Offshore Wind Strategic Spares Hypothesis Testing Report

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PREFACE

Offshore wind has been expanding rapidly over the last decade, and this is further bolstered in the UK by the Clean Power 2030 Action Plan released in December 2024. The development of wind farms is linked to multiple areas, with future development particularly focused in Scotland, East Riding, Berwickshire and the Celtic Sea. Siemens Gamesa has the greatest proportion of turbines in the UK, followed by Vestas and GE.

Off the North East coast there are 15 wind farms at varying stages of development, with the majority of turbines provided by Siemens Gamesa, followed by GE. Grimsby Port and Port of Tyne are the most utilised ports in the region as O&M bases.

Offshore Renewable Energy Catapult has produced this report to provide the North East Combined Authority with insight into the feasibility of an Offshore Wind Strategic Spares Centre (OWSSC) in the region.

Responsibility for spares varies during the lifetime of the wind farm. During the wind turbine warranty period, typically five years, the original equipment manufacturer (OEM) has responsibility for all operations and maintenance (O&M) tasks, including the management of spares. Outside of the warranty period the responsibility may revert to the owner-operator (OO) or remain with the OEM depending upon the contractual arrangement. The balance of plant (BOP), which includes the foundation and elements of the high voltage network, are the responsibility of the OO throughout the life of a windfarm. For the first-year post-construction, the export cable and substations are also the responsibility of the OO, before passing over to the Offshore Transmission Owner (OFTO).

Spares will be stored on the technician transport vessel, at the O&M base in quayside storage, at a UK central stores facility or a continental central storage facility. Typically, the parts required for servicing or most frequent failures are stored on the vessel or O&M base, and those required for infrequent failures that have a high impact in the central stores locations.

Considerations for spares storage include parts servicing and warranty period; facility location; facility size and space; and delivery time of parts to wind farms.

Given the maturity of OEM spares methodology, an independent OWSSC is unlikely to be viable for storing spares for turbines in warranty. However, these future scenarios may create a business opportunity:

- Stockpiling of spare parts for turbines reaching obsolescence, in particular where a life extension programme is planned
- Storage of parts from decommissioned turbines
- Storage of refurbished parts
- Storage of cables and components for floating wind turbines

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NOMENCLATURE

BOP	Balance of plant
CMMS	Computerised Maintenance Management System
CPS	Control and protection system
CTV	Crew transfer vessel
DNP	Defect notification period
HV	High Voltage
J-U	Jack-up vessel
NECA	North East Combined Authority
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OFTO	Offshore Transmission Owner
OO	Owner-operator
OWSSC	Offshore Wind Strategic Spares Centre
SOV	Service operation vessel
SPARTA	System, Performance, Analysis and Reliability Trend Analysis
TP	Transition piece
TSSA	Turbine supply and service agreement

1 INTRODUCTION

The North East Combined Authority (NECA) is seeking to explore the feasibility and potential benefits of establishing an Offshore Wind Strategic Spares Centre (OWSSC) in the region. The OWSSC would aim to address industry challenges in spares management and bring employment and economic growth to the region. A potential synergy to be considered is the planned data centre in Cambois. This report provides an overview of the feasibility of an OWSSC by investigating the following areas:

- Current spares management models
    - The lifecycle of a wind farm, including key stakeholders and types of spares required
    - The location of stores both at a local and national level
    - Physical requirements for a central store
    - Employment associated with wind farm stores
    - Data management
- Current and future offshore wind market around the North East and across the UK
- Future spares management scenarios
- Opportunities and recommendations

1.1 UK Offshore Wind Overview

In the Clean Power 2030 Action Plan (December 2024), the UK Government committed to reaching an installed offshore wind capacity of 43-50 GW by 2030. Achievement of this ambitious target requires an average annual installation rate of 6-8 GW and the development of robust local supply chains to maximise the economic benefits for the UK. ORE Catapult analysis indicates that at the present rate of deployment, the UK will fall short of its target, instead reaching 41 GW commissioned capacity, including partially generating projects, as shown in Figure 1. The current consenting process and the capacity of the grid and supply chains are significant constraints on the rate of deployment.

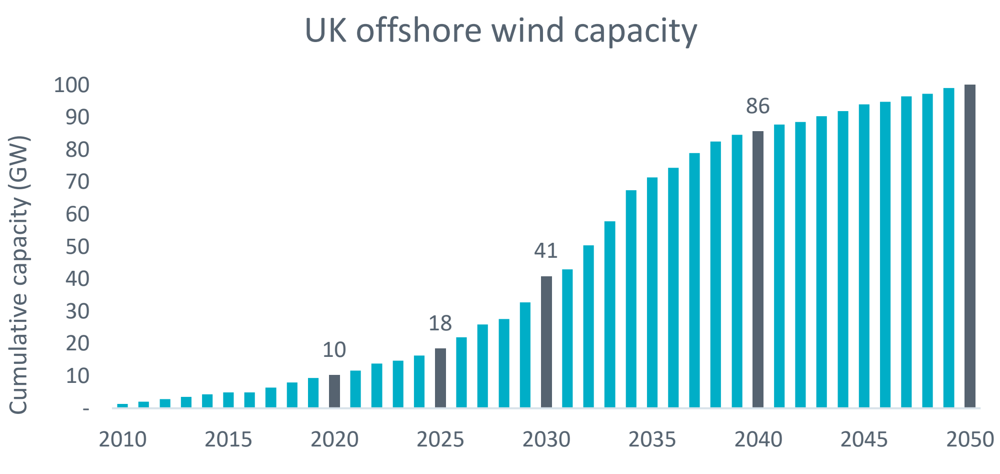


Figure 1 UK offshore wind capacity growth [1]

2 CURRENT SPARES MANAGEMENT MODEL

2.1 Key Stakeholders

The current spares management model for offshore wind involves key stakeholders positioned across different aspects of the wind farm. These include:

- Wind farm owner(s): larger organisations financing the project. These are often multiple organisations that form joint ventures or partnerships
- Operator: Responsible for day-to-day operation of the offshore wind project. They also often hold a financial stake and therefore the term owner-operator (OO) is often used
- Wind turbine original equipment manufacturer (OEM): Manufacturers of the wind turbine
- Service provider: Most operations and maintenance (O&M) tasks are undertaken by third party or independent service providers when the turbine is out of warranty
- Offshore Transmission Owner (OFTO): The O&M responsibility for substations and export cables transitions to the OFTO approximately one year after installation

2.2 Wind farm components

The main assets of an offshore wind farm (shown in Figure 2) include the:

- Turbines and their foundations
- Array cables connecting the turbines
- Offshore substation(s)
- Export cable
- Onshore substation up to the grid transmission system connection

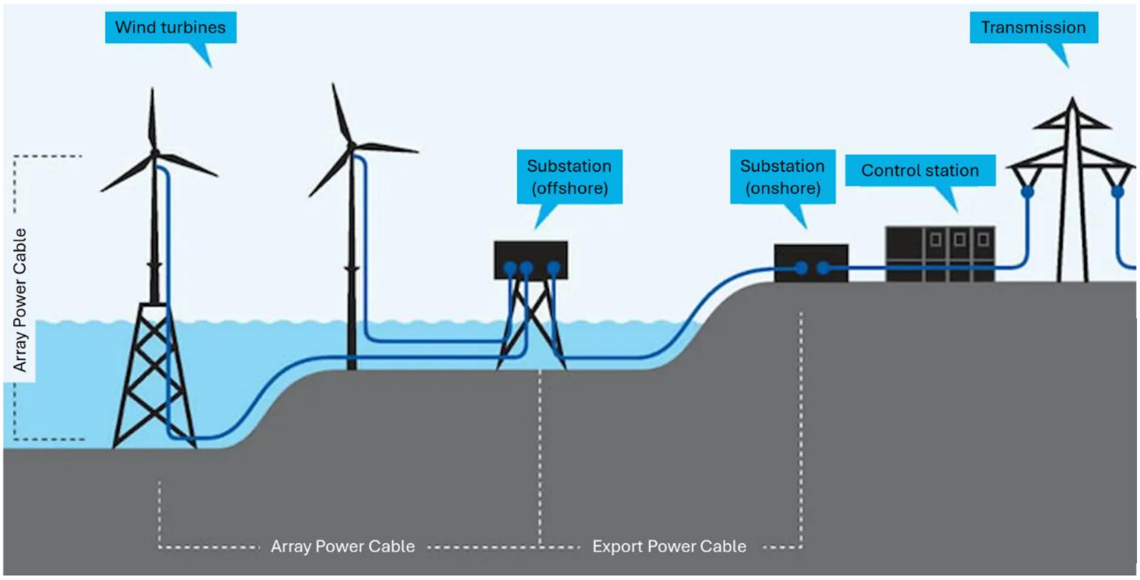


Figure 2 Main assets of an offshore wind farm

2.3 Operations and Maintenance Responsibility

The responsibility for managing different wind farm components varies over time and is summarised in Table 1. Wind turbine responsibility is covered in detail in section 2.3.1.

The OO is responsible for maintenance of the balance of plant (BOP), which includes the transition piece (TP), foundation, array cables and associated high voltage (HV) equipment and, in the early days of operation, the offshore and onshore substations and the export cables. About one year into operation, responsibility for the substations and export cable is transferred to OFTO, and that company will usually outsource maintenance to a third-party provider such as EDS HV Group [2] or RES Group [3].

Table 1 O&M responsibility through wind farm lifetime

	Y1 Y2 Y3 Y4 Y5 Y…
Wind Turbine	OEM OO
Civil BOP (TP and foundation)	OO
Electrical BOP (HV and cable)	OO
Offshore substation	OO OFTO
Onshore substation	OO OFTO

2.3.1 Wind Turbine Responsibility

The wind turbine OEM warranty period, or defect notification period (DNP), is determined as part of the turbine supply and service agreement (TSSA) during project contractual negotiations. Historically these have been three to five years in duration, although more recently agreements have varied from 2-15 years. Hornsea Project Two had a three year warranty period with the site fully commissioned in August 2022 [4] and back in Ørsted's control in June 2025 [5]. Conversely, London Array had a 10 year warranty period with the site fully commissioned in 2013 and RWE winning the service contract in 2023 [6].

During the warranty period the OEM will be responsible for the turbine O&M and as such determines the spares required for storage at the O&M base and, if applicable, at central storage facilities. The OO may purchase and store additional parts as part of their risk management strategy.

Following the warranty period, O&M strategies include:

- Self-perform: The OO becomes responsible for wind turbine O&M and may do this directly or use third party service providers
- Flexible/mixed: The OO signs an initial service agreement with fixed cost options to extend the OEM service agreement in whole or in part
- Wind Turbine OEM: The OO signs an initial service agreement to lock in the O&M delivery by the OEM beyond the standard warranty period

Under self-perform and flexible scenarios, the OO may use the OEM as the sole or chief supplier of spare parts. The price and availability guarantees may differ from those offered under exclusive arrangements.

The operational lifetime of a wind turbine is expected to be 20-25 years, although the introduction of life extension programmes and design of newer turbine models may see these increase to 30+ years. Approximately 70% of UK offshore wind turbines are currently in the 5-15 years age bracket (Figure 3) and therefore likely to be post-warranty. By 2030, over 50% of turbines are anticipated to be out of warranty (Figure 4). These numbers include current and future turbines, and exclude decommissioned turbines. It is unknown which O&M strategy will be implemented following the completion of the warranty period at each wind farm. Further discussion on the impact of obsolescence on sparts parts for many turbines in the 5-15 years bracket is included in sections 4.1 and 5.2.

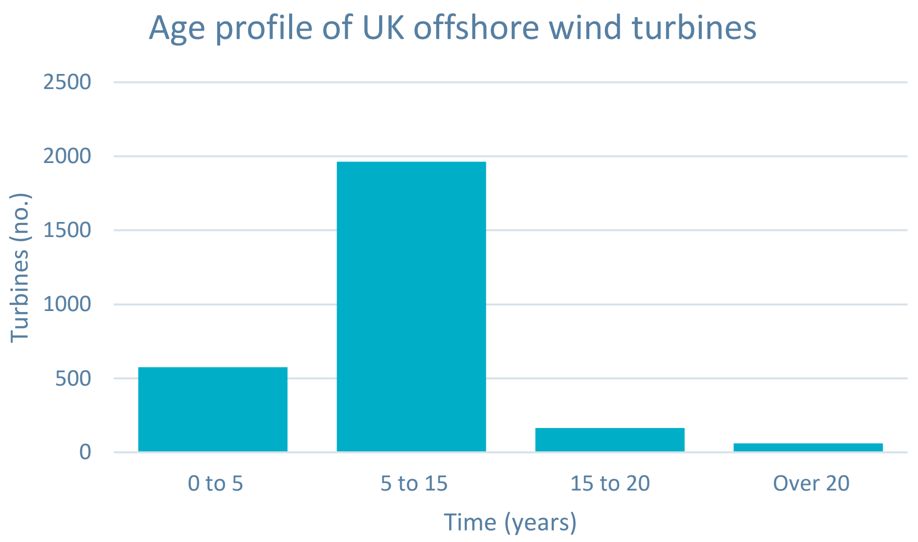


Figure 3 Age profile of UK offshore wind turbines [7]

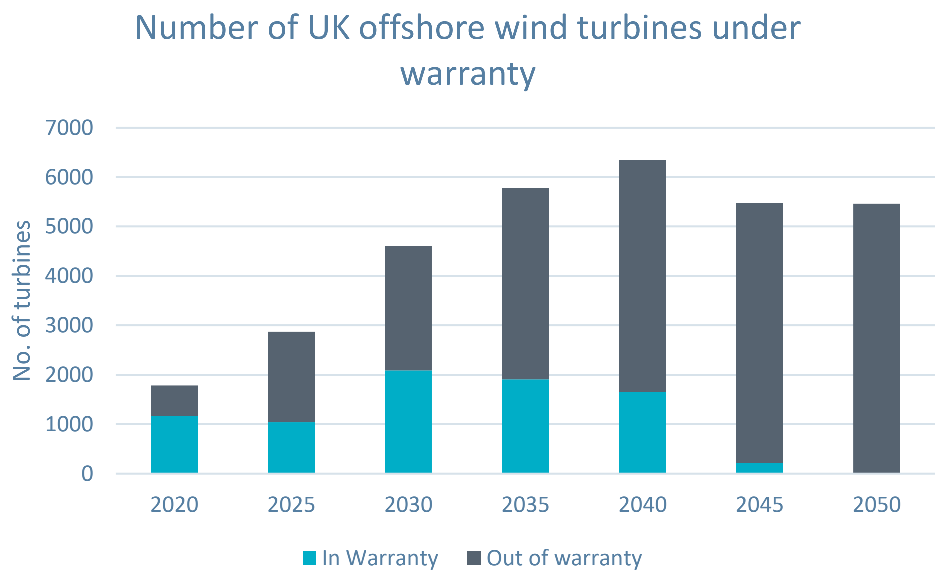


Figure 4 Turbines in and out of warranty

2.4 Operations and Maintenance Models

The O&M model will vary depending on the wind farm location and will utilise crew transfer vessels (CTVs) or service operation vessels (SOVs). Under a CTV model technicians and parts are conveyed from the O&M base to the offshore wind farm and back on a daily basis. This is the typical approach for nearshore sites with a transit time of up to 90 minutes. At far-shore sites, with a transit time over 90 minutes, the SOV model is used. In this operational model, the SOV and technicians remain at the wind farm for up to two weeks before returning to the O&M base to refuel, restock and change over personnel. Figure 5 shows how the logistics model changes at different stages of development and with distance from shore. The currently generating offshore wind farms are typically closer to shore and use a CTV model, whereas the majority in the pre-consent to construction stages will use the SOV model. Defining O&M models as CTV or SOV is an oversimplification as some offshore wind farms are also supported by helicopters or may have a combined SOV and CTV strategy.

The O&M model influences the optimal location of spare parts storage. A CTV model, where the preparation of parts and tools can be very reactive and on a daily basis, is best served by quayside stores. An SOV-only model requires parts and tools on a two-weekly basis and could be served by a stores site further from shore.

