SPARTA
System Performance, Availability
and Reliability Trend Analysis

System Performance, Availability
and Reliability Trend Analysis

Portfolio Review
2020/21

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**

Why Read This Report?

The SPARTA portfolio reviews are the industry standard for information on transparent and trusted benchmarks. Like the reviews before, this report details some of the trends identified over the last financial year (April 2020 - March 2021) and highlights some more notable historical trends.

These reviews highlight some of the key drivers for offshore wind farm performance and give insight as to how the industry can continue to improve.

What is included in this report?

This report is split into 4 main sections:

1. The Year in Review

The report gives highlights of benchmarks from the 2020/21 financial year, showing the trends of metrics such as capacity factor, production-based availability and turbine transfers. The year is compared to previous years in order to evaluate how the industry is changing.

2. Did COVID-19 Impact Offshore Wind?

Performance metrics are analysed in the context of the COVID-19 pandemic, particularly examining the possible effects of social distancing on maintenance operations.

3. Forced Outages and Major Repairs

The review breaks down metrics supplied by the SPARTA group relating to forced outages and major repairs. Showing the failure rates for various outage types and components, the review looks at some of the factors related to failure rates.

4. Technology and Performance

As WTG technology continues to develop, the performance of assets is changing. In a final section, the review examines the performance of different generations of turbine, including a comparison of direct drive and gearbox turbines.

Introduction

Who is Involved?

All major owner/operators with offshore wind farms in UK waters are participating in the 2020/21 SPARTA Portfolio Review. This year Netherlands-based firm Eneco were welcomed to the SPARTA portfolio, marking the first time windfarms out-with the UK have been included in the dataset. The SPARTA group aims to continue gathering members across Europe in order to maximise system data and produce more robust benchmarks for industry.

Sponsoring Organisations

CATAPULT
Offshore Renewable Energy

THE CROWN ESTATE

Participating Owner Operators

RWE
EDF
Ørsted
Eneco
sse
equinor
VATTENFALL
SCOTTISHPOWER RENEWABLES

Principle 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.
- **Representative data volume:** SPARTA benchmarks are based on a representative population, with over 60% of all offshore wind farms in UK waters providing performance data on a monthly basis for over four 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 Year in Review

Highlights and Long-Term Trends from the Industry

Annual Performance 2020/21

Despite the disruption of COVID-19 pandemic to work-life and maintenance procedures, the offshore wind industry has remained close to the excellent bar of performance that has been set in recent years. Compared with averages in the set, the portfolio observed higher than average electricity generation and lower transfers and outages per turbine.

Having had a remarkable year in 2019/20 with new highs in many performance metrics, performance in 2020/21 dipped in terms of a number of metrics – including lower capacity factor, production-based availability (PBA) and electricity generation, and more lost production.

This section explores several of the metrics reported to owner/operators in SPARTA and their trends over the year. It also delves into how those numbers fit into longer-term trends and some of the factors that might affect them.

↑ **66,603 MWh** Total Average Generation per MW

↑ **3449 MWh** Average Generation per MW

↑ **19** Crew Transfer Vessel Days per Turbine

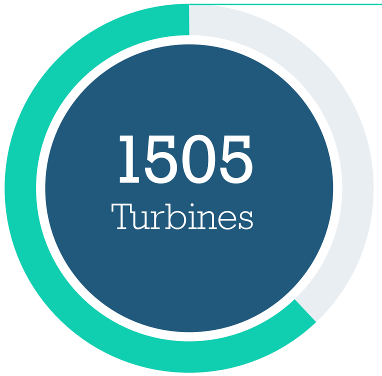
↑ **221 MWh** Average Lost Production per MW

↓ **93.9%** Average Production Based Availability

↓ **28.6** Outages per Turbine

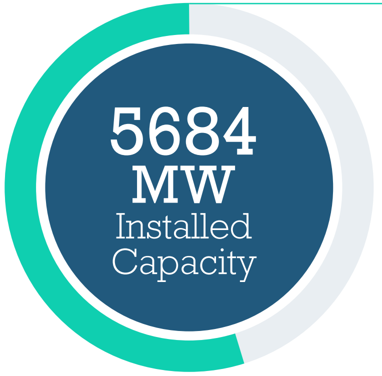
↓ **75.4** Transfers per Turbine

↓ **38.1%** Average Capacity Factor



66%
of UK Turbines

62%
of UK Windfarms



55%
of UK Installed Capacity

*Comparison figures are the average from datapoints before 2020/21

Capacity Factor

High winds allowed for strong electrical output.

