SPARTA
System Performance, Availability and Reliability Trend Analysis

Performance & Reliability Report 2025

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Introduction

What is SPARTA?

SPARTA is an offshore wind farm performance benchmarking tool, run by industry for industry. Standing for 'System Performance, Availability and Reliability Trend Analysis', this tool allows owner/operators of offshore wind farms to compare key performance indicators (KPIs) for their farms to aggregated and anonymised benchmarks. The SPARTA Joint Industry Project (JIP) is sponsored by The Crown Estate and the Offshore Renewable Energy (ORE) Catapult.

Offshore wind performance benchmarks are available from January 2014. In total, owner/operators can supply a maximum of 159 KPIs and then have access to over 500 benchmarks every month, including derived values, covering four main areas:

- Availability
- Production and Lost Production
- Reliability
- Operations

Who is involved?

The owner/operators included here are participating in the 2025 SPARTA portfolio and all are responsible for offshore wind farms in UK waters. The SPARTA group aims to continue gathering members across Europe to maximise system data and produce more robust benchmarks for industry.

Participating Owner Operators

Sponsor Companies

Principles of SPARTA

The SPARTA platform has been designed based on the following principles, which have helped establish SPARTA as the industry-leading performance benchmark provider for offshore wind:

- **Anonymity:** Generation of benchmarks requires sensitive operational data. To ensure operational KPIs are not shared, SPARTA aggregates metrics and securely uploads them into an anonymised data pool.
- **Transparency:** There is complete transparency in definitions and methodologies used and these are published in a Metric Handbook. Consequently, results are clear, comprehensive and consistent.
- **Quality:** Extremely high quality and reliable outputs are achieved through continuous metric assurance and verification activity.
- **Data volume:** SPARTA benchmarks are based on a representative population of offshore wind farms in UK waters providing performance data on a monthly basis for over 10 years.
- **Industry-Led:** The SPARTA system was designed by owner/operators for owner/operators and is continuously improved to ensure it reflects industry needs.
- **Monthly Benchmarks:** New benchmarks are made available to members every month. This reveals seasonal variations and can inform detailed optimisation of operations and modelling of new wind farms.

Why is Benchmarking Important?

Benchmarking with SPARTA allows wind farms to compare their performance to an industry “norm”. This allows a number of potential benefits:

- **Identify underperformance:** Find periods where your wind farm is not performing as well as the industry and be armed with the tools to ask why and perform more in-depth analysis.
- **Identify good practice:** When your wind farm is one of the higher performing wind farms, have the resources available to first identify this period and be able to review what made this period so good.
- **Future planning:** By filtering on certain dimensions see how older wind farms are performing and have the ability to compare yourself to these. This can then be used to plan what can be expected as your wind farm ages.
- **Industry collaboration:** Be part of the future and help the industry improve performance, reduce failures and optimise transfers, together. By getting industry to work together, SPARTA aims to help tackle climate change by improving renewables.

