THE CROWN ESTATE

Offshore Wind Report

2021

Introduction

Huub den Rooijen
Managing Director, Marine

The context for offshore renewables in the UK is undergoing a series of momentous changes. These range from the COP26 climate accord and loss of biodiversity to cost of living concerns and an urgent focus on energy security. All of these impact the pace and scale of the change needed to achieve net zero.

As the energy crisis unfolds, accelerated by the tragic events in Ukraine, we are only now starting to grasp the scale of the challenge ahead.

The marine environment has a huge role to play and the demand for access is becoming ever more urgent, be it for energy development, environmental protection and restoration, or indeed more traditional uses like navigation.

At The Crown Estate, we work closely with markets and stakeholders to seek the right balance in opening up the seabed for sustainable development. Accelerating demand, for what is essentially a finite resource, makes that balancing act ever more important, as we explore every opportunity to add pace and resilience to the offshore delivery system.

Thematically, this talks to integrating environmental considerations into all our decision making. It talks to delivering net zero and biodiversity recovery in harmony, not conflict. It talks to a whole of seabed approach; working for all of the sectors that rely upon the marine environment, including the

11%

Proportion of total UK electricity generated by offshore wind in 2021

33%

UK offshore wind generated enough electricity in 2021 to supply the needs of 33% (9.3m) of UK homes

36.6TWh

The amount of electricity produced by UK offshore wind in 2021

14m tonnes

Avoided CO_2[1]

1 How this is calculated can be found at the end of the report.

communities that depend on it, bringing a focus on societal value creation, safety and inclusivity.

That's why, in line with stretching policy targets, we are changing our approach to offshore leasing. To ensure we can maintain that crucial balance, we are designing simpler and ultimately faster routes to market, and investing in data and evidence to push forward our collective knowledge of a complex marine environment that is still only partially understood.

The strong operational performance of the UK offshore wind fleet is the bedrock for its continued growth, grounded in technical and environmental excellence, and the contributions of individuals and businesses across the UK.

Transparency, through sharing of data and evidence, listening and learning, engaging the widest possible audiences, is one of the most powerful tools to create inclusive dialogues and together reach the best possible decisions.

In this year's report we are focused on that transparent performance of the offshore wind sector. Its success is the success of the many individuals and organisations who are contributing their capital, expertise, challenge and insights. Together, we can enable the transition to a net zero economy whilst maintaining and rebuilding a healthy natural environment. Striking the right balance will truly enable lasting and shared prosperity for our communities and our nation.

Figure 1: UK electricity generation mix 2021 with 2020 comparison[1]

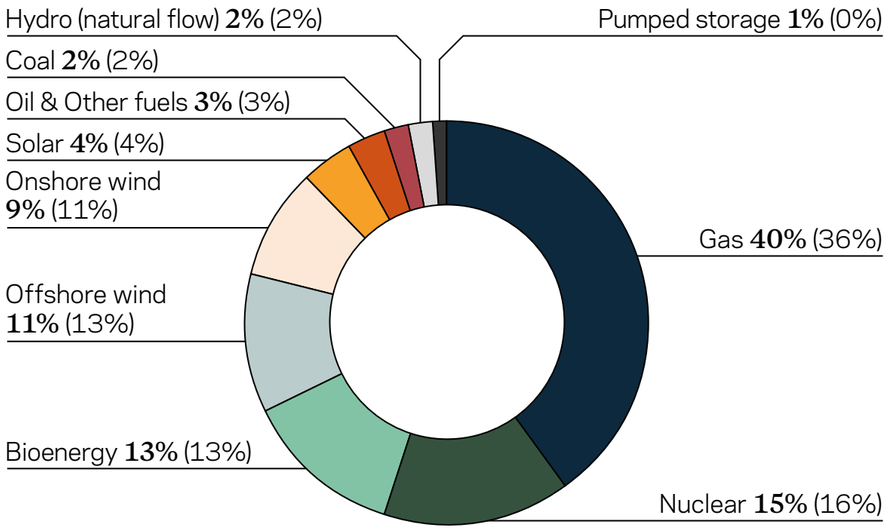
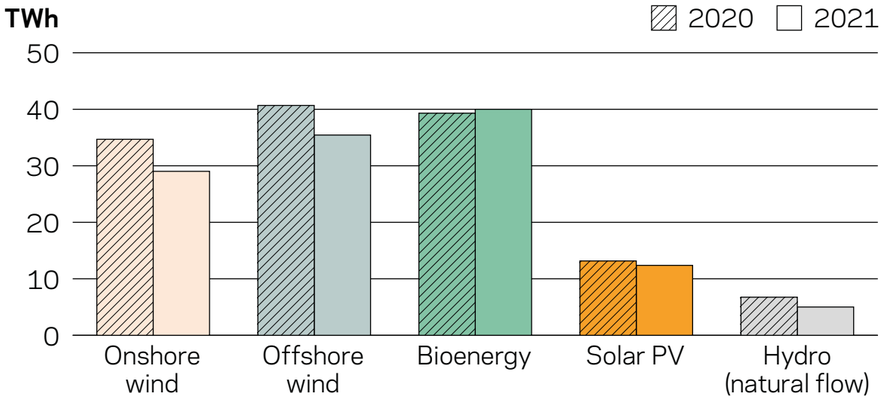
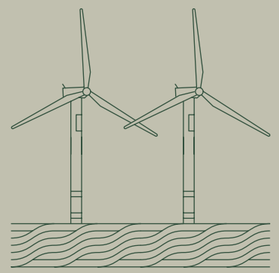


Figure 2: Renewable Energy generated by fuel type[1]



1 Source: BEIS energy statistics



Why we produce this report

This report is produced by The Crown Estate to provide a picture of the UK offshore wind industry, using our own and publicly available data.

The Crown Estate

The Crown Estate manages a unique portfolio, which includes commercial and rural property, as well as Windsor Great Park but also the seabed, natural marine resources and much of the foreshore around England, Wales and Northern Ireland. In this capacity, we are responsible for awarding seabed rights for offshore renewable energy projects as well as marine minerals, gas storage, carbon capture usage and storage, cables and pipelines. We play a unique role in developing and helping sustain UK energy supply and infrastructure, working in collaboration with a wide range of organisations to ensure that this is achieved in a sustainable way, balancing the broad range of interests in the marine environment. Established by an Act of Parliament, The Crown Estate works to create social, environmental and financial value, both now and for the future, for its customers, partners and the nation. We return 100% of our net revenue profit to the Treasury for the benefit of the nation, contributing £3 billion to the public purse over the last ten years.

THE CROWN ESTATE

Acknowledgements

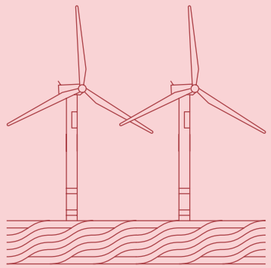
In order to provide a UK wide picture of offshore wind, Crown Estate Scotland has provided statistics for this report and there are features on the performance and development of the Scottish wind farm portfolio.

Crown Estate Scotland
Crown Estate Scotland is a public corporation which manages a range of property, including the seabed, to deliver lasting, valuable benefits to Scotland and its people. Our revenue profits are paid to the Scottish Government for use in public spending. Part of our role is awarding the rights to build and operate renewable energy projects in Scottish waters, and we are committed both to supporting the development of Scotland's blue economy and the Scottish Government's target of reaching net zero emissions by 2045. To learn more about the work we do and the causes we support, visit **crownestatescotland.com**.

Crown Estate Scotland
Oighreachd a' Chrùin Alba

Our thanks to all those who have provided content, in particular: Baringa; Celia Anderson; Diamond Transmission Partners; EDF; Eni; Equinor; Everose; G+ Healthy & Safety organisation; Humber Gateway; J.Murphy & Sons Limited; Jones Bros Civil Engineering UK; London Array; Ørsted; Renewable UK; Scottish Power Renewables; RWE; World Forum Offshore Wind.

Offshore wind farm status



20%+

Over 20% of global offshore wind operating capacity is in the UK.

Triton Knoll turbine installation.

The UK is one of the world's leading markets in offshore wind and here we look at this in the context of global capacity and key changes in the UK offshore wind portfolio during 2021.

Global offshore wind capacity in operation reached over 48.2GW, more than 20% of which was in the UK. By the end of 2021, the capacity of fully commissioned sites reached 11.3GW, an increase of 8% on the previous year. This was due to completion of Triton Knoll, and Kincardine, off the Lincolnshire and Aberdeenshire coasts respectively.

There were some significant milestones during the year:

- Kincardine became the world's largest floating operational offshore wind farm;
- Ørsted installed its 1,000th wind turbine in UK waters;
- Seagreen (Phase 1) installed its first wind turbine in a project set to become Scotland's largest offshore wind farm;
- Hornsea 2 started generating electricity and is the largest site under construction in the world.

The profile of projects detailed in figure 5 changed significantly with a 25% increase in sites classed as under construction, following Final Investment Decisions and lease entry of Dogger Bank C and Sofia wind farms in March 2022.

Construction of sites is taking longer due to their size, distance from shore and complexity. The average size of UK projects under construction is now 1GW, which is more than ten times bigger than the early projects awarded rights under offshore wind Leasing Round 1, held twenty years ago. Latest turbine capacities are over seven times the size of the early technology deployed on the UK seabed.

No new Contracts for Difference (CfD) were announced during 2021 but CfD Allocation Round 4 was launched in December 2021 with results due 2022. In a year where the UK hosted COP26 with all eyes on it in helping navigate global emissions reductions, enabling frameworks such as CfD remain important. This is in spite of shorter term electricity price highs but the recent Government announcement of annual CfD allocation rounds will help enable the Government's ambition of 50GW by 2030 and net zero targets.

The UK is the second biggest global market for offshore wind, as shown in figure 4. In addition to this, there is a robust development pipeline of projects, listed in figure 34. China overtook the UK as the largest offshore wind market during 2021, with Germany the third largest market. The UK closed the year in 5th place in the EY's Renewables Energy Country Attractiveness Index but scored highest in the offshore wind technology-specific scores. The index ranks the world's top 40 markets on their renewable energy investment and deployment opportunities.

Figure 3: Increase in global offshore wind operating capacity

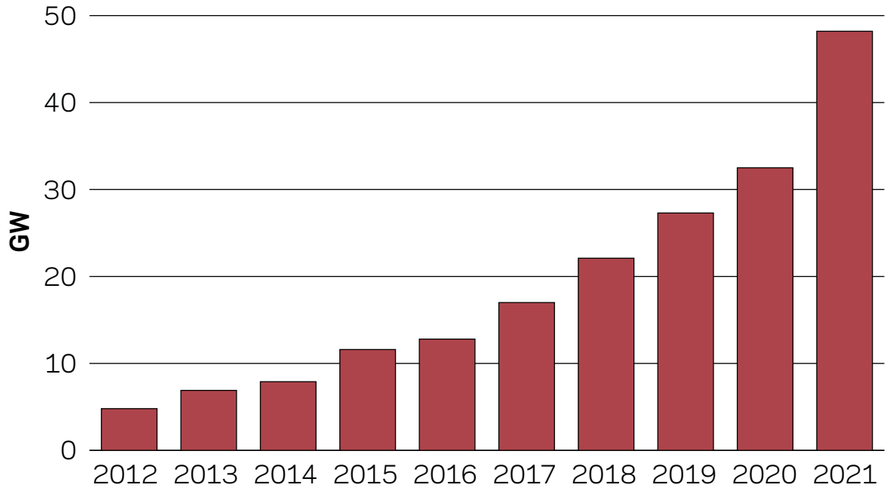


Figure 4: Global offshore wind operating capacity in 2021

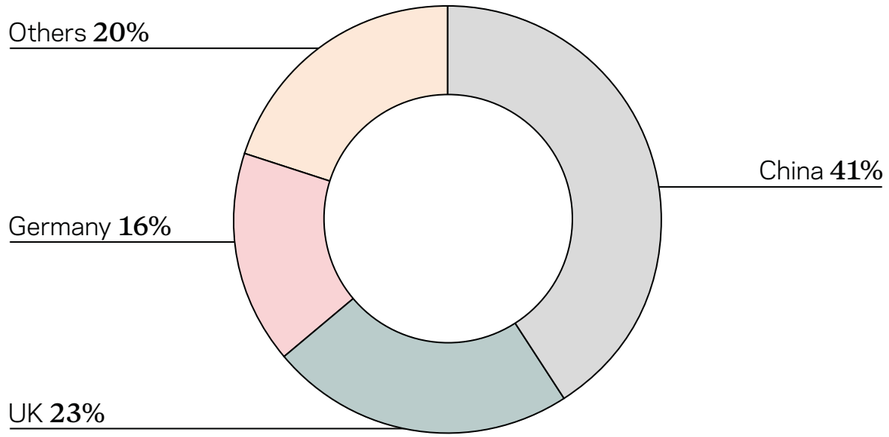


Figure 5: UK offshore wind project pipeline as at 31 December 2021

Operational: Total capacity of wind farms that have been fully commissioned.

		Capacity MW[1]
01	Barrow	90
02	Beatrice[2]	588
03	Blyth Demonstration (Phase 1)	42
04	Burbo Bank	90
05	Burbo Bank Extension	259
06	Dudgeon	402
07	East Anglia ONE	714
08	European Offshore Wind Deployment Centre[2]	97
09	Galloper	353
10	Greater Gabbard	504
11	Gunfleet Sands Demonstration	12
12	Gunfleet Sands I	108
13	Gunfleet Sands II	65
14	Gwynt y Môr	576
15	Hornsea 1	1,218
16	Humber Gateway	219
17	Hywind Scotland[2]	30
18	Inner Dowsing	97
19	Kentish Flats	90
20	Kentish Flats Extension	50
21	Kincardine[2]	50
22	Levenmouth Demonstration[2]	7
23	Lincs	270
24	London Array	630
25	Lynn	97
26	North Hoyle	60
27	Ormonde	150
28	Race Bank	573
29	Rampion	400
30	Rhyl Flats	90
31	Robin Rigg East[2]	84
32	Robin Rigg West[2]	90
33	Scroby Sands	60
34	Sheringham Shoal	317
35	Teesside	62
36	Thanet	300
37	Triton Knoll[3]	857
38	Walney 1	184
39	Walney 2	184
40	Walney Extension	659
41	West of Duddon Sands	389
42	Westermost Rough	210
Total		**11,327**

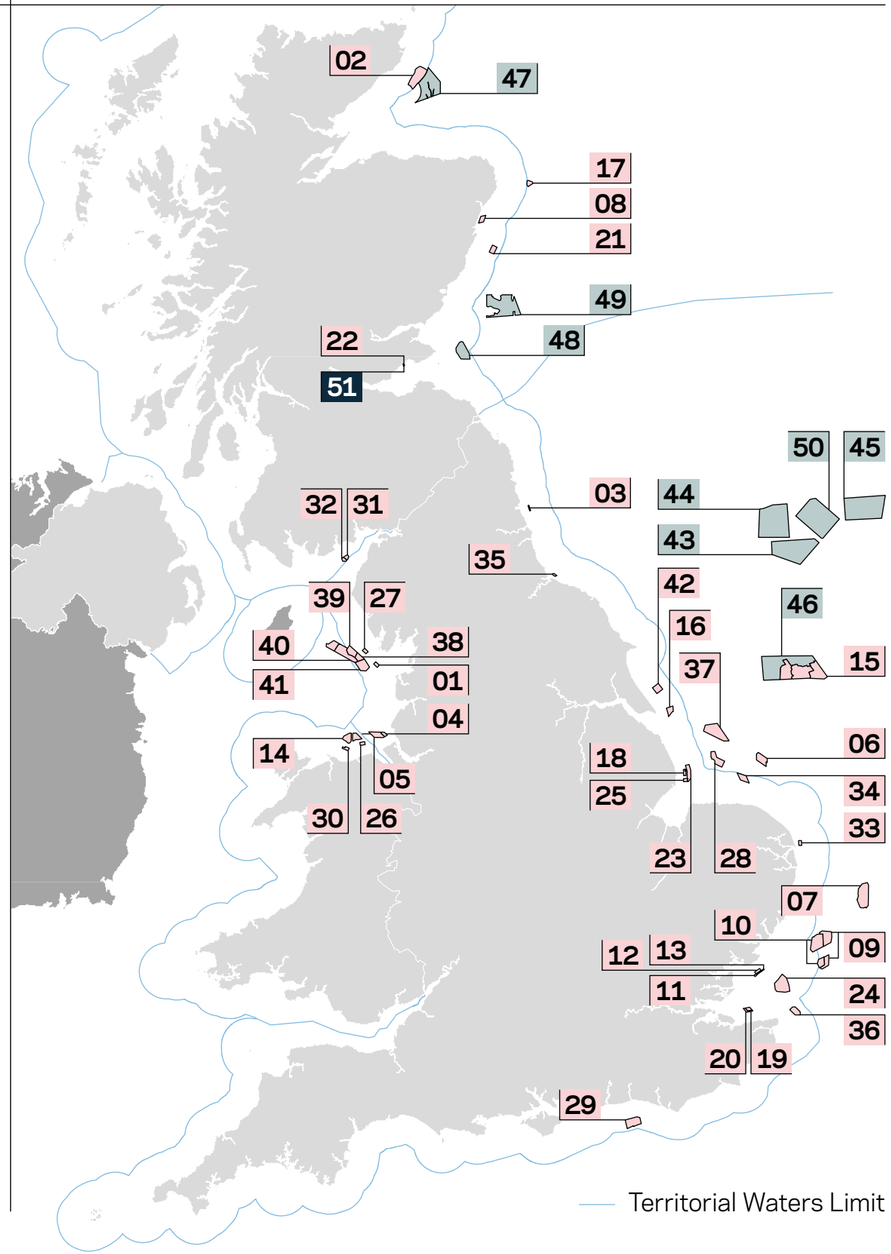
Under construction: Total capacity of wind farms that are under construction or where the developer has confirmed a Final Investment Decision, but are not yet fully operational.