Capacity Factor is a general measure of performance that encompasses the amount of wind resource available at a farm as well as its operational performance. This means that it follows a seasonal trend, correlating strongly with wind speed. This is clearly visible in Figure 1, which displays a low average capacity factor for the fleet during the summer months and a high capacity factor in the windier winter months. Over the years, this pattern has been consistent in the dataset, with 2020/21 failing to reach the heights of a record-breaking 2019/20, in which higher winds and electrical outputs were recorded. The year still managed to attain a strong capacity factor figure anyway, in part thanks to strong winds over several sites.

What is Capacity Factor?

Capacity Factor is a measure of how much power a turbine is producing compared to its rated capacity. Generally, this is reported over a period of time for a wind farm, so is a measure of how well the farm is producing on average compared to its rated capacity.

Example:

A 500MW wind farm produces 219,000 MWh for a month. For a capacity of 500MW for a month (730 hours), the farm had the potential to produce 365,000 MWh.

219,000 MWh / 364,000 MWh = 60%

Figure 1 - Capacity factor over time in 2020/21, featuring quartile ranges and mean wind speed, (top) and capacity factor describe by financial year from 2016/17 (bottom).

Capacity Factor

New wind farms and high winds fuel changes in regional performance.

In the 2018/19 portfolio review, the authors discussed the relative benefits enjoyed by windfarms lying on the East Coast of the UK, where performance was generally better than the West when measured by production-based availability and lost production. However, with a greater mean significant wave height and more non-access days to windfarms, there are also clear drawbacks to the East. In particular, prior to 2019, capacity factors were generally lower despite high availability.

However, for the last two years the east coast has enjoyed greater wind resource than the west, as shown by greater capacity factors than both the west coast and previous years in the east coast itself. This is partly thanks to a number of new (and more modern) windfarms in the East with higher rated capacity and partly due to greater average wind speeds in the region. The wind speeds there bettered the west 2 years in a row after having only ever done it once before in the set.

With regards to the roots of strong performance, there are number of correlations to capacity factor that should be considered beyond region. Factors such as age, maintenance strategy and site accessibility can all affect the availability and thus the capacity factor of a windfarm (for a discussion on drivers of performance, see Portfolio Review 2019/20).

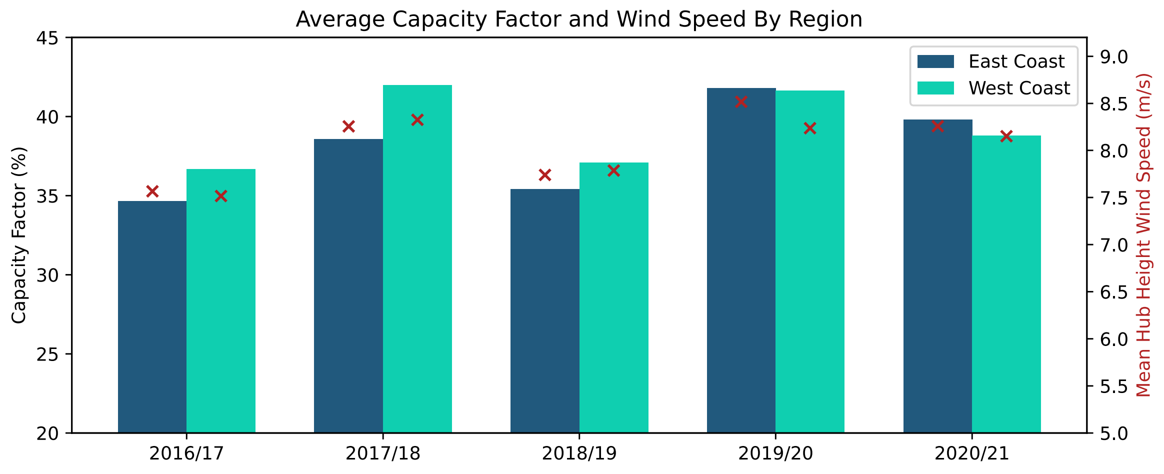


Figure 2 - Capacity factor by financial year in east coast and west coast region, from 2016/17.

Production Based Availability

In terms of PBA, availability took a slight dip compared to recent years.

Given that PBA takes wind speed into account, it is generally accepted to be a more reliable measure of availability than capacity factor. In 2020/21, it shows that despite the relatively good capacity factor owing to high wind speeds, the portfolio experienced its worst year in the set, in terms of availability.