The Portfolio

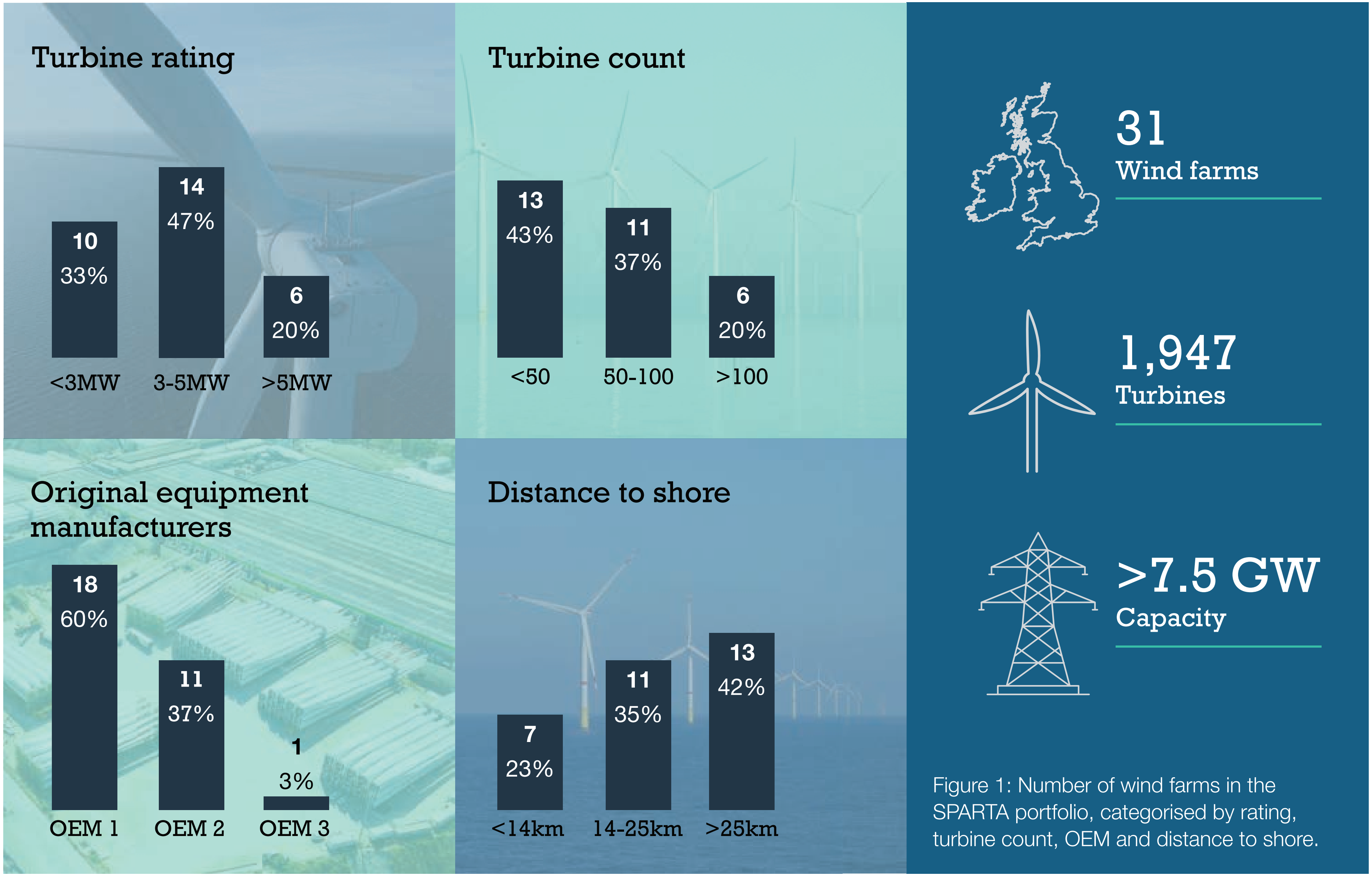
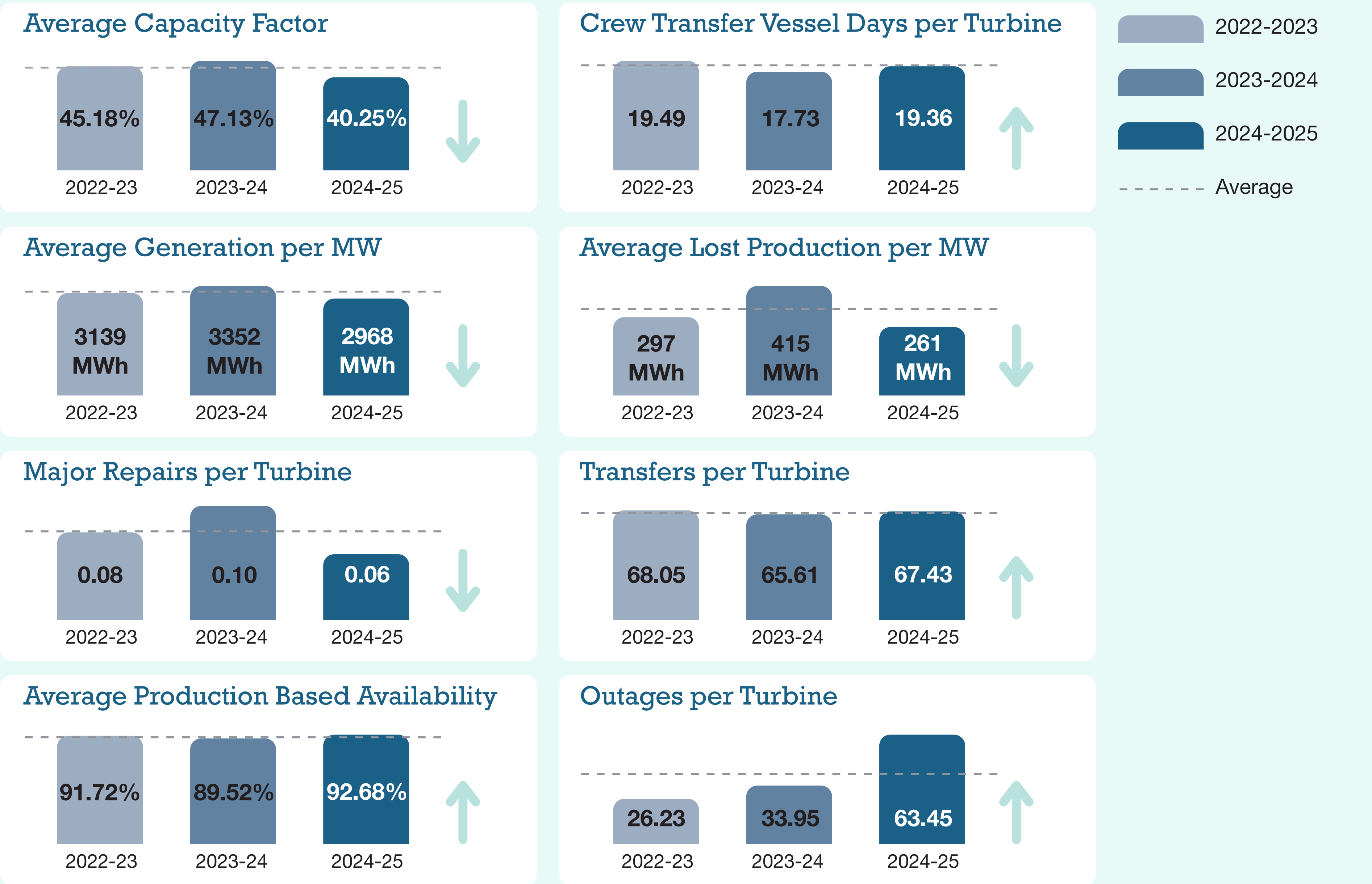