		Up to capacity MW[1]
43	Dogger Bank A	1,235
44	Dogger Bank B	1,235
45	Dogger Bank C	1,200
46	Hornsea 2	1,386
47	Moray East[2]	953
48	Neart na Gaoithe[2]	448
49	Seagreen (Phase 1)[2]	1,140
50	Sofia Offshore Wind Farm	1,400
Total		**8,997**

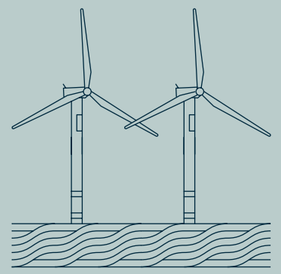
Government support on offer: Total capacity of wind farms that have secured a Contract for Difference.

		Up to capacity MW[1]
51	Forthwind[2]	12
Total		**12**

1 Capacities noted are rounded to the nearest whole MW
2 Asset managed by Crown Estate Scotland
3 Confirmed Works Completion Date January 2022



Offshore wind assets



3,000+

wind turbines on the UK seabed or under construction.

Triton Knoll offshore wind farm.

There are 42 fully operating offshore wind farms around the UK. During 2021, major offshore construction activity occurred at Triton Knoll, Moray East, Hornsea 2 and Seagreen (Phase 1), all significant projects averaging 1GW in size. Autumn 2021 was an exceptionally productive time seeing the hat-trick of Seagreen installing its first jacket foundation on phase 1, floating project Kincardine achieve final commissioning and Ocean Winds installing their final wind turbine at Moray East.

The combined operating and under construction capacity in the UK is over 20GW, however, with 44% of this being under construction it will be an exceptionally busy period over the next few years. Triton Knoll's commissioning marked the completion of Leasing Round 2.

With over 3,000 wind turbines installed or under construction and approaching 100 export cables, the volume of infrastructure on the seabed is growing. This presents challenges in asset co-location in a busy seabed space, decommissioning and circular economy. This requires close collaboration between industry, regulators, stakeholders, The Crown Estate and Crown Estate Scotland.

The majority of turbines currently installed utilise fixed foundation with early floating sites found in Scotland but plans advancing in the Celtic Sea, detailed on page 42. Triton Knoll, Moray East and Kincardine[1] all deployed MHI Vestas 9.5MW turbines with rotor diameters of 164m, whilst under construction site Hornsea 2 is installing Siemens Gamesa 8MW turbines with a rotor diameter of 167m increasing the swept area for energy generation. Figure 7 details the UK offshore wind commissioning rate over the last six years, which averages 1GW per annum.

Figure 7: UK offshore wind grid connected (change from previous year)

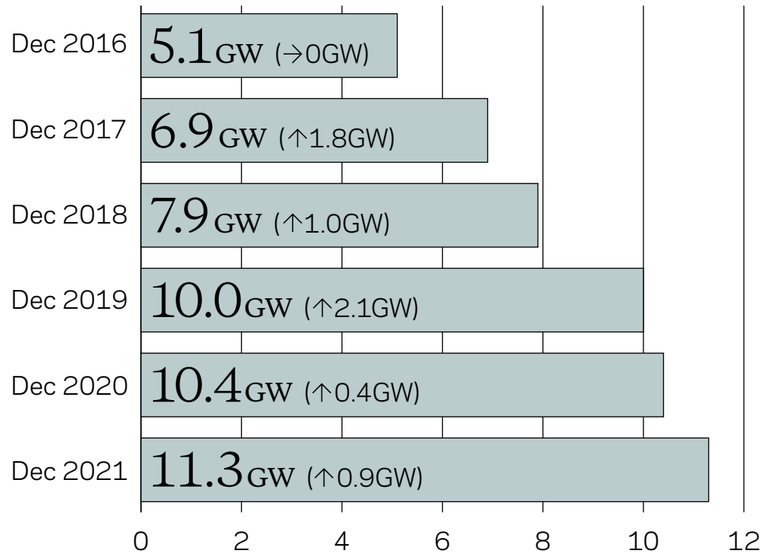
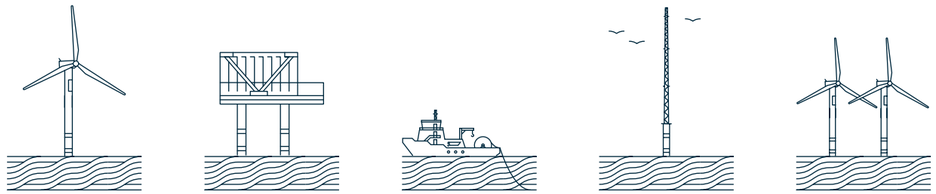


Figure 6: UK offshore wind assets as at 31 December 2021



	GW	Offshore turbines	Offshore substations	Export cables	Met masts	Wind farms
Operational:	11.3	2,387	35	79	10	42
Under construction:[2]	9.0	810	12	19	0	8
Total:	**20.3**	**3,197**	**47**	**98**	**10**	**50**

1 5 x 9.5MW and 1 x 2MW turbines deployed at Kincardine.

2 Sites having reached Final Investment Decision (FID) and those under construction

Figure 8: Asset activity in 2021

Wind farms achieving Final Investment Decision:
- Dogger Bank C
- Sofia

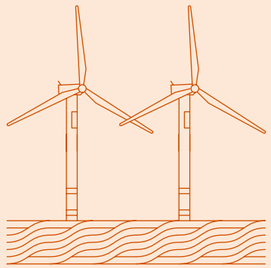
Wind farms starting offshore construction
- Seagreen (Phase 1)

Wind farms under construction
- Dogger Bank A
- Dogger Bank B
- Hornsea 2
- Moray East
- Neart na Gaoithe
- Seagreen (Phase 1)

Wind farms achieving first power
- Hornsea 2
- Moray East
- Triton Knoll

Wind farms becoming fully operational
- Kincardine
- Triton Knoll

Offshore wind farm performance



Turbines at sea with jack-up vessel on horizon.

Fleet performance

The Performance Index compares metered electricity output against the expected output adjusted for actual wind speed during that period. It gives a direct measure of the performance of the offshore wind farm fleet in England and Wales, without any adjustment for outages.

The analysis only includes fully operational wind farms excluding the construction period. The analysis includes the whole system of the wind farm and its associated transmission/export of electricity back to shore.

The Fleet Performance Index calculation uses wind speed data obtained from satellite observations. This can bring a degree of uncertainty to calculations which can result in some years exceeding 100%, as seen in figure 10 for years 2016 and 2017.

In 2021 the Fleet Performance Index was slightly above 97%. Fleet performance over the last ten years has varied, as shown in figure 10, with an overall average of 97.8%. This has been impacted by export cable failures in 2013 and 2015, with cables repairs and grid maintenance affecting the last three years.

Figure 10: Fleet Performance Index – England and Wales

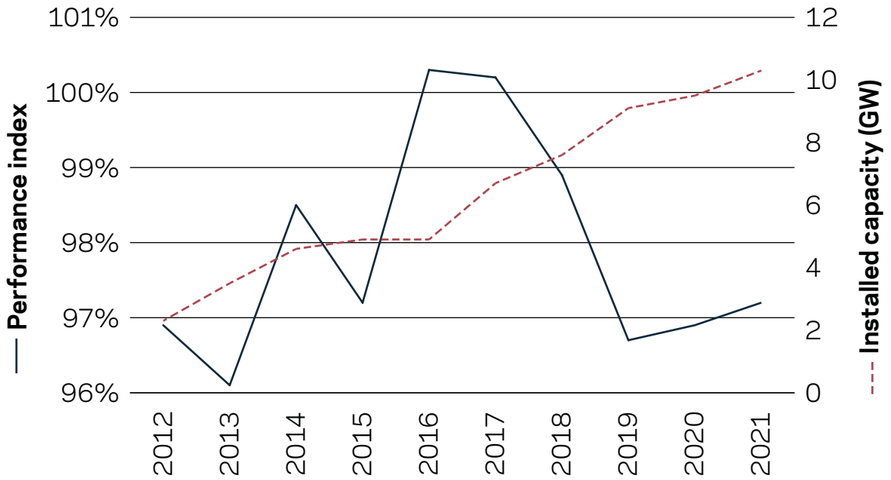
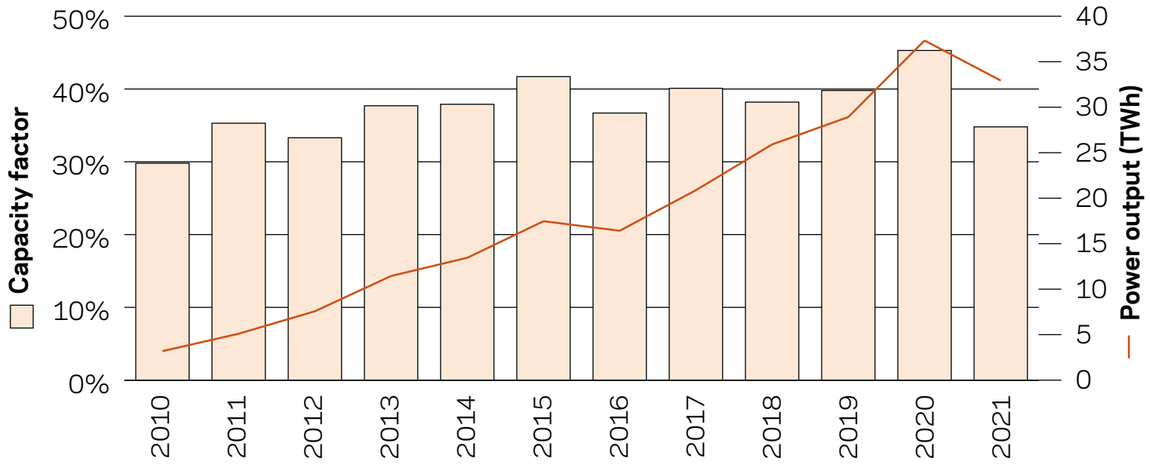


Figure 9: Capacity factor – England & Wales



Capacity factor

Figure 9 shows the evolution of the capacity factor and the power output of offshore wind farms in England & Wales, between 2010 and 2021.

The capacity factor is the average power generated over a period, divided by the rated peak power. It indicates how fully an offshore wind farm's capacity is used.

The capacity factor of offshore wind farms is usually higher than onshore wind farms due to stronger, more stable wind conditions at sea. This is particularly noticeable for the latest wind farms, located further from the coast.

The average wind speed was exceptionally low in 2021, as shown in figure 10, leading to a drop in production of 11% compared to the long-term average, and a capacity factor of only 34%, compared to 45% in 2020, shown in figure 9.

Despite this drop in performance, the power output is above its 2019 level, thanks to the increase in installed capacity.

The average capacity factor over the last 5 years was 40% with newer wind farms having a typical capacity factor of 50% or higher.

Wind variability

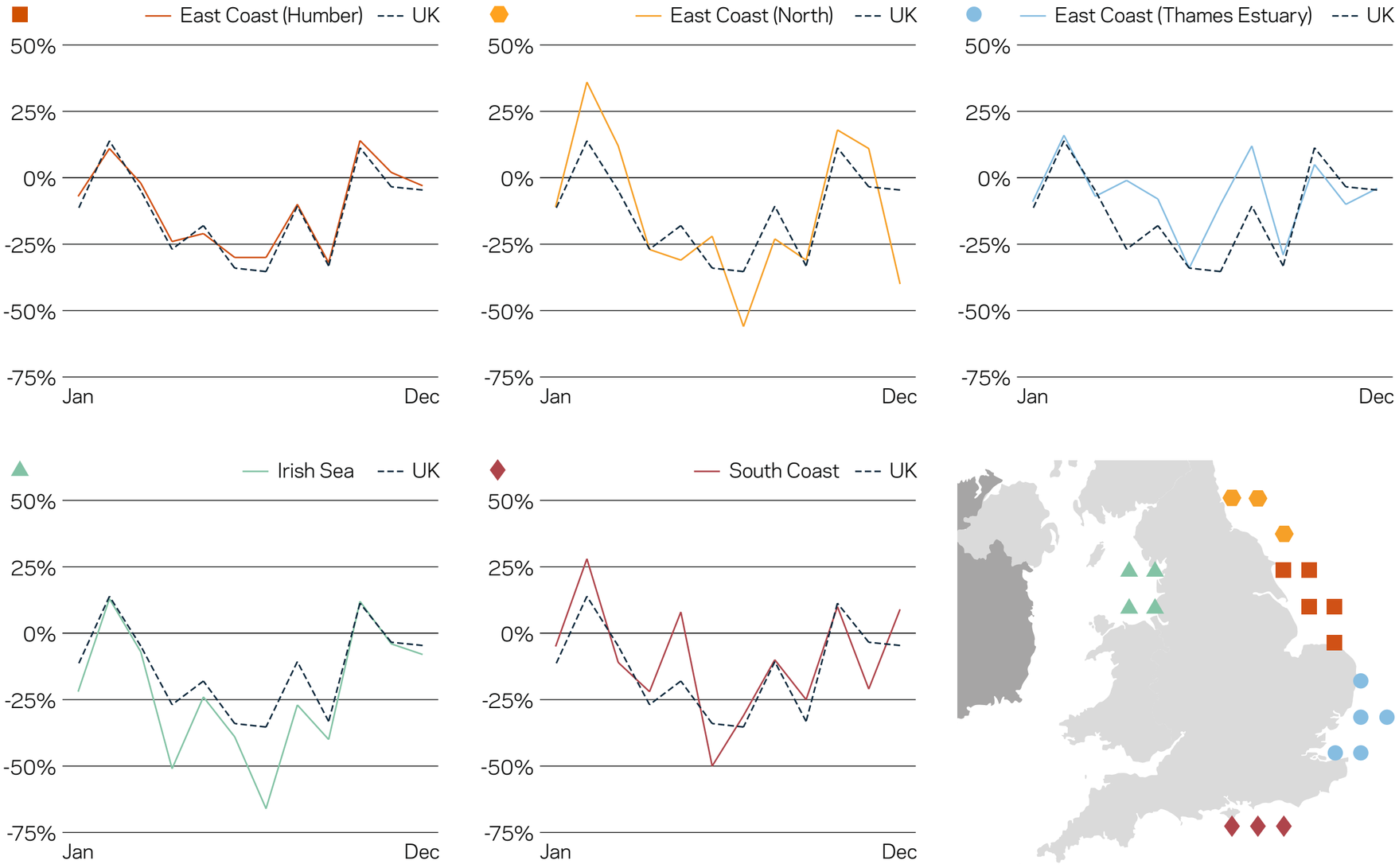
Figure 11 shows the impact on energy production due to monthly wind speed variation in England and Wales. Zero on each graph represents the long-term average for each month.

2021 was exceptionally calm, with February and October the only months above the long-term average for these periods.

Offshore wind production in June, July and September was more than 30% below expectations.

The overall energy deviation at the end of 2021 was 11% below the long term average. While rare, such a large deviation is not unexpected. Historical data suggests a deviation of +/ – 10% occurs once in a decade. In 2021, there have been strong regional variations, with wind farms in the Thames Estuary performing notably better than the rest of the fleet in June and July.

Figure 11: Monthly energy deviation due to wind speed in 2021



Offshore generation

Figure 12 compares the output of the biggest producing wind farms of 2021 compared to production in 2020. Hornsea 1, East Anglia ONE and London Array generated more than a quarter of the UK's total offshore wind power in 2021. When comparing generation by wind farm to figure 5, you will notice the generation of a wind farm does not always follow the order of its size. This can be as a result of cable outages, wind conditions or other maintenance, or even upgrades.