With a PBA of 94.0%, the set experienced a higher share of lost production than any year before. As shown in Figure 3, lost production was generally higher throughout the year than usual, particularly in the latter part of 2020. What had been a gradual upward trend in PBA thus came to end after a disruptive year in industry.

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%.

700kW / 1000kW = 70%

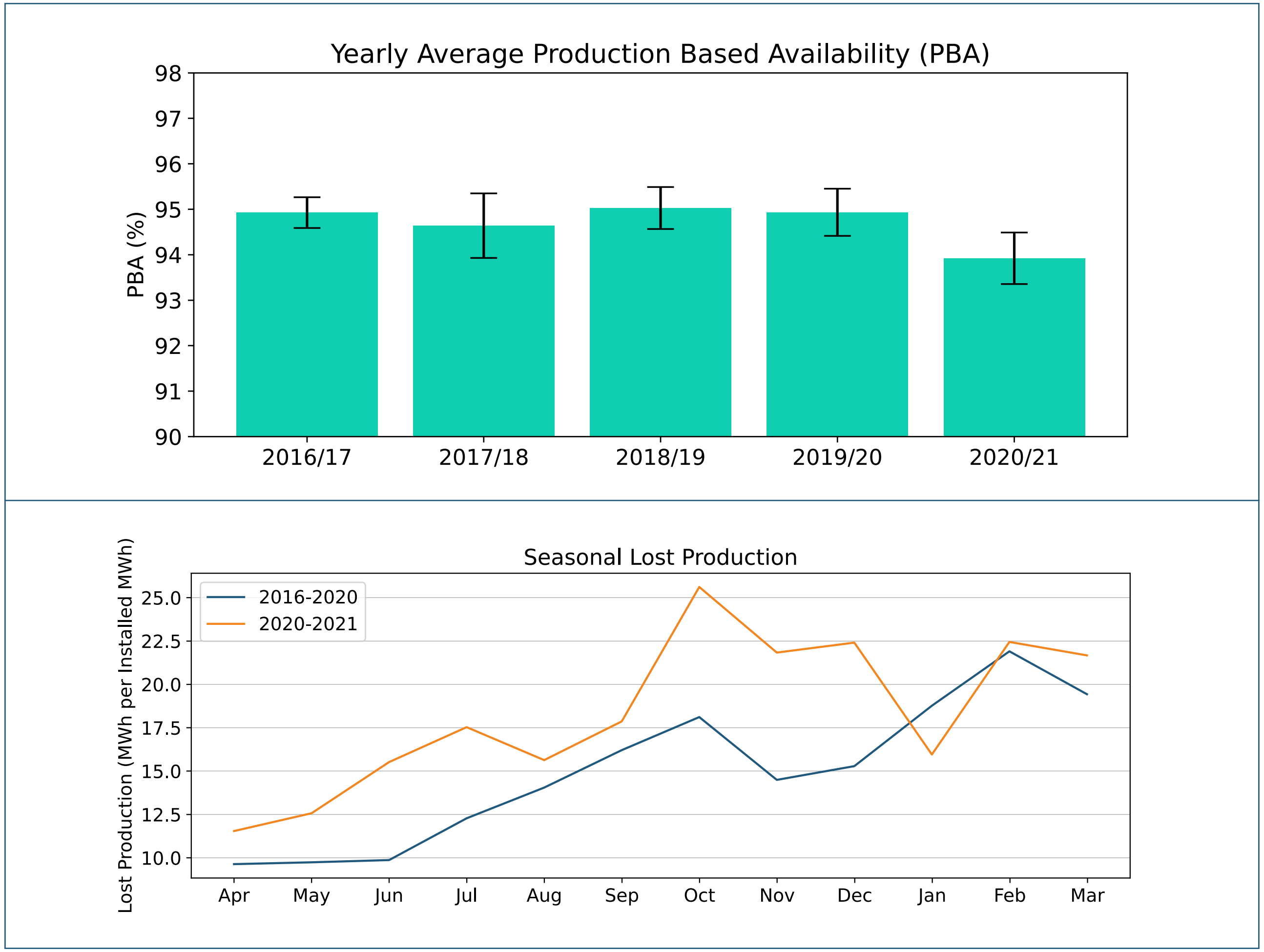


Figure 3 - Average yearly PBA from 2016/17 to 2020/21 (top), and lost production over the year compared with other years (bottom).