Figure 1: Number of wind farms in the SPARTA portfolio, categorised by rating, turbine count, OEM and distance to shore.

Offshore Wind Performance

2022-2025

Facts and Figures for 2022 – 2025 Financial Years



Production Based Availability

A turbine will mostly be operating at and above 95% availability

What is Production Based Availability?

Production Based Availability, or PBA, is a measure of how well a turbine is using the wind resource available to it. Unlike capacity factor, PBA does not punish for low winds, as it measures how well the turbine is performing compared to its power curve, given the wind speeds that occur at that site.

Example:
The wind at site is 6m/s and the power curve says the turbine should be generating 1000kW but the turbine is only producing 700kW. This would give the turbine a PBA of 700kW/1000kW, so 70%.

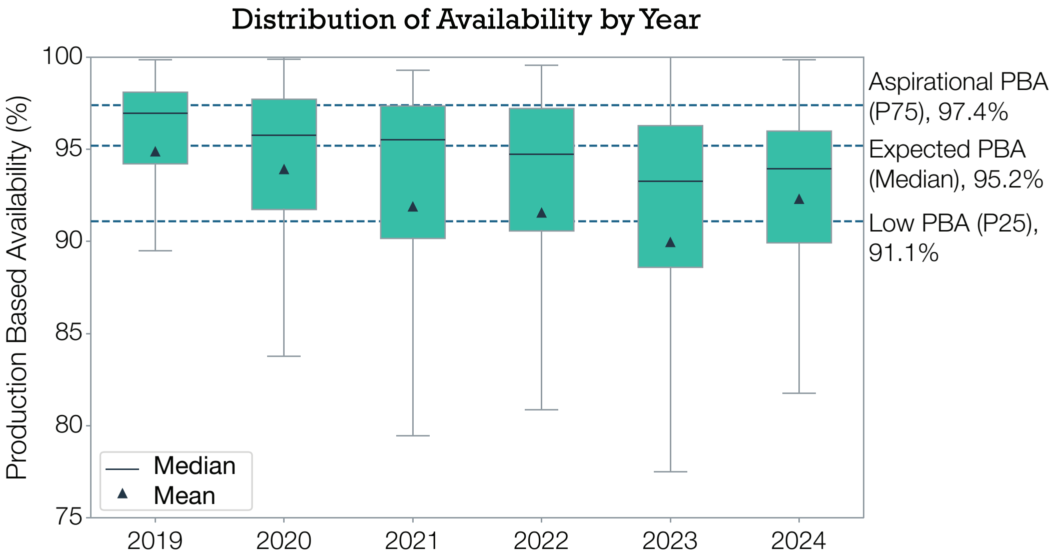


Figure 2: Distribution of monthly PBA reported across financial years 2019/20-2024/25.

Looking at the range of availabilities achieved over the course of the SPARTA program, we can see what PBA might be attainable or even aspirational for a windfarm.

You would expect your farm would generally be operating at or above 95% availability. This figure is likely in line with some agreed targets made with manufacturers, which if broken might result in compensation or action from the OEM.

Up to 97% availability, windfarms will be seeking a more aspirational level of generation. Approximately a quarter of windfarm months supplied fit into this bracket. This is no small feat, with the common small issues that turbines experience daily.

On the lower end of the scale, bad months can vary dramatically in character. Availability will often depend on the nature of any faults that occur. For example, a cable failure is liable to take out a large section of the operating capacity at one time, severely disrupting generation. An issue with a singular turbine might disrupt generation less.

Over time, we have seen more months with distinctly low availability. This is partly due to the increasing amounts of grid curtailment in the UK and partly due to individual farms that were long-affected by significant outages.

Transfers

Transfers on and off turbines continues in a declining trend for the good of Health & Safety

We have now seen 4 consecutive years with an average monthly number of transfers per turbine of 6 or lower, having reduced from 11 back in 2014/15. This suggested the industry has reached a point of matured O&M strategy in this respect.

Turbine maintenance activity peaks in the summer months due to the favourable weather conditions for vessel operations and decreased generation potential, prompting operators to conduct scheduled maintenance.

What is a turbine transfer?

A turbine transfer is defined as the number of completed transfers of technicians from a vessel onto a turbine or substation.

A technician transferring onto and then subsequently off of a turbine counts as one transfer.

A single technician can transfer onto several turbines in a day and a vessel can transport several technicians to a singular turbine.