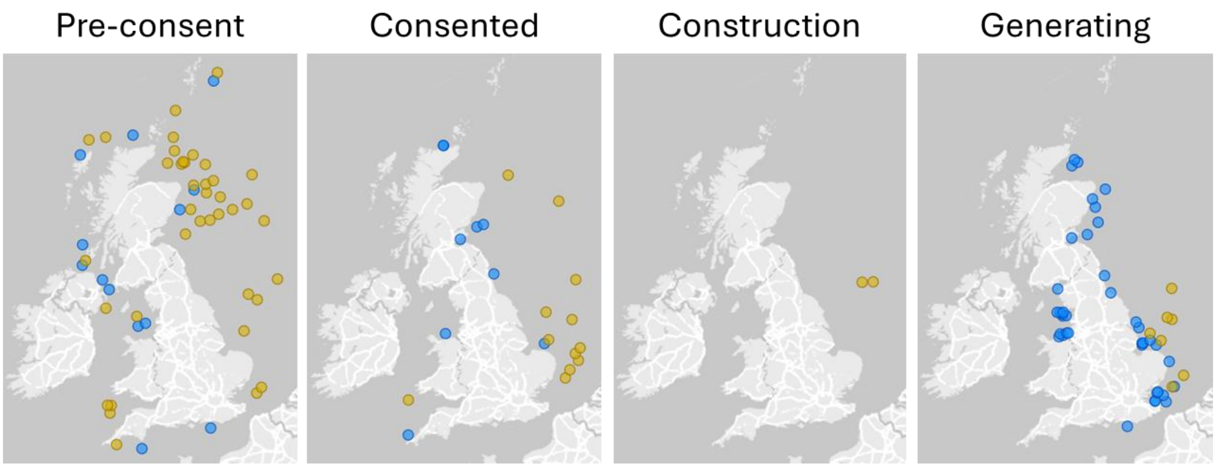


Figure 5 O&M CTV/SOV model (blue = CTV, yellow = SOV)

2.5 Current Spare Parts Management Methodologies

The number and types of spare parts stored are primarily determined by the OEM during the turbine warranty period. The OO may choose to hold additional strategic spares based on their experience and knowledge of the turbine. For wind farms out of warranty the number of spares will be determined by the service provider or operator. This is typically led by the OEM recommendations and learning during the warranty period. Strategic spares are those deemed critical to maintaining operation, such as components on long lead times or where frequent failures are expected.

Spare parts are stored in different facilities, as shown in Figure 6 and Figure 7. Frequently used spares are typically stored at the quayside or in local warehouses, with the possibility of a holding area on the vessel for small, predictable items that may be needed within a day's work. Infrequently used spares and those on longer lead times are often stored in national central warehouses with easy access to all OEM serviced wind farms. High risk parts with a low probability of failure are stored in a continental central warehouse were, for example, there may only be three parts for all wind farms globally. Parts delivered from stores outside the UK would be subject to all standard customs and import duties, unless there are exceptional circumstances such as the use of freeport. This has the potential to impact lead times and therefore the time taken to return the asset to full operation.

The strategy and location of spares storage facilities will vary between wind farms depending on the location of available storage facilities at the quayside and turbine OEM. Examples of these are shown in Figure 8.

Level 1 - SOV storage (SOV serviced wind farms only). Some CTVs may also have small storage facilities, although this is less common.

a. Routine spares
b. Service kits

Level 2 - Quayside storage

a. Strategic spares (depending on space, floor loading capacity, crane capacity, heavy lift vessel access)
b. Service kits for following operations

Level 3 - In-country central storage

a. Strategic spares, such as generators, gearboxes, blades, HV switchgear and cables
b. Parts on long lead times
c. Reduces risks of delays due to customs.

Level 4 - Continental central storage

a. High risk but low probability spares. For example, may hold three spares for across the world

Figure 6 Tiered kanban system for OEM serviced wind farms

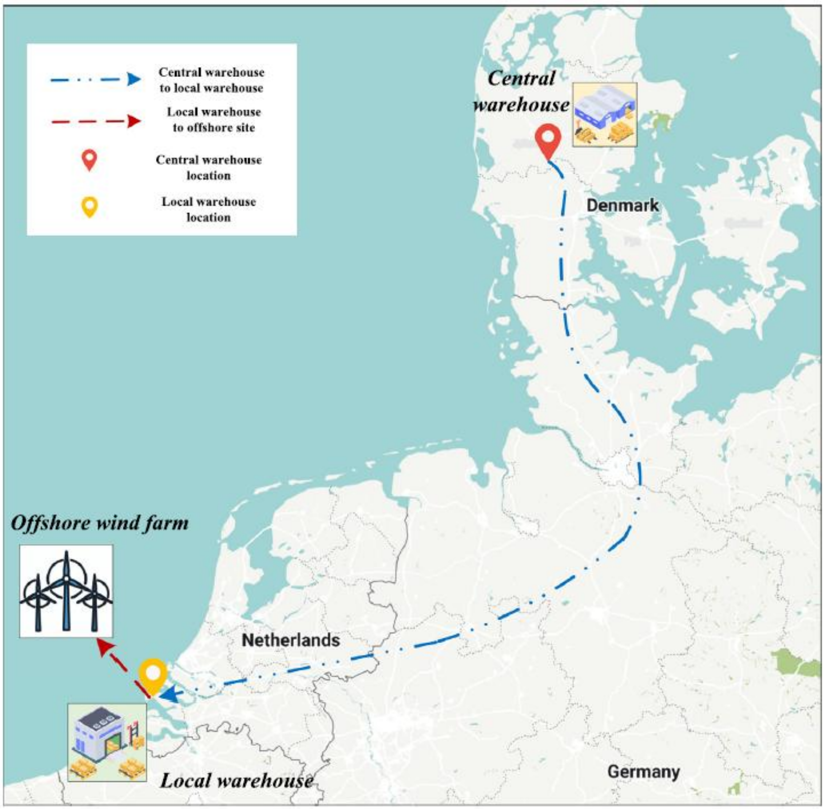


Figure 7 Example geographical location of offshore wind farm and warehouses [8]

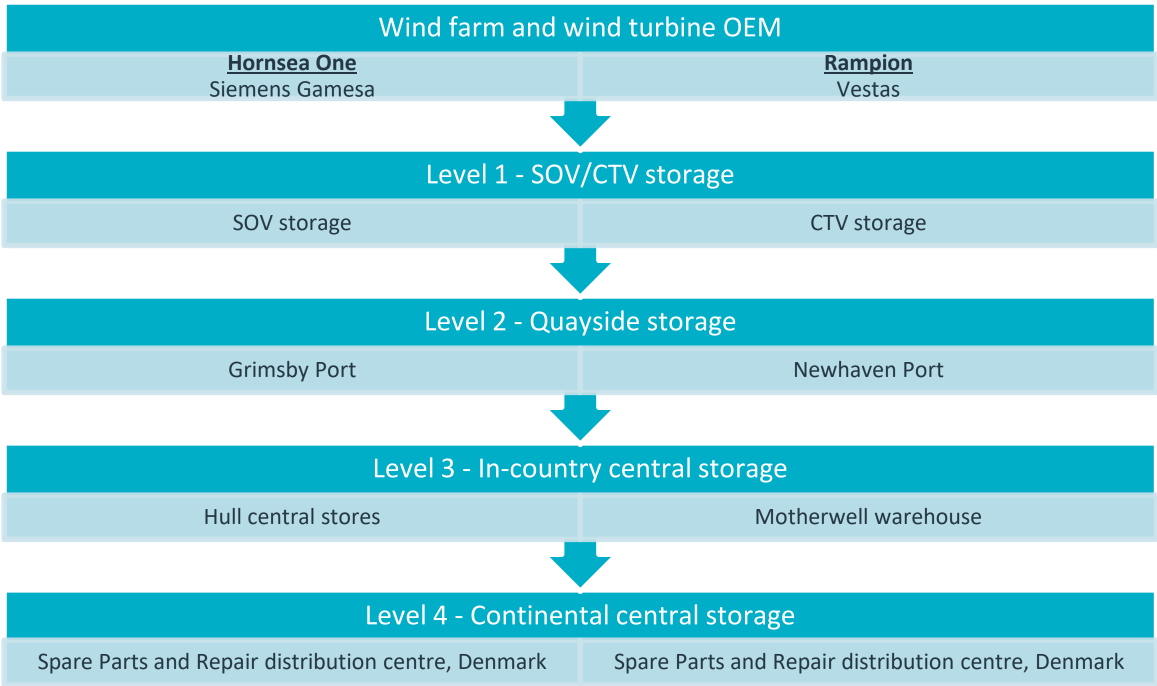


Figure 8 Example storage strategies for Siemens Gamesa and Vestas wind farms

2.5.1 Parts Compatibility

There is the potential for the compatibility of some smaller parts between turbine types and OEMs, however there is unlikely to be compatibility with the larger parts such as generators and blades. Further in-depth analysis is required to confirm any potential cross over.

2.6 Requirements

2.6.1 Parts Warranty and Servicing

Beyond the turbine availability warranty, all spare parts will come with a warranty. The warranty is likely to start with the delivery of the part from the supplier. However, there may be scope to agree an alternative start date with the supplier at the contractual stage. One possibility is to extend the warranty through a servicing regime and by providing environmental data of the storage location. Extended warranties are expected to incur additional cost.

Some parts require servicing during storage. For example, the short and long-term storage of ABB generators require [9]:

- Storage in temperatures ranging 10°C to 50°C and relative air humidity below 75%
- Paint and coating inspections every three months
- Creating ventilation openings in the storage box
- Rolling bearings 10 revolutions every two months
- Checking the integrity of bearing locking devices
- Lubricating sleeve bearings every six months

The shelf life of parts must be balanced against the predicted rate of use to minimise waste. This is of particular importance for COSHH substances such as adhesives or oil.

2.6.2 Location

The location of the storage facility is dependent on the parts being stored. For example, Siemens Gamesa has a warehouse in Hull on the same site as their blade manufacturing facility. This is positioned on the dock as most of these blades would be transported to the wind farm directly by a jack-up (J-U) vessel. However, smaller parts stored here would still be transported by road. In contrast, the Vestas spare parts storage facility in Motherwell is completely landlocked and parts are only transported from here to the wind farm O&M base by road. This storage location would therefore not store larger parts, such as blades, which would be handled by specialist heavy lift teams from Europe.

The gearbox of the Siemens Gamesa 3.6MW turbine has a mass of approximately 47 tonnes. This exceeds the maximum gross weight allowed on a 6-axle heavy goods vehicle, therefore requiring special arrangements for road transport. Transporting an abnormal load such as this requires permission from the police and National Highways Agency which takes time to process. In comparison, the mass of the gearbox for a 15MW turbine is estimated to be 196 tonnes and therefore facilities storing these parts will almost certainly need to be accessible by jack-up vessel.

2.6.3 Delivery Time of Parts

SOVs will be loaded during the 6 – 12-hour port call window. CTVs may be loaded the night before sailing or immediately prior to sailing. Parts are normally picked and packed ahead of time, with only urgent items for reactive work packed in the 30 – 60 minutes before sailing. This means that even if the storage facility requires a vehicle to transport parts to the quayside the delay would not normally affect the loading process. Where parts are required from the central storage facilities, delivery times are often dependent on the size:

- Small parts could take up to 24 hours using couriers, depending on the size and distance from the central storage facility
- Larger parts requiring specialist transport vehicles typically take 48 hours, however as a turbine strip down is likely to be required before the parts can be fitted this delivery time is not a delaying factor.

While parts delivered from the continental central store are likely to take longer, the work often involves a considerable turbine strip down or other logistics to be put in place, such as the availability of a J-U vessel (see section 3.2.3 for further details). These tasks typically take longer than delivery although delays through customs have resulted in delays to repairs.

Little information is publicly available correlating the effects of lead time, delivery, installation and re-commissioning on the yield of an asset. Much of this information will be held confidentially by OEMs and OOs, however it will inform the decision on which spares to hold.

2.6.4 Storage Space

The space required for storage is dependent on the purpose of the facility and the size of the wind farm it is serving.

The rough quayside storage facilities of two wind farms are shown in Figure 9 and Figure 10. Both stores have the following approximate characteristics:

- Overall dimensions of 20m x 25m
- 20 racks with space for 300 pallets
- A temperature-controlled store with 10 racks for smaller parts, including electrical components
- Four major components such as generators or transformers
- Tools storage
- Rigging storage
- A lay down area for packing service kits and other items
- One or two roller shutter doors providing access for a 20T forklift truck

Although both wind farms hold a similar quantity of spares the wind farm size and turbine types vary. Wind farm A contains 30 x V80 2 MW turbines and wind farm B contains 25 x SWT3.6 MW turbines.

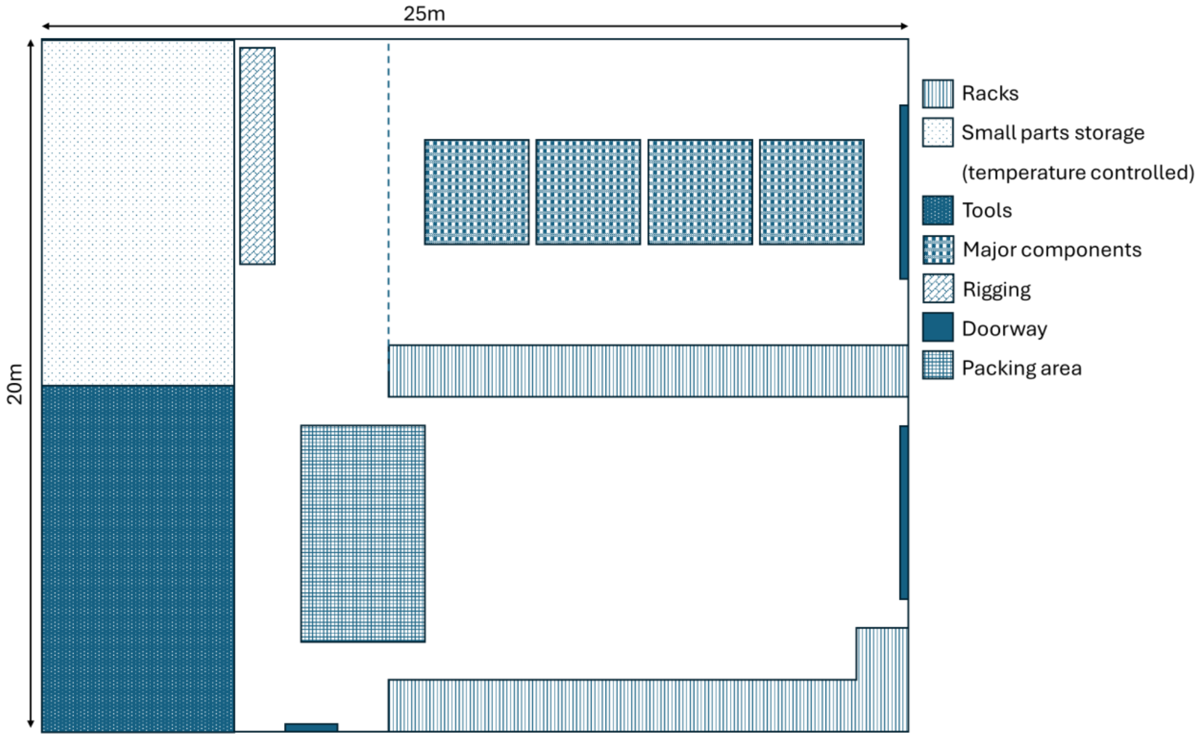


Figure 9 Indicative stores layout for wind farm with 30 x V80 turbines

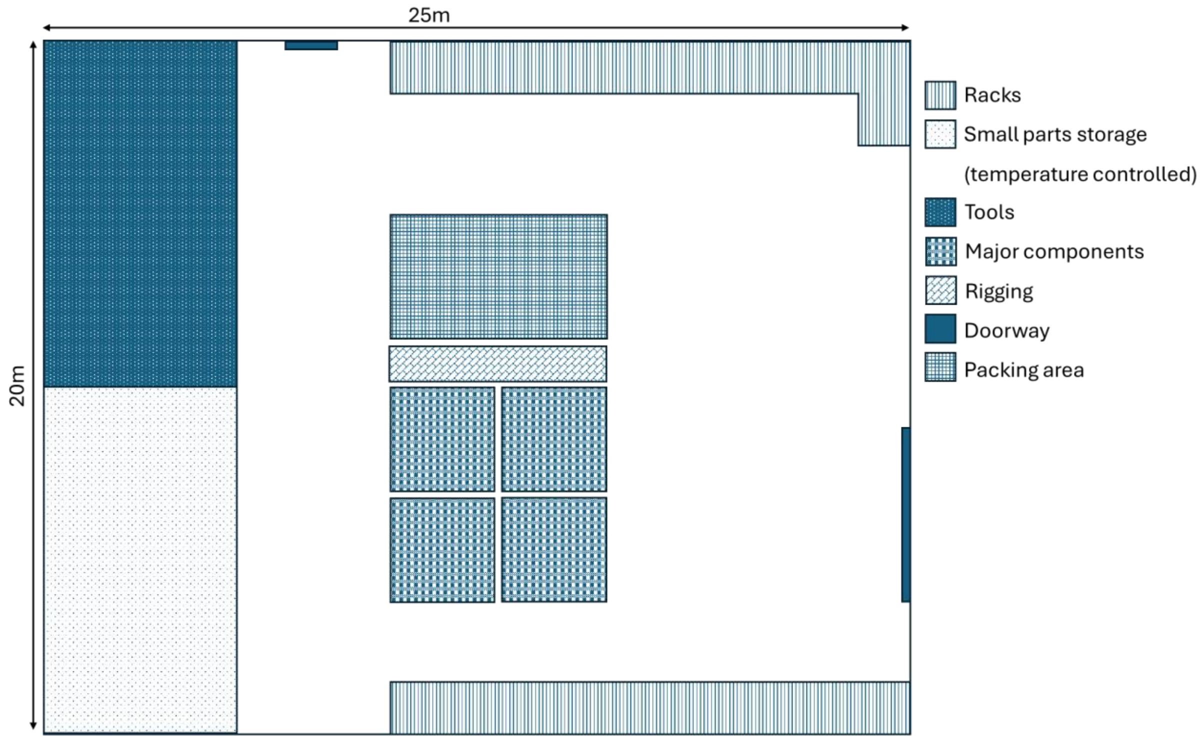


Figure 10 Indicative stores layout for wind farm with 25 x SWT3.6 turbines

In comparison, a third O&M base has a storage facility approximately 50m x 30m with 35 racks for 525 pallets and an area for small parts storage. This serves three wind farms with 277 x 13/14 MW turbines. An additional 113 turbines are planned for a fourth wind farm, which is in the pre-consent phase and operating from the same facility. This shows that the increase in turbine quantity or size is not necessarily proportional to the increase in stores space.