Figure 12: Percentage of electricity generated by UK assets in 2021 (position change from 2020)

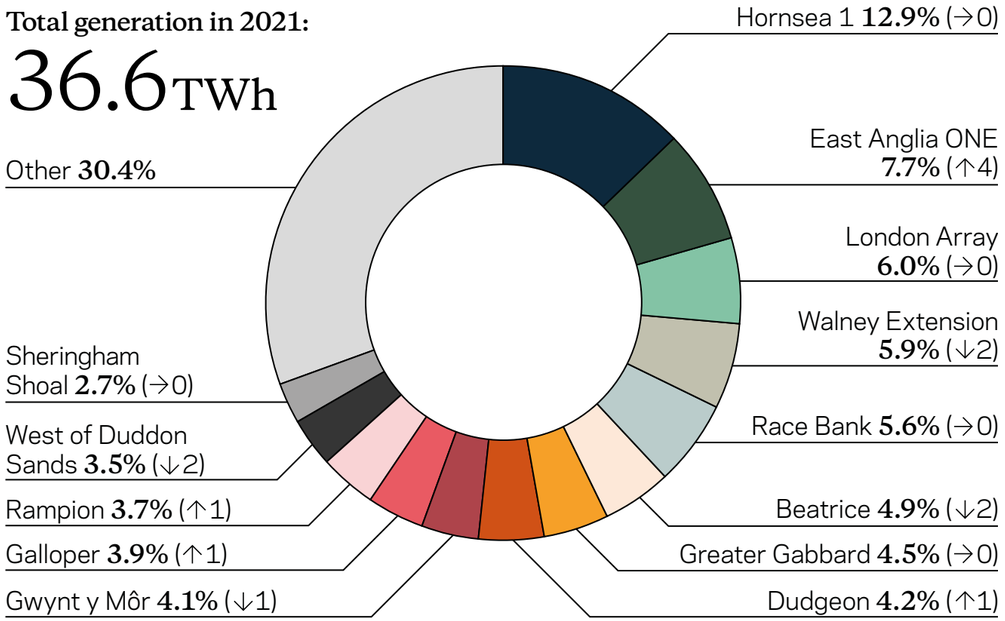


Figure 13: Percentage of UK homes annual electricity needs that can be supplied by offshore wind

4%
2011 1.2m homes

15%
2016 4.1m homes

33%
2021 9.3m homes

43% *estimated*
2022 11.9m homes

UK offshore wind generated **36.6 TWh** last year. That's enough to supply the electricity needs of **9.3m homes**, around a third of the UK homes.

Performance in Scotland

Portfolio managed by Crown Estate Scotland

Kincardine floating offshore wind farm came into full operation in November 2021. At 49.5MW operating capacity, it is the world's largest floating wind farm and a key stepping stone for floating offshore wind at a commercial scale in Scotland.

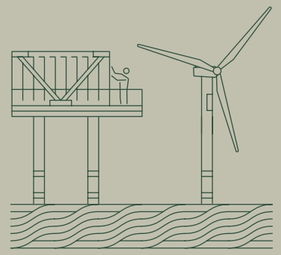
The relevance of this milestone was recently underlined with the conclusion of the ScotWind application process and announcement of options being offered: c.60% of those options' total generation capacity is attributable to floating wind projects.

Construction of both the Neart na Gaoithe and Moray East offshore wind farms have been ongoing during 2021, with Neart na Gaoithe conducting export cable and onshore substation works. Moray East has reached the stage of turbine installation, and achieved first generation in June 2021.

The Seagreen (Phase 1) project concluded its development phase, taking up its lease and moving into the construction phase with the installation of its first turbine jacket foundation in October 2021. Once completed, it will become Scotland's largest operating wind farm, with a generating capacity of up to 1.1GW of electricity.

As the portfolio of wind farms being progressed in Scottish waters matures, the operational fleet is also increasing. At the end of 2021, just under 1GW of capacity was fully operational with a further 2.5GW in construction. 2021 saw the Scottish fleet generate in excess of 3,600GWh electricity.

Offshore Transmission Owner (OFTO) performance



98.8%

The average OFTO availability for 2020/21.

Dudgeon offshore wind farm
Photo: Jan Arne Wold.

Offshore Transmission Owner (OFTO) performance is important for offshore wind electricity generation because it provides the transmission connection to the onshore electricity network. Its availability is critical in ensuring electricity can get to consumers.

By the end of 2020/21, the OFTO network comprised 21 offshore substations, supporting over 7.8GW of generating capacity, connected by 40 export cable circuits. These interface with either National Grid's National Electricity Transmission System (NETS), or the lower voltage distribution networks owned and operated by Distribution Network Operators (DNO). A breakdown of OFTO ownership is shown in figure 29. Transmission system availability for OFTOs is published by National Grid each September in the annual NETS Performance Report, the information in this section covers data up to March 2021.

OFTOs are incentivised through the regulatory framework to provide prescribed minimum levels of availability. The default is 98%, with specific targets established for each OFTO. The average availability for 2020/21 was above this at 98.81% and over the last five years average availability was 99.02%.

Unplanned OFTO outages were the main cause of system unavailability. There can be a variety of reasons for a drop in availability. These include planned outages required for maintenance or modification of the assets, unplanned outages as a result of plant or equipment failure, i.e. circuit trips/faults, or outages requested by the DNO. Figure 15 shows the breakdown of system unavailability.

Annual availability data for each OFTO features in figure 16. This includes all outages that originate on an OFTO's system but excludes outages that originate elsewhere, for example on a wind farm generator or DNO system. The OFTO availability incentive then adjusts the reported outage data to calculate incentivised performance for each OFTO.

Another contributing factor can also be regulation changes, such as the National Grid update to the grid compliance code for Fault Ride Through (FRT) requiring notification of a suspected FRT, resulting in potential restrictions on capacity output for a time period agreed between the User and Operator. This could result in longer outages.

OFTO life extension

As wind farms mature, greater focus is required to ensure transmission assets enable life-extension of wind farms preventing premature retirement of generation assets. At The Crown Estate, we have been engaging with offshore wind generators, OFTOs and Ofgem on transmission asset and offshore wind life extension. With over 60% of the UK offshore wind capacity connected to a transmission asset with a regulated revenue stream limited to 20 years, enabling cost effective transmission asset life extension, which maintains asset integrity, is an important area. Ofgem will be consulting further on this topic in 2022.

Figure 14: OFTO availability trend

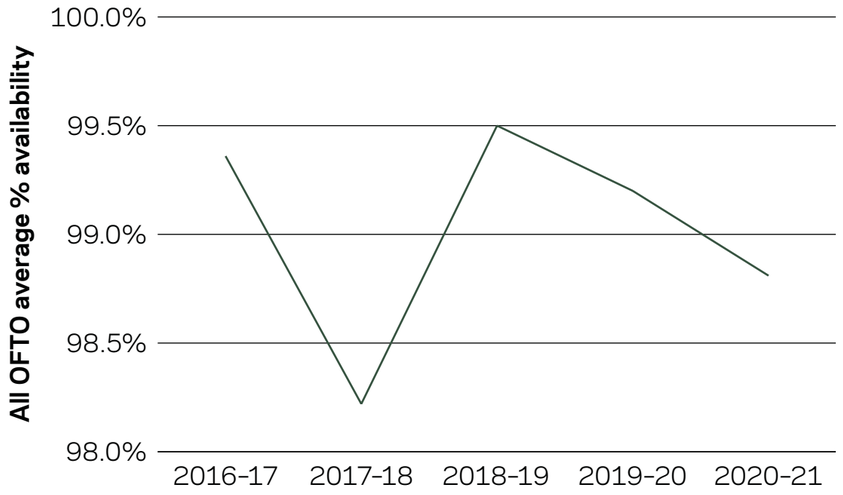


Figure 15: 2020/21 OFTO system unavailability

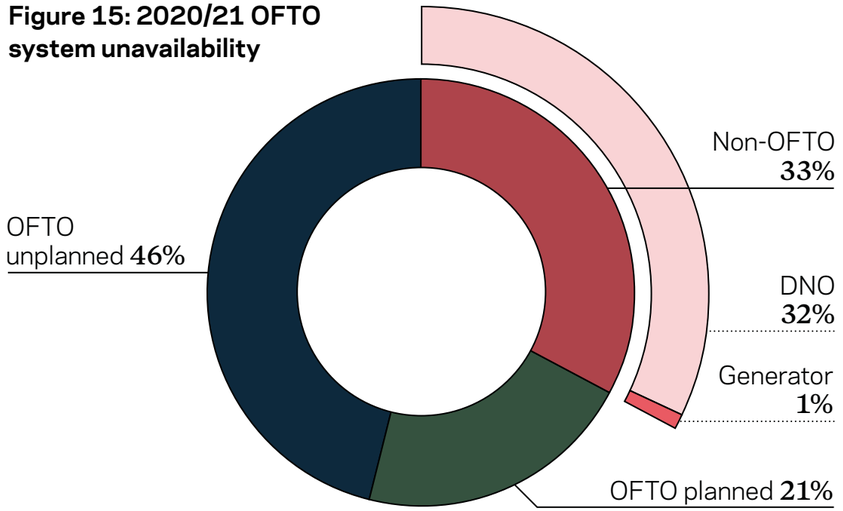


Figure 16: Offshore Transmission Networks % annual system availability

OFTO	2016-17	2017-18	2018-19	2019-20	2020-21
Barrow	100	99.99	100	100	100
Bubo Bank Extension	N/A	N/A	98.15	99.67	99.99
Dudgeon	N/A	N/A	100	99.31	99.83
Galloper	N/A	N/A	N/A	100	99.95
Greater Gabbard	98.78	99.61	99.82	99.78	99.78
Gunfleet Sands	99.95	99.81	99.97	100	99.66
Gwynt y Môr	99.71[1]	100	99.93[1]	96.10	86.31
Hornsea One	N/A	N/A	N/A	N/A	100
Humber Gateway	100	100[1]	100	99.83	99.76
Lincs	99.93	99.78	100	99.56	99.44
London Array	98.88	99.80	99.94	99.88	99.77
Ormonde	99.59	100	100	100	100
Race Bank	N/A	N/A	N/A	100	99.26
Robin Rigg	99.99	100	100	99.87	99.95
Sheringham Shoal	99.95	99.23	99.40	100	100
Thanet	100[1]	100	100	100	99.84
Walney 1	99.62	99.70	100	99.95	100
Walney 2	100	100	91.42	100	100
Walney Extension	N/A	N/A	N/A	N/A	99.97
West of Duddon Sands	99.64	99.45	100	95.42	99.50
Westermost Rough	100	100	99.73	100	100

1 Figure has been updated as an exceptional event with agreement from OFGEM

Policy shifts toward delivering coordinated grid connection solutions

The Government's Offshore Transmission Network Review (OTNR) is a major reform programme that is expected to deliver more integrated – or coordinated – grid connection solutions. Cost-benefit analysis by National Grid ESO in 2020 found that more coordinated solutions would be more cost effective than radial links as well as delivering significant environmental and societal benefits from reduced infrastructure requirements. In the shorter term, coordinated grid solutions are expected to be delivered by allowing projects currently in development to invest on an anticipatory basis to allow for the connection of future capacity. Over the longer term, the policy framework is shifting to a more strategic approach, with coordinated grid designs planned earlier in the process and new delivery models emerging. National Grid ESO is undertaking a 'Holistic Network Design' for projects emerging from Leasing Round 4 and ScotWind, which will enable detailed design of coordinated infrastructure. This process should provide a preliminary view on coordination opportunities in the Celtic Seas region. Results are expected in summer 2022.

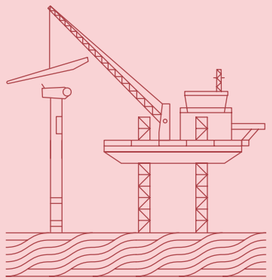
The Crown Estate is a Project Partner to the OTNR, working alongside a range of key stakeholders. We sit on the Project Board and Working Groups to help steer the review and have contributed specific inputs: (i) the East Coast Spatial Grid study, funded by the Offshore Wind Evidence and Change Programme (OWEC), highlights the importance of including marine spatial and environmental context of future grid development; (ii) the 2030 Generation Map presents a temporal perspective of potential offshore wind development over the next decade by combining publicly available data on the location of existing and planned offshore wind projects in the UK waters with a perspective on when they could connect to the system.[2] It also includes data on existing and planned export cable corridors; cable routes of operational interconnectors; the onshore transmission system and a range of environmental designation.

There are several other major consultations in which we are actively engaged. The Electricity Transmission Planning Network Review is seeking to introduce a holistic approach to the planning of onshore and offshore grid infrastructure, whilst a consultation on the role of the Future System Operator is aiming to consolidate system operation for both electricity and gas and reform responsibilities. These consultations are part of a wider review of system architecture and governance to support delivery of the Government's net zero targets, and will undoubtedly impact how future offshore wind projects connect.

2 Dates are taken from National Grid ESOs Transmission Capacity Register

Net zero

This section looks at offshore wind and the complexity of net zero, touching on supply chain, biodiversity, construction, operations and circular economy.



80%

Manufacturing and installation account for almost 80% of the lifecycle carbon emissions of an offshore wind farm.

Offshore wind and the pathway to net zero

Every year human activities emit more than 40bn tonnes of greenhouse gases that increase global temperature.[1]

The latest Intergovernmental Panel on Climate Change (IPCC) report showed that failing to limit global warming to 1.5°C above pre-industrial levels would have profound consequences, and may trigger feedback loops that could cause a runaway increase in global temperatures.

In order to limit global warming to manageable levels, the UK government pledged to reach net zero emissions by 2050, which will require transforming entire sectors of our society, so dependent are we on hydrocarbons, which account for 80% of the world's primary energy consumption.

The Crown Estate has a responsibility to sustainably manage the seabed for future generations and reduce the negative impacts of our business on the environment. We work with others to ensure development on the seabed is sustainable and in harmony with the complex ecosystems within our waters. These challenges are becoming more complex and we are conscious that the pursuit of net zero should not be at the expense of biodiversity.

On page 19 we highlight some of the efforts across the industry to help enable the transition to a net zero future for offshore wind.

1 Source: Intergovernmental Panel on Climate Change

SS Persier – runner up in the British Waters Living Together category of the 2022 Underwater Photographer of the Year. Photo: Kirsty Andrews.

Where are the carbon emissions associated with an offshore wind produced and how can they be reduced?

Manufacturing and installation accounts for almost 80% of the lifecycle carbon emissions of an offshore wind farm.

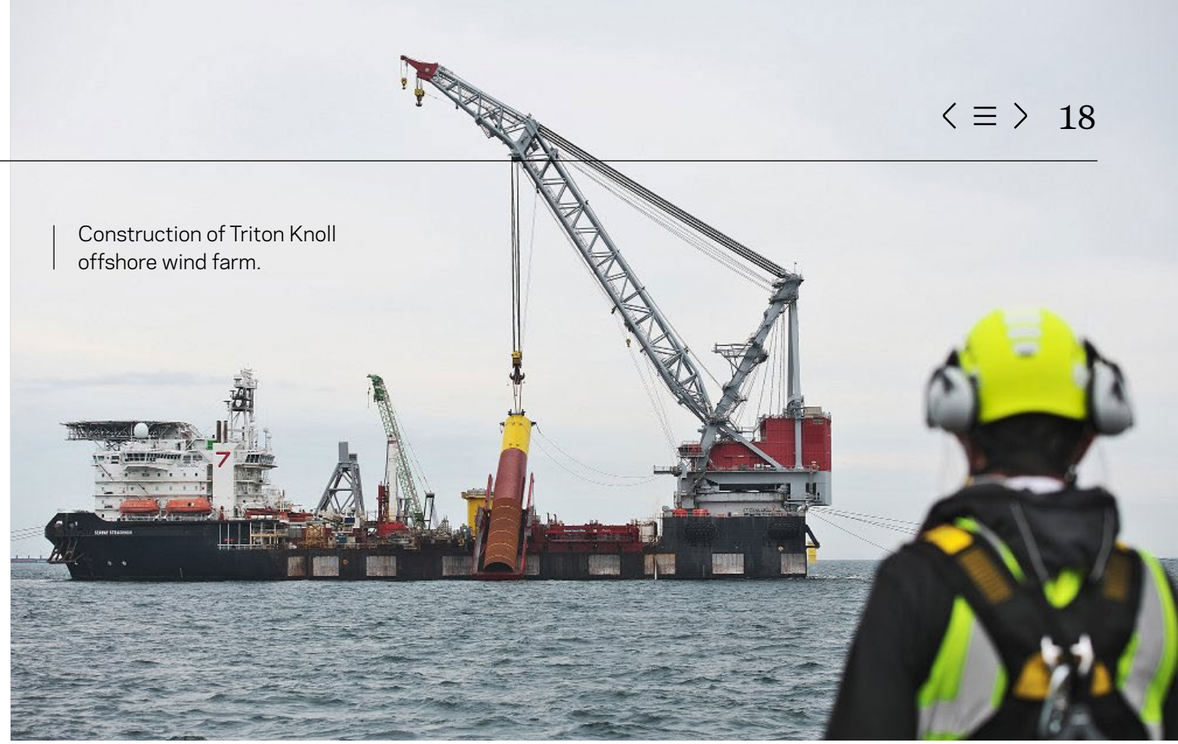
Greenhouse gas emissions occur throughout the supply chain, from primary materials extraction up to the disposal of decommissioned infrastructure.