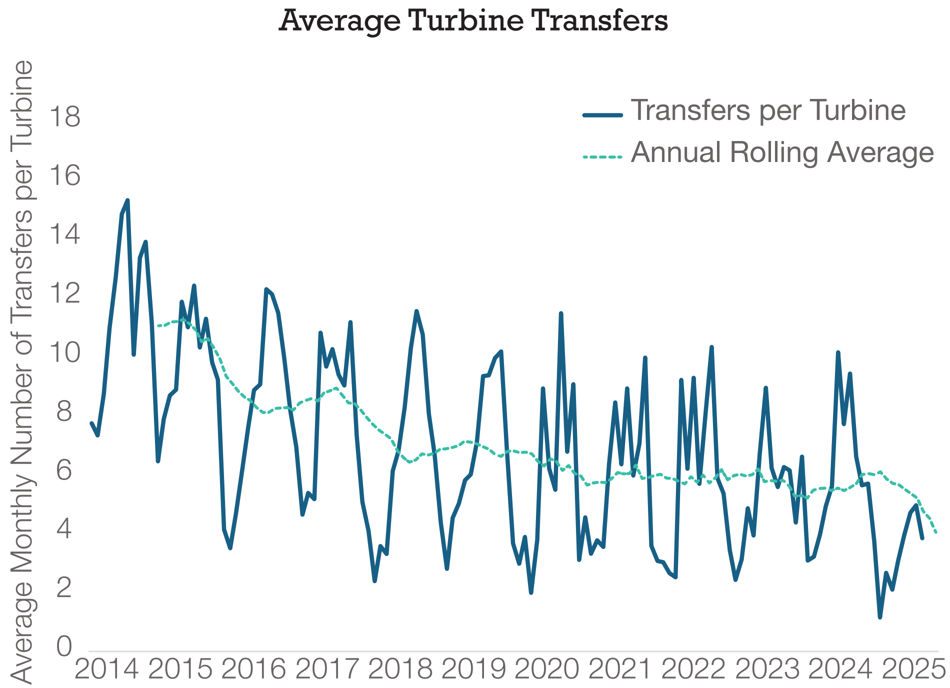


Figure 3: Turbine transfers over time with annual rolling average.

Average Turbine Transfers per Month

Jan	Feb	Mar	Apr	May	Jun
4.75	4.89	7.25	8.48	8.92	9.51
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
9.90	10.23	8.98	6.66	5.23	3.39

Forced Outages

Certain systems fail often for short periods and others fail less often with higher impact

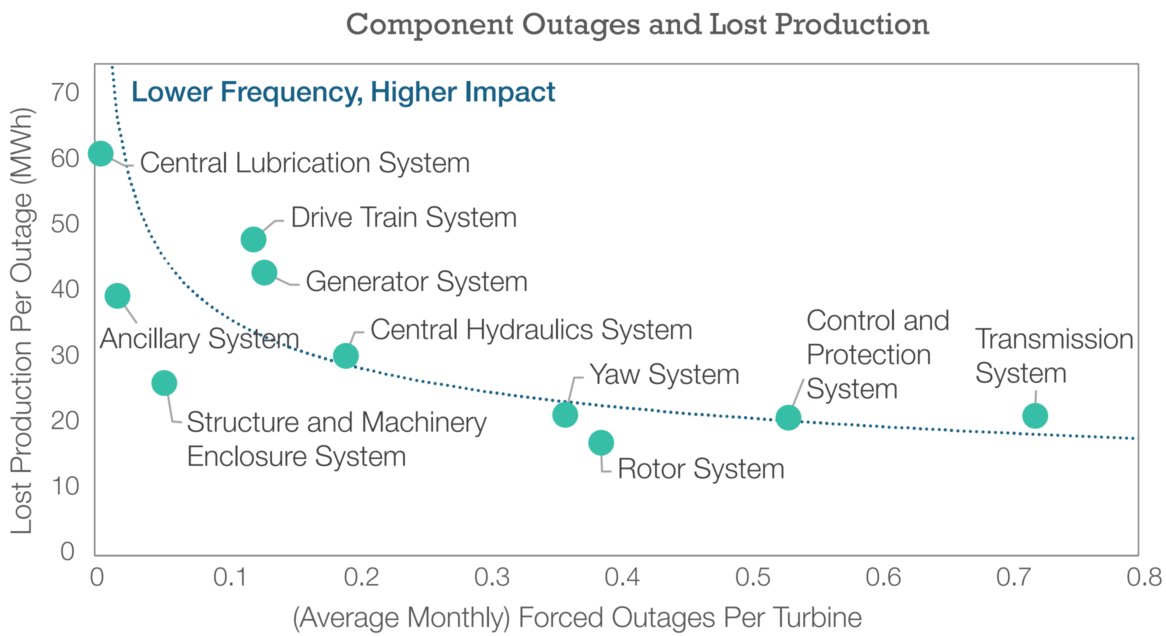


Figure 4: Average monthly forced outages per turbine and lost production per outage, by component.

What is a forced outage?