2.7 Employment associated with wind farm stores

The shift cover requirements for offshore wind farm stores varies with the logistics strategy, which in turn influences the overall employment opportunities at an OWSSC. Stores roles include picking the required items from shelves, packing them into lifting bags and loading them onto vessels. General skills and qualifications involve forklift licence, crane operation, rigging and slinging, waste management and pollution prevention.

Stores roles are also involved in the replenishment of stock by taking deliveries, managing calibration and inspections of equipment and stock-taking. More senior staff may be involved in procurement or arranging refurbishment and repair.

2.7.1 CTV

Technicians and boat crew will tend to work 12-hour shifts, 7 days a week. Stores cover is required at the beginning and end of the day for loading and unloading vessels. Cover is also required to take deliveries throughout the day, to manage waste from vessels and to respond to emergent works.

A minimum team of three is usually required to provide cover unless roles are shared with other members of the O&M team.

2.7.2 SOV

Onshore warehouse cover is particularly required on port call days so that the vessel can be loaded and unloaded. Outside of these times, a lower level of stores cover is required depending on the frequency and size of deliveries, which are likely to be restricted to weekdays and office hours.

At least one person is required, with assistance from the O&M team. This person may be involved in auditing and procurement activities between port calls.

2.8 Data management

Offshore wind farms use a Computerised Maintenance Management System (CMMS) such as SAP or Maximo. This connects maintenance task allocation through to parts ordering and stock management. Minimum holdings are agreed with management to control the cost of stock and ensure resilience. The replenishment levels are set manually and trigger automatic reordering processes of standard items from the central store or the regular supplier.

Other records include goods received notes, calibration documents, safety reports and quarantine information. These will be a mixture of hardcopy and digital records.

As offshore wind farms adopt more condition monitoring of components there will be more data management requirements to run analyses and trigger investigations. However, at a stores level the interaction is likely to be restricted to receiving pick lists with the parts and tools required to complete the maintenance, regardless of the source of the alert.

3 UK OFFSHORE WIND OVERVIEW

To achieve the UK's ambitions, a rapid buildout of wind farms is being planned across an increasing number of UK areas. Figure 11 and Figure 12 show the number of turbines and total offshore wind capacity across different UK regions. These are also categorised by the wind farm development stages shown in Figure 13. For the purpose of this analysis decommissioned wind farms and development zone opportunities have been excluded. The bubble map in Figure 14 has been included to show the locations and relative size of wind farms. As the maximum number of turbines is not confirmed until wind farms are consented, the number of pre-consent turbines may reduce. This is particularly prevalent for Aberdeenshire where 89% of turbines (over 1,400) are in the pre-consent stage.

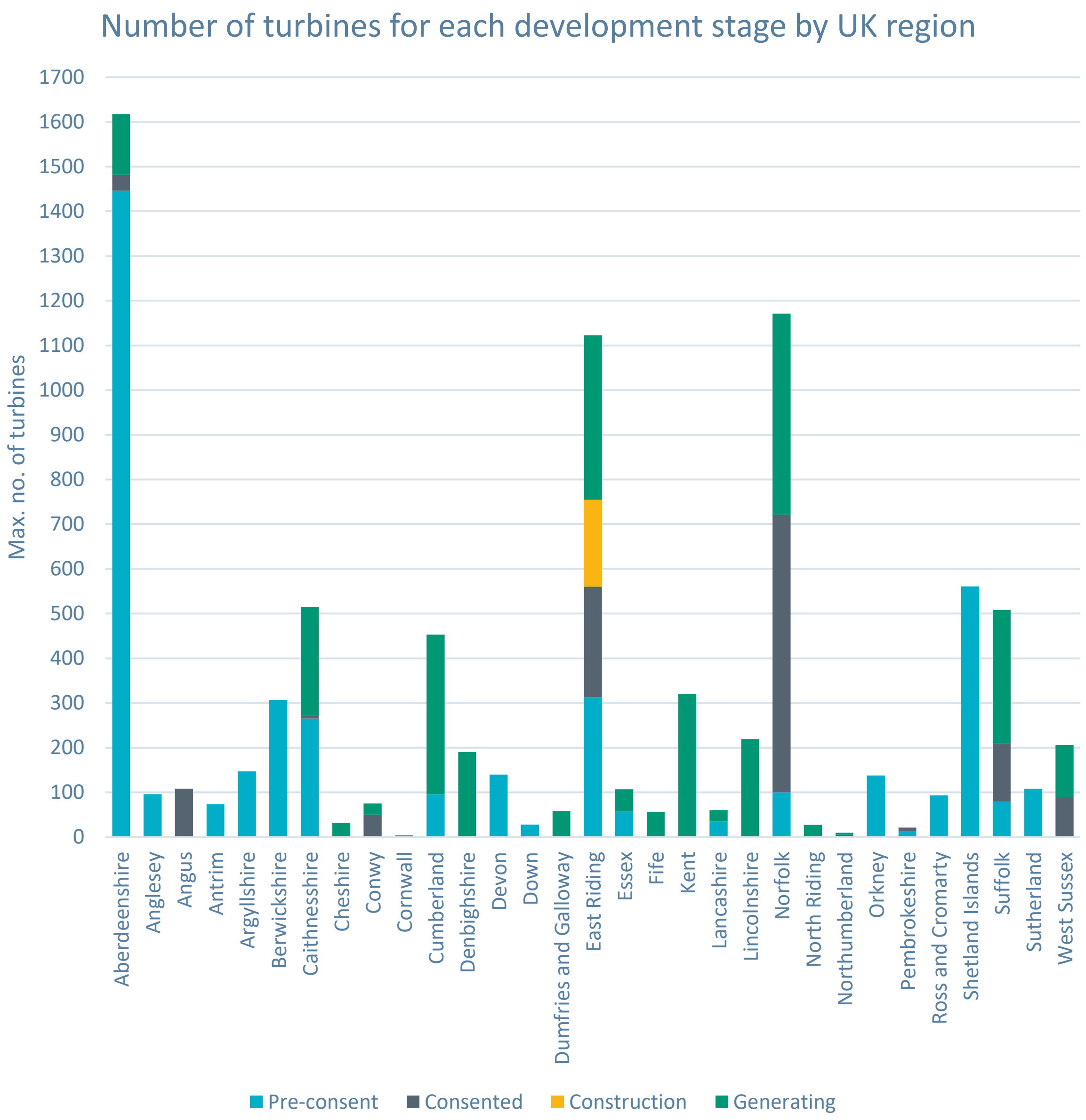


Figure 11 Predicted number of turbines at each development stage by UK region [1]

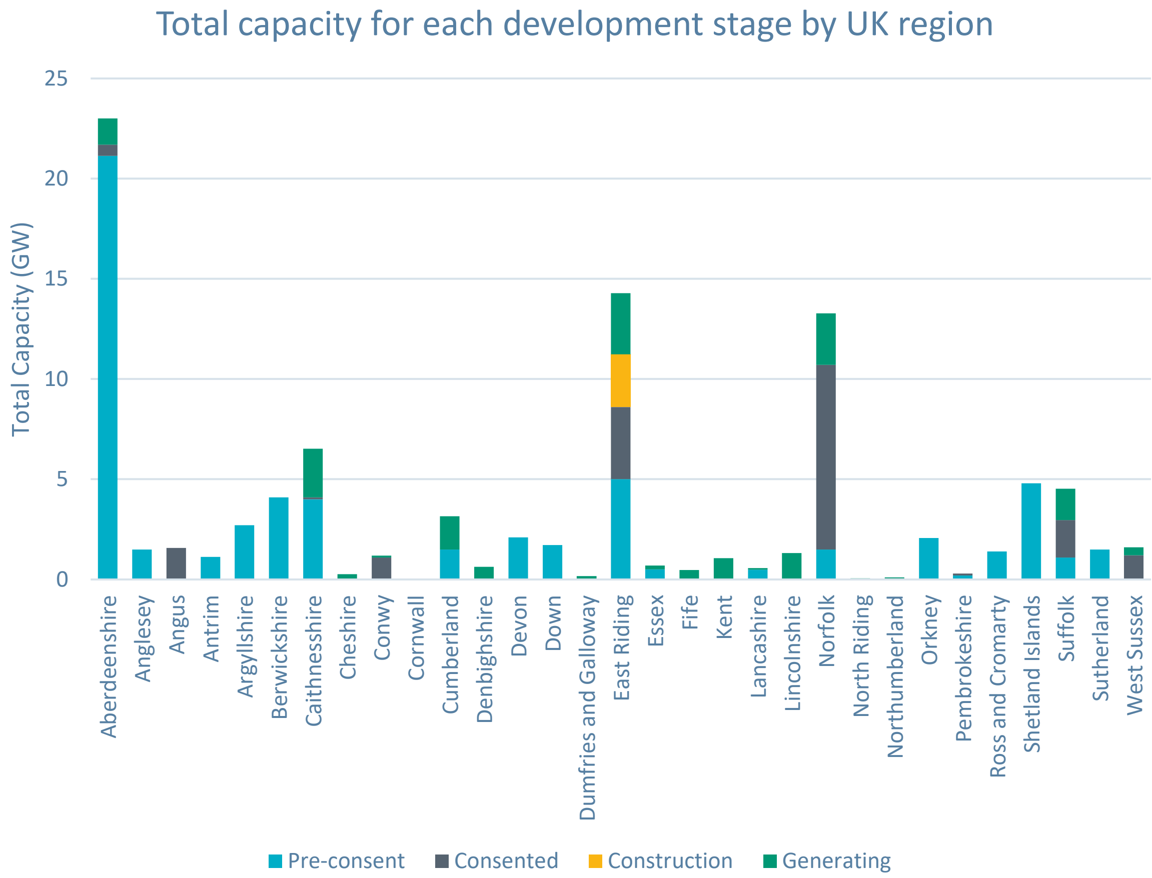


Figure 12 Expected total capacity of wind farms at each development stage by UK region [1]

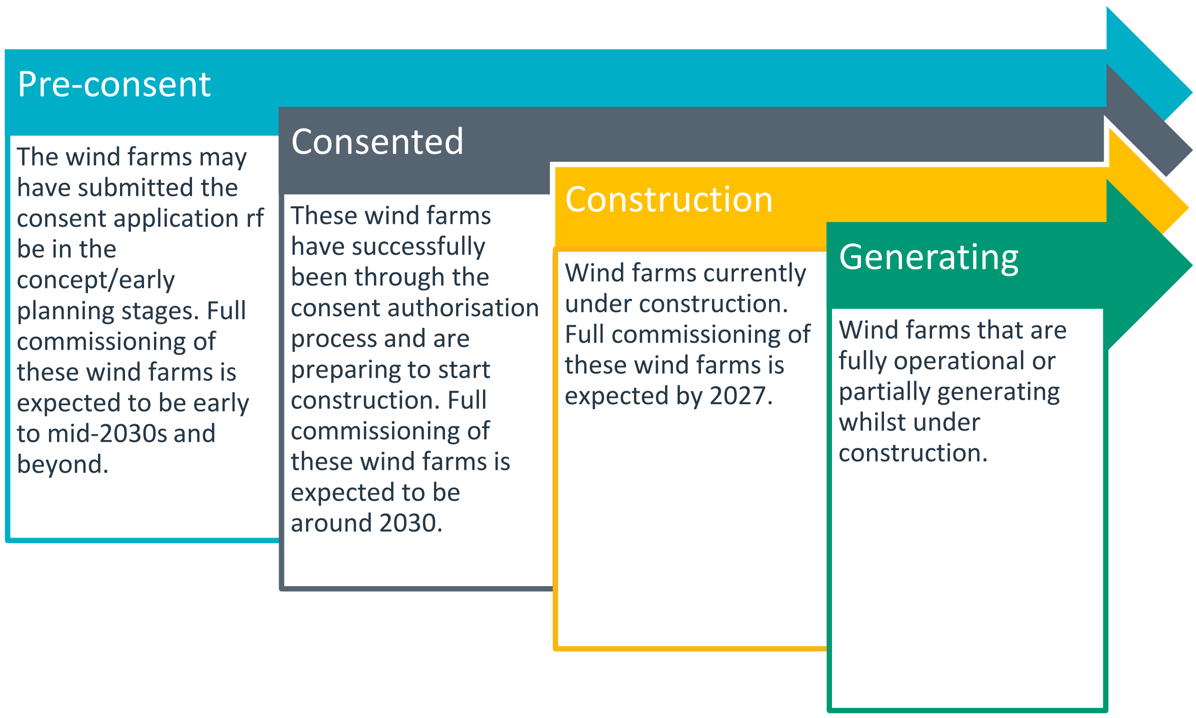


Figure 13 Wind farm development stages

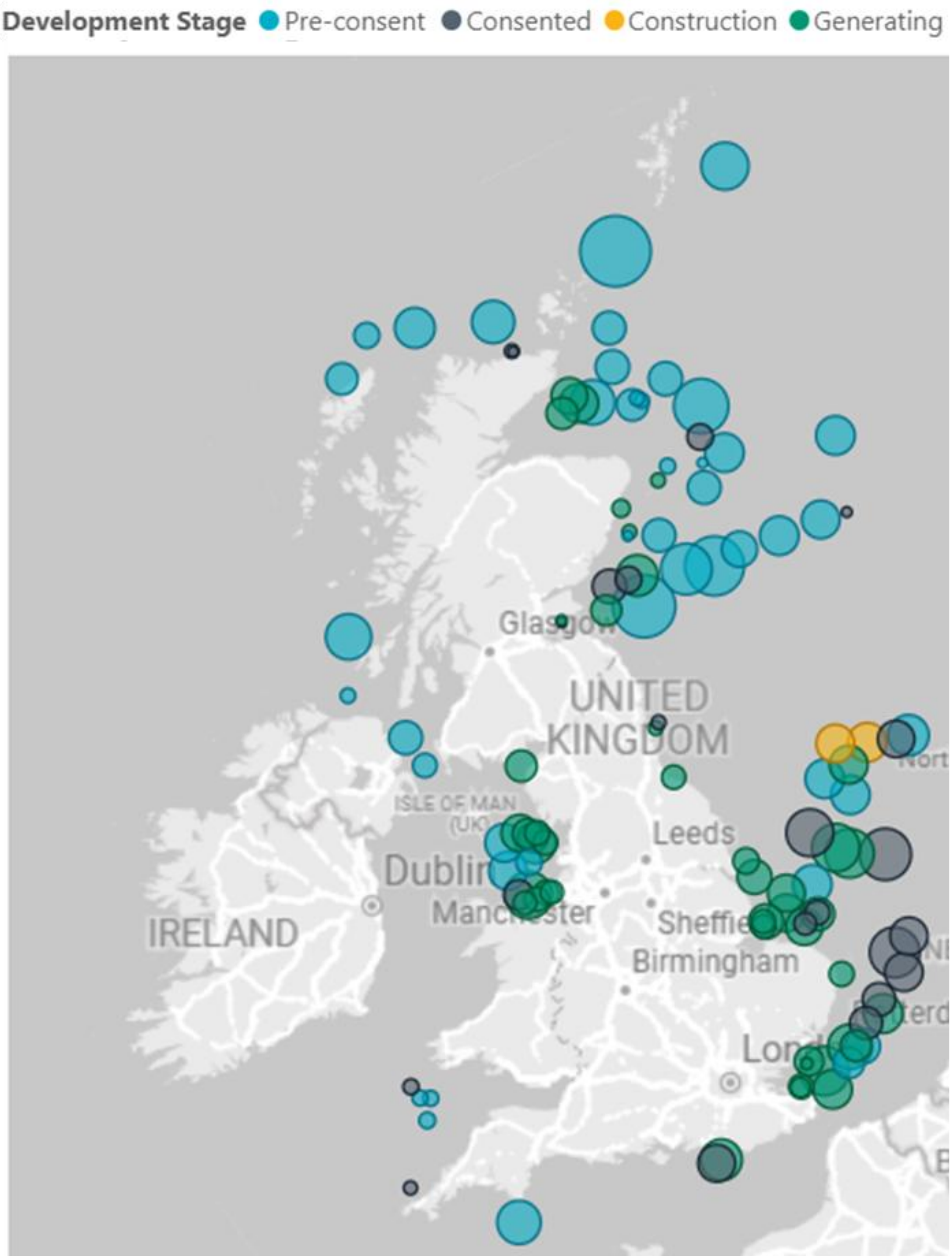


Figure 14 Bubble map of the UK showing the number of turbines and development stage for each wind farm location

Figure 15 shows the number of turbines across each OEM and UK region across all wind farm development stages. In this analysis Vestas includes Vestas and MHI Vestas Offshore Wind turbines, and Siemens includes Siemens and Siemens Gamesa turbines. Any turbines where the OEM has not yet been determined have been excluded from Figure 15, equating to approximately 4,500 turbines across all regions and mostly covering wind farms in the pre-consent authorisation stage. Of these, most noticeably 33% are in Aberdeenshire, 10% in East Riding, 7% in Berwickshire and five turbines in Northumberland.