Coal is an energy source and a reducing agent for manufacturing steel. Diesel and heavy oils power shipping, installation and maintenance vessels. Carbon fibre, which is increasingly common in turbine blades, emits vast amounts of greenhouse gases through its manufacturing process.

Reaching net zero will require novel manufacturing techniques and alternative sources of energy to minimise these emissions. Some technical solutions are emerging, such as using hydrogen and renewable energy to manufacture steel with close to zero emissions, or using electric crew transfer vessels for operation and maintenance. At The Crown Estate, we are supportive of innovations that minimise emissions and will continue to discuss with developers and operators how we can facilitate their transition to carbon neutrality. We are also considering how we develop sustainability metrics and accelerate the adoption of circular economy principles within existing and future offshore wind farms.

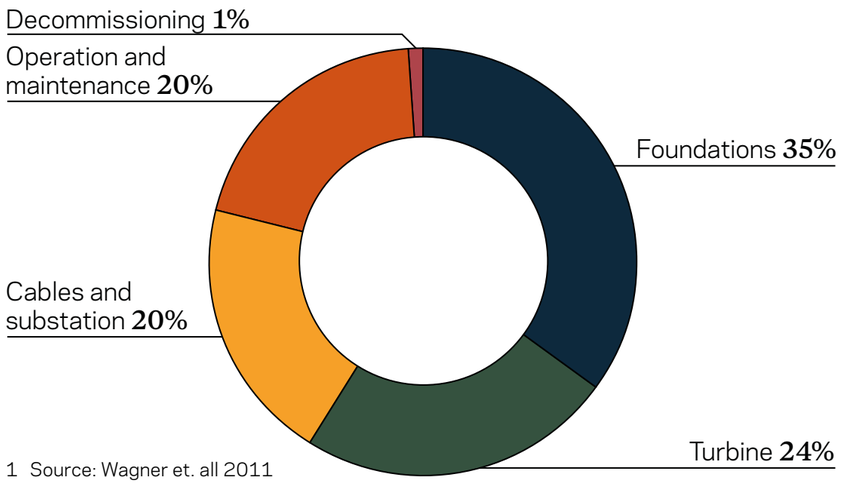
Companies are also increasingly mindful of the sustainability of supply chains: from artisanal mining conditions of cobalt, to the environmental impacts of rare earth extraction; there are environmental and social consequences to our dependence on scarce but critical minerals. Rising demand for these elements, as well the necessity to reach net zero, encourage strong traceability certification and the transition towards a more circular economy.

Accurately pricing-in the cost of carbon emissions will increase demand for cleaner, recycled materials, and will accelerate the shift to a more sustainable and resilient economy. Net zero presents a unique opportunity to transform our industrial systems; wind farms designed to ease dismantling, turbine blades that are fully recyclable, and crucially, a waste management system that provides uncontaminated, high quality feedstock to recycling plants.



Construction of Triton Knoll offshore wind farm.

Figure 17: Breakdown of carbon emissions for an offshore wind farm[1]



1 Source: Wagner et. all 2011

Offshore wind in the future energy system

The cost of offshore wind energy has substantially decreased, with CfD strike prices falling from £150/MWh in 2014 to less than £40/MWh in 2019. However, due to a combination of factors, wholesale electricity prices have risen sharply.

Low wind in 2021 and a fire at the IFA interconnector site in Sellindge contributed to the strain on supply, but the main reason why electricity prices are so high lies with natural gas, which plays a crucial role in the energy mix.

Gas currently supplies 40% of annual electricity demand, operating as baseload, mid-merit, and peaking capacity. As a source of flexible generation, it plays a key role in balancing supply and demand. The electricity market follows a marginal model, meaning wholesale prices are set by the most expensive power station that is necessary to meet demand. With the current capacity mix, the marginal power station is typically gas-fired, meaning that wholesale electricity prices are largely correlated with the price of natural gas, which soared in late 2021 due to a global surge in demand and reductions in supply.

Managing the inherent variability of wind and solar power plants in a low carbon energy system will require utility-scale energy storage to balance supply and demand. Batteries are able to provide a fast response to grid requirements, but they do not offer significant economies of scale. Other technologies, such as storing energy in the form of heat, could prove more appropriate for large capacity storage. When weather conditions are unfavourable, the stored heat is used to vaporise water and drive steam turbines. These turbines and associated synchronous generators have the immense advantage of providing inertia to the grid by means of the kinetic energy "stored" in their rotating mass. When the grid frequency fluctuates, these spinning parts will carry on spinning and oppose the change in frequency.

Encouragingly, National Grid ESO have recently announced an amendment to the Grid Code, allowing them to procure grid stability services from renewable generators.

Flexibility, energy storage and grid-stability service systems are crucial in an electricity network powered only by renewable energy. The Crown Estate is keen to engage with operators and regulators to discuss the technical and financial implications, and support the implementation of these systems.

Case studies: Offshore wind sustainability

Electric foiler crew transfer vessel (CTV)
Led by Artemis Technologies, in partnership with ORE Catapult, Lloyd's Register and Tidal Transit, the key objectives of the eFoiler CTV project are to validate the technical and environmental benefits of the Artemis eFoiler™ electric propulsion system and create a roadmap for a large-scale demonstration of the technology.

Sustainable composites for wind turbine blades
The SusWIND project, led by the National Composites Centre (NCC) and the Centre for Process Innovation (CPI), in partnership with ORE Catapult, aims to accelerate the development of materials and processes that address the recyclability of wind turbine blades.

Recyclable blade
Siemens Gamesa, as part of their ambition to make turbines fully recyclable by 2040, have launched the world's first recyclable wind turbine blade. The process dissolves the resin and protects the properties of the fibre reinforcements.

Zero waste
Vattenfall announced that it has made an immediate commitment to a landfill ban on decommissioned wind turbine blades from owned wind farms. Additionally, Vestas announced the launch of a new circularity roadmap to help reach zero-waste turbines by 2040.

Health & safety

Preparatory onshore cable works for Dogger Bank offshore wind farm.

An ever-sharper focus on health, safety and wellbeing is important as project complexity increases and major challenges like Covid-19 measures have the potential to draw attention away from other risks.

Here we report on latest health and safety data from G+, the global health and safety organisation for the offshore wind industry. The data used is from their 2020 incident data report. The data for 2021 is due to be published in summer 2022.

G+ has an ambition during 2022 to focus on sharing knowledge within the fabrication yards, good lifting practice and producing videos on manual handling, which has great relevance for the UK as these, shown in figure 19, are the top work processes causing the most incidents in the UK.

Health and safety performance based on the injury rates and frequency for the three countries[1] with the largest number of sites, is shown in figure 20. The UK remains the largest of these and when compared to 2019, it has improved its performance by reducing LTIF[2] by 35% and TRIR[3] by 40%. These dropped even though the number of sites rose from 41 to 47 and the number of hours worked increasing by 17% between 2019 and 2020. Danish operators made improvements in their health and safety performance in 2020, with the lowest LTIF and TRIR from reporting countries. Overall 2020 saw the lowest number of recordable injuries, as detailed in figure 18, with the number of injuries falling below 100 for the first time.

1 Countries with the largest number of sites and G+ membership.
2 Lost time injury frequency (LTIF) – The number of fatalities and lost day work incidents per million hours worked.
3 Total recordable injury (TRIR) – The number of fatalities, lost work day incidents, restricted work day incidents and medical treatment injuries per million hours worked.

Figure 18: Global offshore wind industry recordable injuries (2019 v 2020)

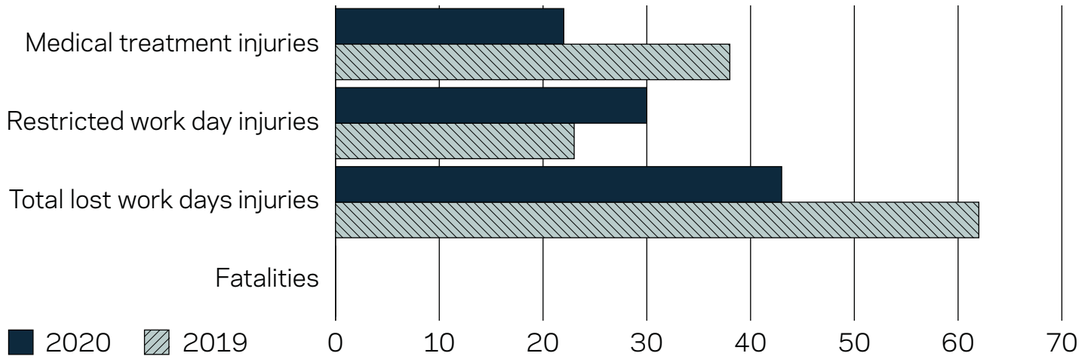
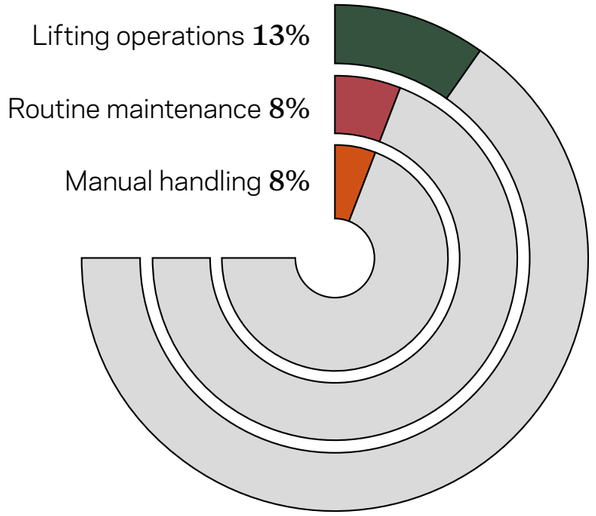


Figure 19: UK top 3 work processes causing most incidents in 2020



G+, the global health and safety organisation for the offshore wind industry, have recently announced Jakob Nielsen as their new chairman.

Figure 20: 2020 injury rates and frequency for countries with largest number of sites[1]

UK

47 sites
1.5 LTIF[2]
3 TRIR[3]

Germany

12 sites
5.4 LTIF[2]
11.2 TRIR[3]

Denmark

10 sites
0.6 LTIF[2]
2.3 TRIR[3]

The UK's performance in 2020 highlights there have been substantial improvements in a number of areas:

- 49% of global High Potential Incidents[1] were attributed to the UK, compared to 67% in 2019;
- 41% reduction in UK High Potential Incidents in 2020, 99 compared to 168 in 2019;
- 20% reduction in incidents resulting in an emergency response or medical evacuation from 20 in 2019 to 16 in 2020.

At The Crown Estate, we work closely with industry to provide support and understand the challenges faced in maintaining high performance levels in offshore wind safety. We do this through regular engagement with wind farm operators and industry bodies like G+ and Trinity House. During 2020/21 we worked closely with Trinity House, offshore wind and OFTO operators to help reduce the deficiency rate of local aids to navigation on offshore renewable energy installations to 8% in 2020/21 (17% 2019/20).

1 High potential incidents are incidents or near misses that had the potential to cause a fatality /life changing injury.

2 G+ definition of a hazard was updated after the 2018 report was published, only hazards which are considered to be of high potential are included for 2019 & 2020.

Figure 21: UK incident consequence profile 2020

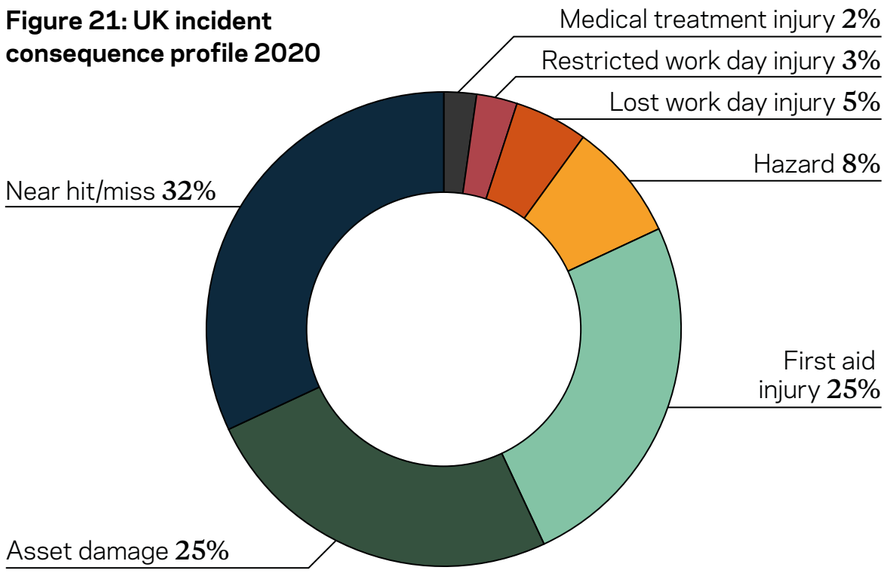
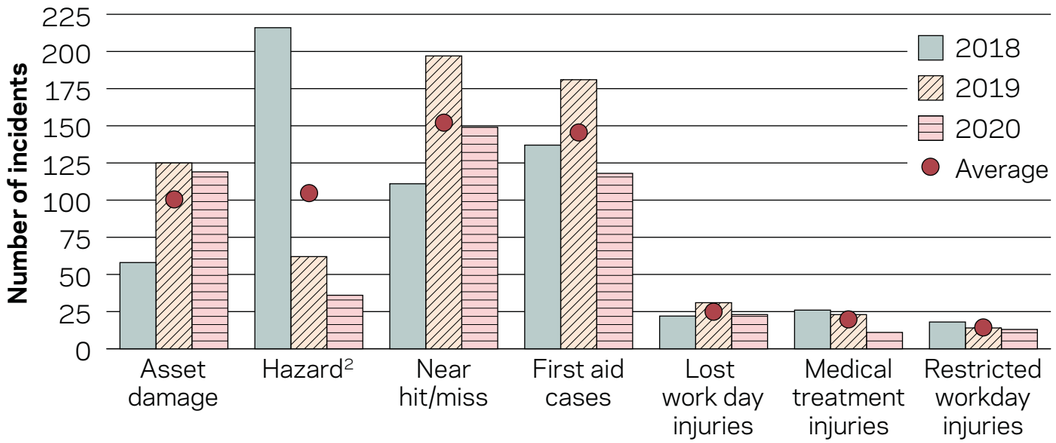


Figure 22: UK 3 year incident profile



Case study: award winning health and safety

Ørsted achieved great success with their Thrive safety training programme winning both the Energy Institute's 2021 Award for Health and Safety and the Gold Award for Best Training Event at the EVCOM London Live and Film Awards.

"As the global leader in offshore wind, Ørsted wanted to develop a new and immersive safety programme as a legacy of the Hornsea Two wind farm, which will be the world's largest offshore wind farm when it is operational later in 2022.

The Thrive programme developed by Ørsted and safety leadership specialists, ATT, bridges the gap between theoretical safety training and the reality of the offshore working environment. Using a creative approach combining interactive experiences, film, live action exercises and facilitated discussion, the programme's hypothetical scenario examines the build-up to a fatal incident on a load-out operation and its consequences.

The training programme has been completed by construction and operations teams throughout Ørsted and their partners."

Paul Haines
Head of UK media relations, Ørsted

Diversity & skills

Offshore technician on location in the wind farm array.

Update on Offshore Wind Sector Deal workforce targets:

Female employees

16%
Baseline (2019)

33%
Target (2030)
(40% if feasible)

19%
Progress (2021)

Sustaining a diverse and inclusive workforce is critical to the UK, not only in achieving a fairer society but in meeting its ambitions in line with the UK's net zero targets. The innovation and creative thinking needed in all phases of the offshore wind life cycle will only be achieved if the barriers of unconscious bias are removed and the recruitment net is cast as wide as possible. New talent is being nurtured across various apprenticeship programmes and on the next page some of the programmes run by RWE are featured.

As an industry, we haven't got all the answers, but diversity of talent is something we collectively continue to hold ourselves to account on and the Offshore Wind Sector Deal Gender updates are highlighted at the start of this section.

The gender balance is improving, but more data on the ethnicity statistics is needed to validate progress on employing people with Black, Asian and minority ethnic backgrounds. Due to insufficient baseline data for offshore wind the original 5% was a proxy from the power sector. In 2020, there was no movement and it highlighted the lack of granular employee data. In 2021 more success was achieved in collecting data resulting in this figure now being 3.7%. This ethnicity percentage marks a step forward in the collection and accuracy of data. Two lessons can be drawn from this: 1. Organisations continuing the focus on employee data collection, building trust around confidentiality of data and the benefit the aggregation of statistics can bring; 2. The need to attract diversity of talent into offshore wind, pushing beyond existing recruitment pools, attracting talent from other industries and shining a light on future opportunities to those of school age.

