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Initial Predictions for Offshore Wind Farms in the ScotWind Leasing Round

EXECUTIVE SUMMARY

ScotWind is a seabed leasing round, run by Crown Estate Scotland, and aims to enable up to 10GW of new offshore wind farms to be constructed in Scottish waters from a total area of 12,810km^2, in accordance with the Scottish Government's Sectoral Marine Plan for Offshore Wind Energy. The seabed rights are likely to be awarded by the end of 2021, with the projects enabled by ScotWind expected to be built around 2030. This paper by ORE Catapult seeks to provide some initial predictions for the supply chain, including estimating how many of each foundation type (i.e. monopile, jacket or floating) might be required to build the 10GW (maximum) of offshore wind farms enabled by the ScotWind seabed leasing round.

Many of the ScotWind plan options (POs) have large areas of deep water (greater than 70m) which makes the introduction of commercial scale floating offshore wind farms a likely outcome of the ScotWind leasing round. The absence of shallow water (less than 50m) means it is highly unlikely that monopiles will be heavily utilised on the offshore wind farms stemming from ScotWind (i.e. 21 structures in the 10GW case, out of nearly 660, assuming 15MW turbines). However, some plan options do have large areas of 50m to 60m water depths, which means that XXL monopiles may be preferable to jacket foundations at those sites. Whilst the initial assumption for floating foundations was deployment in water depths greater than 70m, a credible scenario is deployment in water depths greater than 50m, given the potential for floating wind turbines to have a higher price point than bottom-fixed alternatives (depending on upcoming policy decisions). If this were the case, then floating foundations would be used for 97% of the offshore wind capacity enabled by ScotWind (i.e. 633 structures in a 10GW deployment scenario). The analysis also suggests at least 1,295km of High-Voltage (HV) export cables will be required for the offshore wind farms enabled by ScotWind. The analysis is subject to a number of sensitivities and caveats, detailed throughout the report.

INTRODUCTION

Offshore wind is expected to be a major contributor to the clean energy mix of global economies as many countries target 'Net Zero' emissions.[i] For example, the UK government has a target to reach 40GW of installed offshore wind capacity by 2030, as part of an effort to reach Net Zero by 2050.[ii] These targets demonstrate the scale of ambition for growth of the sector, given that the UK currently has 14GW of offshore wind farms either fully commissioned or under construction (as of March 2021). There is a further 3.5GW in the pre-construction phase and 9GW with consent authorised. The UK's latest seabed leasing round (Round 4), operated by the Crown Estate, saw a further 8GW of seabed rights awarded for offshore wind deployment.[iii]

In Scotland, there are currently seven offshore wind farms either fully commissioned or under construction, totalling an installed capacity of 2.3GW (see Table 1). There is a further 3.5GW in the project pipeline (i.e. pre-construction or with consent authorised), including major sites at Inch Cape, Moray West and Seagreen. The Scottish Government recently announced a target to reach 11GW of offshore wind capacity in Scottish waters by 2030.[iv] This indicates a significant ramp up of activity over the coming decade.

Table 1: Offshore wind farms in Scotland fully commissioned or under construction (as of February 2021)

WIND FARM	STATUS	SITE CAPACITY	TURBINE SIZE	FOUNDATION TYPE
Robin Rigg (O&M base and cable landfall in England)	Fully Commissioned	174MW	3MW	Monopile
Hywind Scotland Pilot Park	Fully Commissioned	30MW	6MW	Floating Spar
Aberdeen Offshore Wind Farm (EOWDC)	Fully Commissioned	93.2MW	8MW	Jacket
Beatrice	Fully Commissioned	588MW	7MW	Jacket
Kincardine Phase 2	Under Construction	48MW	9.6MW	Floating Semi-Sub
Neart na Gaoithe	Under Construction	448MW	8MW	Jacket
Moray East	Under Construction	950MW	9.5MW	Jacket

Scotland's primary enabler for achieving this 2030 target is the ScotWind leasing round, detailed in the Scottish Government's 'Sectoral Marine Plan for Offshore Wind Energy'.[v] ScotWind is a seabed leasing round being run by Crown Estate Scotland (CES), whereby rights to areas of the Scottish seabed (see Figure 1) will be awarded to project developers, leading to construction and operation of a maximum of 10GW of offshore wind capacity (10GW cap defined in the Sectoral Marine Plan).[vi] The original closing date for applications has been extended to allow CES to reconsider the seabed leasing fee strategy. This move was forced after the winning bids from the Crown Estate England and Wales Offshore Wind Leasing Round 4 auction were far higher than expected. However, it is still expected that the seabed rights from ScotWind will be awarded by the end of 2021.[vii]

Figure 1: Offshore wind plan options ('ScotWind') and existing Scottish offshore wind developments (Source: Scottish Government)

What does this report aim to do?

ORE Catapult published a blog in 2020 highlighting what we expect a 2030 offshore wind farm to look like in terms of turbine sizes, site capacity, array cable voltage etc.[viii] This report aims to build on that work with a focus on the ScotWind seabed leasing round. In particular, this report seeks to provide some initial predictions about how many of each foundation type (i.e. monopile, jacket or floating) might be required to build the 10GW (maximum) of offshore wind farms enabled by the ScotWind leasing round. Consideration is also made to inter-array and export cabling. The intention is to highlight the future opportunities to the supply chain for offshore wind farms in Scotland.

Why ORE Catapult?

ORE Catapult acts as an independent, centralised, forward-thinking organisation at the heart of the offshore renewable energy industry, working closely with partners across industry and academia to develop new ways of working and prove, de-risk and develop promising new technologies. This publicly available report has been compiled by ORE Catapult using internal modelling informed by related industry engagement, in conjunction with Geographic Information System (GIS) modelling expertise provided by Aquatera.