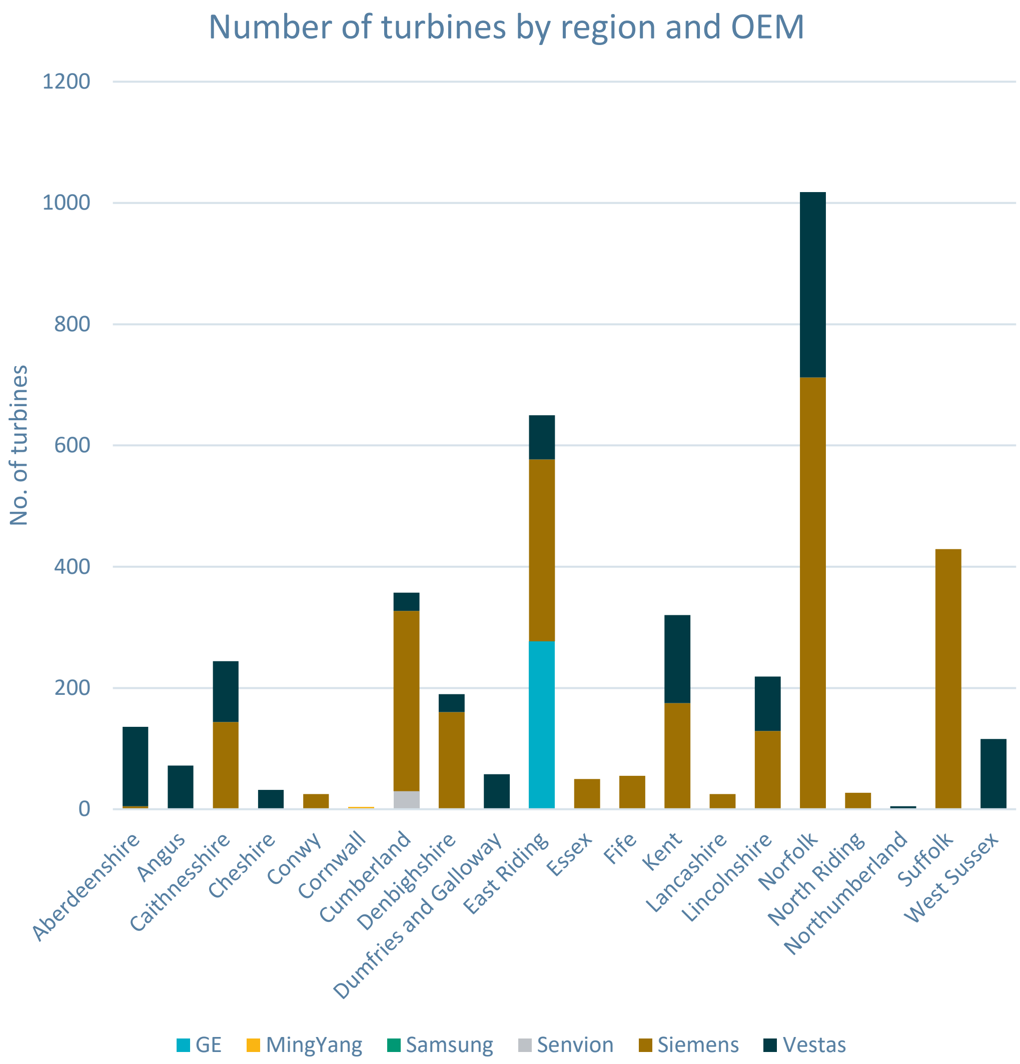


Figure 15 Number of turbines by UK region and OEM [1]

Figure 16 shows the number of each turbine model across UK offshore wind farms, with colours denoting the OEM. The turbine models MySE 8.0, S7.0 and V66 do not show as these are less than five. Siemens has the greatest share of UK wind turbines with over 2,500 turbines across six different models. Vestas has the second greatest proportion of wind turbines in the UK market with over 1,100 turbines across six different models. Both Siemens and Vestas are spread across a variety of UK regions. GE is the third largest OEM with 277 turbines in the UK, all in the East Riding region at the Dogger Bank wind farms.

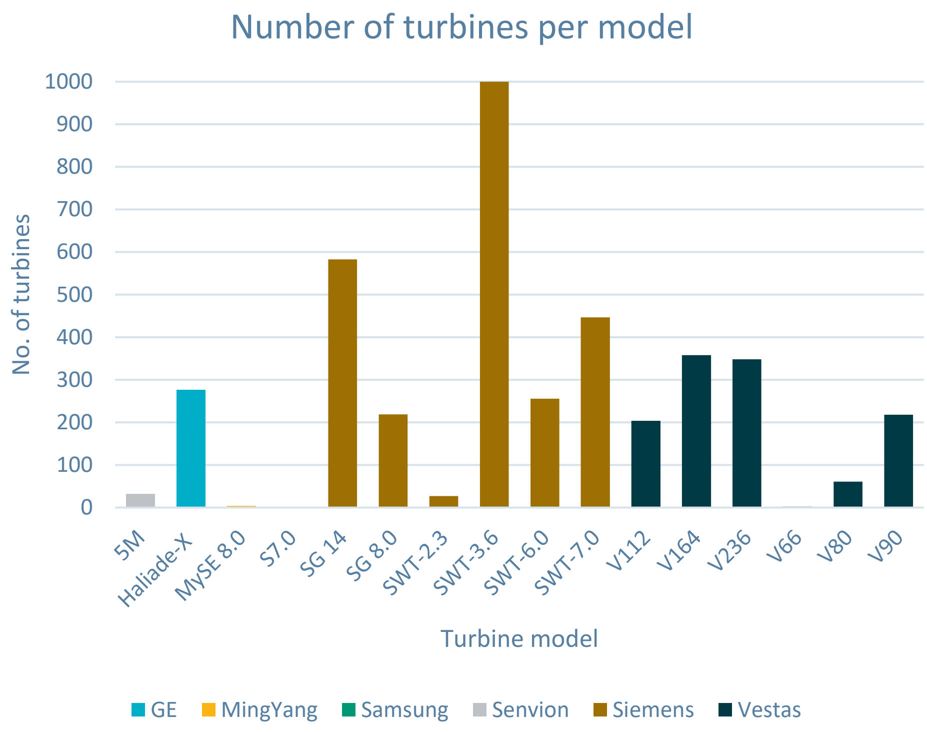


Figure 16 Number of turbines by model across the UK [1]

Figure 17 shows the different O&M ports utilised across the UK for each wind farm with a known turbine OEM and confirmed O&M port. The 14 wind farms shown as (blank) include those with a confirmed O&M port and undefined turbine OEM, the regional location of these is shown in Figure 18. The Northumberland region contains a single wind farm with an estimated five turbines.

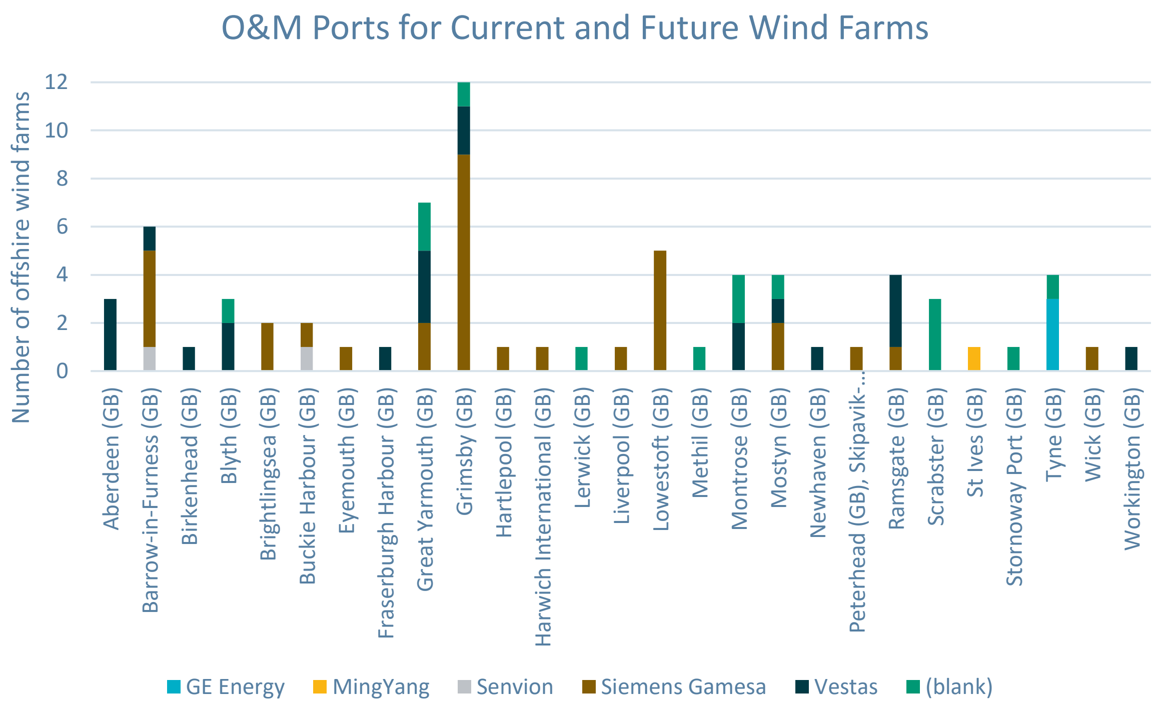


Figure 17 Known O&M Ports of each turbine OEM for all current and future wind farms [7]

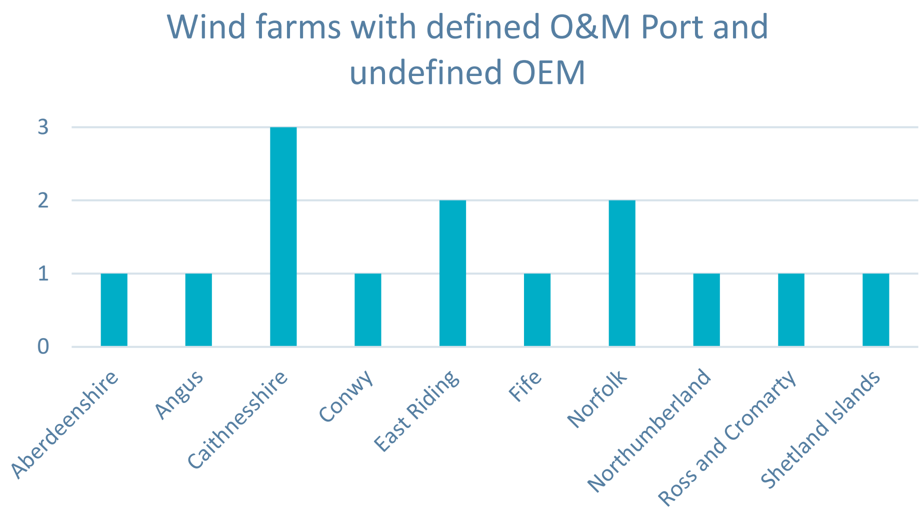


Figure 18 Number of offshore wind farms with a defined O&M Port and undefined OEM [7]

The greatest number of wind farms operate from O&M ports in Grimsby, Barrow-in-Furness, Great Yarmouth and Lowestoft. This is roughly in line with the regions housing the greatest number of turbines in Figure 15. As with turbine OEMs, the O&M port has not yet been determined for all wind farms. This includes 42% of offshore wind farms, as shown by region in Figure 19.

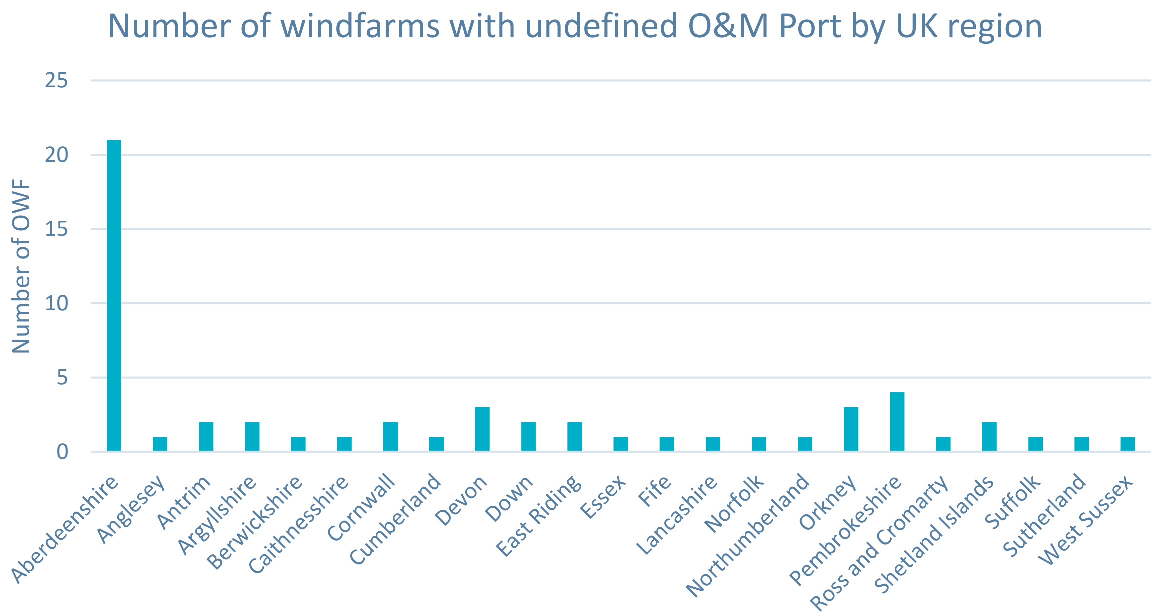


Figure 19 Number of offshore wind farms with unknown O&M Ports by region [7]

3.1 North East Coast Offshore Wind Overview

There are 15 wind farms proposed off the North East coast (Figure 20), from Berwick-upon-Tweed to Hull. There are six generating, two under construction, four consented and three pre-consent wind farms.

Hornsea Project Four (consented) has been included in the analysis performed throughout this report. However, it should be noted that Ørsted discontinued the development of this wind farm in its current form in May 2025 [10]. The future form of the project is currently unclear and therefore it has been included as previously consented. An anticipated 160 x 15 MW turbines were included with an undefined OEM. The O&M Port was planned to be Grimsby, and it is reasonable to expect this would continue to be so if the development does go ahead in the future.