There can be commercial implications of not making progress in this area. The Supply Chain questionnaire for CfD Allocation Round 4 included questions in the skills section to provide a description of how your recruitment process removes barriers to recruitment of suitably qualified and skilled workers and provides equal and fair consideration of UK residents. The skills section formed up to 25% of total scoring. It is good to see several in the industry increasing focus on this space and showing leadership, with a few examples highlighted in these pages.

"As a business that drives innovation within the industry, champions the environment and inspires everybody to create sustainable value in their work, we're passionate about providing a supportive and inclusive environment."

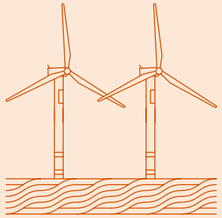
Keith Anderson
CEO, Scottish Power Renewables

The Crown Estate Diversity

At the Crown Estate, within our Marine and offshore wind division we have a gender balance of 60% male and 40% female, with 5% of employees with Black, Asian or minority ethnic backgrounds. However, 31% did not declare their ethnicity and we face the same data challenges as we continue our diversity and inclusion journey. We know we have more to do in this area, but we have increased our focus on data declaration and trust on how data is used. In the summer, we appointed Deborah McCalla as our Diversity & Inclusion Manager to build on the fantastic work of our Accessibility & Inclusivity, LGBT+, Gender and Race, Ethnicity and Culture networks, helping us to strengthen our diversity and inclusion strategy to create a more inclusive employee experience for everyone.

During the year, we launched a reverse mentoring programme, which began with our Group Leadership Team taking part. The programme's objective was to share knowledge, lived experiences and create greater understanding of difference.

We ran our Marine Futures and Coast Explorer Internship Programmes in partnership with: Ørsted, Vattenfall, Natural England, Canterbury City Council, the North West Wildlife Trusts and Kent Wildlife Trust Consultancy Services. The programmes are based in Kent and Cumbria and we welcomed three paid interns for six months. They gained a variety of experiences across the marine sector, including carrying out research projects on the feasibility of nature inclusive design within UK wind farms and more general co-location opportunities.



In 2021, East Anglia ONE commenced their first apprenticeship programme, supporting a national target to employ 3,000 new apprentices across the industry by 2030.

"The offshore wind sector continues to expand at an exciting pace.

Diversity and inclusion matters. It's not just the right thing to do, but if we are to meet the energy needs of our customers, we must better reflect the society we serve.

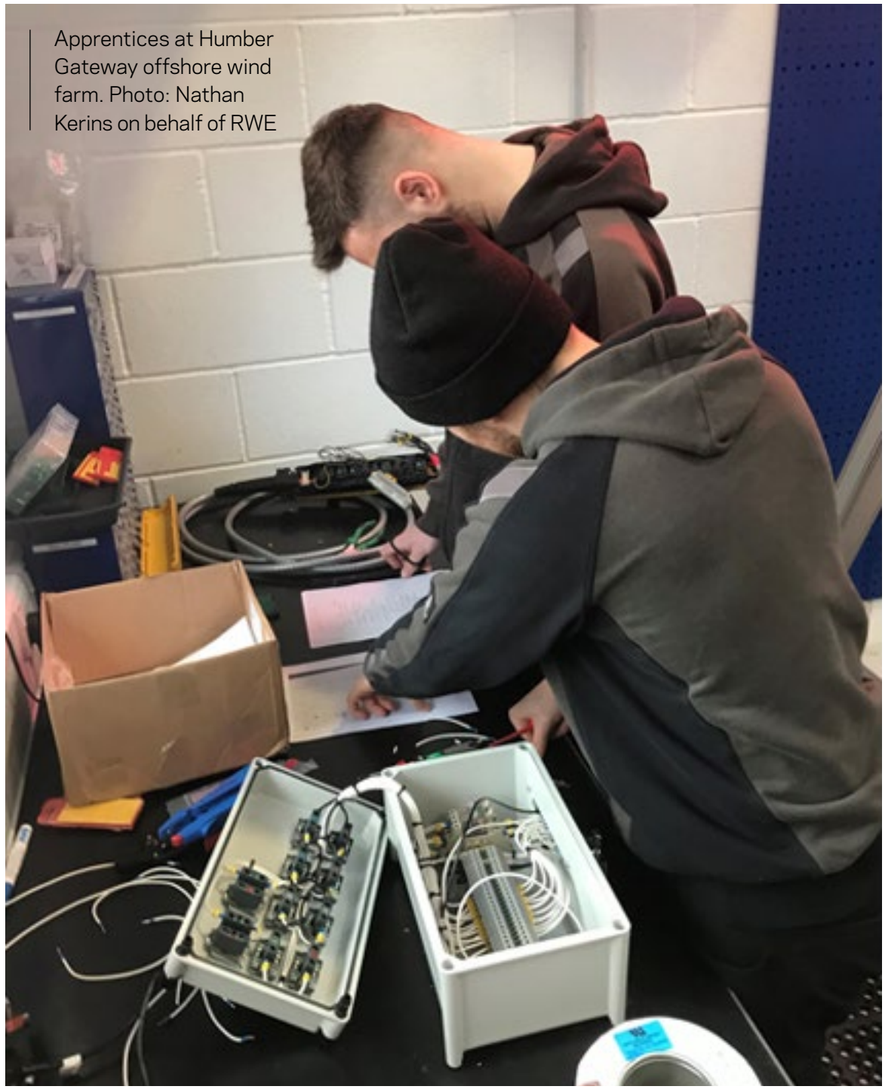
We want to attract the best and brightest to join our dynamic sector, so why restrict ourselves from top talent?

G+ once again put diversity front and centre at our annual Stakeholder Day on March 8th 2022, this time hearing from female offshore wind farm technicians on challenges they face.

We all own health and safety in the offshore wind sector, it's time for the same approach with diversity and inclusion."

Jakob Nielsen
Chair, G+ Global Offshore Wind Health and Safety Organisation

Case study: RWE's graduate programme and apprenticeships



Apprentices at Humber Gateway offshore wind farm. Photo: Nathan Kerins on behalf of RWE

RWE have graduate and apprenticeship programmes and launched their Wind Turbine Technician Apprenticeship in partnership with Grŵp Llandrillo Menai. This three year apprenticeship provides the opportunity to gain qualifications such as the C&G NVQ Level 3 Diploma in Wind Turbine Operations and Maintenance, covering all aspects from health & safety, environmental protections and diagnostic skills for low voltage and control system faults.

Humber Gateway offshore wind farm are one of RWE's locations actively involved in the programme and pride themselves on team development. Humber Gateway currently have five apprentices with three due to complete their apprenticeship at the end of the year and two in their first year of college.

"Engineering holds global accountability to provide the required engineering and technical capabilities and solutions to support the onshore & offshore business units to deliver an optimised asset design. It supports all asset operation units (development, construction and operations) in governance, quality and risk management. The function optimises all assets in terms of efficiency and energy output, along the entire lifetime cycle and aims for technical leadership. By leveraging the expertise & know-how in all areas of the organisation, it drives levelised cost of energy improvement through the lifecycle of all projects."

Lee Taylor
Engineering Manager at Humber Gateway

Offshore wind achievements

This section highlights that even through a challenging year our customers can still achieve major deliverables and drive operational excellence whilst protecting the environment and reducing emissions.

Loadout of 1000th wind turbine for Ørsted.

2021 marks the **10th year** we have produced an annual report for offshore wind and we would like to thank all of those who have contributed to the publication over the years.

Achieving major deliverables

East Anglia ONE marked **a year of operation** in July 2021 and are proud of the commitment and achievements of the team. With the turbine installation and commissioning completed during lockdown, the team and partners adapted how they worked to ensure the wellbeing and health of their teams while keeping work going through the pandemic.

In 2021, Ørsted installed its **1000th offshore wind turbine** in UK waters.

Since 2015, Ørsted has awarded almost **£7 million of funds** and supported **over 500 projects** through their UK Community Benefits Fund.

Triton Knoll are proud to have been able to achieve first power of **the most powerful wind turbine ever to be commissioned in the UK,** particularly as the entire offshore construction phase was completed during the pandemic.

Achieving first power in December 2021 was an important milestone for Hornsea 2, which will soon become the **world's largest offshore wind farm,** and a proud moment for the whole team who have worked through the pandemic to keep the project on track.

The **largest OFTO divestment to date** completed with Hornsea 1 OFTO transferred to Diamond Transmission Partners for £1.17bn from Ørsted.

Driving operational excellence

Equinor have successfully **consolidated their two Norfolk operation bases into one**, aligned with their new operating model which combines the competency and expertise of their operations & maintenance teams. The shared use of the existing Service Operations Vessels maximises time in the field and reduces emissions from overall operations, demonstrating ability in the industry to reach towards net zero. The control room also incorporates their pioneering floating offshore wind farm Hywind Scotland which achieved record breaking figures for 2021.

Walney Extension OFTO returned a tripped grid transformer to service in **less than 12 & 54 hours** following 2 separate incidents. Both incidents involved investigation works including oil sampling and gas analysis.

Walney 1 OFTO mobilised a specialist team **within 2 days of an export cable fibre fault**. The team undertook Optical Time Domain Reflectometry of all fibres from the onshore substation and Distributed Acoustic Sensing testing, **identifying the cable fault with a 90% certainty**. Repair work was completed during a two day outage.

Reducing carbon emissions

East Anglia ONE have gone further to cut their carbon emissions with the use of waste vegetable oil to help power crew transfer vessels with predicted results expecting a **30% reduction in equivalent CO_2 emissions** compared to standard marine gas oil.

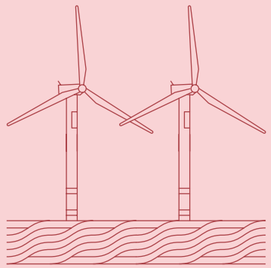
Hybrid crew transfer vessels are being used to assist with the construction of Hornsea 2 offshore wind farm.

Protecting the environment

Scottish Power Renewables were honoured to receive a **global award at the Energy Institute Awards** for efforts to protect the environment and give back to the planet whilst constructing East Anglia ONE offshore wind farm. Scottish Power Renewables were recognised for going beyond their statutory responsibility to mitigate their impact on the onshore environment and help native species thrive by creating a wetland habitat, now home to a variety of marine and bird species.

East Anglia ONE are proud to collaborate with six other offshore wind developers in a new industry-led forum, the **Offshore Wind Strategic Monitoring and Research Forum (OWSMRF),** launched to better understand how the industry can minimise potential effects of large-scale offshore wind developments on the environment and marine birds.

Offshore wind farm ownership



Turbine blades at Port of Nigg.

We track offshore wind farm ownership to understand the dominance and change in the industries invested in offshore wind. In figure 23 we detail ownership dominance by company. Ownership by category of operating and under-construction offshore wind farms in 2021 remained broadly similar to 2020, as shown in figure 24, with an increase in the oil and gas sector's share to 15% (from 12%) and an increase in the ownership of utilities to 63% (from 61%) reflecting transactions in Dogger Bank A and B and the progression of Dogger Bank C and Sofia to Final Investment Decision. The supply chain stake in the industry is minimal, with their interest being primarily in floating wind.

Figure 23: Operational and under construction wind farm ownership as a % of total capacity in 2021 by company

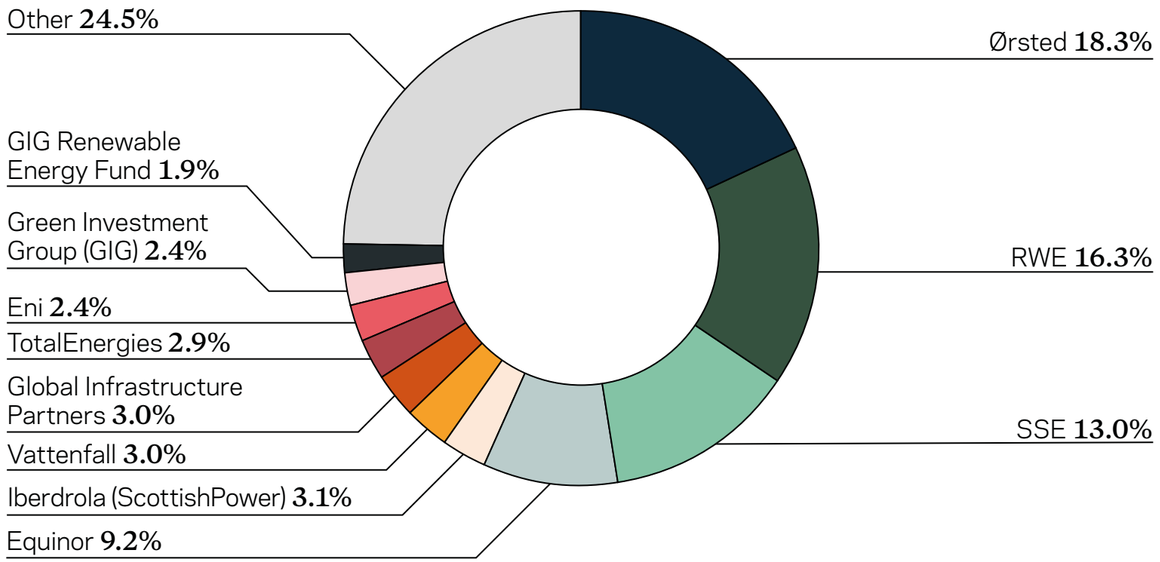
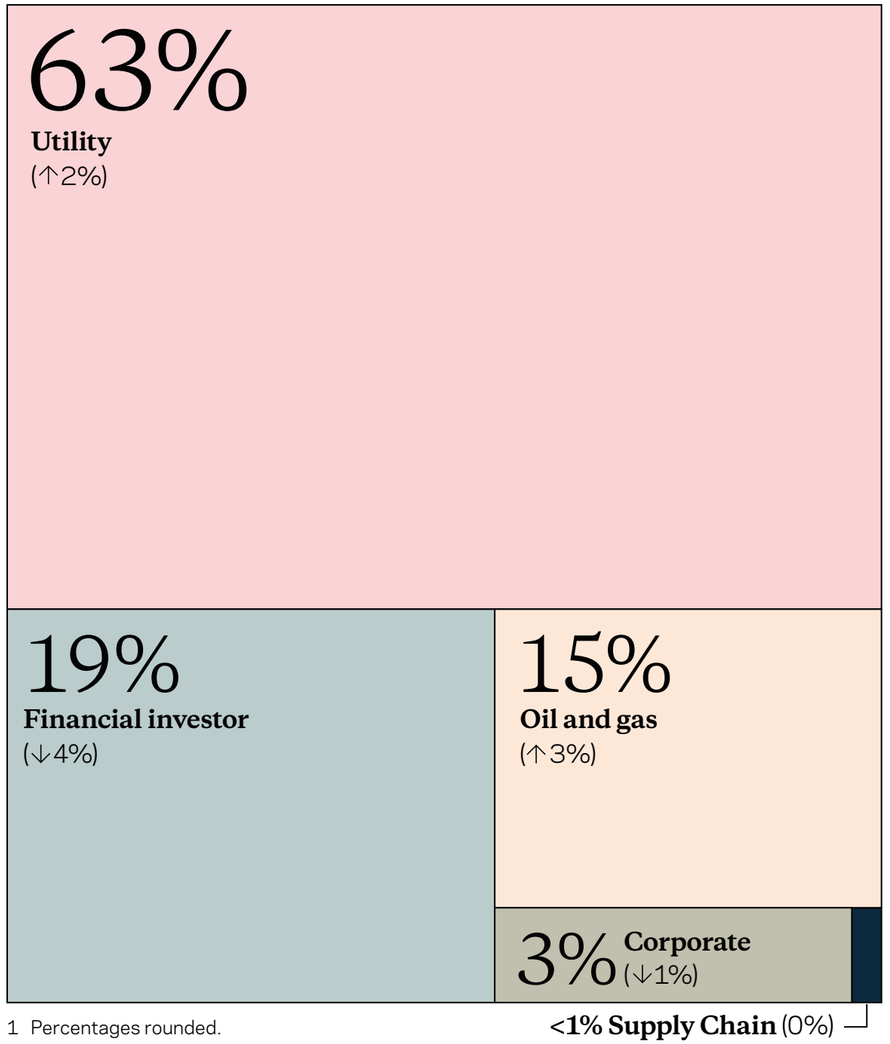


Figure 24: Capacity ownership by category in 2021 v 2020 (Operational and under construction wind farms)[1]

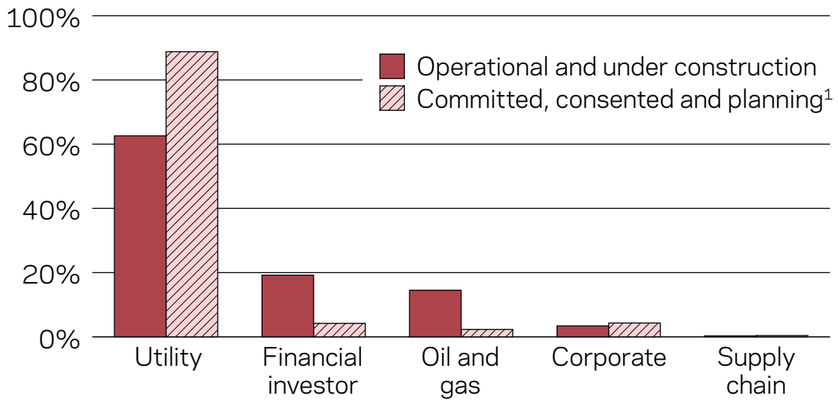


1 Percentages rounded.

The dominance of utility company ownership continues beyond the operational and construction stages into the development stage of projects at 89% as shown in figure 25, which shows ownership by category at different project stages (excluding Leasing Round 4 and ScotWind). It's clear to see that financial investors and oil and gas companies have generally become involved in later stage projects, albeit becoming more comfortable with construction risk. That's a trend we are seeing change in the oil and gas sector witnessed by bids into later auction rounds and written about in last year's report. A full breakdown of offshore wind farm ownership for operating and under construction sites can be found on our website.