METHODOLOGY

GIS Mapping

This study has been undertaken with support provided by Aquatera in the form of GIS mapping. A shapefile of the plan options in the Sectoral Marine Plan for Offshore Wind Energy has been made publicly available by Marine Scotland.[ix]

Site Capacity

The Sectoral Marine Plan for Offshore Wind Energy highlights the realistic maximum deployment for each plan option, which varies depending on size of the area, known constraints, early indicators of developer interest, and established infrastructure. This amounts to 26GW of maximum deployment (see Table 2). However, the ScotWind leasing round is capped at 10GW, meaning that: i) not all of these plan options will be awarded seabed rights through ScotWind, and ii) some plan options will be awarded significantly lower deployment capacity than is realistically possible.

Table 2: Summary of maximum realistic development scenarios (Source: The Sectoral Marine Plan for Offshore Wind Energy)

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM^2)	REALISTIC MAXIMUM DEPLOYMENT FOR EACH PLAN OPTION (GW)	REALISTIC DEPLOYMENT AS PERCENTAGE OF TOTAL PLAN OPTION AREA (%)
East	E1	3,742	3	16%
	E2	1,287	2	31%
	E3	474	1	42%
North East	NE1	751	2	53%
	NE2	345	1	58%
	NE3	265	1	76%
	NE4	440	1	45%
	NE6	699	2	57%
	NE7	684	3	88%
	NE8	339	1	59%
North	N1	1,163	2	34%
	N2	561	2	71%
	N3	1,106	2	36%
	N4	200	1	100%
West	W1	754	2	53%
	Total	12,810	26	

For this study, we have looked at three approaches for identifying the maximum site capacity of each plan option:

1. **The absolute maximum** - the seabed area of all plan options (i.e. 12,810km^2) is fully utilised.
2. **The 26GW case** – all plan options are fully utilised in accordance with the Sectoral Marine Plan for Offshore Wind Energy realistic maximum deployments (i.e. without constraints), totalling 26GW.
3. **The 10GW case** – as with the 26GW case but scaled back equally across all plan options to 10GW.

Approach 1 represents the absolute maximum deployment (within the assumptions detailed in the 'turbine numbers' section below) based on the total available seabed area. This does not account for the constraints available to Scottish Government when the realistic deployment scenarios were defined in the Sectoral Marine Plan for Offshore Wind Energy. It is useful to consider approach 1 in this analysis, despite it vastly overestimating the likely outcome, as ScotWind is a seabed leasing round, rather than an attempt to define what project developers can or cannot build in each area. Those constraints are applied later in the project development process (i.e. consenting). Potential constraints have been identified by Marine Scotland (on behalf of Scottish Government) to define the realistic deployments for each plan option that feed our approaches 2 and 3, but these have not been made publicly available. Approach 2 is useful in this analysis because the full breakdown of results (i.e. for each plan option) are presented in the Appendices. This means that, despite the overall outcome being unrealistic (i.e. 26GW when the round is capped at 10GW), an assessment of individual plan options is still accessible. It also provides a view of the potential long-term capacity possible in the identified areas beyond ScotWind if existing consenting barriers can be overcome in the future. Approach 3 is the most realistic case in terms of the outcome of the overall ScotWind seabed leasing round, although there are many permutations of what the actual build-out of offshore wind farms in these ScotWind areas will be.

Turbine Numbers

The total number of turbines in each of our three approaches can be calculated from the plan option areas (in the case of approach 1), or the realistic maximum deployment (for approaches 2 and 3), combined with deployment density and anticipated turbine sizes. The deployment density stated in the Sectoral Marine Plan for Offshore Wind Energy is 5 MW/km^2. Turbine sizes have increased dramatically in recent years. For example, GE's 13MW turbines are to be installed at Dogger Bank in 2024.[x] 14MW and 15MW turbines have recently been unveiled by Siemens Gamesa and Vestas respectively.[xi, xii] It is expected that by the time the projects awarded seabed rights in the ScotWind round are being constructed (i.e. around 2030), standard turbine sizes will be upwards of 15MW. A conservative estimate of 15MW has been assumed for this study, however, the impact that this assumption has on the results is addressed later in the report.

Foundation Type

Three foundation types are considered in this study: i) monopiles, ii) jackets, and iii) floating substructures. No distinction is made in this study between different types of floating substructure (i.e. semi-submersible, spar etc.). Project developers consider a number of factors when selecting a foundation type for an offshore wind farm. These include soil characteristics, wind & wave parameters, turbine size and port infrastructure. However, the primary factors when deciding on foundation type tend to be water depth and impact on project cost. Whilst there is no standardised method, it is generally agreed that monopiles are most suited to shallower sites. Jackets become more feasible in slightly deeper waters, but a transition depth is reached where floating foundations are deemed more economical. The transition water depths between monopiles and jackets, and then jackets and floating foundations, are very much site dependent. Monopiles, for example, historically deemed suitable for water depth around 30-40m, are now being constructed with larger diameters and can be suitable for sites with up to 60m water depth according to Empire Engineering.[xiii] The article states that these XXL monopiles may be able to support a 10MW turbine, provided installation challenges are met. Since we are using 15MW as the reference turbine in this study, we have assumed the monopile limit to be 50m. Our base case assumptions in this paper for foundation types in different water depths are:

- Less than 50m – Monopiles
- Between 50m and 70m – Jackets
- More than 70m - Floating

Sensitivity analyses have been presented later in the report to assess the impact if; i) monopiles are deployed in areas with water depth up to 60m, ii) jackets are deployed in water depths up to 80m, and iii) floating foundations fully displace the need for jackets.

Cabling

66kV is likely to be the standard rating of array cables for offshore wind farms by 2030, and we have assumed 220kV will be the standard for High-Voltage Alternating Current (HVAC) export cables. It is possible that these voltage ratings will be higher (e.g. 132kv array cables, or 275kv export cables). In estimating the number of array cables at each plan option, we have assumed it matches the number of turbines. However, many array cable topologies in modern wind farms adopt a ring or double-ring layout, thereby providing redundancy in case of cable fault, so this number may be higher. The length of export cables is estimated in this study by identifying the nearest cable landfall point, and assuming a realistic value for the maximum capacity carried by a single export cable.