Production Based Availability

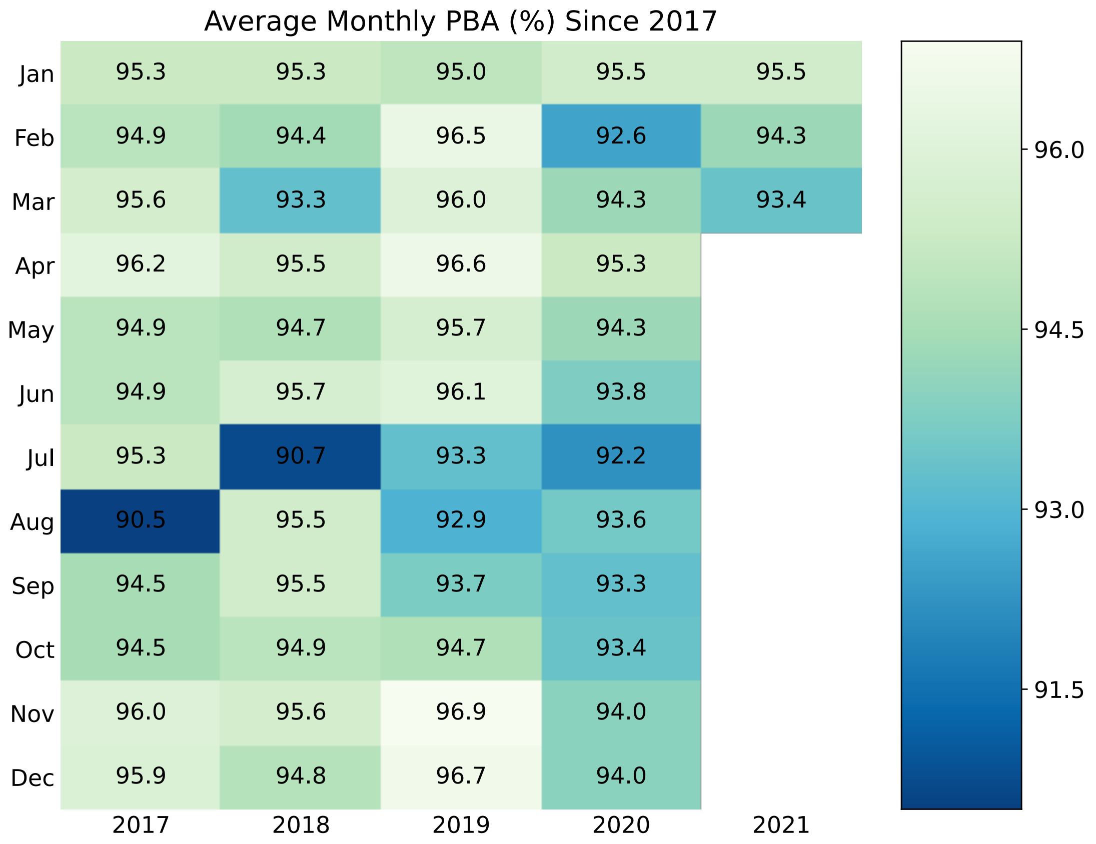
Low PBA values occurred throughout the year, particularly in the second half.

Whereas other years have had off-months or periods, 2020 had consistently low availability throughout the year when compared to similar time periods in other years. As early as February in the prior financial year, availability was struck low, but the string of low values in the summer show the negative impact of a disruptive year.

The coronavirus pandemic influenced all fields of work in strange and unforeseen ways and the offshore wind sector is no exception. The impact of the pandemic on the sector is explored more on page 13, but some of its effect on the industry is alluded to in Figure 4.

Even though PBA was generally lower than usual during the year, the impact of any disruption on availability can be see to be limited by the fact that PBA values only stray up to a few percentage points away from regular. Furthermore, the average PBA was only 1 percentage point lower than in 2019/20. This should not detract from the fact that a few percentage points can indicate a large change in income for an offshore windfarm.

Factors identified in previous reviews that impact PBA include the average number of non-access days due to weather, age of windfarm and maintenance strategy. For example, more non-access days in a windfarm mean that there will be more downtime per outage and thus more lost production. In 2020/21 there was a monthly average of 8.2 non-access days due to weather, slightly lower than the previous average of 8.9 days. This factor is therefore unlikely to explain the lower availability in the year.



