre core
Insulation	Approximately £0.1 - £0.3 per m	XLPE	Approximately 70 g per m – 230 g per m	OD typically 3 mm – 16 mm Wall thickness 1 mm – 1.5 mm	Typically, two layers of insulation, one over the steel tube and another over the armouring
Hang offs	**£8,900 per MW**	**See below**	**-**	**-**	**Must support and secure the termination points of subsea cables**
Casing	Approximately £200 per hang-off	S355 steel	Approximately 150 kg	OD approximately 500 mm or greater	Must be able to securely fit into the I- or J-tube. *A separate fact sheet has been produced dedicated to Secondary Steel*
Clamp	Approximately £50 - £100 per hang-off	S355 steel	50 kg – 100 kg	Inner diameter 120mm or greater, depending on cable design	The inner diameter of the clamp must securely fasten around the outer diameter of the cable
Seal	Approximately £20- £40 per hang-off	Typically, two-component sealing resin is used	Approximately 0.5 kg – 1 kg	-	Seal must achieve at least IP44 ingress protection rating, in compliance with IEC 60529
Bolts	Approximately £120 per set	Stainless steel	Approximately 1 kg per unit	M12 - M20 bolts	-

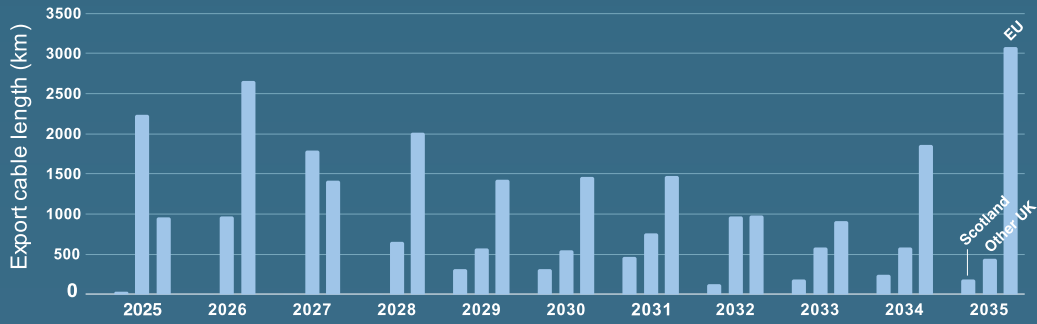
Cables and accessories: Design data

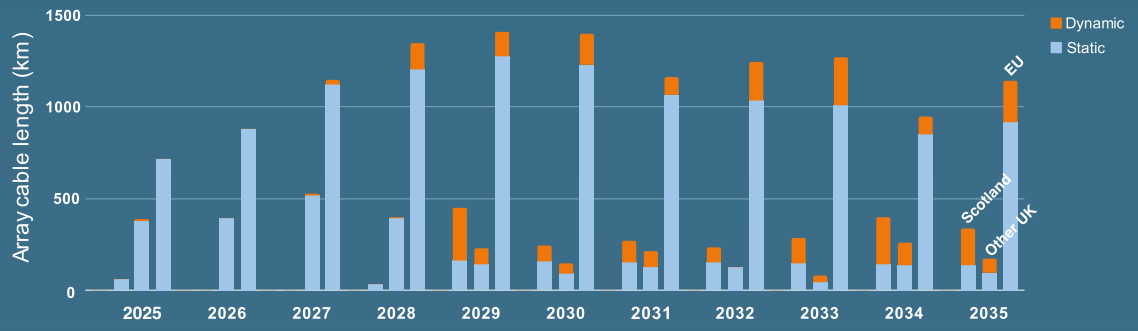
Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Connectors and joints	**£13,000 per MW**	**See below**	**-**	**-**	**Must be able to transmit required power without overheating and survive the fatigue and ultimate loads applied at installation and over lifetime**
Housing	Approximately £300 or more per connector depending on size	316L steel	Approximately 300 kg or more	OD approximately 500 mm	Houses and protects the joined section
Seal	Approximately £10,000 - £20,000 per joint	Two component sealing resin	Approximately 200 kg – 400 kg	-	Connectors are typically resin filled to protect cables from corrosion and mechanical load
Bolts	-	-	-	-	*See hang-off entry on page 6*
Buoyancy elements	**£5,500 per MW**	**See below**	**-**	**-**	**Are designed to pull the cable into a "lazy wave" shape. Exact specifications will depend on cable properties and environmental conditions**
Core	Depending on size, £500 to £5,000 per unit	Polyurethane foam	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. Maintains shape of the cable to help it resist fatigue
Bolts	-	-	-	-	*See hang-off entry on page 6*
Clamps	Approximately £50 to £1,000 per unit each depending on design requirement	Stainless steel, titanium or glass fibre composite	Large range, typically based on the buoyancy element size	Varies depending on design and dimensions buoyancy element	Clamp to connect halves of buoyancy element together and hold it in place on the cable
Ballast elements	**-**	**See below**	**-**	**-**	**Are designed to pull the cable into a "lazy wave" shape. Exact specifications will depend on cable properties and environmental conditions**
Core	Large range depending on size. Approximately £5,00 to £5,000 per tonne	Cast iron or carbon steel	In the range of 250 kg to 10 tonnes per weight	Large range, typically 1 cubic metre to 4 cubic metres	Provide the mass of the system. Are typically barrel shaped and come in a number of modules that can be combined
Bolts	-	-	-	-	*See hang-off entry on page 6*

Cables and accessories: Market

Available market

The export cable market has been forecast based on average project size (and therefore number of export cables) and the average distance from shore for each year and project region. This is given below:





The table below shows forecast values for ScotWind and INTOG projects based on an 18 MW turbine capacity. Designs for these projects are not yet confirmed, so forecasts are variable.