A forced outage is defined as when an immediate action to disable the generating function of the wind turbine is required as unforeseen damage, faults, failures or alarms are detected. The SPARTA methodology dictates that members should take the first in a cluster of alarms as the one that is the most likely root cause of the failure. Forced Outages do not include major repairs – instances where a jack up barge is required for significant maintenance or replacement.

To understand what parts of the turbine require the most attention, the turbine is broken down into several components and sub-components. The group uses the non-vendor specific component taxonomy created by the Reference Designation System for Power Plants (RDS-PP) Renewables Best Practice group (formerly known as the RDS-PP Nordic group) - a group of Turbine OOs and OEMs who agree common identifications for wind turbine subcomponents.

Plotting the frequency of outages against the lost production per outage allows some interpretation of which competent failures may benefit from additional attention or innovation. The component that consistently triggers alarms the most is that of the transmission system, the electrical section that transmits the energy provided by the generator system into the medium voltage grid. The yaw system, central control and protection system, and rotor system are also frequent causes of forced outage and pose as potential targets for industry wide improvement.

Forced outages associated with the drive train system, generator system and central hydraulics systems occur less often but when they do, they can have the most significant impact on production.

Grid Curtailment

Wind farms are increasingly curtailed due to transmission constraints

One factor affecting turbine availability is the availability of the grid to receive any generation. Over the past few years the UK has had an increase in the amount of curtailment placed on offshore windfarms from the Transmission System Operators (TSOs). This will occur if there is not enough demand or if the transmission capacity is insufficient to get the electricity where it is needed.

Supplementary analysis using public data from Elexon's Balancing Mechanism Reporting Service shows that this has been acutely present since the latter half of 2021. On a monthly basis, this can restrict operating capacity by as much as 15% - a significant amount considering most of this curtailment will be coming from a few farms.

Curtailed Production from Grid Constraints

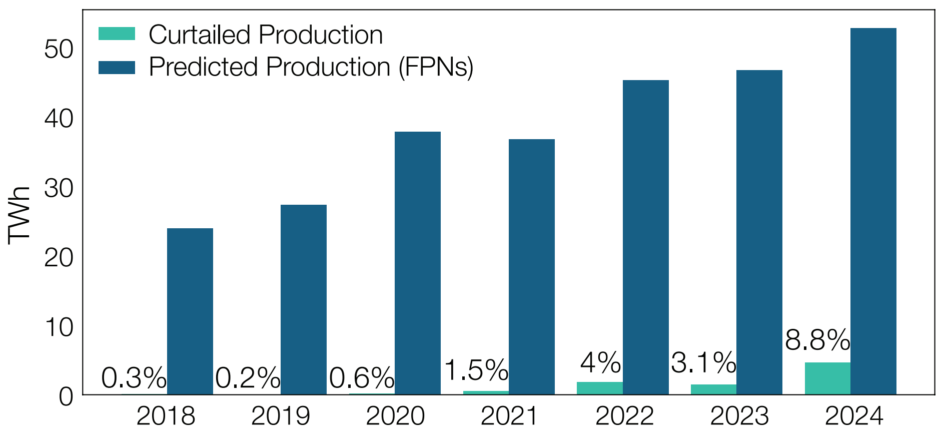


Figure 5: Estimated curtailed production as a percentage of expected, measured as agreed reductions to 'Final Physical Notifications'.

Energy Curtailed by the TSO (GWh)

	2021	2022	2023	2024
Jan	3.8	235.8	105.9	281.6
Feb	4.1	331.8	99.0	339.5
Mar	13.8	160.5	33.7	324.0
Apr	5.6	102.0	110.2	382.5
May	2.5	76.8	55.1	104.2
Jun	1.0	152.9	13.4	366.3
Jul	1.9	70.3	100.6	146.2
Aug	0.8	71.0	78.8	644.3
Sep	19.3	103.0	53.0	300.6
Oct	104.9	223.5	256.3	589.5
Nov	233.1	198.7	224.3	462.5
Dec	162.3	74.3	327.8	694.7

Figure 6: Curtailed production in GWh by month.

In 2024, grid curtailment of offshore wind farms reached a new high, at over 8% of potential production, primarily in the winter. This year has seen increased network outages during upgrades to the system (particularly to boundaries 'B4' and 'B6'), coupled with added capacity in the most affected areas.

Regional Grid Curtailment

Transmission bottlenecks acutely affect wind farms in Scotland

On a regional basis, the biggest impact comes to farms in Scottish waters due to key transmission bottlenecks above the Scottish central belt and at the Scotland-England border.

In particular, Seagreen, which came fully operational in October 2023, had the majority of its production curtailed in its first year of operation. Over a longer term, Beatrice and Moray East had over 13% and 27% curtailed, respectively. Smaller curtailments such as 1-2% for Moray West, Walney Extension and East Anglia 1 are also still significant amounts when it comes to lost energy and compensation payments.