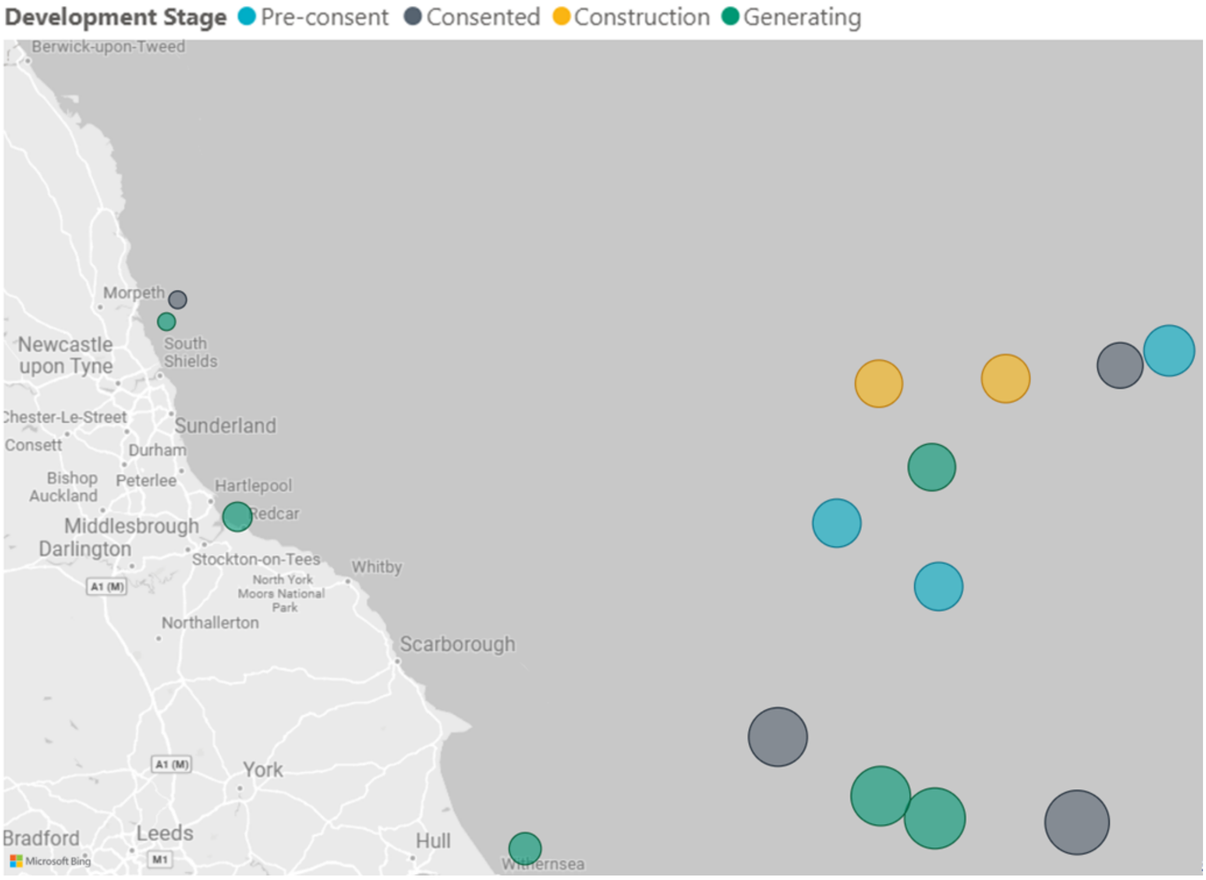


Figure 20 Bubble map of the North East coast showing the number of turbines and development stage for each wind farm location

Of the 15 wind farms identified, Siemens Gamesa provides the greatest proportion of the market at 48%, followed by GE (Figure 21). Five wind farms have undefined OEMs, with an estimated total of 478 turbines. These wind farms include two consented and three pre-consent wind farms.

Turbine numbers are not confirmed until wind farms are consented with an agreed OEM and turbine model. The values used are the maximum numbers of turbines according to 4C Offshore, who take the data from publicly available developer planning applications.

For the identified 15 wind farms, Grimsby and Hartlepool are the ports for all Siemens Gamesa turbine sites and Port of Tyne for all GE turbine sites (Figure 22 and Figure 23). This clustering of OEMs is coincidental, but influenced by external factors such as:

- Siemens Gamesa has a wind turbine blade manufacturing facility in Hull and this proximity to the wind farm construction site and opportunity for UK content could be factors when considering which OEM to use
- OEMs with a workforce established in the region may be more competitive when bidding for nearby wind farm contracts
- Established relationships between developers and OEMs may build trust, leading to future projects together

The undefined OEMs in Figure 21 are expected to be split across Grimsby and Port of Tyne. The wind farms with an O&M base at Port of Blyth consist of 10 turbines in total. It should be noted that other wind farms south of the North East coast also utilise Grimsby as an O&M port, and these have a variety of OEMs including Siemens and Vestas, as shown in Figure 23.

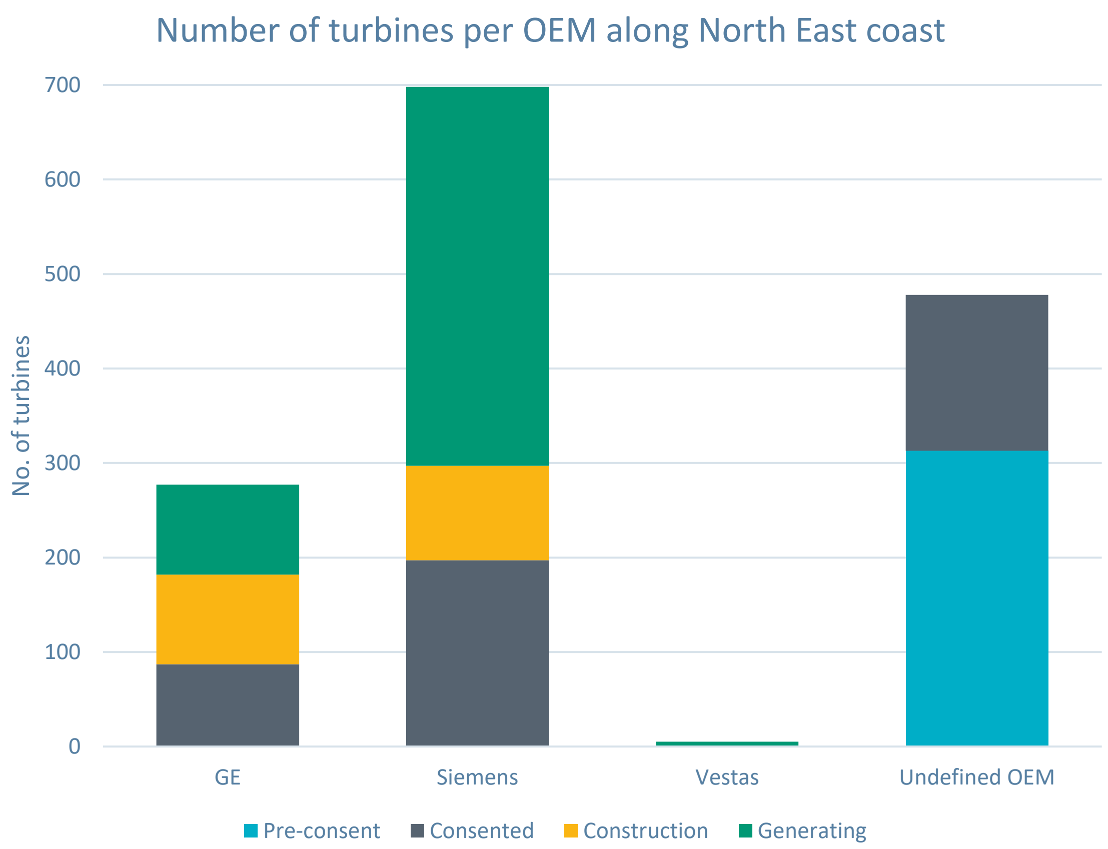


Figure 21 Number of turbines per OEM along the North East Coast [1]

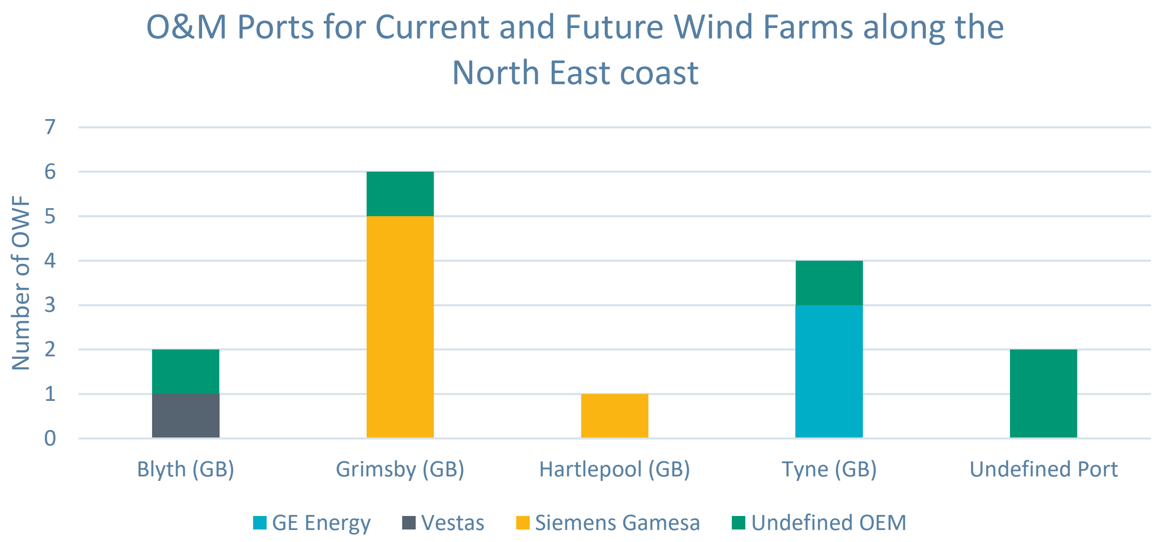


Figure 22 Known O&M Ports of each turbine OEM for all current and future wind farms along the North East Coast [1]

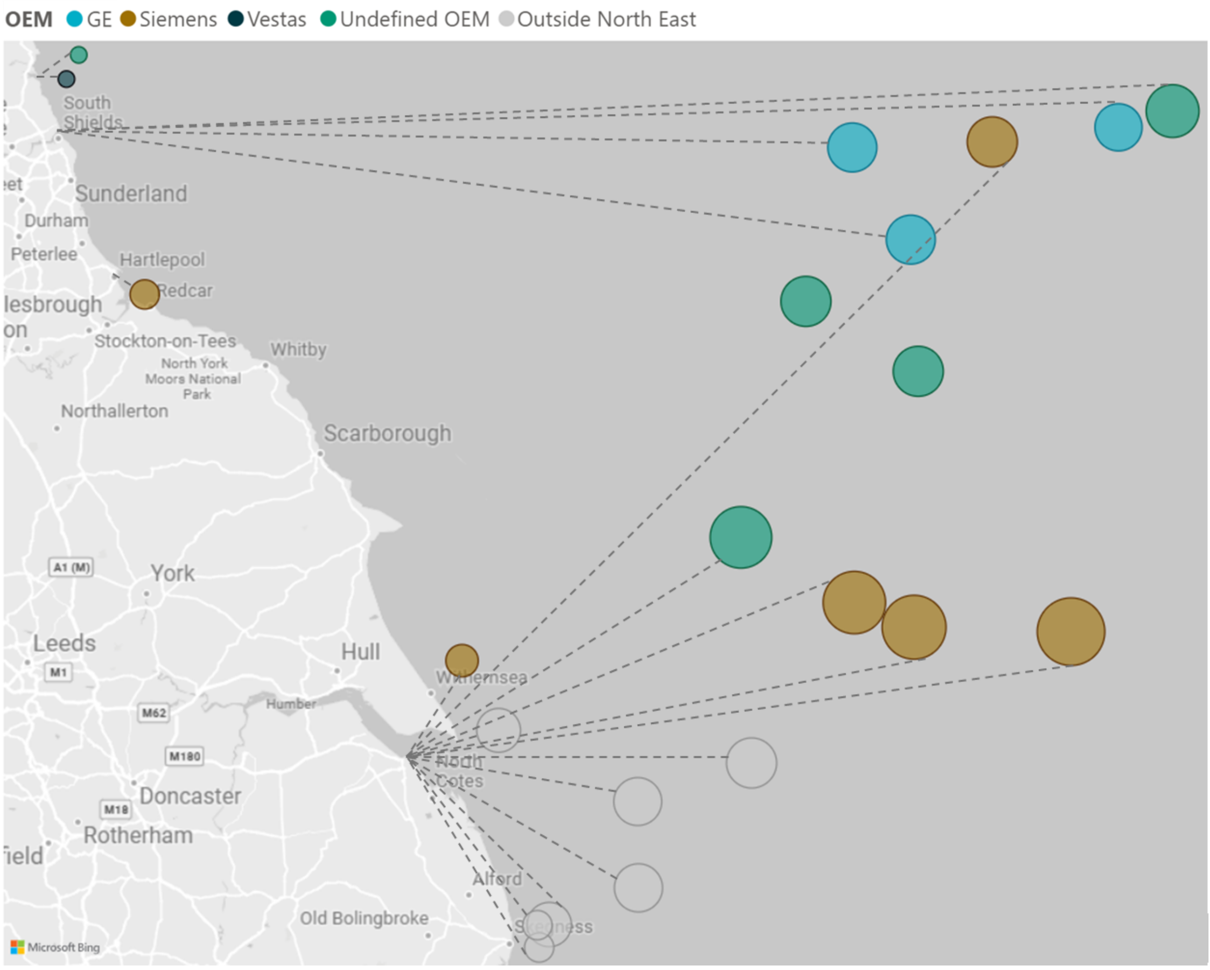


Figure 23 Bubble map of the North east coast showing the turbine OEM and O&M port for each wind farm location Greyed out wind farms also use Grimsby as an O&M base but are further from the North East coast. [1]

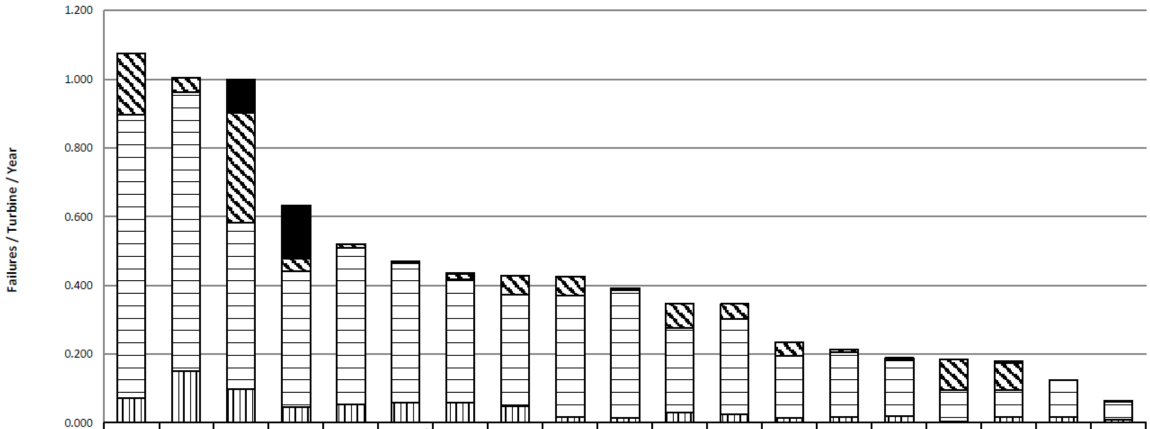
3.2 Failure Rates

3.2.1 Wind Turbine Major Component Failure Rates

The major components in a wind turbine include the gearbox, generator, transformer and blades. A study of 350 offshore turbines across 5-10 wind farms over a five-year period calculated the failure rates shown in Figure 24. For this analysis the following definitions were used [11]:

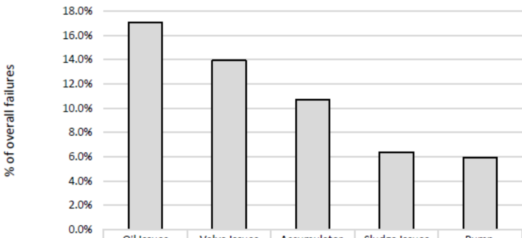
- A failure requires a “visit to a turbine, outside of a scheduled operation, in which material is consumed.” Material is defined as “anything that is used or replaced in the turbine” from consumables to major components
- Major replacement – material cost greater than €10,000
- Major repair – material cost between €1,000 and €10,000
- Minor repair – material cost less than €1,000
- No cost data – no material cost data is available for the failure

This shows the components with the greatest failure rates are the pitch/hydraulic system, other components and gearbox. The failure modes of these components are shown in Figure 25, giving an idea of some of the most common failures seen and components affected.