	2017	2018	2019	2020	2021
Jan	95.3	95.3	95.0	95.5	95.5
Feb	94.9	94.4	96.5	92.6	94.3
Mar	95.6	93.3	96.0	94.3	93.4
Apr	96.2	95.5	96.6	95.3	
May	94.9	94.7	95.7	94.3	
Jun	94.9	95.7	96.1	93.8	
Jul	95.3	90.7	93.3	92.2	
Aug	90.5	95.5	92.9	93.6	
Sep	94.5	95.5	93.7	93.3	
Oct	94.5	94.9	94.7	93.4	
Nov	96.0	95.6	96.9	94.0	
Dec	95.9	94.8	96.7	94.0	

Figure 4 - Heatmap showing monthly averages of PBA in the portfolio and how they compare with other years.

Operations

The number of visits to turbines continued its downward trend. This is good news for health and safety.

As reported in previous reviews, the number of turbine transfers has been on a decreasing trend over the last decade. Though the number of monthly transfers may be beginning to level out, this year was no exception to the trend in that the number of transfers over the year reached an all-time low. This is likely to also have been impacted by social distancing rules as companies aimed to limit the number of technicians on vessels, as will be discussed in Section 5.

One positive impact of decreasing transfers is the impact that it has on health and safety in the industry. Lower transfers have been accompanied with lower injury rates in the industry as less people have been travelling to turbines and been exposed to risks. This is demonstrated in Figure 5 by a decreasing trend in the total recordable injury rate – the number of recordable injuries per 1 million hours worked. This number is reported by the G+ Offshore Wind organisation in their yearly incident report.

What is a turbine transfer?

Turbine transfers are 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 transfer several technicians onto a singular turbine.