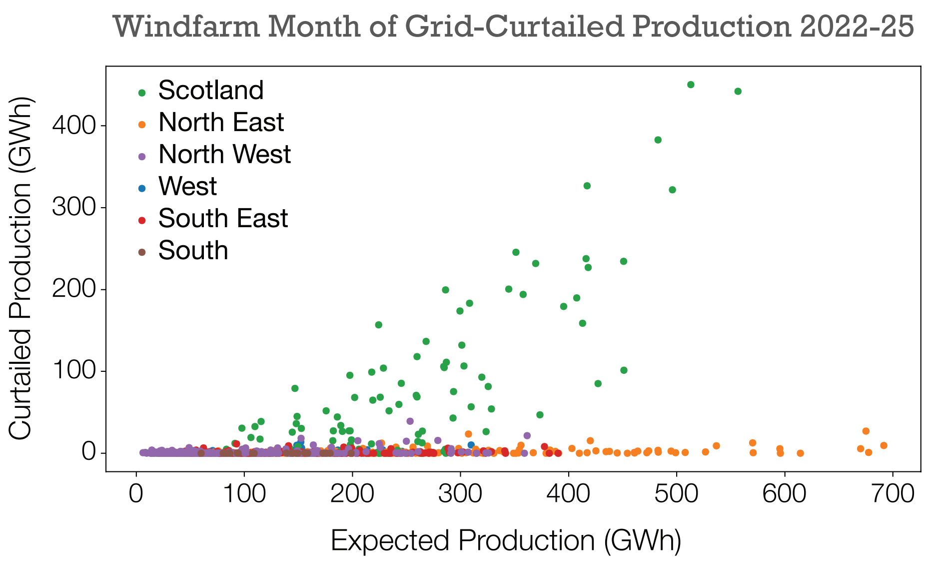


Figure 7: Individual months of wind farm grid curtailment data.

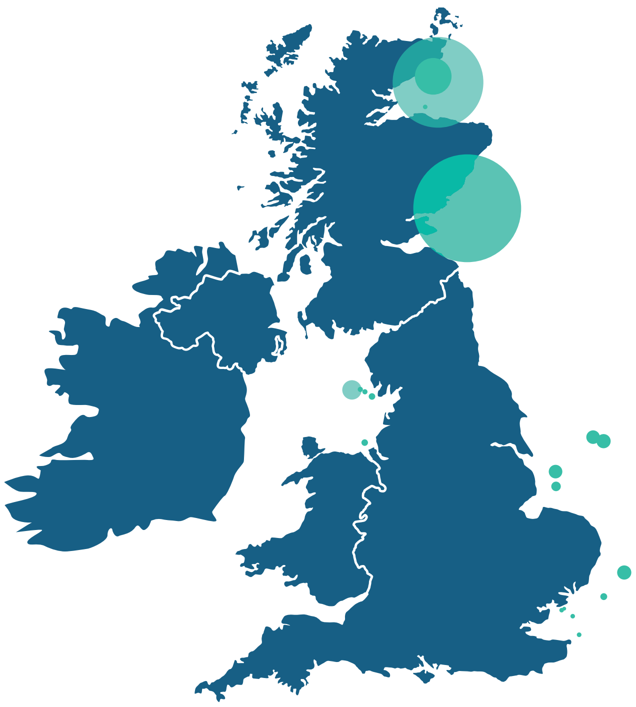


Figure 8: Wind farm curtailment in location. Size of bubble indicates percentage lost.

Farm	Lost Production (GWh)	Expected (GWh)	Percentage Lost (%)
Seagreen	3,044	5,871	64.7
Moray East	2,949	9,362	31.5
Beatrice	623	6,761	9.2
Moray West	15	746	2.0
Walney Extension	112	7,875	1.4
East Anglia 1	70	8,003	0.9

Major Repairs

Major Repairs

Costly replacements using Jack Up Vessels may be expected on average 1.5 months a year

What are major system repairs?

A major system repair is defined as a repair requiring mobilisation efforts far and above those normally seen during routine wind farm operations, using jack-up vessels.

These repairs incur large financial costs and halt turbine production for extended periods of time.

In general, major repairs are rare events, meaning that the data surrounding them is limited.

0.09 annual rate of major repairs per turbine

2.8 expected major repairs over turbine lifetime

28 days expected downtime per major fault

3277 MWh expected downtime per major fault

Approximately an eighth of major repair inputs are non-zero, which means you might expect at least one major repair being conducted up to 1.5 months a year on your farm. Considering that major repairs are more likely to be grouped together while a jack-up vessel (JUV) is one site, it is more likely that a 2-month campaign is performed every 3 out of 4 years.

Major repairs are extremely expensive operations, driven by the high cost of JUVs and the long interruption to generation.

Splitting major repairs out by component, one can see that blades and gearboxes are repaired or replaced more frequently over shorter periods, whereas balance of plant and large electrical components (such as a transformer) may be replaced less frequently and take longer to fix.