KEY FINDINGS

The key findings from approaches 2 and 3 (i.e. the 26GW and 10GW cases respectively) have been presented and discussed here. Approach 1 is included in the Appendices for completion.

Site Capacity and Turbine Numbers

The three approaches stated previously have been used to identify the maximum site capacity and number of turbines located in each of the ScotWind plan option areas (see Table 3 for approaches 2 and 3). When realistic maximum deployment for each plan option is considered (approach 2), the total number of turbines required is 1,727 if the turbine size were 15MW. In the more realistic 10GW case (approach 3), where all plan options are scaled back to 10GW for the overall leasing round, there is a total of 659 turbines.

An area of sensitivity in this analysis is our assumption that the standard rated capacity of turbines in the ScotWind-enabled offshore wind farms will be 15MW. Although we expect turbines to be announced in coming years that are greater than 15MW, it may be that turbines with lower rated capacities are still extensively used for offshore wind farms in 2030. This may be dependent on foundation type or other factors such availability of fabrication facilities. Figure 2 shows that, in the 10GW case (approach 3), 832 turbines are deployed in total if 12MW is the standard rating, while 494 turbines are deployed if the rating of each is 20MW (compared to 659 in the 15MW base case).

Table 3: Estimated site capacities and turbine numbers of each PO, using the 26GW and 10GW approaches and a 15MW turbine assumption

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	APPROACH 2 (26GW CASE)		APPROACH 3 (10GW CASE)	
			CAPACITY (MW)	TURBINE NUMBERS	CAPACITY (MW)	TURBINE NUMBERS
East	E1	3742	3,000	200	1,140	76
	E2	1287	1,995	133	765	51
	E3	474	990	66	375	25
North East	NE1	751	1,995	133	765	51
	NE2	345	990	66	375	25
	NE3	265	990	66	375	25
	NE4	440	990	66	375	25
	NE6	699	1,995	133	765	51
	NE7	684	3,000	200	1,140	76
	NE8	339	990	66	375	25
North	N1	1163	1,995	133	765	51
	N2	561	1,995	133	765	51
	N3	1106	1,995	133	765	51
	N4	200	990	66	375	25
West	W1	754	1,995	133	765	51
	Total	***12,810***	***25,905***	***1,727***	***9,885***	***659***

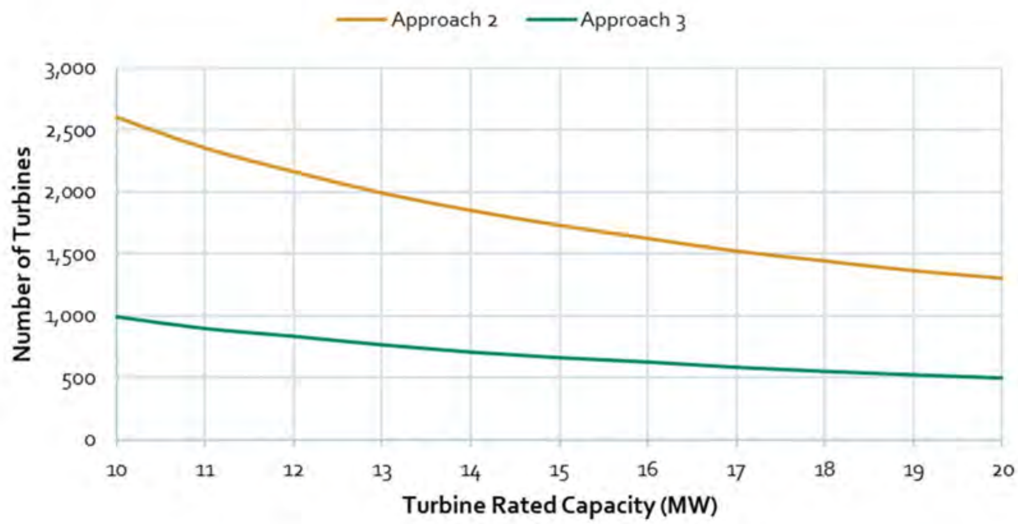

Figure 2: Sensitivity analysis of the number of turbines enabled by ScotWind given different rated capacities

Foundation Types

A GIS map, supplied by Aquatera, of water depth in Scottish waters and the positions of the ScotWind sites is given in Figure 3. From this mapping, the percentage of each plan option area that lies in each of the three water depth bands can be identified (Table 4).