Component	Assumption	Forecast for ScotWind / INTOG*	
		ScotWind	INTOG
Dynamic array	1.5 km per floating turbine	1,600 km	460 km
Static array	1.5 km per fixed turbine	900 km	0 km
Export	Based on average number of export cables required and distance to shore	4,100 km	2,000 km
Cable accessories			
Hang-offs	2 per array cable	3,500 units	600 units
Terminations	2 per array cable	3,500 units	600 units
Buoyancy and ballast elements	2 strings per dynamic array cable, consisting of 5 units	11,000 units	3,000 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

- Cables and cable accessories make up a portion of the balance of plant expenditure of a development.
- Cable manufacturers must source aluminium and copper wires, steel or lead wire, fibre optic cables, polypropylene rope and insulation material (commonly XLPE or EPR in the form of pellets) to assemble components.
- Cable accessory manufacturers must source steel profiles and sealing resin.
- EPCI contractors have historically been the main purchasers of cable systems.
- More recently, developers will purchase cables directly and hire a transport and installation contractor to install the cable package.
- Incumbent suppliers include Hellenic Cables, JDR Cable Systems, LS Cable & Systems, Nexans, NKT, Prysmian, Sumitomo Electric and TKF.

Accreditation / regulatory landscape

Cables are subject to type testing according to IEC 60840. Third party vendors such as KEMA and DNV are used, who will send witnesses to observe type testing and issue certification.

Standards applying to cables and cable accessories include but are not limited to:

- DNV – ST – 0359
- DNV – ST – 0119
- IEC 60793
- IEC 60794
- IEC 60840

Cables and accessories: Costs

Typical costs / CAPEX requirements

- Cables and accessories cost approximately £130 million for a 450 MW floating offshore wind farm.
  - Export cables: £88 million, 3.4%
  - Array cables: £32 million, 1.2%
  - Cable accessories: £12 million, 0.5%
- This equates to 295,000 £/MW
  - Export cables: 200,000 £/MW
  - Array cables: 70,000 £/MW
  - Cable accessories: 25,000 £/MW
- This totals approximately 5 % of the total project cost.
- This cost is for the cable accessories work packages for a typical floating offshore windfarm as outlined in the cost assumptions. This will include all the components described above.
- This cost will vary significantly depending on what is included in the cable accessories package, environmental conditions, site layout 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

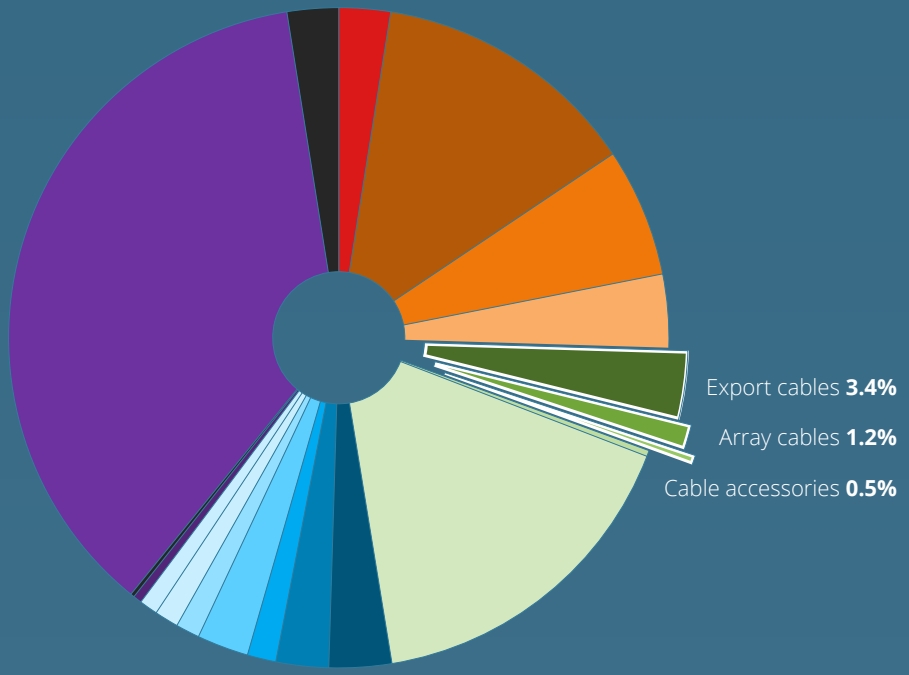
- End users of cables and cable accessories must bear transport and installation costs for the cable system.
- Cables also require inspection, maintenance and repair. Although this cost can be reduced if cable protection systems are used, regular inspection is still required. See Factsheet 3: Cable protection systems for more information.

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.



- Development and project management
- Turbine nacelle
- Turbine rotor
- Turbine tower
- Export cables
- Array cables
- Cable accessories
- Cable protection
- Floating substructure
- Jewellery
- Offshore substation
- Onshore substation
- Cable installation
- Mooring and anchoring pre-installation
- Floating substructure - turbine assembly
- Floating substructure - turbine installation
- Offshore substation installation
- Other installation
- Operations and maintenance
- Decommissioning

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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 2: Anchors and moorings

Fact sheet 3: Cable protection systems, and

Fact sheet 5: Corrosion protection

Thanks to JDR Cable Systems 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 elements 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-1-3-cable-accessories

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