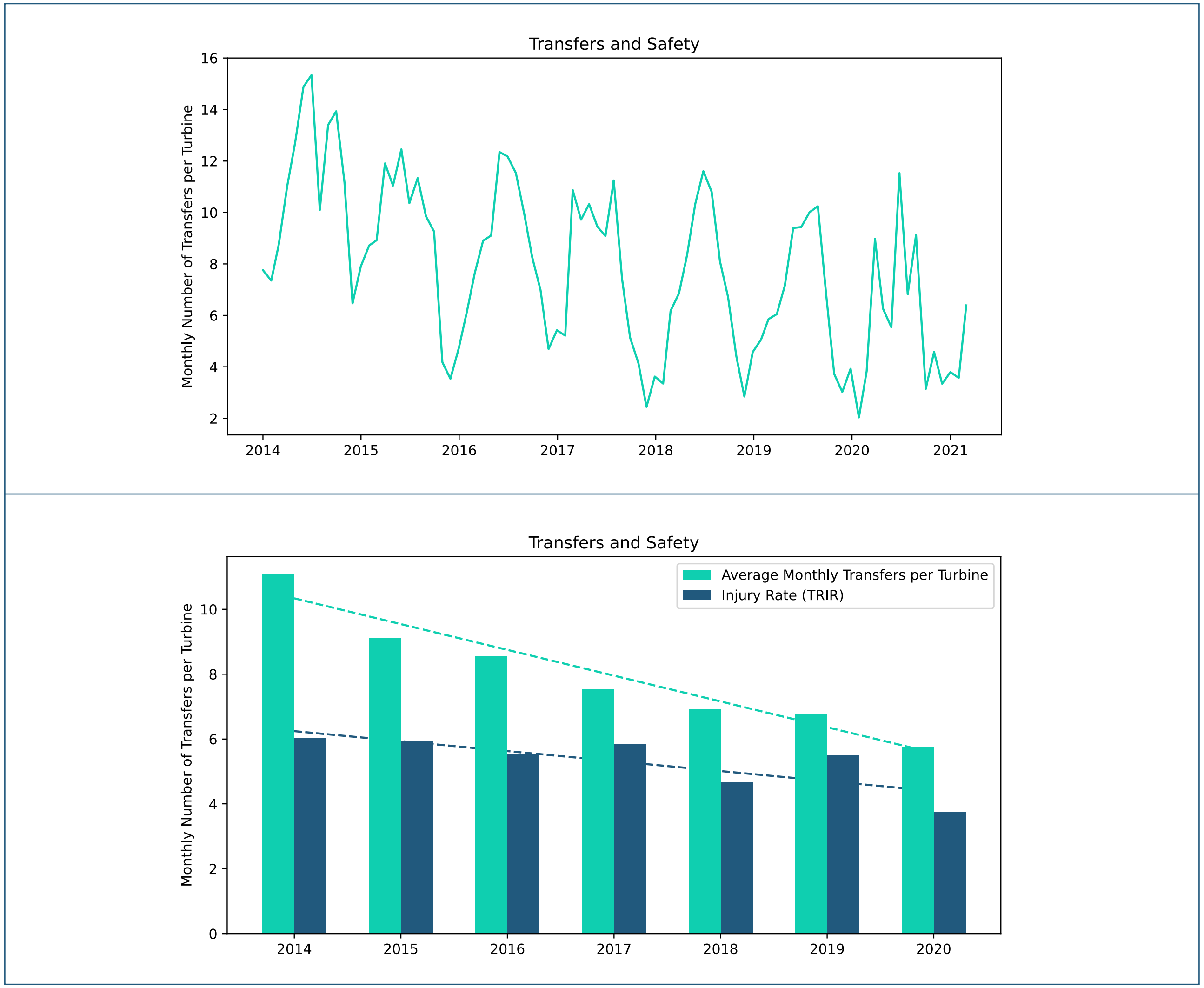


Figure 5 - Number of transfers over time and yearly total recordable injury rates.

Turbine Failures

The number of forced outages per turbine is on a downward trend and was particularly low the past 2 years.

Forced outages are common occurrences in windfarms, as alarms will be triggered by a variety of events which, in theory, will cause a turbine to shut down. On average a turbine will trigger such an alarm 2-3 times a month. This monthly average has been lower in the previous 2 years than it was before, indicating that the industry is getting better at limiting turbine failures.

As discussed in the 2019/20 portfolio review, the industry still has some way to go to make outage data reliable as there does not currently exist a standard robust method of classifying alarm codes. For a discussion of this issue and a further look in to forced outage data, see page 19.

What is a forced outage?

Forced outages are defined as instances where turbine generation is disabled as a result of unforeseen damage, fault or failure. These can be categorised by the component /sub-component that is identified as the root of the outage. Forced outages are distinct from instances of major replacement to the turbine or outages caused by cable outage.

A farm with a relatively high number of alarms that indicate forced outages is more likely to have less availability and higher lost production.

Figure 6 - Average monthly forced outages per turbine over time (top) and per year (bottom).

General Correlations

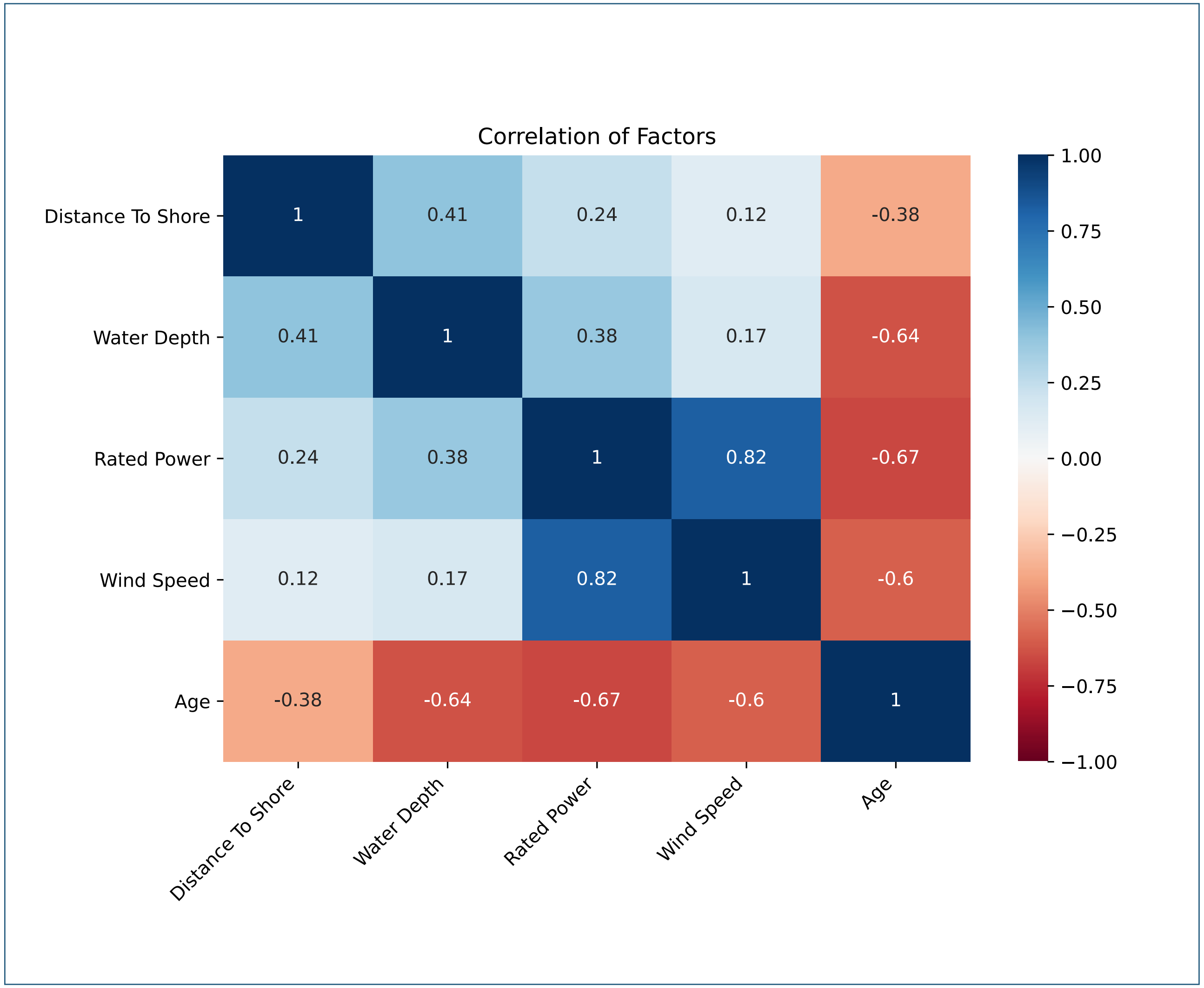
The set shows that newer farms are more likely to be further from shore, in deeper waters and with higher rated power.