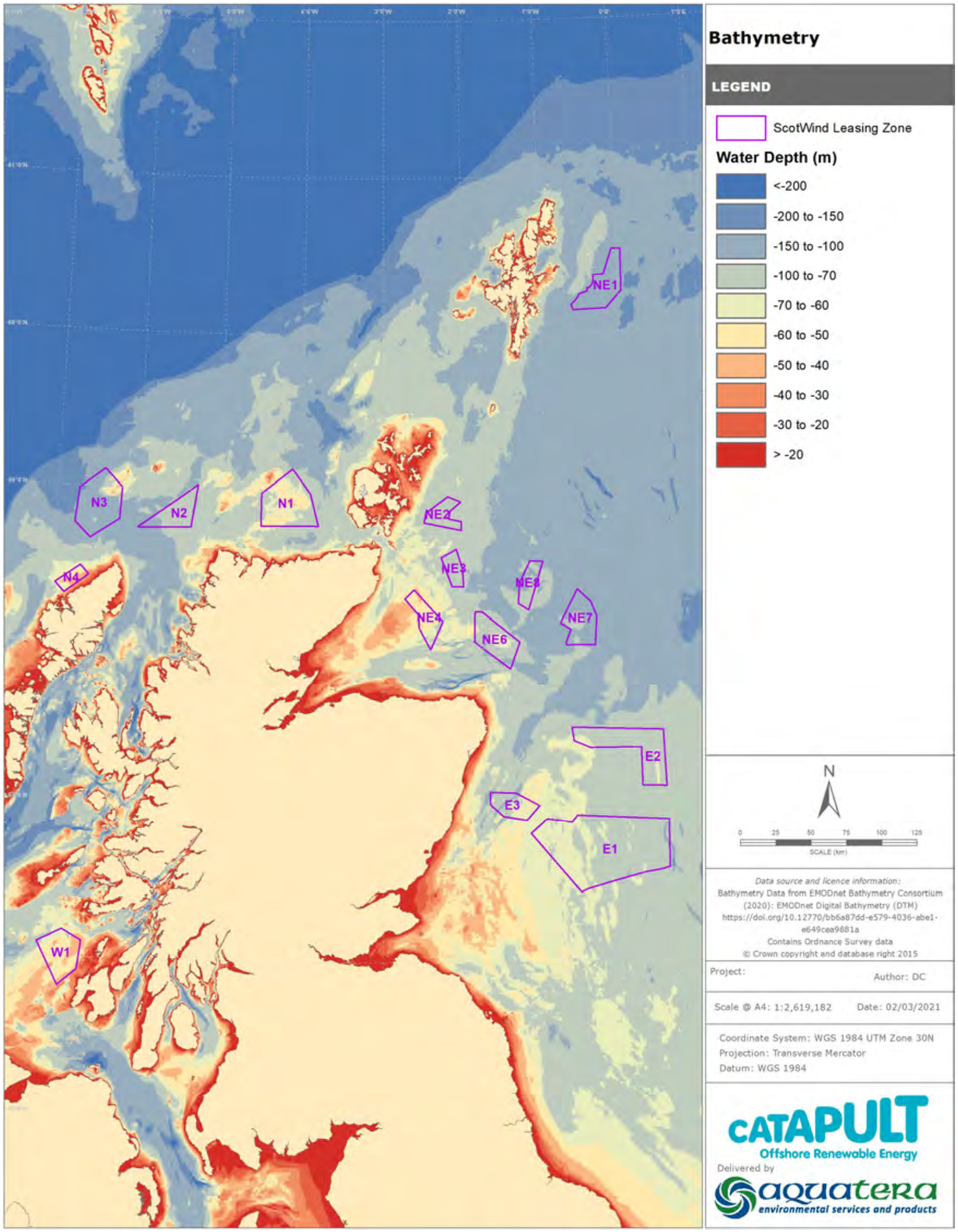

Figure 3: Bathymetry of Scottish waters, with the ScotWind leasing sites highlighted (GIS map supplied by Aquatera)

Table 4: Proportion of each plan option area in the three water depth bands defining foundation type

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	WATER DEPTH BAND LESS THAN 50M (MONOPILE)	50M TO 70M (JACKET)	OVER 70M (FLOATING)
East	E1	3,742	0.00%	33.31%	66.69%
	E2	1,287	0.00%	10.20%	89.80%
	E3	474	0.00%	46.38%	53.62%
North East	NE1	751	0.00%	0.00%	100.00%
	NE2	345	0.00%	0.00%	100.00%
	NE3	265	0.00%	0.00%	100.00%
	NE4	440	4.14%	84.47%	11.39%
	NE6	699	0.00%	19.07%	80.93%
	NE7	684	0.00%	0.00%	100.00%
	NE8	339	0.00%	0.00%	100.00%
North	N1	1,163	1.43%	62.13%	36.44%
	N2	561	0.00%	0.00%	100.00%
	N3	1,106	0.89%	7.70%	91.41%
	N4	200	37.10%	62.86%	0.04%
West	W1	754	23.01%	73.45%	3.54%

Combining the water depth percentages in Table 4 with the estimation of turbine numbers in Table 3 (rounding down to be conservative) results in an indication of the maximum number of each foundation type expected to come out of the ScotWind leasing round (see Table 5). The full results of each analysis can be found in the Appendices.

Table 5: Number of foundations of each type estimated by the three approaches, base case

APPROACH	MONOPILES (LESS THAN 50M)	JACKETS (50M TO 70M)	FLOATING (OVER 70M)	TOTAL
2 The 26GW Case	58 (3% of total)	419 (24% of total)	1,238 (72% of total)	1,715
3 The 10GW Case	21 (3% of total)	157 (24% of total)	469 (72% of total)	647

Monopiles

With a constraint of less than 50m water depth, monopiles are estimated to be the least utilised foundation type in the offshore wind farms stemming from the ScotWind leasing round. Taking some constraints into account from the Sectoral Marine Plan for Offshore Wind Energy in the 26GW case (approach 2), the estimated number of monopiles is 58 (3% of total). When this is scaled back to 10GW (the cap on ScotWind imposed by the Sectoral Marine Plan), there are only 21 monopiles required (out of 647, 3%). These figures are subject to turbine capacity, as our assumption for 15MW is unlikely to be true for all offshore wind farms enabled by ScotWind. XXL monopiles are currently being considered by industry, where the water depth limitation may be in the region of 60m. With 60m as the constraint, the maximum number of monopiles in the round is estimated to be 265 (15% of total) in approach 2 (compared to 58), and 98 (15% of total) in approach 3 (compared to 21), as shown in Table 6. Plan options N4 and W1 have the highest percentage of area below 60m water depth (see Table 10 in the Appendices). Increasing the water depth constraint on monopiles would reduce the number of jackets (which would be restricted to 60m to 70m depth as a consequence), as can be seen in Table 6. This analysis has not considered any restrictions on turbine capacity stemming from placing a monopile in 60m water depth.