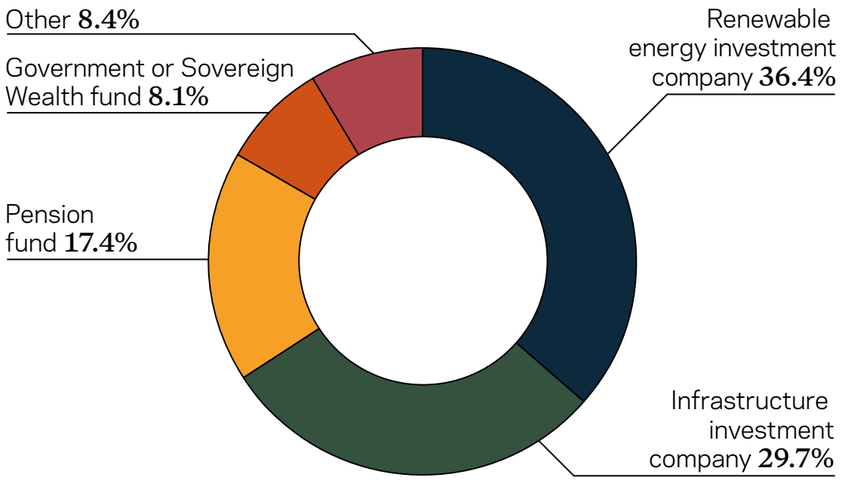
The proportion of the operational and under construction fleet owned by financial investors has reduced slightly this year but we've dug into the profile of those investments as detailed in figure 26. Pension companies have been increasing their share over the last few years but still only make up around 17% of the investor share total. The majority of investments are held by renewable energy and infrastructure funds at 66%.

Figure 25: Capacity ownership by category and lifecycle stage in 2021



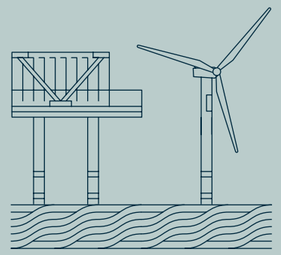
1 Excludes ScotWind and projects under Habitats Regulations Assessment (HRA) such as Leasing Round 4

Figure 26: Financial investor capacity ownership (operational and under construction wind farms)



Blyth Demonstration wind turbine. © EDF

Offshore Transmission Owner (OFTO) ownership



23 OFTOs

There are now 23 licenced OFTOs in the UK

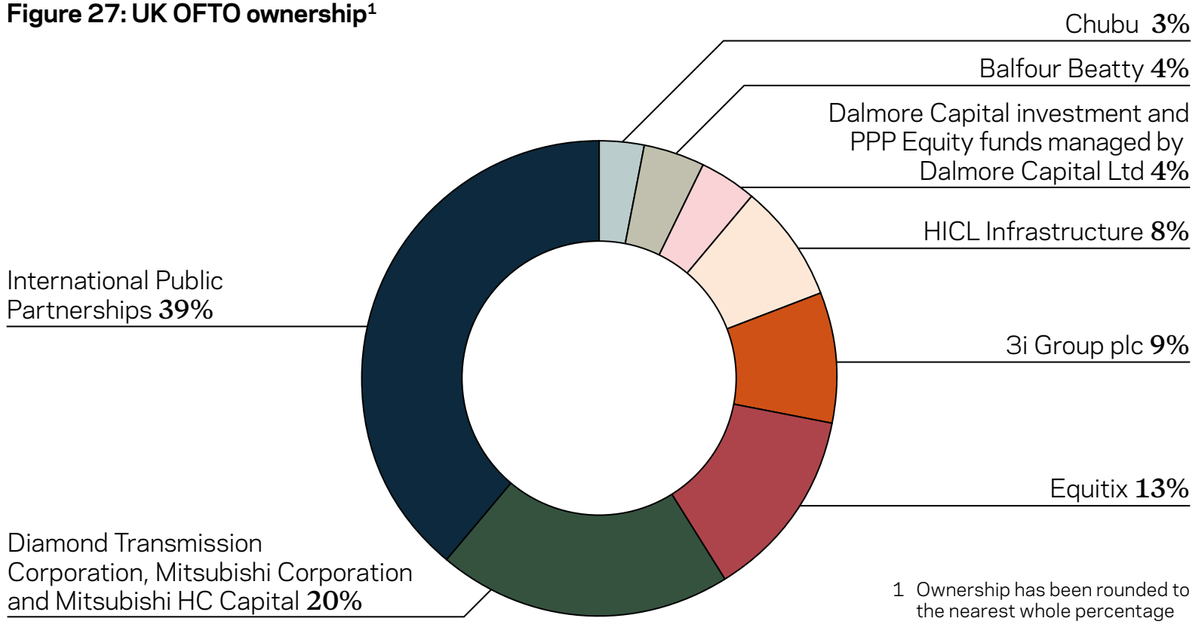
Service Operation Vessel (SOV) operating at Triton Knoll offshore wind farm.

The divestment of the transmission assets to the offshore transmission owner (OFTO) on the basis of a competitive tender process is a key part of the OFTO regime. 2021 was yet another pivotal year, which saw three licences granted, one from Tender Round 5 and two from Tender Round 6. The remaining OFTO in Tender Round 6, East Anglia ONE, has been delayed with the licence to be granted early 2023.

2021 also saw the largest OFTO divestment to date completed during lockdown in March 2021 with Hornsea 1 OFTO transferred to Diamond Transmission Partners for £1.17bn from Ørsted.

As shown in figure 29, OFTOs continue to be operated by the main OFTO players: Transmission Capital Partners, Balfour Beatty, Diamond Transmission and Equitix who are owned by infrastructure investment groups and venture capital companies. A breakdown of OFTO ownership is detailed in figure 27.

Figure 27: UK OFTO ownership[1]



1 Ownership has been rounded to the nearest whole percentage

Figure 28: Offshore transmission tenders

Ofgem is responsible for managing the competitive tender process through which offshore transmission licences are granted. The following tenders are currently underway:

Tender Round 5	**Licences granted 2021** **Rampion** November 2021
Tender Round 6	**Licences granted 2021** **Hornsea One** March 2021 **Beatrice** July 2021 **Licences to be granted by early 2023** **East Anglia ONE** Preferred bidder appointed December 2020
Tender Round 7 *Launched in 2020*	**Licences to be granted 2022** **Triton Knoll** Preferred bidder appointed October 2021 **Moray East** Preferred bidder to be appointed March 2022
Tender Round 8 *Launched in 2021*	**Preferred bidder to be appointed 2022** **Hornsea 2** ITT stage commenced January 2022
Tender Round 9 *Launched in 2022*	**Invitation to Tender (ITT) stage to commence** **Seagreen (Phase 1)** Estimated Q3 2022

For more information on the tenders, please visit Ofgem's website.

Figure 29: UK OFTO ownership as at 31 December 2021

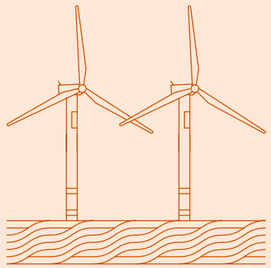
OFTO	Export cable circuits	Offshore substations	Ownership %	Operator	Operations & maintenance provider
Barrow	1	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
Beatrice	2	2	100% International Public Partnerships	Transmission Capital	Transmission Capital
Burbo Bank Extension	1	1	50% Diamond Transmission Corporation[1]; 50% HICL Infrastructure	Diamond Transmission UK	RES
Dudgeon	2	1	100% International Public Partnerships	Transmission Capital	Equinor
Galloper	2	1	51% Diamond Transmission Corporation[1]; 49% HICL Infrastructure	Diamond Transmission UK	RES
Greater Gabbard	3	2	100% Equitix	EDS HV	EDS HV
Gunfleet Sands	1	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
Gwynt y Môr	4	2	60% Balfour Beatty; 40% Equitix	EDS HV	EDS HV
Hornsea 1	3	3	20% Mitsubishi Corporation; 49% Chubu; 31% Mitsubishi HC Capital	Diamond Transmission UK	Ørsted
Humber Gateway	2	1	80% Equitix; 20% Balfour Beatty	EDS HV	EDS HV
Lincs	2	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
London Array	4	2	50% Diamond Transmission Corporation[1]; 50% 3i Group plc	Frontier Power	London Array Limited
Ormonde	1	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
Race Bank	2	2	51% Diamond Transmission Corporation[1]; 49% HICL Infrastructure	Diamond Transmission UK	RES
Rampion	2	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
Robin Rigg	2	1	100% International Public Partnerships	Transmission Capital	RWE
Sheringham Shoal	2	2	50% Diamond Transmission Corporation[1]; 50% 3i Group plc	Frontier Power	Equinor
Thanet	2	1	80% Equitix; 20% Balfour Beatty	EDS HV	EDS HV
Walney 1	1	1	50% Diamond Transmission Corporation[1]; 50% 3i Group plc	Frontier Power	RES
Walney 2	1	1	50% Diamond Transmission Corporation[1]; 50% 3i Group plc	Frontier Power	RES
Walney Extension	2	2	51% Diamond Transmission Corporation[1]; 29% HICL Infrastructure; 20% Chubu	Diamond Transmission UK	RES
Westermost Rough	1	1	100% International Public Partnerships	Transmission Capital	Transmission Capital
West of Duddon Sands	2	1	100% Dalmore Capital investment and PPP Equity funds managed by Dalmore Capital Ltd	Frontier Power	Ørsted

You can view this table on our website.

1 Subsidiary of Mitsubishi Corporation

Investment & market

Turbine foundation installation.



50%+

East Anglia ONE exceeded its commitment by awarding more than half its supply contracts to UK companies.

2021 was once again an exceptional year for UK offshore wind transactions, with the largest ever UK Power Purchase Agreement in volume signed between RWE and EDF, confirming the UK's position as one of the world's most attractive countries for renewable energy. Some buyers were new entrants in the market, such as Eni, who we hear from on page 37, whilst others strengthened their existing position, as seen in figure 30. Offshore wind in the UK will continue to play a pivotal role in the route to net zero and presents one of the most attractive investment pathways to help achieve this.

Figure 30: Transaction activities completed in 2021 in date order (percentages rounded)

Asset	Seller (share before sale)	Buyer (share in the project after transaction)	Value (£m)	Indicative timing
Rampion OFTO	RWE (50%) Macquarie (25%) Enbridge Rampion UK Ltd (25%)	Transmission Capital Partners (100%)	£279.5m	Nov-21
Burbo Bank Extension	PKA (25%)	Greencoat UK Wind (16%) Greencoat Renewable Income LP (9%)	£250m Unknown	Nov-21
Blyth Demo 1, 2, 3	EDF (100%)	Tenaga Nasional Berhad (49%)	Unknown	Oct-21
Beatrice OFTO	SSE Renewables (40%) Red Rock Power Limited (25%) The Renewables Infrastructure Group (18%) Equitix (18%)	Transmission Capital Partners (100%)	£437.9m	Aug-21
Wave Hub	Cornwall Council (100%)	Hexicon (100%)	£2.4m	Jul-21
Gwynt y Môr	Macquarie Infrastructure & Real Assets (MIRA) (20%)	GIG (10%)	Unknown	Jun-21
Rampion 1	Green Investment Group (GIG) (25%)	Macquarie European Infrastructure Fund 5 (13%) Universities Superannuation Scheme (6%)	Unknown Unknown	Jun-21
Rampion 1	EON (20%)	RWE (50%)	Unknown	Jun-21
Hornsea 1 OFTO	Ørsted (50%) Global Infrastructure Partners (GIP) (50%)	Diamond Transmission Partners (100%)	£1,170m	Mar-21
Dounreay Tri	Hexicon AB (100%)	Copenhagen Infrastructure Partners (CIP) (75%)	Unknown	Jan-21
Beatrice	Copenhagen Infrastructure Partners (CIP) (35%)	The Renewables Infrastructure Group (TRIG) (18%) Equitix Funds (18%)	Unknown Unknown	Jan-21
Dogger Bank A&B	Equinor (50%) SSE (50%)	Eni (20%)	£405m	Jan-21

Operations at an offshore wind farm array.

To facilitate the framework for further investments, last November at COP26 Finance Day in Glasgow, the Chancellor of the Exchequer Rishi Sunak unveiled the UK's ambition to become the world's first net zero aligned financial centre. This includes new requirements for UK financial institutions and listed companies to publish net zero transition plans detailing how they will adapt and decarbonise as the UK moves towards to a net zero economy by 2050.

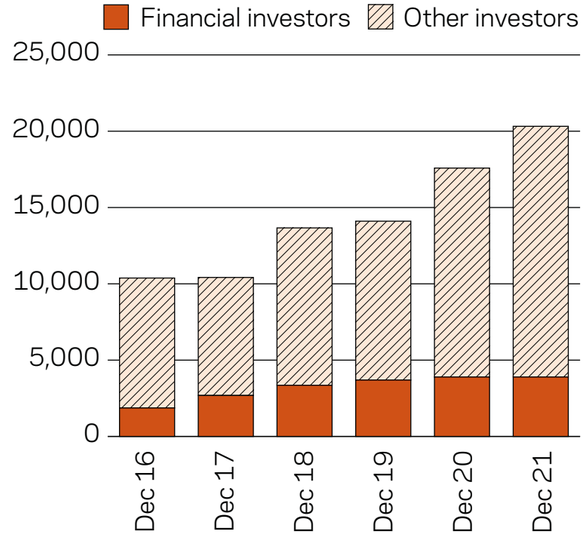
A Transition Plan Taskforce made up of industry and academic leaders, regulators, and civil society groups will draw up a science-driven "gold standard" for transition plans to guard against "greenwashing".

The earliest iteration of this emissions disclosure regime is expected to come into force in April 2022, and will only apply to the largest UK businesses. This will include many of the UK's largest traded companies, banks, and insurers, as well as private companies with over 500 employees and £500 million in turnover. Once that happens, the UK will officially become the first G20 country to make it mandatory for companies to disclose their climate-related risks and opportunities.

While many firms, such as SSE through its Net Zero Acceleration Programme, were already taking this step, the new rules will ensure that the UK sets the pace internationally. Aligning public finance, regulatory and fiscal tools, and regulatory guidance under net zero is needed to rewire the global financial system and mobilise the trillions necessary to transform the global economy in line with net zero.

As the Chancellor stated at COP26 "Six years ago, Paris set the ambition, today in Glasgow, we're providing the investment we need to deliver that ambition."

Figure 31: Operational and under construction portfolio ownership (MW capacity)



Construction engineer for J.Murphy & Sons.

Eni entered the UK offshore wind market for electricity production in early 2021 through the acquisition of a 20% stake from Equinor and SSE Renewables of the Dogger Bank (A and B) project. This acquisition saw Eni enter the Northern Europe offshore wind market with two partners that have extensive experience in the sector, and with whom it will be able to enhance its own expertise in the construction and operation of offshore wind farms for future projects in other areas.

Subsequently Eni announced its intention to purchase a 20% share of Dogger Bank C. The investment completed February 2022, strengthening its foothold in the UK market. The alignment in the participating interest across the three phases will facilitate the capture of material synergies during construction and operation.

"Through this important transaction we continue to accelerate our growth strategy in renewable energy, as well as strengthening our presence in the offshore wind market in Northern Europe, one of the most promising and stable markets in the world. This new capacity further enhances and expands Eni's portfolio that integrates renewables and retail, a fundamental strategic lever for the decarbonisation of emissions related to the use of our products by our customers. It is therefore a new concrete step in our process of complete reduction of the net emissions of industrial processes and products."

Claudio Descalzi
Chief Executive Officer, Eni

6GW+

Plenitude/Eni Gas e Luce has a target to install over 6GW of renewable capacity by 2025.