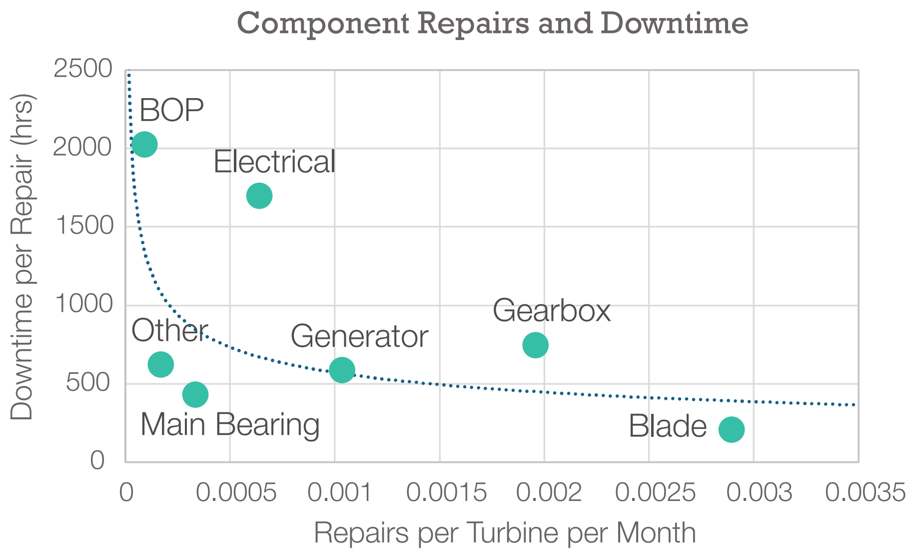


Figure 9: Average monthly major repairs per turbine and lost production per outage, by component.

Determinants of Major Repairs

Major repairs were most prevalent around the warranty period

There was no significant correlation between specific component failures and turbine manufacturer or type. Gearbox repairs were done on almost all applicable turbine types, and blades and generators have been replaced on approximately two-thirds of turbine types.

Relatively few major repairs occur within the first 3 years of life. The wind farms with the highest rate of major repairs in the set is those aged 3-6 years at the time of reporting. During this time, the warranty period for the turbine will typically come to an end and a new maintenance agreement is established. Any persistent issues will look to be dealt with within these years at the cost of the manufacturer.

While most repairs occur in the Summer and Autumn, the majority of downtime owed to these faults occurs in the Winter, when the wind is high and the turbine is more frequently in full operation. If a fault requiring a major repair does occur in the Winter, it will incur a lot of downtime due to the restricted operations allowed during this period. Operators are likely to try and at least operate at reduced capacity until the Summer when it is easier to replace a component. A significant number of major repairs have also been done in the Autumn.

The risk of these faults is heightened by a scarcity of JUVs in industry. With vessels often booked in advance for installation at new wind farms, it can be hard to procure a capable vessel at short notice, increasing the downtime at the farm.

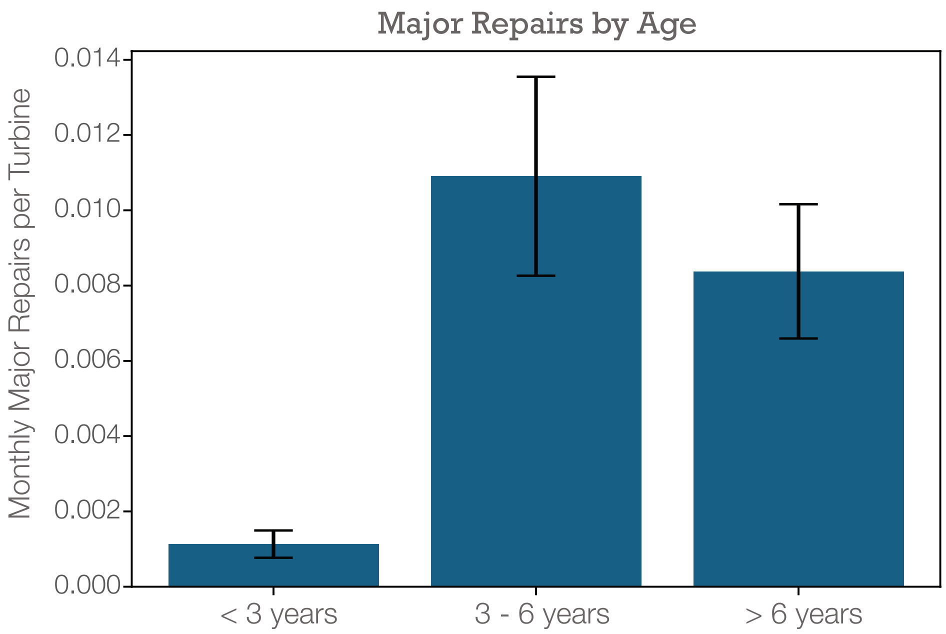


Figure 10: Monthly major repairs per turbine per windfarm by age.

Major Repairs Split Across The Year (%)

Jan	Feb	Mar	Apr	May	Jun
1.94	4.87	7.38	4.11	7.9	11.06
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
12.37	6.62	10.66	13.19	13.73	6.19

Campaigns

Most major repair campaigns last up to a couple months, but they could last over 6 months

As the data provided to SPARTA is monthly, repairs are reported monthly even though they could be part of a single repair campaign spread over multiple months. Repairs were clustered into consecutive periods of associated downtime and repair work to estimate the impact a campaigns in general.