Table 6: Number of foundations of each type estimated by the three approaches, when the monopile limit is 60m water depth

APPROACH	MONOPILES (LESS THAN 60M)	JACKETS (60M TO 70M)	FLOATING (OVER 70M)	TOTAL
2 The 26GW Case	265 (15% of total)	214 (13% of total)	1,238 (72% of total)	1,717
3 The 10GW Case	98 (15% of total)	79 (12% of total)	469 (73% of total)	646

Jackets

Some of the ScotWind plan options have large areas between 50m and 70m water depth which would likely make them well suited to jacket foundations. The 26GW case (approach 2) shows that 419 jackets (24% of total) would be required, although this reduces to 157 (24% of total) in the 10GW case (approach 3). A large proportion of jackets would be required for plan options E1, N1 and W1 given these depth constraints (see Table 11 in the Appendices). If the maximum depth for jacket deployment was increased to 80m, then the estimated number of jackets increases. In this case, 786 jackets (46% of total) is estimated by approach 2 (compared to 419, 24%, with the original 50m to 70m constraint). However, manufacturing and installing jackets in a depth of 80m is considerably more expensive than in shallower waters, so project developers of these deeper sites would need to consider floating foundations. Policy decisions for the next Contract for Difference (CfD) auctions in the UK are yet to be decided, but it may be that floating wind farms are eligible for higher price points than jackets, making them more attractive in these deeper waters. If the water depth for jackets were restricted to 60m to 70m, then the number of jackets estimated for the whole round is 214 in approach 2 and 79 in approach 3, as shown in Figure 4.

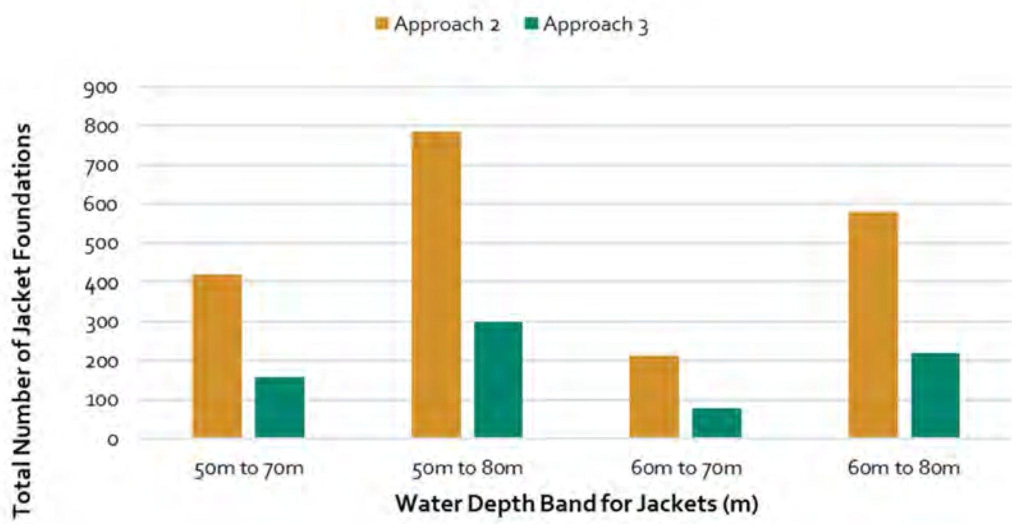

Figure 4: Estimated total number of jackets given different water depth bands

Floating Foundations

We have estimated floating foundations to be the most utilised foundation type in the offshore wind farms enabled by the ScotWind seabed leasing round (assuming deployment in water depths greater than 70m). A total of 1,238 and 469 (72-73% of total in each case) floating foundations are estimated from approaches 2 and 3 respectively. Even if the water depth is constrained to over 80m, floating foundations are still heavily utilised, with 327 (51% of total) of them deployed in the 10GW case (approach 3). Given the rapid increase in Technology Readiness Level (TRL) over recent years, as well as potential higher revenues from CfD strike prices compared to bottom-fixed alternatives, it may well be the case that floating foundations are selected for areas with water depths below 70m. If floating wind farms were deployed in water depths above 50m, then the 10GW case (approach 3) estimates a total of 633 to be required (97% of the total, with the remainder being monopiles). Deployment of floating foundations in water depths above 50m would encourage a rapid build-out which would enable quicker cost reduction according to an ORE Catapult study.[xiv] This analysis has not investigated further details that would determine the type of floating foundations (e.g. spars require deep-water ports).

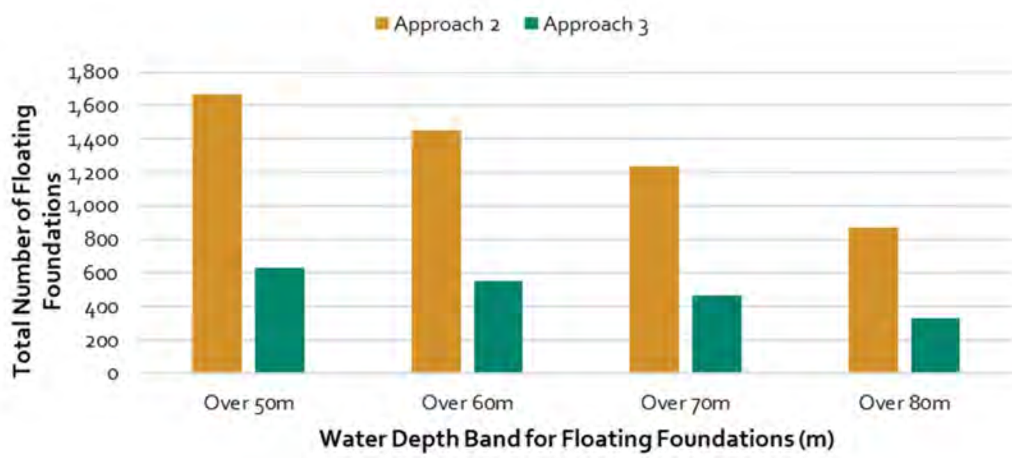

Figure 5: Estimated total number of floating foundations given different water depth bands

Cabling

The offshore wind farms stemming from the ScotWind seabed leasing round would use a minimum of one array cable per turbine. That would equate to a minimum of 659 array cables for the whole round in the 10GW case (taken from the estimations of total foundation numbers in approach 3, Table 3), each estimated to have a rating at 66kV. It is likely that more array cables would be required, given that modern wind farms tend to adopt ring or double-ring cable topologies to build redundancy into the system. This analysis has identified that significant numbers of floating foundations are expected to be enabled by the ScotWind leasing round, meaning that dynamic cables, mooring systems and anchors would also be required.