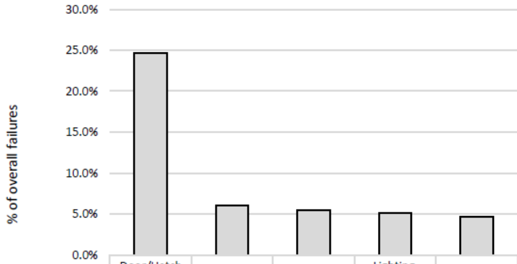


	Pitch / Hyd	Other Components	Generator	Gearbox	Blades	Grease / Oil / Cooling Liq.	Electrical Components	Contactor / Circuit Breaker / Relay	Controls	Safety	Sensors	Pumps/ Motors	Hub	Heaters / Coolers	Yaw System	Tower / Foundation	Power Supply / Converter	Service Items	Transformer
Major Replacement	0.001	0.001	0.095	0.154	0.001	0.000	0.002	0.002	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.005	0.000	0.001
Major Repair	0.179	0.042	0.321	0.038	0.010	0.006	0.016	0.054	0.054	0.004	0.070	0.043	0.038	0.007	0.006	0.089	0.081	0.001	0.003
Minor Repair	0.824	0.812	0.485	0.395	0.456	0.407	0.358	0.326	0.355	0.373	0.247	0.278	0.182	0.190	0.162	0.092	0.076	0.108	0.052
No Cost Data	0.072	0.150	0.098	0.046	0.053	0.058	0.059	0.048	0.018	0.015	0.029	0.025	0.014	0.016	0.020	0.004	0.018	0.016	0.009

Figure 24 Failure rate Pareto chart for subassembly and cost category [11]



	Oil Issues	Valve Issues	Accumulator	Sludge Issues	Pump
Pitch/Hydraulic	17.0%	13.9%	10.7%	6.4%	5.9%



	Door/Hatch Issues	Covers	Defect Bolts	Lighting issues	Lift
Other Components	24.6%	6.0%	5.5%	5.2%	4.7%

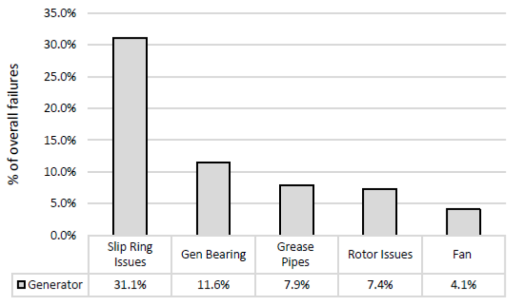


Figure 25 Failure modes of the components with the highest failure rates. Top-left: Pitch/Hydraulic system. Top-right: Other Components. Bottom: Generator.

3.2.2 Cables and Ancillaries Failure Rates

The main cable and ancillary components include the array cables, export cable and interconnectors. A 2024 report published by TGS|4C Offshore found the failure rates shown in Table 2 from analysis of failures since 2020. The report sets out various root causes of failure, and although the data cannot be provided by ORE Catapult, a risk classification table (Table 3) has been created from this.

Table 2 Cables and interconnector failure rates [12]

Component	Failure rate
Array cable	0.0017 failure/km/year
Export cable	0.0024 failure/km/year
Interconnectors	0.0018 failure/km/year

Table 3 Risk classification for failure causes for major subsea cable types

Cause of Failure	Array Cable Risk	Export Cable Risk	Interconnector Risk
Jointing	Low	Low	Low
Age-related	Low	Low	Low
Fibre Optic	Moderate	High	Moderate
Manufacturing	High	High	Moderate
Human Activity	Low	Low	Moderate
Cable Protection System	Very High	Moderate	Moderate
Environmental	Moderate	Low	Moderate
Design	Moderate	Moderate	Low
Mechanical	Moderate	Low	High
Installation	High	High	Moderate

3.2.3 Failure Rates Overview

The failure rates of a wind turbine are likely to follow the curve of a bathtub trajectory throughout the asset life, with the greatest failure rates seen at the start and towards the end of the asset life (Figure 26). Early failures are likely to occur during the warranty period and therefore come under the responsibility of the OEM. Later failures will be outside the warranty period and therefore responsibility will be determined by the wind farm O&M strategy.

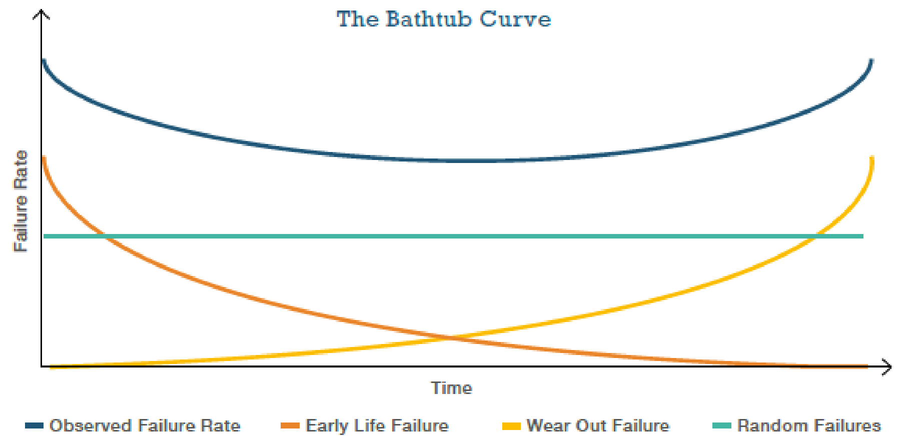


Figure 26 Bathtub curve illustration [13]

The SPARTA (System, Performance, Analysis and Reliability Trend Analysis) tool is a joint industry project enabling offshore wind farm OOs to benchmark their key performance indicators across the industry. The most recent review [13] provides insights into the impacts of component failures. The transmission system and control and protection system (CPS) trigger the most alarms (Figure 27), resulting in the most outages. However, these result in minimal lost production. Failures in the BOP, drive train and central lubrication systems result in the most downtime per failure. Although they have a low failure rate there are large consequences if failure occurs. This is reinforced in Table 4, which highlights some components that have a low frequency of failure and high impact, or a high frequency of failure and low impact per failure. Due to the confidentiality of the background data further information cannot be shared. However, it can be deduced that the spares for the components deemed as high impact/low frequency are likely to be stored in the central store, whereas those deemed as low impact/high frequency will be stored in the quayside storage facility. In addition to the areas shown in Table 4, the Reliawind project found that electrical systems had the highest failure rate with the least impact in onshore turbines [14]. One such electrical part is the delta module which is part of the invertor-convertor system. The failure rate of these is sufficiently high that specific lifting bags have been developed to protect them.

Table 4 High impact/low frequency failures and low impact/high frequency failures

High impact/Low frequency	Low impact/High frequency
Drive train system	Yaw System
Central lubrication system	Control and Protection System
Generator System	Transmission System

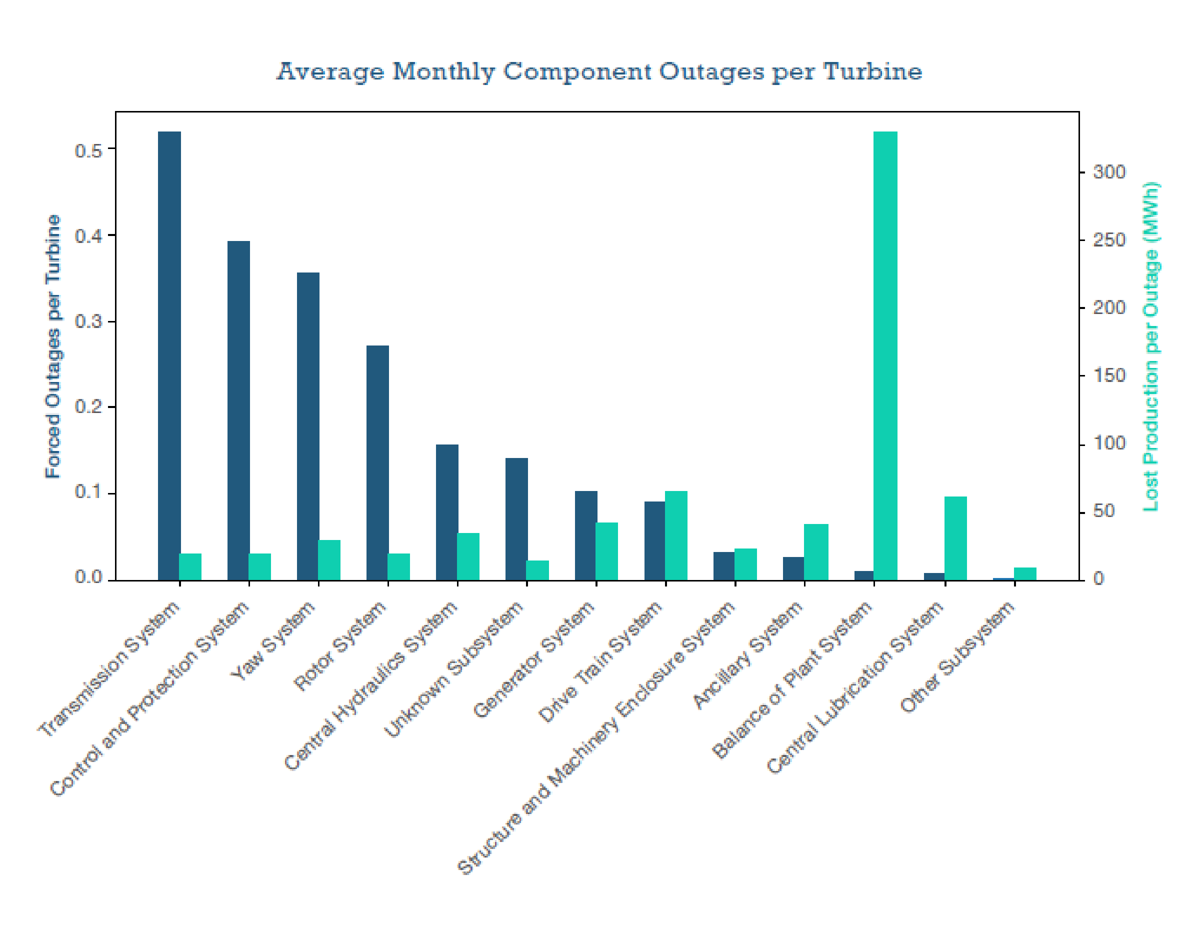


Figure 27 Average monthly forced outages per turbine and lost production per outage, by component [13]

Failures result in periods of turbine downtime and therefore loss of production. There are many factors affecting repair time, such as:

- Transit time to and from the turbine
- Availability of technicians
- Lead time of parts
- Availability of support vessels, such as jack-ups (J-U)
- Inaccessibility due to weather conditions

Table 5 highlights a possible scenario for gear box replacement in the event of an unexpected failure. Although the timelines can vary, the longest delay is invariably the waiting time for the J-U.

Table 5 Gantt chart of factors affecting a gearbox replacement

	Gearbox fails	Week number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Delivery of new gearbox															
J-U waiting time															
J-U onsite															
Technician availability															
Turbine repair preparation															
Gearbox replacement															
Poor weather delay															
Task complete															

4 FUTURE SPARES MANAGEMENT SCENARIOS

The management of spares by OEMs for wind farms in warranty, or with an extended OEM agreement, is well defined and unlikely to change. When a wind farm is out of warranty and operating under a self-perform strategy there is more scope for the development of alternative strategies. Whilst operators may choose to opt for OEM-supplied parts, they have the freedom to access the secondary market and purchase parts from alternative manufacturers. Some of the larger service providers such as RWE Services and Ørsted have spares management systems similar to the OEMs due to the size and scale of their operations. However, smaller service providers do not have the same set up and therefore require access to other suppliers.

There are three groups of personnel likely to impact the number parts stored:

- Stores manager/warehouse operator: They ensure the required number of parts are available, by setting minimum levels and reordering when stock levels are too low. In the event parts are being used more quickly than they are replenished, the stores person may request an increase in the number of parts held. These reviews are likely to be ad hoc and dependant on the experience of the stores person and will have to be agreed by the budget holder.

- Engineers: The engineering teams may request a change in the number of parts stored based on the failure rates and experience they are gaining from other turbines. For example, if three turbines show the same failures at a similar number of operational hours, they may request additional parts be stored as other turbines reach the same threshold. These reviews are likely to be related to wind farm events.

- Finance: The finance team may request a change, usually a reduction, to the stock of parts levels held based on the balance sheet and stock value. This review is likely to be at the end of a quarter or the financial year.

4.1 Stockpiling

As more turbines move towards the end of their operational life and newer models are being used, obsolescence of parts is a concern for the industry. Stockpiling of spare parts to ensure their availability would require analysis of the parts most at risk of obsolescence to determine their failure rate and criticality, and would incur significant up-front cost to purchase the spare parts with no guarantee that they would be used.

4.2 Decommissioned turbines

Parts from decommissioned turbines may be stored for use in turbines nearing the end of their operational life. For example, an operator may not wish to replace an irreparable blade with a new one if the turbine is only expected to operate for five more years. An alternative solution is to replace this with a used blade. Similarly, if the blade is no longer manufactured then replacement with second hand parts may be the only alternative. Storage of seven blades of up to 100m length would require an area approximately 75m x 110m. Ideally this would be at the quayside so that blades can be lifted directly onto a vessel.

4.3 Refurbished parts

The onshore wind market has an older and more varied fleet of turbine models from a wider range of OEMs, several of which have since ceased to trade. In addition, the UK's nine-year moratorium on onshore wind developments resulted in many turbines being operated beyond their original design life. This has driven a reliance on refurbished or non-OEM parts.

Companies such as Spares In Motion [15], Wind Sourcing.com [16] Deutsche Windtechnik [17], Windy Productions [18] and Renewable Parts [19] sell secondhand and refurbished wind turbine parts, primarily to the onshore market (Table 6). Similarly, Vestas has an online shop [20] for spare parts which also offers parts from other OEMs. These companies tend to operate from one warehouse location from which parts can be couriered to O&M ports.

Table 6 Secondhand and refurbished parts suppliers including company details [21]

Company	Operations Location	Coverage	Employees	Annual Revenue
Deutsche Windtechnik	Lowestoft (offshore) & Livingston (onshore)	UK	1,200[1]	$260.1M[1]
Renewable Parts	Renfrew	UK	40	$1M
Windy Productions	Nottingham	UK	1	$60K
Spares in Motion	Rotterdam, NL	Europe	44	$5.2M
Vestas	Aarhus, DK	Europe	30,900[1]	$16.9B[1]
Windsourcing	Hamburg, DE	Europe	4	$200K

[1] These values are based on the full company, not the specific area focused on the delivery of spare parts.

The offshore wind spares market is still largely controlled by the OEMs and limited information on parts is shared with other suppliers. The OEM operating model focusses on rapid replacement of failed parts with new items and to date OEMs have shown little interest in refurbishment of parts other than major components such as generators and gearboxes. Renewable Parts has made some inroads into post-warranty offshore wind farms, in particular with mechanical parts such as yaw gear that can be refurbished and even improved. As an indication of scale, in 2024 Renewable Parts employed 46 people in research and development, refurbishment and inventory management of wind turbine parts.

4.4 Vessel parts

Vessels are an often overlooked but critical part of the operation of offshore wind farms. The vessels may be on short or long-term charter in ports around the UK and North Sea. The use of apps and websites such as VesselFinder [22] can be useful in understanding the current chartered operational area of certain vessels.

Vessel spares are primarily stored at the operational port of the vessel operator, with a select and limited number stored on the vessel. Field engineers are deployed by vessel operators to support with maintenance and breakdowns. More complex breakdowns during deployment may require the vessel operator to use local suppliers if it is not appropriate for the vessel to return to the operational port.

Vessels tend to use one of a limited number of engine types and have greater commonality of parts than wind turbines. This could be an area of opportunity for a strategic holding of critical parts. More research is required on parts availability and lead times, but anecdotal information suggests vessel operators have struggled with disrupted global supply chains as a result of changes in trading relationships and conflicts.

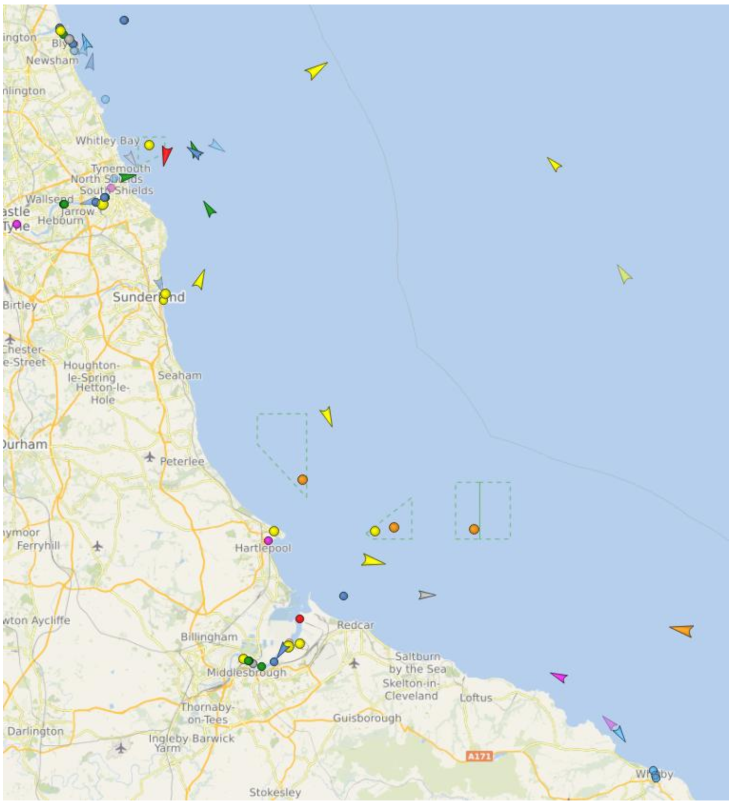


Figure 28 VesselFinder map from Blyth to Whitby [22]

5 OPPORTUNITIES AND RECOMMENDATIONS

5.1 End of Warranty Turbines

Wind farms reaching the end of warranty and moving to a self-perform model may be looking for a service provider, each of whom will require access to spares. There is an opportunity to link with service providers to understand their spares requirements and possibly provide a suitable alternative to their current strategy.