A correlation matrix shows how and to what extent different variables are related to each other. A positive correlation means that one variable increases with another. A negative correlation indicates one increases while the other decreases. The correlation matrix in Figure 7 examines relationships between attributes of the windfarms in the set.

For example, there is a positive relationship between water depth and distance to shore indicated by a shared blue square. That means that farms further out from shore are more likely to be in deep water. However, the relationship is not dark blue due to some farms that are close to shore in deep water and some far away in more shallow waters that skew the correlation.

Some significant relationships between the age of windfarms and other factors give a particularly good insight into the direction of the offshore wind industry. Age has a negative correlation with turbine rated power, water depth and distance to shore. This means that newer, younger farms are generally of higher rated power and are often placed in deeper waters, further from shore.

With vast technology improvements over the last decade, windfarm developers are investing in newer turbines that offer higher electrical output. New technology also allows the construction of windfarms in deeper waters that are further from shore and generally offer higher wind speeds. Including availability in the figure does not yield significant correlations, but page 32 draws some comparisons on the performance of different generations of turbines, including a comparison of direct drive generator turbines to traditional gearbox generators.



	Distance To Shore	Water Depth	Rated Power	Wind Speed	Age
Distance To Shore	1	0.41	0.24	0.12	-0.38
Water Depth	0.41	1	0.38	0.17	-0.64
Rated Power	0.24	0.38	1	0.82	-0.67
Wind Speed	0.12	0.17	0.82	1	-0.6
Age	-0.38	-0.64	-0.67	-0.6	1

Figure 7 - Correlation matrix of windfarm details

Did COVID-19 Impact Offshore Wind?

Possible Effects of the Pandemic on the Offshore Wind Industry

A Dip in Performance

Many windfarms experienced lower availability during the past year. Older, lower rated turbines seem to be hit worse.

Lower levels of production-based availability in the year must be examined in the context of the profound disruption to the work patterns and the economy caused by the pandemic. It should however be noted that factors other than the pandemic may have affected individual wind farms.

Examining deviations between windfarm performance compared to organisational averages, the distribution in Figure 8 shows the spread of companies with losses of PBA compared to average. What is first notable is the significant number of windfarms – over a third - that managed to improve their availability compared to other years.

However, there were still a significant number of windfarms that registered notable losses to their availability scores. For reference, previous portfolio reviews have reported that a rise in a few percentage points of PBA could equate to increases in income of approximately £400,000 per month and approximately £5M a year. This means that a loss of a few percentage points in PBA could have a significant financial impact for owner operators.

The disruption seems to have affected the industry unevenly, as PBA dropped on average for windfarms with lower rated turbines – windfarms that are likely older – and increased for the younger windfarms with higher output. Comparing last financial year with averages from the previous 3 financial years, the data shows high average losses for most of the older farms in the set. This could be impacted by the fact that older turbines are likely to need more maintenance to stay at high productivity.