HVAC export cables, estimated to have a standard rating of 220kV by 2030, connect the offshore and onshore substations for each site. The shortest distances to cable landfall for each plan option are shown in Table 7. By assuming a realistic capacity per export cable, we estimate that a minimum of 1,295km of export cable routes would be required for the whole leasing round in the 10GW case (approach 3). The true length of export cabling is likely to be higher as, for example, mainland connections may be preferable to islands at some locations (e.g. Islay for W1). Some of the sites may utilise High-Voltage Direct Current (HVDC) export cables, particularly if they are far-from-shore projects.

Table 7: Estimated export cable lengths, based on shortest distance to cable landfall, for each plan option

REGION	PLAN OPTION	SITE CAPACITY (MW)		SHORTEST DISTANCE TO CABLE LANDFALL (KM)	CABLE LANDFALL (ESTIMATED)	ESTIMATED EXPORT CABLE LENGTH (KM)[1]	
		APPROACH 2	APPROACH 3			APPROACH 2	APPROACH 3
East	E1	3,000	1,140	65	Stonehaven	650	260
	E2	1,995	765	65	Peterhead	390	130
	E3	990	375	25	Aberdeen	75	25
North East	NE1	1,995	765	35	Lerwick	210	70
	NE2	990	375	45	John o' Groats	135	45
	NE3	990	375	50	John o' Groats	150	50
	NE4	990	375	30	Wick	90	30
	NE6	1,995	765	40	Fraserburgh	240	80
	NE7	3,000	1,140	80	Fraserburgh	800	320
	NE8	990	375	80	Fraserburgh	240	80
North	N1	1,995	765	25	Thurso	150	50
	N2	1,995	765	35	Durness	210	70
	N3	1,995	765	30	Lewis	180	60
	N4	990	375	5	Lewis	15	5
West	W1	1,995	765	10	Islay	60	20
	Total =	25,905	9,885		Total =	3,595	1,295

[1] Cable length is calculated with the estimated number of cables multiplied by the shortest distance to cable landfall, where the estimated number of cables is rounded to the nearest whole number for each plan option.

DISCUSSION AND RECOMMENDATIONS

This report has presented an analysis of the ScotWind seabed leasing round, with a particular focus on what the supply chain can expect in terms of foundation types of the resulting offshore wind farms. It is important to note that Crown Estate Scotland (CES) is leasing seabed areas in ScotWind, not site capacity. The 'absolute maximum' case in this analysis (approach 1) is based on a total available seabed of 12,810km^2, utilised without constraints assuming a capacity density of 5 MW/km^2 (in line with Scottish Government's Sectoral Marine Plan for Offshore Wind Energy), and results in 64GW of offshore wind energy. Approach 2 is more realistic with 26GW, as it uses the 'Realistic Maximum Deployments' for each plan option outlined in the Sectoral Marine Plan, which have been defined using constraints and industry indicators. However, the Scottish Government has indicated that 10GW would be the upper limit on offshore wind farms enabled by ScotWind. Therefore, approach 3 presents a version of approach 2, where all plan options are scaled back equally to a total of 10GW. The actual total capacity of projects that eventually get constructed in the ScotWind leasing areas could be lower or higher than 10GW, depending on the outcome of the consenting process for each site, as well as the number of ScotWind leasing rounds that are run over coming years (i.e. multiple rounds are implied in the Sectoral Marine Plan). No attempt has been made in this study to present the countless permutations of what the actual build-out of offshore wind farms in these ScotWind areas will be.

The base case assumption in this study for individual turbine size is 15MW. This is an area of sensitivity in this type of analysis. Although we expect turbines to be announced in coming years that are greater than 15MW, it may be that turbines with lower rated capacities are still used for offshore wind farms in 2030 (e.g. due to lower perceived risk, consenting restrictions etc.). A brief sensitivity analysis showed that the 10GW case (approach 3) would result in 832 turbines if 12MW is the standard rating, and 494 turbines if the rating is 20MW (compared to 659 in the 15MW base case).

The GIS mapping and engineering knowledge captured in this study has made it clear that the deep waters around Scotland are well suited to floating foundations. The analysis suggests that if the 10GW limit is fully realised (approach 3), assuming 15MW turbines, then there could be a minimum of 469 (i.e. 73% of the total) floating foundations required for constructing the offshore wind farms enabled by ScotWind if they are deployed in water depths above 70m. If floating foundations were deployed in waters greater than 50m depth, then the 10GW case would require 633 of the structures (i.e. 97% of the total). This is a credible scenario, given that policy decisions for the next Contract for Difference (CfD) auctions in the UK are yet to be decided, and may enable floating wind farms to be eligible for higher price points than bottom-fixed alternatives, making them more attractive in these 50m+ waters.

Monopiles, widely seen as the most economical choice for turbine foundations, are unlikely to be heavily utilised. The analysis indicates that 21 monopiles (i.e. 3% of total) would be needed in the 10GW case (approach 3) if they were limited to 50m water depth or less. This value rises to 98 (i.e. 15% of total) if the water depth limit on monopiles is increased to 60m or less. Jacket foundations are likely to be utilised more than monopiles, given their increased suitability to water depths of 50m to 70m, although this is the transition depth where floating structures may become the dominant foundation type. Two factors that may limit such a rapid build-out of floating foundations, thereby forcing an increased number of jackets to be required, are (but not limited to):

i. A capacity cap on the potential separate CfD pot for floating wind (yet to be decided),
ii. Issues with fabrication of floating foundations at scale.