5.2 Turbines Nearing End of Operational Life

The opportunity to provide storage of second hand and refurbished parts will become more critical in the short to medium term future. Turbines such as Siemens SWT3.6 are being discontinued and parts like blades are no longer manufactured. This model makes up 34% of the current fleet of generating turbines in the UK.

Purchasing and storing parts from decommissioned turbines, or providing rental storage space for service providers to store parts from decommissioned turbines, could provide benefit to the industry.

5.3 Ports

Ports are critical to the current and future prospects of the UK offshore wind industry. Ports will become more critical for the storage and transport of parts as turbines grow in size.

The compatibility of the seven ports along the Energi Coast (Figure 29) with the current and future requirements of the offshore wind industry have been assessed and are shown in Table 7. The assessment model is not owned by ORE catapult and therefore cannot be shared. The assigned categories are as follows:

- Red - **Not Ready to Limited**: No to basic infrastructure; significant to major upgrades needed.
- Orange - **Developing to Competent**: Some to good infrastructure; several key upgrades needed.
- Light green - **Ready to Well-Prepared**: Sufficient to strong infrastructure; minor improvements needed.
- Dark green - **Highly Prepared to Optimal**: Excellent to state-of-the-art infrastructure; minimal adjustments to fully ready for offshore wind activities.

Port of Tyne and Seaton Port are the most prepared overall, however other ports offer strengths in specific areas. Blyth is particularly strong for cable and electrical related activities, especially with its proximity to the manufacturer JDR cables. This is similar to Hartlepool, although Hartlepool appears to be ‘not ready to limited’ in most other areas. Whereas Blyth is ‘developing to competent’ in all further areas, except foundation and substructure related activities. Middlesbrough and Sunderland have the most limitations with preparation only seen for asset management, decommissioning and offshore substation system integration. Teesport has strengths in all areas except floating substructures and turbine tow out. Designated as one of the UK’s eight freeports, Teesport benefits from advantages such reduced taxes and simplified customs procedures. Each port offers a unique opportunity in the offshore wind industry, and depending on the parts being stored may offer a suitable storage location. For example, if cables were to be stored, a site near Port of Blyth may be appropriate. Whereas, if focusing on floating offshore wind a site near Seaton may prove useful.

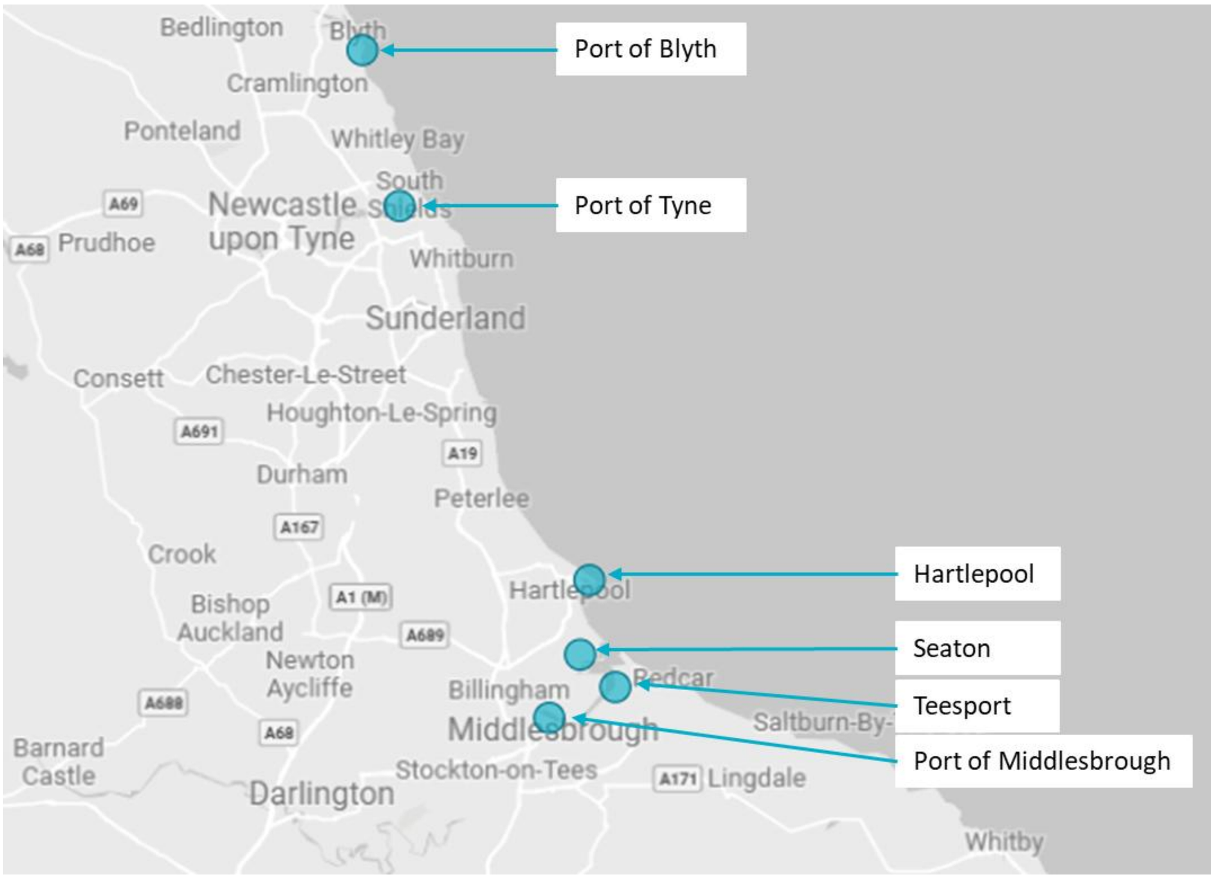


Figure 29 Map of Energi Coast ports

Table 7 Energi Coast Port assessment

Activity Area	IGP Alignment	Activity	Definition	Energi Coast						
				Blyth	Hartlepool	Middlesbrough	Seaton	Sunderland	Teesport	Tyne
Manufacturing	Advanced Turbine Technology	Blades & Towers	*Manufacture of blades & tower sections (Cruxhaven and Hull)*							
		Nacelle assembly	*Storage of components, assembly of nacelles, and storage of completed nacelles (Cruxhaven)*							
	Industrialised Foundations and Substructures	Foundations & Substructures	*Fabrication of subassemblies, tubulars, rebar sections, pre-cast elements and secondary steel*							
	Industrialised Foundations and Substructures	Moorings & Anchors	*Manufacture of mooring chain, rope, anchors and staging of components before load out*							
	Future Electrical Systems and Cables	Electrical & Cables	*Cable manufacture and storage (JDR Blyth)*							
	Future Electrical Systems and Cables	Offshore Substation Topside	*OSS topside systems integration halls and storage of OTM (HSM)*							

Activity Area	IGP Alignment	Activity	Definition	Energi Coast						
				Blyth	Hartlepool	Middlesbrough	Seaton	Sunderland	Teesport	Tyne
Services	Next Gen Installation and O&M	Fixed Foundation Installation	*Storage of Foundations (jacket, monopile or TPs) and load out*							
	Next Gen Installation and O&M	Fixed Turbine Installation	*Storage of nacelles, towers and stacked blades and load out*							
	Industrialised Foundations and Substructures	Floating Substructure Assembly	*Storage and assembly of prefabricated sections into complete substructure unit, with launch of complete foundation*							
	Industrialised Foundations and Substructures	Floating Turbine Assembly & Integration	*Storage, assembly and integration of turbine components with floating substructure.*							
	Next Gen Installation and O&M	Floating Turbine Tow Out & Hook Up	*Tow out of integrated Substructure-Turbine assemblies to site*							
	Next Gen Installation and O&M	Cable Installation	*Storage of IAC, Export Cable Reels/Carousels and load out*							
	Next Gen Installation and O&M	Asset Management & O&M	*One O&M facility with warehouse and one SOV berth*							
	Next Gen Installation and O&M	Decommissioning	-							

6 CONCLUSION

The offshore wind industry is expected to see significant growth in the next 10-20 years with the UK focussing on moving towards clean energy. Much of the anticipated growth is expected around Scotland, the East of England and the Celtic Sea (See Appendix 1 to Appendix 5).

Of the six turbine OEMs in the UK, Siemens Gamesa and then Vestas have the biggest share of the market. The North East coast is home to 15 wind farms in the pre-consent to generating phases. As with the UK as a whole, Siemens Gamesa holds the majority of turbines, but in the North East GE follows in second. At present, approximately 33% of wind turbines proposed for the region currently have an undefined OEM.

The responsibility for spares management is defined by the O&M model of the wind farm. During the warranty period the OEM is responsible for spares management, and they have robust models to deal with this. Outwith the turbine warranty period the operator may move to a self-perform model, using a service provider to manage the O&M programme and therefore spares. In this scenario the management of spares is less constrained, and operators are able to purchase spares from different suppliers which may provide an opportunity for a new spares storage model to be developed.

Table 8 provides an analysis of the opportunities, including a red/amber/green assessment, the advantages, the disadvantages and the future outlook. The areas highlighted green and amber are most applicable to NECA in the short and medium term future. There is a particular opportunity to look at spares management for obsolete turbines and wind farms nearing end of life and a follow-up study to a greater level of detail would be beneficial to better understand this.

Table 8 Analysis of future opportunities for NECA

Future management strategies and opportunities		Advantages	Disadvantages	Future outlook
Storage of parts for wind farms along the North East coast		• Reduced transit times for parts to the O&M ports in the region	• Of the 15 wind farms in the region, three are generating but still within the warranty period and nine are between the pre-consent and construction stages • The majority of turbine parts in the region will be supplied by the OEM for the next 10-15 years	• It is considered very unlikely the spares model would change for Siemens Gamesa and Vestas in the future. • GE are currently operational at Dogger Bank Wind Farm only, with an O&M base at Port of Tyne. If GE were contracted for further UK wind farms, they would likely require a UK central stores facility which may provide an opportunity for NECA. This would likely be in 10+ years. • New OEMs are also coming to the UK market, such as MingYang at the TwinHub wind farm in Cornwall. An OWSSC may provide a facility for these newer firms, but the outlook is unclear. This would likely be in 10+ years.
Stockpiling of obsolete parts for turbines nearing end of operational life		• Siemens Gamesa SWT3.6 turbine is now obsolete and accounts for 46% of out of warranty turbines • Accessibility of parts is becoming increasingly difficult • Operators would likely welcome a solution that reduces the procurement time	• Significant up-front cost required to procure parts • Further analysis with operators needed to determine the most critical parts needed	• The challenge of obsolete parts is already affecting the industry and will continue to grow in the upcoming years. As the industry moves to larger turbine models the smaller sizes are likely to be discontinued.

Future management strategies and opportunities		Advantages	Disadvantages	Future outlook
Storage of decommissioned turbine parts for turbines nearing end of operational life		• Currently appears to be an untapped market • The onshore market is more mature than offshore and therefore a greater proportion of turbines are reaching the end of operational life • Parts would likely need to be stored near the quayside for easy loading onto vessels • Life extension of turbines is currently being considered by numerous wind farms. It is anticipated that 80% of wind farms constructed pre-2010 may pursue life extension (approximately 344 turbines across eight wind farms). However, it should be noted that these numbers are speculative.	• Significant up-front cost required to procure parts • Analysis required to understand the similarity of turbine types between onshore and offshore • Analysis required to determine the compatibility of parts between onshore/offshore turbine types • A large stores footprint will be required. For example, storing 7 blades up to 100m would require an area approximately 75m x 110m	• The need to store parts from decommissioned turbines will likely expand in the next 5-10 years as more sites reach a decision point for life extension or decommissioning.
Storage of refurbished parts for turbines nearing end of operational life		• Refurbished parts are an excellent alternative to new parts, especially where they are becoming obsolete	• A number of suppliers already operate in this area. There may be scope to work with them, but further investigation is required • Analysis required to better understand the most useful parts for refurbishing and therefore storage	• As with decommissioned parts, the storage needs of refurbished parts will likely expand in the next 5-10 years as more sites reach a decision point for life extension or decommissioning

Future management strategies and opportunities	Advantages	Disadvantages	Future outlook
Storage of vessel parts	• Vessels have greater commonality of parts than wind turbines and therefore a smaller variety of spare parts is required. • Port of Tyne and Port of Blyth may provide good locations for storage of vessel parts • Reduce the impacts of global supply chain disruption caused by changes in trading relationships and conflict	• Further analysis required to determine most suitable port area for vessel parts storage. Partially dependent on the ability of the port to support vessel repair • Analysis of the most common failures and required spares is needed	• May become more prevalent with the increasing number of SOVs used during O&M. As the majority of these wind farms are in the consented or pre-consented stages it is likely to be 5-10 years before this need is fully realised.
Storage of cables and components for floating wind turbines	• 41% of consented or pre-consent turbines are floating wind turbines. New infrastructure and planning are currently underway for these. • The Port of Seaton appears to offer a good opportunity to support the manufacturing and buildout of floating wind turbines • The Port of Tyne and Port of Blyth have particular strengths around cable manufacturing	• Detailed analysis is required to determine the compatibility of specific ports • As a minimum, minor improvements will be required to the port to support these areas • Development of multiple ports, particularly around Aberdeenshire, is already underway to support the floating offshore wind industry	• Investment and development of the ports is needed now for them to be considered by developers and supply chain • The majority of floating offshore wind farms are in the consented or pre-consented stages, and it is likely to be 5-10 years before storage is required.