Variable generators and capture prices

Exceptional events are currently affecting electricity markets and led to the UK Government's recently published Energy Security Strategy, which includes an ambition for 50GW of offshore wind by 2030, almost five times the current UK offshore wind operating capacity.

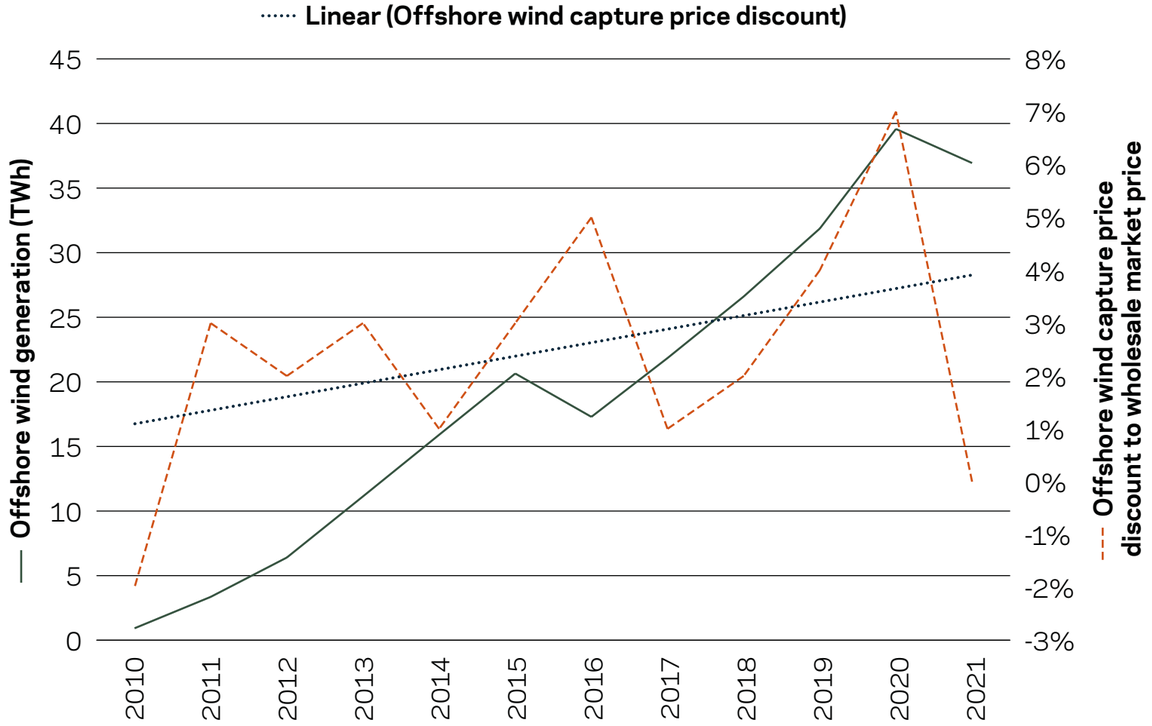
Variable generators, such as offshore wind farms have limited control over when they generate. Electricity is normally produced at a time when wind resource is available, rather than just being planned for periods when electricity prices are high. Although, typically options include production based availability and management.

With electricity production across nearby wind farm sites often correlated due to similar wind speeds and supply in the same electricity market increasing during high wind periods, this means the "capture price" (the price earned by an asset selling electricity on the market) is generally lower than the wholesale market price (the average baseload electricity price over a period). This is often referred to as the "cannibalisation effect" and is a longer-term trend.

Figure 32 illustrates this phenomenon: the offshore wind capture price discount to the wholesale market price increases as wind energy production grows, with a clear upward trend over the past decade. Over the last 10 years, you can observe that offshore wind capture prices are an average 2-4% discount to wholesale prices and this discount increased to as much as 7% in 2020. Bucking the trend, 2021 saw no capture price discount on the back of below average wind production at the start of the year when prices were low. This contrasted with the end of the year when production was higher and prices rose significantly. Whilst increasing levels of wind energy generation can be beneficial to the UK consumer, by lowering electricity market prices, the cannibalisation effect may be detrimental to the profitability of those offshore wind farm projects which are not supported by a Contract for Difference due to the reduced income received, and this effect may not have been anticipated by early investors.

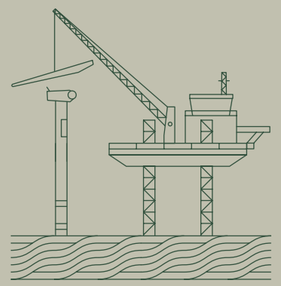
The arrival of flexible demand solutions such as batteries, bi-directional electric vehicle chargers, hydrogen production and smart charging have the potential to alleviate some of the negative effects caused by price cannibalisation by shifting demand to periods of higher renewable generation. Although substantial investment has been achieved in some technologies, scale and supporting regulation will be needed before any concrete results can be seen on the wholesale electricity markets.

Figure 32: UK offshore wind generation vs offshore wind capture price discount to average wholesale market price



Source: Aurora EOS

Offshore wind development



London Array offshore wind farm. © London Array

Our 2020 report marked 30 years until the all-important 2050 horizon for net zero, with the narrative touching upon how foundational activities established in the present era will be pivotal to the continued expansion and success of the offshore wind industry within the UK. As we begin to broaden our view beyond a historical financial and engineering focus, and shift focus beyond 2030 to 2050, environmental, spatial and socio-economic considerations are being brought to the forefront of project considerations.

We're helping to address these challenges by encouraging technological innovation, such as floating wind and hybrid projects, and by working in partnership with a wide range of stakeholders to deliver a programme of enabling actions that will start to tackle some the challenges to be overcome to enable future expansion. This section includes an update on the existing portfolio of projects, including those which may emerge from Round 4; an overview of our work to enable floating wind in the Celtic Sea; and a nod to the future with a look at the Future Offshore Wind Scenarios project.

Onshore cable burial dig out.

Offshore Wind Evidence and Change Programme (OWEC)

In December 2020, we committed a £25 million kick starter investment to fund and deliver the Offshore Wind Evidence and Change programme in partnership with Government. It brings together key stakeholders, including devolved Government bodies, non-governmental organisations and industry to gather and share evidence. This enhanced evidence base will be used to facilitate the growth of the offshore wind sector in a way that best protects and enriches the environment. During early 2022 we published the programme's first annual report with further updates to the programme's projects expected to be announced later this year.

Offshore Wind Evidence + Change Programme

Existing portfolio and development pipeline

The portfolio of projects continues to progress with both the Sofia and Dogger Bank C projects achieving Final Investment Decision (FID) in 2021, and being granted leases in the first quarter of 2022. This represents 2.6GW of new capacity entering the construction phase. Norfolk Boreas secured its Development Consent Order (DCO) in December 2021, whilst Norfolk Vanguard secured its DCO in February 2022. This represents a further 3.6GW of capacity ready to move towards financing and construction.

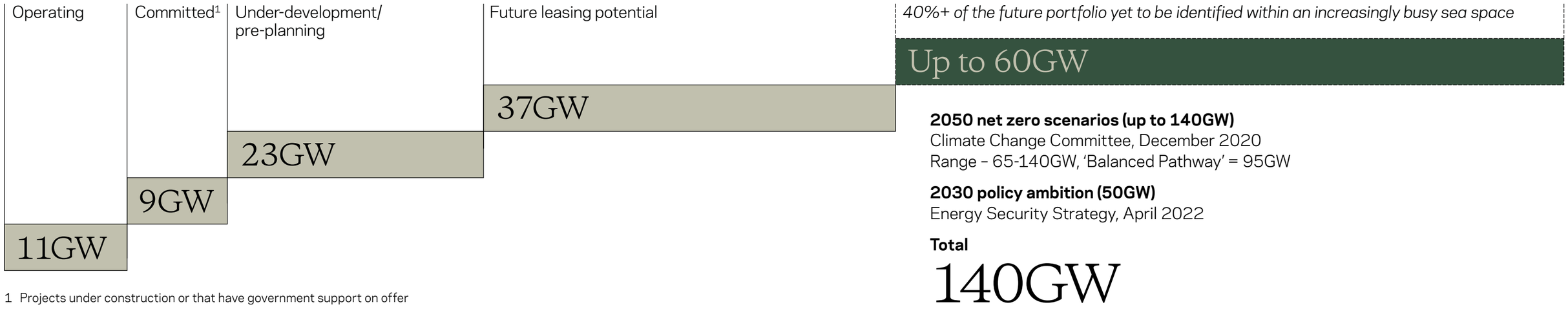
Leasing Round 4 created the opportunity for at least 7GW of new offshore wind projects in the waters around England and Wales by the end of the decade. The Crown Estate has completed its work on the Plan-Level Habitats Regulations Assessment (HRA) and given notice to the UK and Welsh Governments of its intent to proceed with the Round 4 plan on the basis of a 'degoration'. Further information can be found on our website.

2021 ushered in an era of new floating wind technology in the UK, which has taken an important step forward with the announcement that 300MW of new projects, identified through The Crown Estate's Test and Demonstration leasing opportunity, have been given the green light to progress to the next stage of assessment. November 2021 then saw the announcement of proposals for floating wind in the Celtic Sea, outlining our ambition to unlock up to a 4GW opportunity. Further information can be found on the next page.

We recently welcomed the announcement by Crown Estate Scotland that 17 new offshore wind projects are to be awarded through the ScotWind leasing process, representing a mix of fixed, floating and hybrid projects, totalling just under 25GW of potential new capacity.

Leasing Round 4, ScotWind, Celtic Sea Floating Wind and Test & Demonstration leasing potential could give rise to 37GW of additional capacity, signifying progress towards the 2050 net zero scenario of up to 140GW. Realising that the spatial impacts of thousands of turbines on ecosystems, communities and other industries pose important planning challenges, we'll continue to work with our partners and a wide range of stakeholders to achieve strategic solutions and support sustainable growth of the industry, including through initiatives such as our Offshore Wind Evidence & Change Programme, and the Offshore Transmission Network Review.

Figure 33: UK offshore wind development pipeline waterfall (gigawatts rounded)



1 Projects under construction or that have government support on offer

Hywind Scotland, the world's first floating wind farm, operated by Equinor. Photo: Michal Wachucik. © Equinor

Celtic Sea Floating Wind

The Celtic Sea leasing opportunity for up to 4GW of wind power capacity from floating wind turbines was announced in November 2021. Our ambition for floating wind highlights the need to ensure our activities secure maximum social and environmental prosperity – as well as economic benefits.

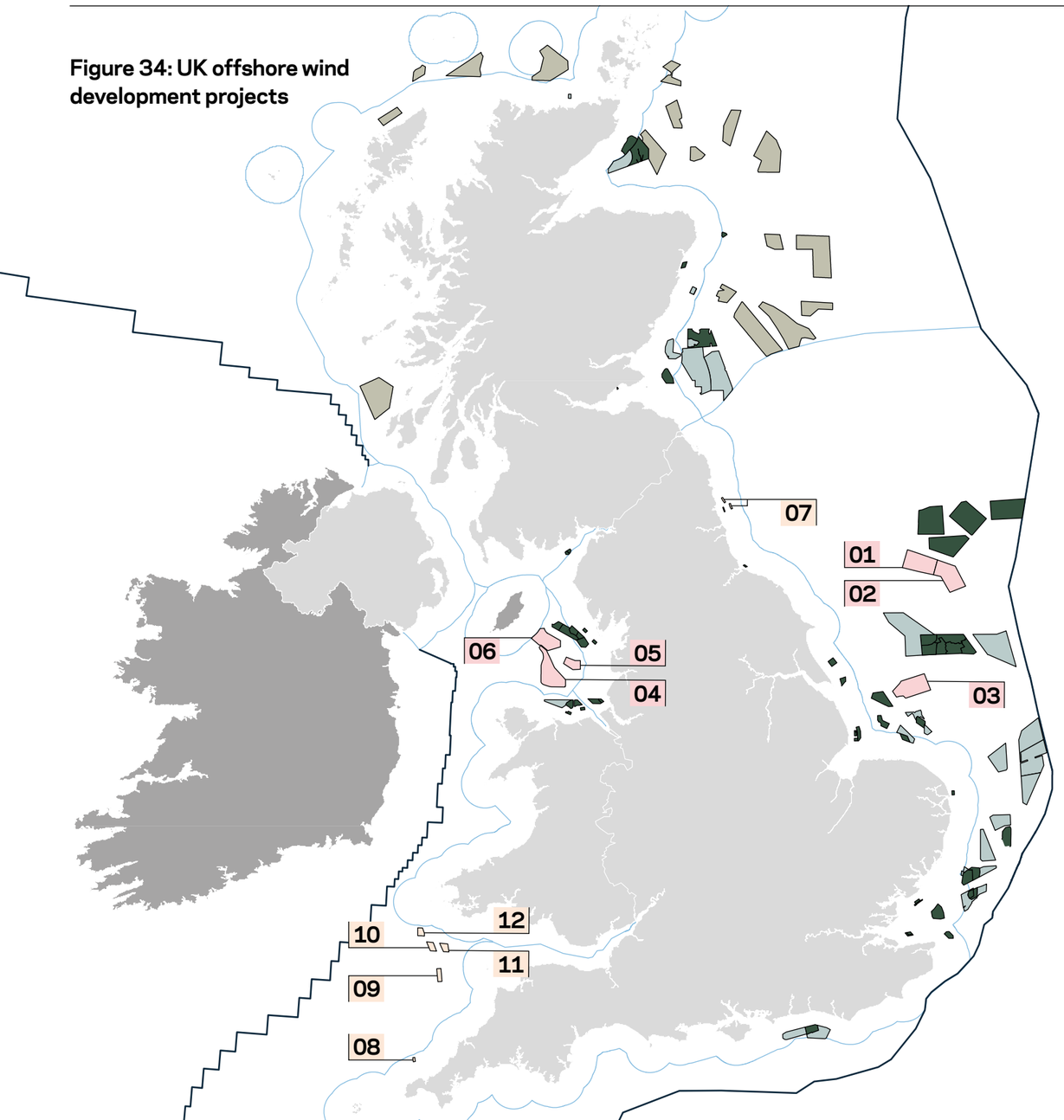
The Celtic Sea today contains no wind farms, though its seabed hosts critical national infrastructure in the form of many subsea broadband cables. Many residents of the communities on its coasts, which is host to two national parks, make their living from the sea, including from its rich fishing grounds. The Celtic Sea is also a precious marine habitat, enriched by many unique and important species.

South Wales and the South West share a rich industrial legacy, providing minerals and material that catalysed the first Industrial Revolution. Both regions now look to fuel the 'Green Industrial Revolution', with lithium and 'green steel'. It is befitting that the sea that they overlook will be home to the newest generation of wind farms – based on structures that float in our deepest waters, and which could tap – and power – its low-carbon era.

Continual engagement with the market and stakeholders is at the heart of our approach to developing the Celtic Sea leasing opportunity for the benefit of all. A good example is our support for the Celtic Sea Cluster, which launched in 2021, and includes on its board the Cornwall & Isles of Scilly Local Enterprise Partnership, and Welsh Government. Our engagement with marine stakeholders includes environmental charities, advocacy groups and public regulators.

The Crown Estate has a rich legacy as steward of many of the nation's important assets and for considering those that live near them. It is with that long-term focus that we aim to replicate the insights and experience gained from our new approach to creating leasing opportunities – with interconnected focus on environmental, social and economic value creation, into our future commercial activities.

Figure 34: UK offshore wind development projects



- Test and Demo scale floating wind projects
- Leasing Round 4 Preferred Projects
- ScotWind Projects
- Projects under development or pre-planning
- Projects in operation or committed
- Territorial Waters Limit
- UK Continental Shelf

ScotWind

Successful ScotWind Project applicants are pending entering into option agreements at the time of writing. The latest project and tenant names, as well as updates can be found on this weblink.

Leasing Round 4 Preferred Projects[1]

		Up to capacity MW
01	RWE Renewables	1,500
02	RWE Renewables	1,500
03	Green Investment Group – TotalEnergies	1,500
04	Consortium of EnBW and BP	1,500
05	Offshore Wind Limited, a joint venture between Cobra Instalaciones y Servicios, S.A. and Flotation Energy plc	480
06	Consortium of EnBW and BP	1,500
Total		**7,980**

Test and Demonstration scale floating wind projects

		Up to capacity MW
07	Blyth Demonstration (Phases 2 and 3)	58
08	Wave Hub	40
09	White Cross[1]	100
10	Llŷr 1[1]	100
11	Llŷr 2[1]	100
12	Erebus	96
Total		**494**

1 Subject to the outcome of a plan-level Habitats Regulations Assessment (HRA)

Looking to the future: Future Offshore Wind Scenarios

The Future Offshore Wind Scenarios (FOWS) project, an Offshore Wind Evidence and Change Programme (OWEC) project led by the Department for Business, Energy & Industrial Strategy and supported by The Crown Estate and Crown Estate Scotland, has the objective of identifying potential future spatial deployment scenarios for UK offshore wind to 2050, in order to understand opportunities, trade-offs and relative cost implications.