A key caveat of the analysis in this paper is that we don't know the constraints that Marine Scotland (on behalf of CES) has used to produce the realistic maximum deployment scenarios for each plan option. This data may skew the expected number of each foundation type in this study. For example, 66% of plan option NE4 has a water depth below 60m (see Table 10). If all development is contained in that part of the plan option, then it is possible that monopiles will be exclusively used in that area. Another caveat of this study is the fairly crude assumptions for expected foundation types given different water depths. Project developers undertake detailed engineering and economic analyses on a case-by-case basis when selecting a foundation type, considering additional parameters such as soil characteristics, wind & wave parameters, turbine size, and port infrastructure. For example, a certain site may have a suitable port nearby which makes it more attractive for floating foundations.

In addition to the estimates of foundation types and numbers, this analysis has also identified the requirement for a minimum of 1,295km of export cable routes, assuming HVAC 220kV is the standard by 2030. Although, again, the true requirements will vary based on the size of actual build-out and potentially reducing as larger export cable ratings become available. High-Voltage Direct Current (HVDC) has not been considered in this analysis, however, it is possible that HVDC substations are deployed on some of the offshore wind farms enabled by ScotWind.

Appendices

SITE CAPACITY – FULL RESULTS

Table 8: Estimated site capacities and turbine numbers of each PO, using the three approaches and a 15MW turbine assumption

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	APPROACH 1 (ABSOLUTE MAXIMUM)		APPROACH 2 (26GW CASE)		APPROACH 3 (10GW CASE)	
			CAPACITY (MW)	TURBINE NUMBERS	CAPACITY (MW)	TURBINE NUMBERS	CAPACITY (MW)	TURBINE NUMBERS
East	E1	3742	18,705	1,247	3,000	200	1,140	76
	E2	1287	6,435	429	1,995	133	765	51
	E3	474	2,370	158	990	66	375	25
North East	NE1	751	3,750	250	1,995	133	765	51
	NE2	345	1,725	115	990	66	375	25
	NE3	265	1,320	88	990	66	375	25
	NE4	440	2,190	146	990	66	375	25
	NE6	699	3,495	233	1,995	133	765	51
	NE7	684	3,420	228	3,000	200	1,140	76
	NE8	339	1,695	113	990	66	375	25
North	N1	1163	5,805	387	1,995	133	765	51
	N2	561	2,805	187	1,995	133	765	51
	N3	1106	5,520	368	1,995	133	765	51
	N4	200	990	66	990	66	375	25
West	W1	754	3,765	251	1,995	133	765	51
	Total	***12,810***	***63,990***	***4,266***	***25,905***	***1,727***	***9,885***	***659***

FOUNDATION NUMBERS – FULL RESULTS

Table 9: Estimated number of monopiles in each plan option area using the three approaches, with less than 50m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	NUMBER OF MONOPILES (< 50M)		
			APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	0	0	0
	E2	1,287	0	0	0
	E3	474	0	0	0
North East	NE1	751	0	0	0
	NE2	345	0	0	0
	NE3	265	0	0	0
	NE4	440	6	2	1
	NE6	699	0	0	0
	NE7	684	0	0	0
	NE8	339	0	0	0
North	N1	1,163	5	1	0
	N2	561	0	0	0
	N3	1,106	3	1	0
	N4	200	24	24	9
West	W1	754	57	30	11
		Total =	95	58	21

Table 10: Estimated number of monopiles in each plan option area using the three approaches, with less than 60m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA < 60M	NUMBER OF MONOPILES (< 60M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	0.00%	0	0	0
	E2	1,287	0.00%	0	0	0
	E3	474	9.18%	14	6	2
North East	NE1	751	0.00%	0	0	0
	NE2	345	0.00%	0	0	0
	NE3	265	0.00%	0	0	0
	NE4	440	66.37%	96	43	16
	NE6	699	0.86%	2	1	0
	NE7	684	0.00%	0	0	0
	NE8	339	0.00%	0	0	0
North	N1	1,163	30.98%	119	41	15
	N2	561	0.00%	0	0	0
	N3	1,106	5.32%	19	7	2
	N4	200	90.65%	59	59	22
West	W1	754	81.38%	204	108	41
			Total =	513	265	98

Table 11: Estimated number of jackets in each plan option area using the three approaches, with 50-70m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM^2)	NUMBER OF JACKETS (50M - 70M)		
			APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	415	66	25
	E2	1,287	43	13	5
	E3	474	73	30	11
North East	NE1	751	0	0	0
	NE2	345	0	0	0
	NE3	265	0	0	0
	NE4	440	123	55	21
	NE6	699	44	25	9
	NE7	684	0	0	0
	NE8	339	0	0	0
North	N1	1,163	240	82	31
	N2	561	0	0	0
	N3	1,106	28	10	3
	N4	200	41	41	15
West	W1	754	184	97	37
		Total =	1,191	419	157

Table 12: Estimated number of jackets in each plan option area using the three approaches, with 50-80m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM^2)	PROPORTION OF AREA 50-80M	NUMBER OF JACKETS (50M – 80M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	91.23%	1,137	182	69
	E2	1,287	61.53%	263	81	31
	E3	474	71.57%	113	47	17
North East	NE1	751	0.00%	0	0	0
	NE2	345	56.90%	65	37	14
	NE3	265	52.12%	45	34	13
	NE4	440	93.68%	136	61	23
	NE6	699	43.55%	101	57	22
	NE7	684	0.00%	0	0	0
	NE8	339	8.05%	9	5	2
North	N1	1,163	84.50%	327	112	43
	N2	561	11.14%	20	14	5
	N3	1,106	10.41%	38	13	5
	N4	200	62.90%	41	41	15
West	W1	754	76.78%	192	102	39
			Total =	2,487	786	298