On average a campaign would take just over 2 months. Most repair campaigns took place over multiple months, though a substantial amount (45%) only took place in a single month. Several campaigns took longer than 4 months, though they were the minority (5%). At least one campaign was also split over two years of work.

Major repairs rarely address only one component replacement due to the high cost of the operation. The average number of component repairs reported was 5.4. Anecdotally, there were instances where repairs were postponed so that additional components could be replaced.

Approximately a third of campaigns tackled the replacement of more than one component type. These mixed campaigns maximise efficiency by addressing multiple high-failure components in a single mobilisation, reducing downtime and costs.

The average downtime for each fixed component was 1000 hours, meaning that the downtime of an average campaign was over 5000 hours. This interruption to generation is costly, even before the cost of the maintenance is considered.

2.1 months average campaign length

32.4% campaigns with mixed component types

5.4 average number of component repairs

1,000 hours mean downtime per component fixed

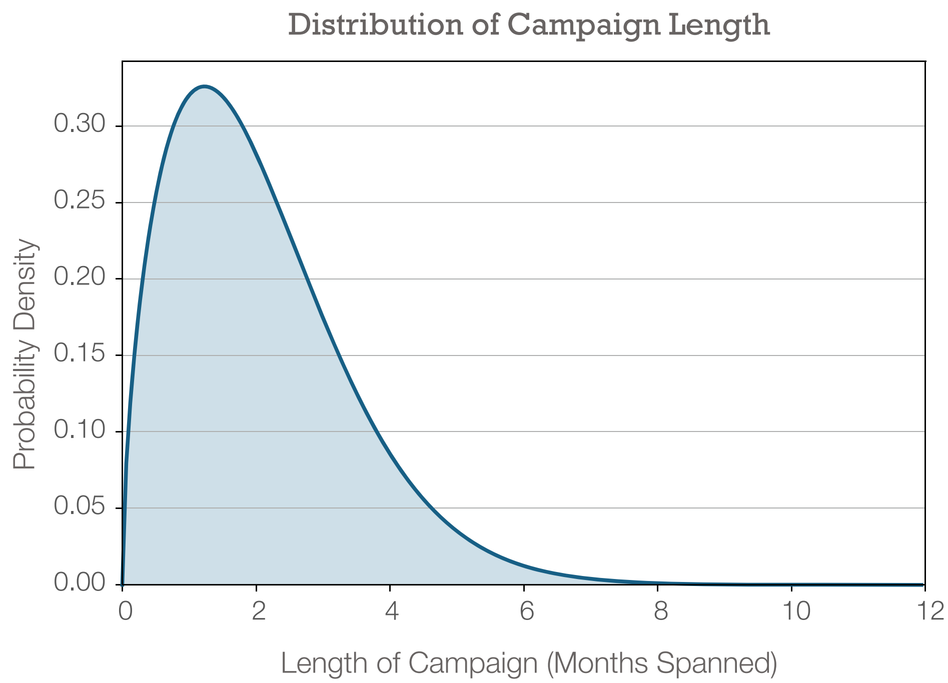


Figure 11: distribution of campaign lengths.

Conclusion

Summary

Offshore wind has continued to grow as a substantial contributor to the UK electricity mix and looks to grow further as the UK aims to close in on its 2030 deployment targets. The performance of this critical infrastructure continues to be of paramount importance to the energy security of the country. Benchmarking gives owners and operators of wind farms a key insight into the relative performance of their assets in an industry that is notoriously guarded about data sharing. Performance benchmarking allows them to set realistic targets and pointedly address specific areas of underperformance to make sure the energy keeps flowing into the UK market.

This performance and reliability analysis of SPARTA wind farms shared key insights from the group:

Availability of wind turbines can range significantly, particularly for outliers with large outages, but generally a turbine should generate over 95% of its expected power.

- The number of transfers on and off turbines has continued to remain low and even decrease in the last year, as operators prioritise the safety of the workforce and reduce risk.
- The failure rate and impact of various component outages were shared, highlighting the large impact of failures to systems such as the drive train and generator, and the frequency of failures to the transmission and CPS systems.
- Grid curtailment continues to grow in Scotland and reduce availability, particularly with the introduction of large new farms and the outage of transmission assets while the grid gets upgraded.

The report also explored the high impact of major system repairs on turbines, which happen infrequently but require large expensive vessels to achieve. The analysis showed the contribution of different component types to these major faults and gave insights on the way that they are grouped together and resolved in campaigns.

Membership

Owner/operators not currently involved in the SPARTA programme are invited to join the group through the members collaborative agreement, to add to the anonymised benchmarking data set and benefit quickly from an analysis of their performance against their peers.

Participation in SPARTA also provides owner/operators with the opportunity to work with seasoned professionals in the field of offshore wind farm O&M performance measurement.

Applications or enquiries for new members may be made at any time by contacting the SPARTA team:

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