FOWS modelled three deployment pathways to 2050 (65, 95 and 140GW). For each pathway, a range of options were considered for the treatment of offshore constraint, alongside various sensitivities in relation to cost assumptions. This resulted in the creation of a diverse range of potential future spatial deployment scenarios, which help illustrate geospatial trade-offs and the corresponding impact on relative costs. The full report can be found here.

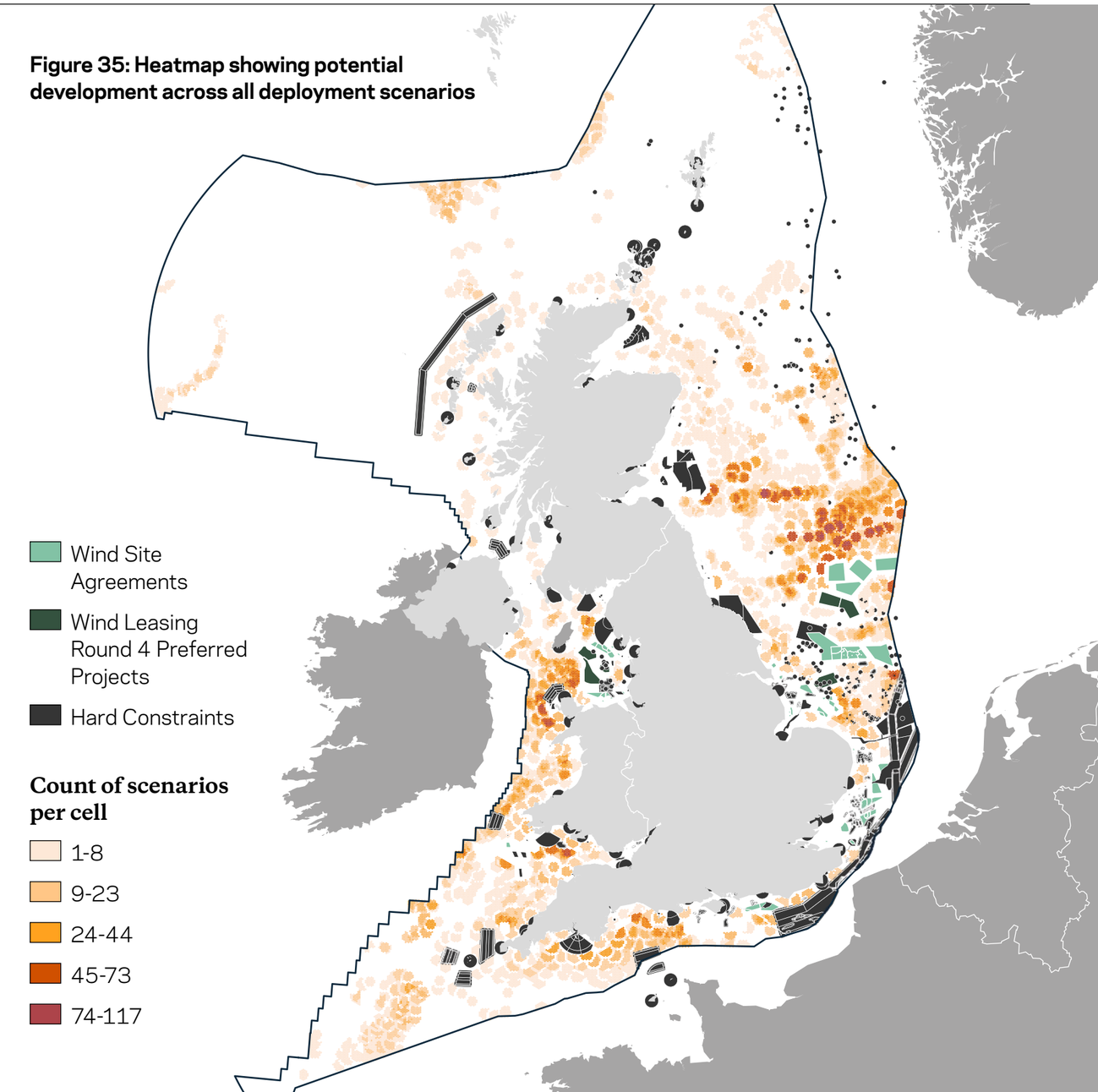
It is important to note that this exercise does not constitute – and should not be treated as – a plan for development. Furthermore, data limitations are significant and further analysis of UK level deployment can only come from broader and better data. However, some key themes have emerged from the project:

1. It shows significant UK-wide opportunity for offshore wind deployment, with ample potential for floating wind assuming a high learning rate and capable supply chain;
2. The project has highlighted the importance of collaboration to find effective ways of approaching issues of marine spatial prioritisation, with more work to be undertaken in this space;
3. Modelling electricity system considerations and cumulative environmental impacts is necessary to optimise cluster size and the ultimate viability of deployment areas.

The FOWS project is part of OWEC which was established by The Crown Estate in December 2020 with the aim to facilitate the sustainable and coordinated expansion of offshore wind to help meet the UK's commitments to low carbon energy whilst supporting clean, healthy, productive and biologically diverse seas.

The FOWS project will inform thinking on new offshore wind programmes and it demonstrates that large, diverse deployment is feasible across the breadth of the UK, as shown in figure 35, by the potential development across all spatial deployment scenarios. Although challenging trade-offs need to be considered, there is an exciting opportunity for offshore wind to support UK and net zero and reach its full potential.

Figure 35: Heatmap showing potential development across all deployment scenarios



Crown Estate Scotland Development

The results of ScotWind, the first leasing round in Scottish waters for over a decade, were announced in January 2022.

From 74 applications, 17 projects with a total capacity of 25GW were offered option agreements. The level of interest and ambition demonstrated by these figures, when initial projections suggested a total of around 10GW, is hugely encouraging, and represents a major step toward achieving the Scottish Government's target of net zero emissions by 2045.

ScotWind will realise £700m in option fees, and draw billions of pounds of investment into the Scottish supply chain. Of particular note is the c.60% of projects (by generating capacity) which will utilise a floating wind approach: this push will take floating to a commercial scale, and provide great opportunities for Scottish companies to become early adopters of a technology which has a huge future role to play in global energy generation.

A new round of leasing, focussed on Innovation and Targeted Oil and Gas Decarbonisation (INTOG) was launched, accepting applications for Innovation projects (up to 100MW in capacity) and projects to support the electrification and decarbonisation of oil and gas production in the North Sea. It is forecast that INTOG could add 5GW to the existing pipeline of Scottish projects and crucially, support the 'just transition' of Scotland's economy by tapering down oil and gas producer's carbon emissions as the country moves toward net zero.

Several longer-standing projects from Round 3 and the Scottish Territorial Waters leasing rounds have made important strides forward in 2021. It is hoped that some of these may be able to move into the final stages of development if they achieve success in CfD Allocation Round 4.

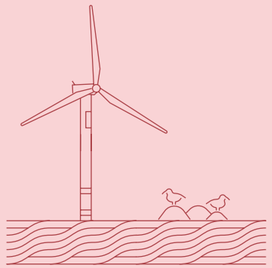
Two test and demonstration projects are working towards securing consents to allow them to start construction:

- Pentland has recently secured almost £10m of funding from the UK Government to develop and demonstrate new mooring system technologies, cable protection, floating turbine base design and an advanced digital monitoring system at the site.
- Forthwind, which secured a CfD in Allocation Round 3, passed the Low Carbon Contracts Company milestone requirement in 2021 – the first significant milestone in a CfD project's journey to becoming operational.

Crown Estate Scotland
Oighreachd a' Chrùin Alba

Turbine construction at Port of Nigg.

Data & evidence



MDE

Marine Data Exchange (MDE) is the world's largest database of marine industry survey data

Snug in my pipe – third place in the British Waters Living Together category of the 2022 Underwater Photographer of the Year. Photo: Alison Pettitt

We remain committed to investing in data and evidence to help support and accelerate the sustainable development of the seabed; unlocking social, environmental and financial value for the nation. By sharing survey data collected during the lifecycle of an offshore wind project and investing in evidence programmes that address knowledge gaps, we hope to support the marine industry from feasibility through to decommissioning.

The Marine Data Exchange (MDE)

The first of its kind and the world's largest database of marine industry survey data, research and evidence. By making this wealth of data freely available through cutting-edge technology, we aim to give offshore projects in the UK a valuable head start.

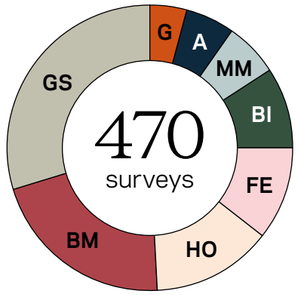
Explore survey data, research and outputs from evidence programmes on the Marine Data Exchange and on following page.

Resource Identification and Optimisation (RIO) Tool

We are working to create a cutting-edge digital tool that will enable us to draw on a wide range of datasets providing a sophisticated view of seabed constraints. We will use this to help build a picture of risks, opportunities and interactions to inform sustainable offshore development around England, Wales and Northern Ireland.

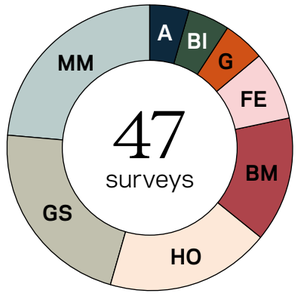
Inquisitive Cuttlefish – British Waters Living Together category of the 2022 Underwater Photographer of the Year. Photo: Saeed Rashid

A breakdown of surveys held on the Marine Data Exchange



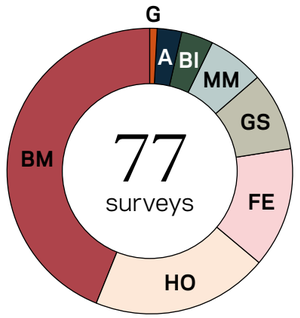
1. Irish Sea

Dig into the post-construction geophysical consenting surveys from Walney Offshore Wind Farm, which explore changes to seabed topography.



2. Celtic Sea

Get washed away by the metocean assessment from the withdrawn Atlantic Array zone in the Bristol Channel, with data from acoustic wave and current equipment.

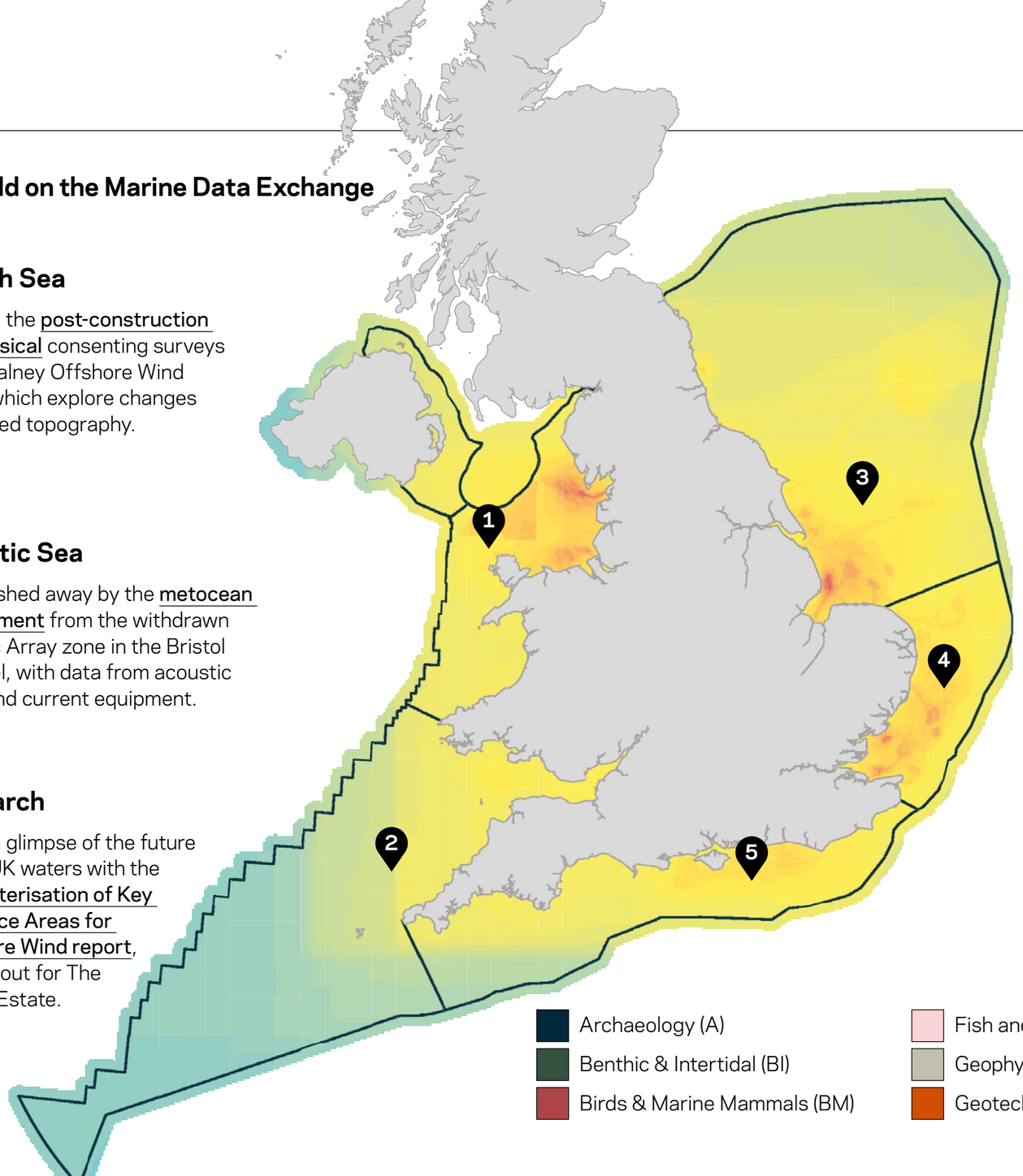


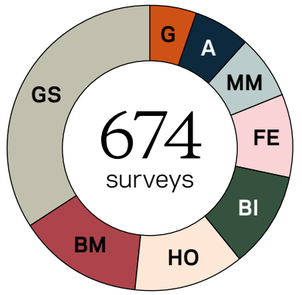
Research

Catch a glimpse of the future of the UK waters with the Characterisation of Key Resource Areas for Offshore Wind report, carried out for The Crown Estate.

Coverage

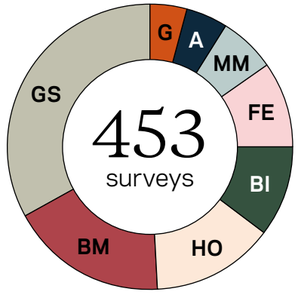
Low — High





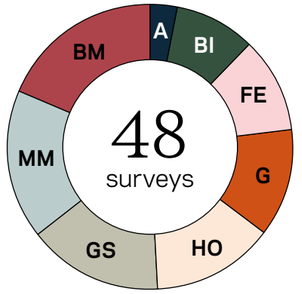
3. North Sea (N)

Stay up to date with the Ørsted seabird collision risk modelling and displacement analysis produced for Hornsea Three Offshore Wind Farm.



4. North Sea (S)

Delve into the work of the Subacoustech Environmental Ltd, exploring the monitoring and assessment of Operational Subsea Noise at Gunfleet Sands 3.



5. English Channel

Explore pre-construction marine archaeology assessments for the Rampion Offshore Wind Farm, including 16th century sailing wrecks, to sunken Flemish cargo vessels and fallen World War II fighter planes.

- Archaeology (A)
- Benthic & Intertidal (BI)
- Birds & Marine Mammals (BM)
- Fish and Epifauna (FE)
- Geophysical & Sedimentology (GS)
- Geotechnical (G)
- Human & Onshore (HO)
- Meteorology & Metocean (MM)

Carbon dioxide displacement due to renewable energy

Displaced CO_2: Represents the carbon dioxide that would have been emitted by traditional power stations to generate electricity, in the absence of renewable energy.

A study of greenhouse gas emissions of the UK electricity system by R.C. Thomson (2014)[1] demonstrated that wind power displaces coal - and gas-fired power stations, and that partial loading of fossil-fuelled power stations has an efficiency penalty of 11%.

The CO_2 displaced by offshore wind can be calculated by using BEIS' emissions statistics for "all fossil fuels" and subtracting 11% to account for the induced efficiency penalty.

The Crown Estate uses this method to measure the benefit of offshore wind.

Displaced CO_2 in 2021: 14,325,142 tonnes[2]

1 *Carbon and Energy Payback of Variable Renewable Generation*, Rachel Camilla Thomson (2014)

2 Provisional figure based on 2020 emissions data from BEIS.

Correct as of April 2022, unless otherwise stated.

Report designed by RF Design (UK) Ltd

The Crown Estate
1 St James's Market
London SW1Y 4AH

+44 (0) 20 7851 5000
@TheCrownEstate
thecrownestate.co.uk

THE CROWN ESTATE