Table 13: Estimated number of jackets in each plan option area using the three approaches, with 60-70m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA 60-70M	NUMBER OF JACKETS (60M – 70M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	33.31%	415	66	25
	E2	1,287	10.20%	43	13	5
	E3	474	37.20%	58	24	9
North East	NE1	751	0.00%	0	0	0
	NE2	345	0.00%	0	0	0
	NE3	265	0.00%	0	0	0
	NE4	440	22.24%	32	14	5
	NE6	699	18.21%	42	24	9
	NE7	684	0.00%	0	0	0
	NE8	339	0.00%	0	0	0
North	N1	1,163	32.58%	126	43	16
	N2	561	0.00%	0	0	0
	N3	1,106	3.27%	12	4	1
	N4	200	9.31%	6	6	2
West	W1	754	15.08%	37	20	7
			Total =	771	214	79

Table 14: Estimated number of jackets in each plan option area using the three approaches, with 60-80m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA 60-80M	NUMBER OF JACKETS (60M – 80M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	91.23%	1,137	182	69
	E2	1,287	61.53%	263	81	31
	E3	474	62.39%	98	41	15
North East	NE1	751	0.00%	0	0	0
	NE2	345	56.90%	65	37	14
	NE3	265	52.12%	45	34	13
	NE4	440	31.45%	45	20	7
	NE6	699	42.69%	99	56	21
	NE7	684	0.00%	0	0	0
	NE8	339	8.05%	9	5	2
North	N1	1,163	54.95%	212	73	28
	N2	561	11.14%	20	14	5
	N3	1,106	5.98%	22	7	3
	N4	200	9.35%	6	6	2
West	W1	754	18.41%	46	24	9
			Total =	2,067	580	219

Table 15: Estimated number of floating foundations in each plan option area using the three approaches, with greater than 70m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	NUMBER OF FLOATING FOUNDATIONS (> 70M)		
			APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	831	133	50
	E2	1,287	385	119	45
	E3	474	84	35	13
North East	NE1	751	250	133	51
	NE2	345	115	66	25
	NE3	265	88	66	25
	NE4	440	16	7	2
	NE6	699	188	107	41
	NE7	684	228	200	76
	NE8	339	113	66	25
North	N1	1,163	141	48	18
	N2	561	187	133	51
	N3	1,106	336	121	46
	N4	200	0	0	0
West	W1	754	8	4	1
		Total =	2,970	1,238	469

Table 16: Estimated number of floating foundations in each plan option area using the three approaches, with greater than 80m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA > 80M	NUMBER OF FLOATING FOUNDATIONS (> 80M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	8.77%	109	17	6
	E2	1,287	38.47%	165	51	19
	E3	474	28.43%	44	18	7
North East	NE1	751	100.00%	250	133	51
	NE2	345	43.10%	49	28	10
	NE3	265	47.88%	42	31	11
	NE4	440	2.18%	3	1	0
	NE6	699	56.45%	131	75	28
	NE7	684	100.00%	228	200	76
	NE8	339	91.95%	103	60	22
North	N1	1,163	14.07%	54	18	7
	N2	561	88.86%	166	118	45
	N3	1,106	88.70%	326	117	45
	N4	200	0.00%	0	0	0
West	W1	754	0.21%	0	0	0
			Total =	1,670	867	327

Table 17: Estimated number of floating foundations in each plan option area using the three approaches, with greater than 50m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA > 50M	NUMBER OF FLOATING FOUNDATIONS (> 50M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	100.00%	1,247	200	76
	E2	1,287	100.00%	429	133	51
	E3	474	100.00%	158	66	25
North East	NE1	751	100.00%	250	133	51
	NE2	345	100.00%	115	66	25
	NE3	265	100.00%	88	66	25
	NE4	440	95.86%	139	63	23
	NE6	699	100.00%	233	133	51
	NE7	684	100.00%	228	200	76
	NE8	339	100.00%	113	66	25
North	N1	1,163	98.57%	381	131	50
	N2	561	100.00%	187	133	51
	N3	1,106	99.11%	364	131	50
	N4	200	62.90%	41	41	15
West	W1	754	76.99%	193	102	39
			Total =	4,166	1,664	633

Table 18: Estimated number of floating foundations in each plan option area using the three approaches, with greater than 60m water depth

REGION	PLAN OPTION	TOTAL PLAN OPTION AREA (KM²)	PROPORTION OF AREA > 60M	NUMBER OF FLOATING FOUNDATIONS (> 60M)		
				APPROACH 1	APPROACH 2	APPROACH 3
East	E1	3,742	100.00%	1,247	200	76
	E2	1,287	100.00%	429	133	51
	E3	474	90.82%	143	59	22
North East	NE1	751	100.00%	250	133	51
	NE2	345	100.00%	115	66	25
	NE3	265	100.00%	88	66	25
	NE4	440	33.63%	49	22	8
	NE6	699	99.14%	230	131	50
	NE7	684	100.00%	228	200	76
	NE8	339	100.00%	113	66	25
North	N1	1,163	69.02%	267	91	35
	N2	561	100.00%	187	133	51
	N3	1,106	94.68%	348	125	48
	N4	200	9.35%	6	6	2
West	W1	754	18.62%	46	24	9
			Total =	3,746	1,455	554

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Dr Anthony Gray has been researching and working in the field of offshore renewable energy for seven years. He is currently a techno-economic analyst at the Offshore Renewable Energy Catapult in Glasgow, UK, where he undertakes a wide range of cost modelling and economic assessment activities. He gained a Masters degree in Civil Engineering (MEng) from Cardiff University in 2011 and an Engineering Doctorate (EngD) in Offshore Renewable Energy from the University of Exeter in 2017 through the Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE).

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