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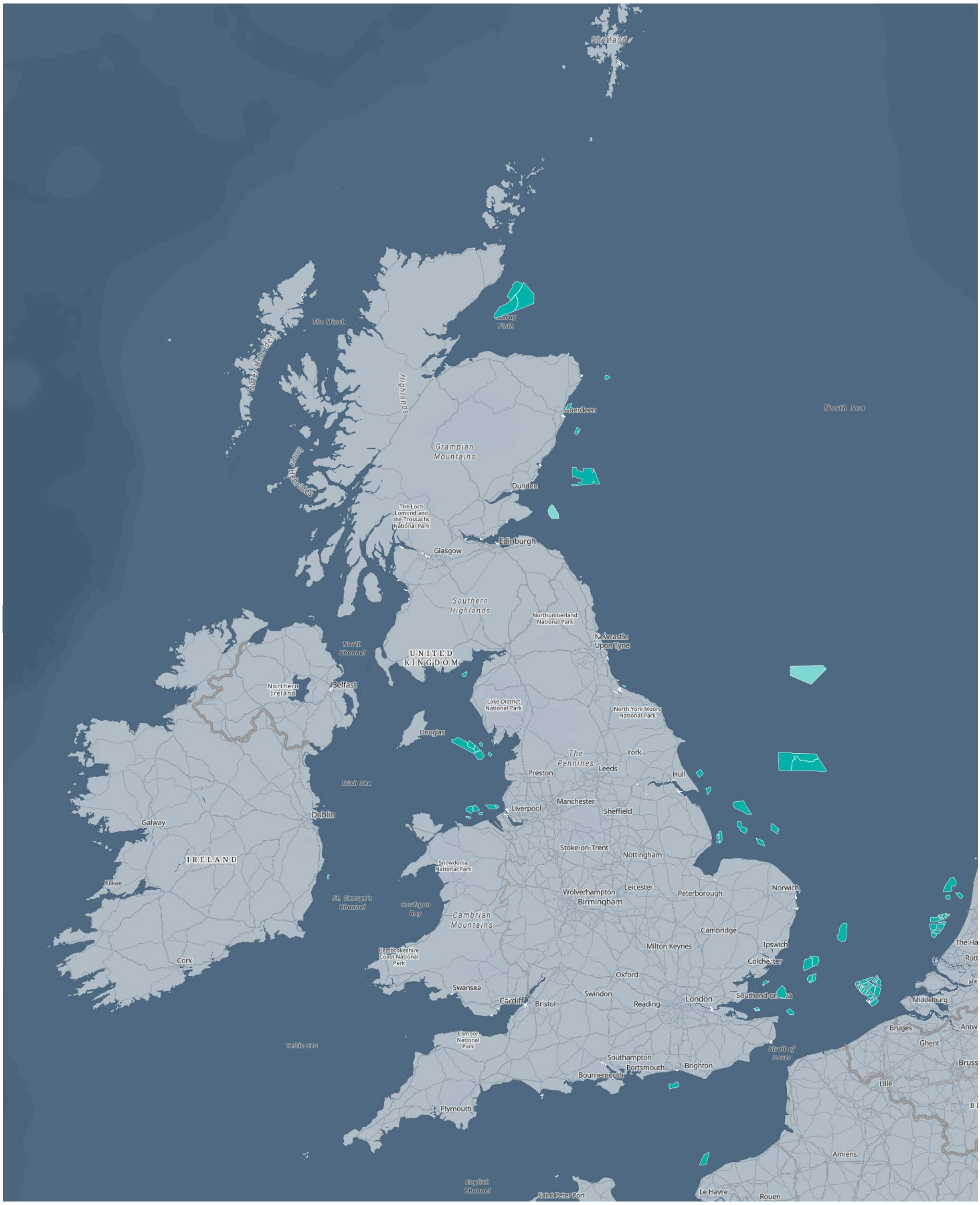
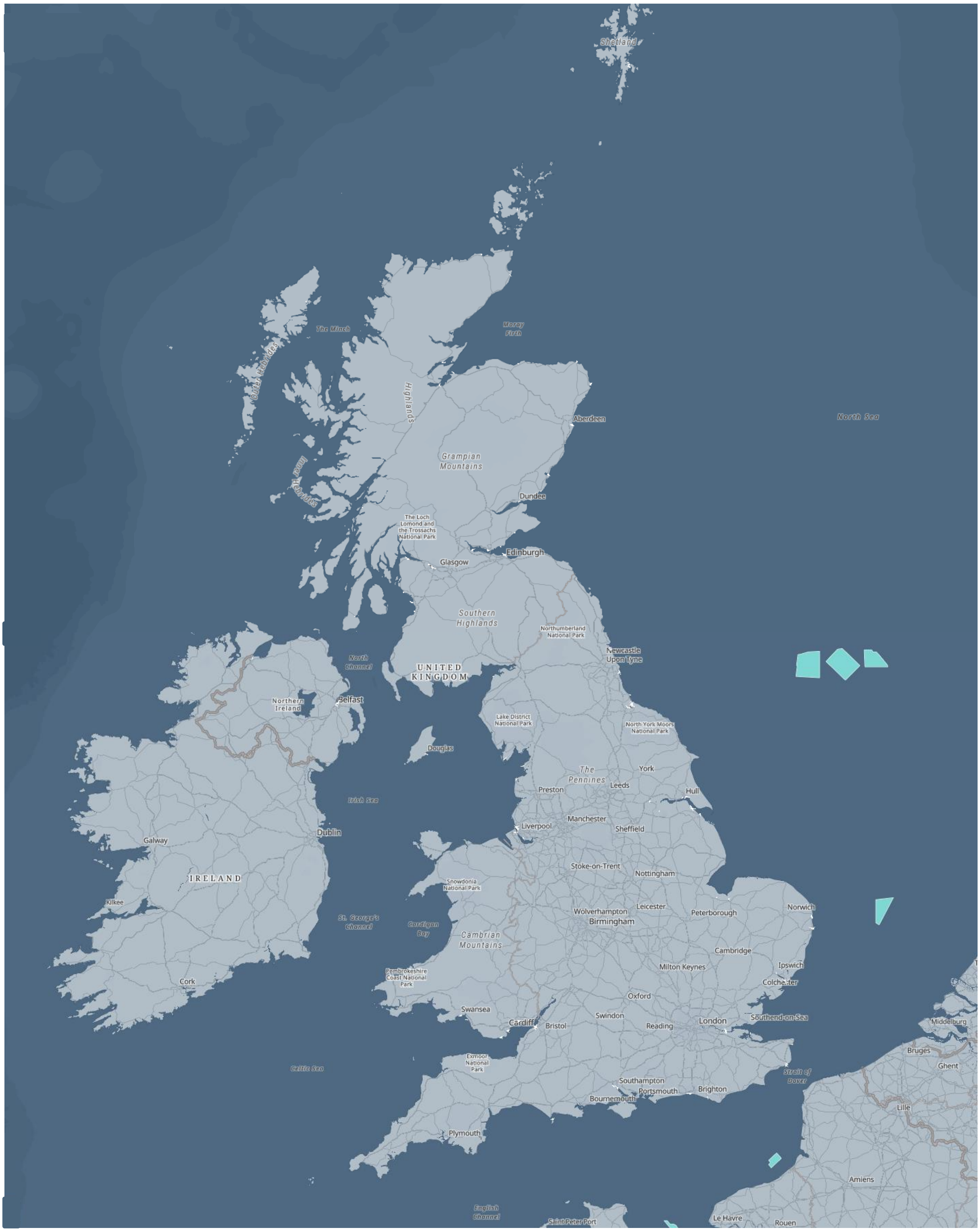
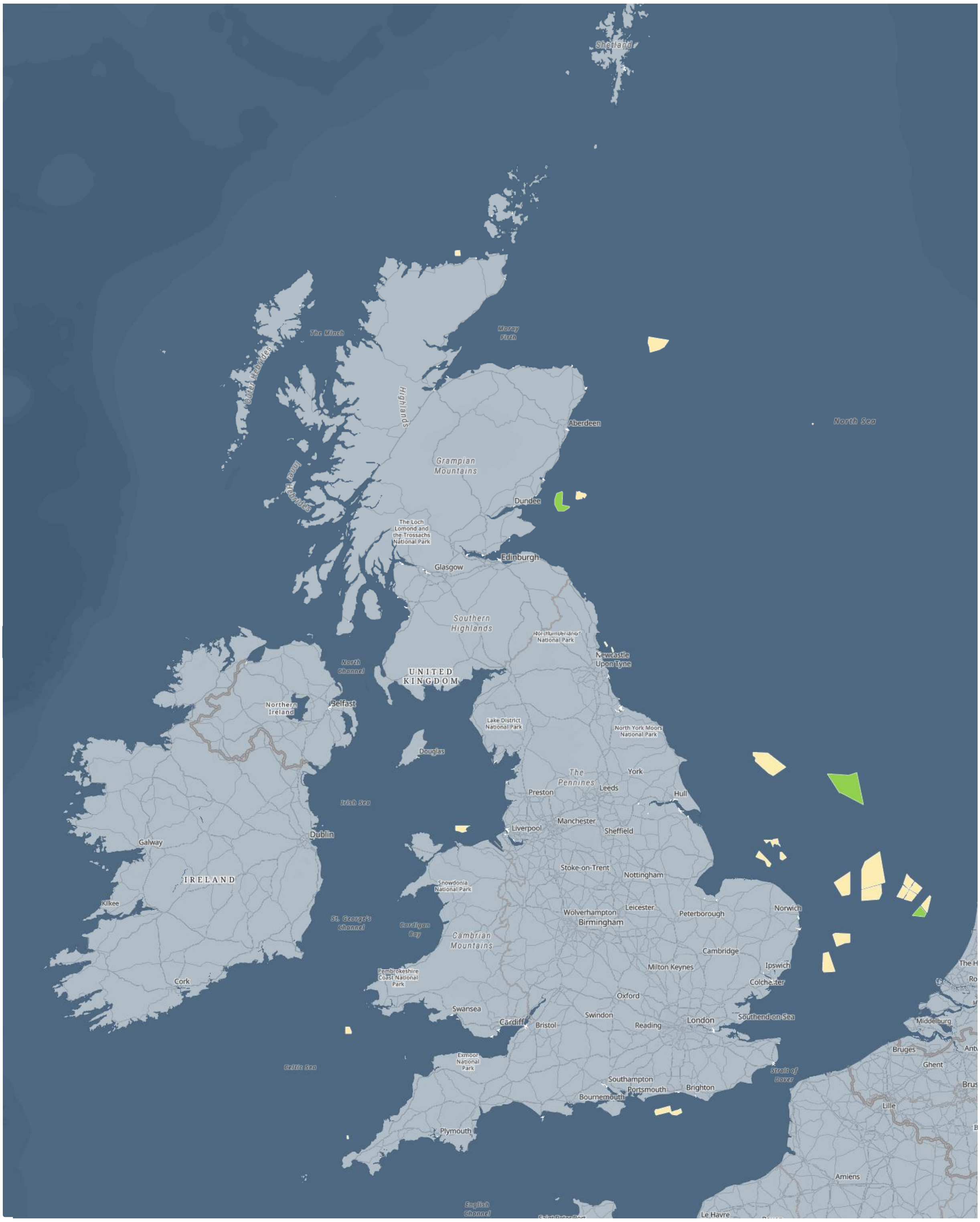
APPENDIX 1 OFFSHORE WIND FARM MAP – GENERATING



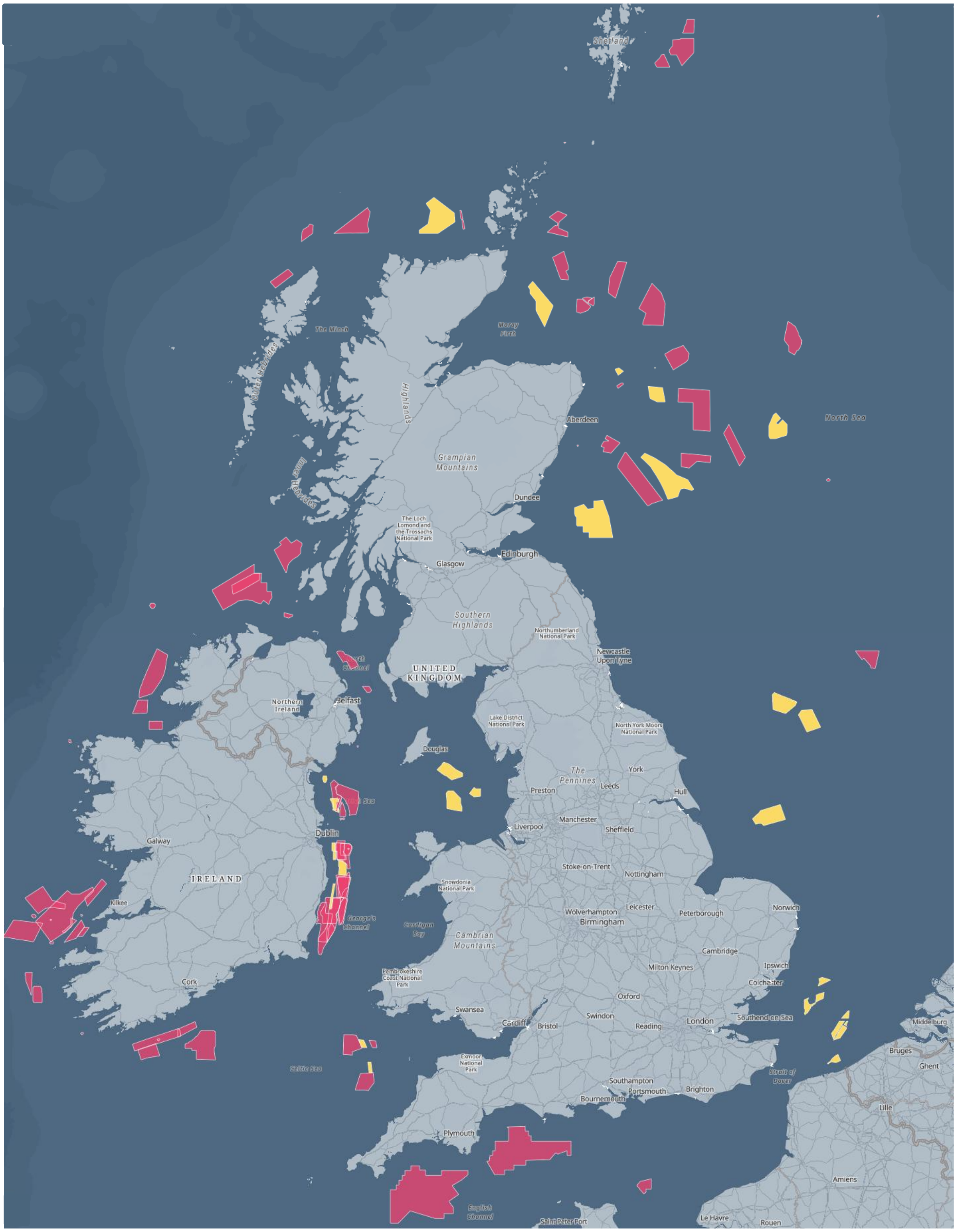
APPENDIX 2 OFFSHORE WIND FARM MAP – CONSTRUCTION



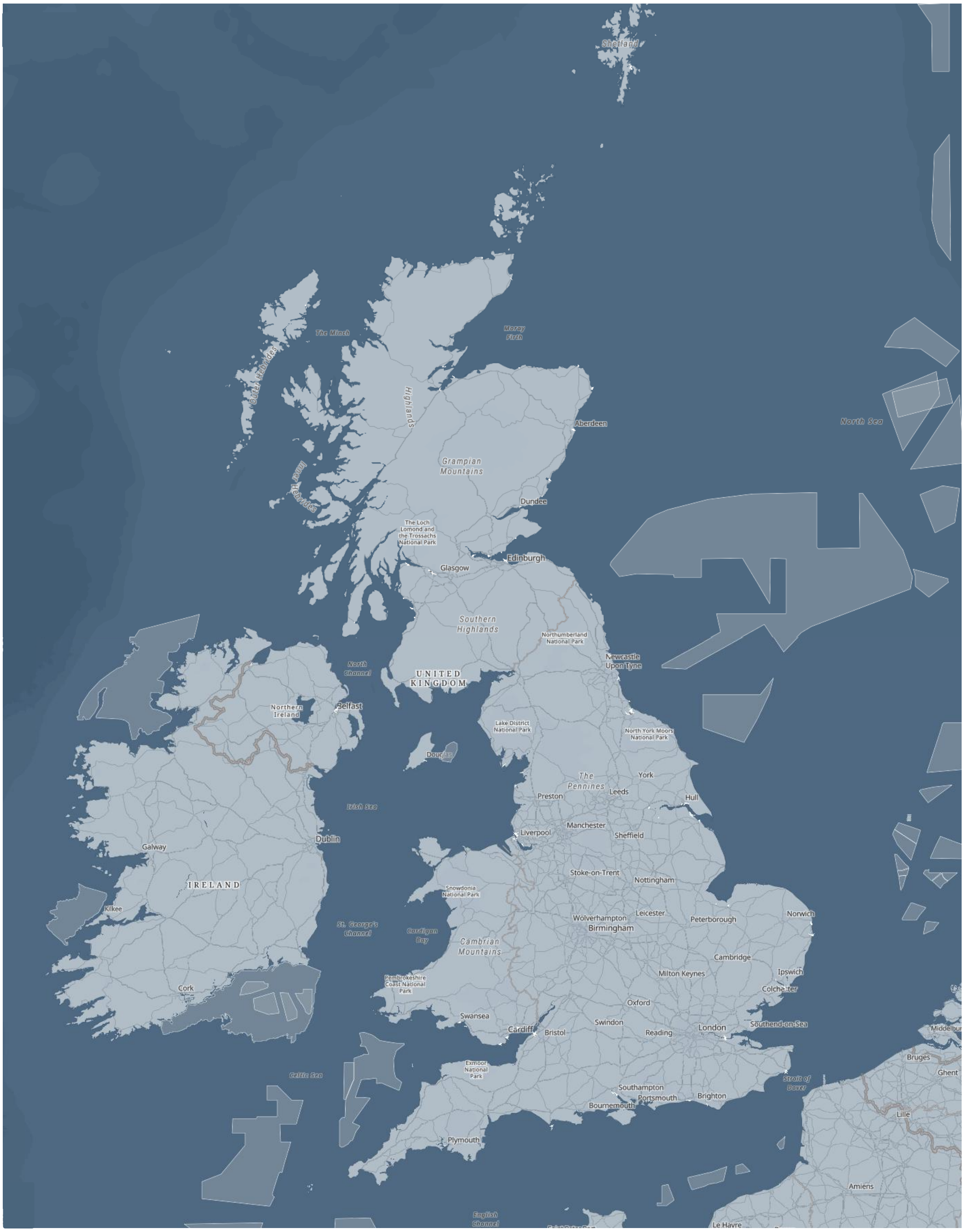
APPENDIX 3 OFFSHORE WIND FARM MAP – CONSENTED



APPENDIX 4 OFFSHORE WIND FARM MAP – PRE-CONSENT



APPENDIX 5 OFFSHORE WIND FARM MAP – DEVELOPMENT ZONES



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