In general, the slightly lower performance should not be automatically attributed to the pandemic without further evidence. There are multiple factors that impact windfarm performance and all should be considered.

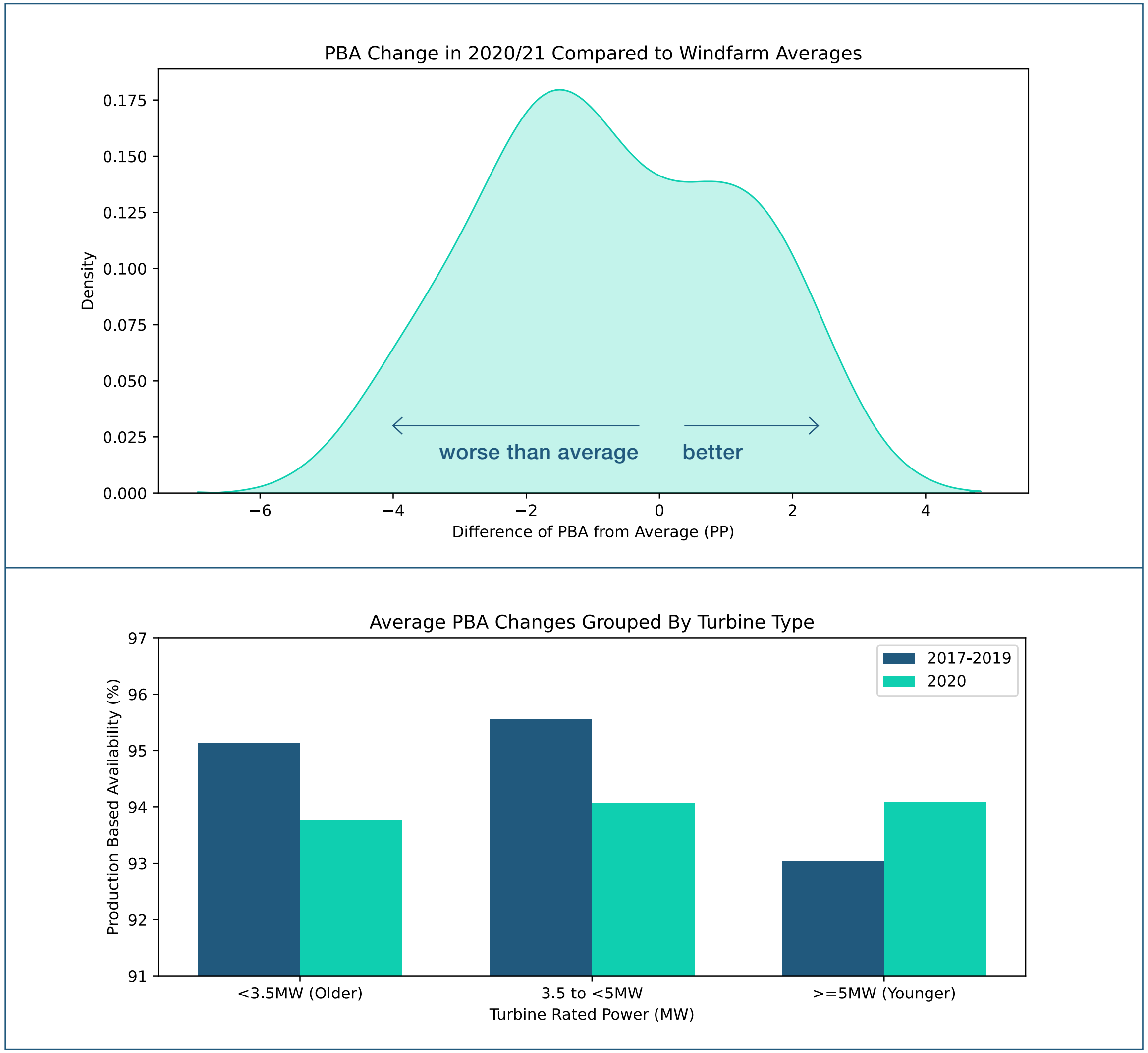


Figure 8 - Percentage point change in PBA as distribution (top) and by generation (bottom).

Varied Performance

The year was characterized by varied performance with a flatter distribution of PBA than ever before.

The differences in age groups are an indication that the coronavirus pandemic did not affect all companies in the same way, with some windfarms maintaining high performance and some having record low PBA for the year.

This variety in performance is typified by a more spread-out distribution of PBA values compared to previous years. That is shown in the cumulative distribution function (CDF) of monthly points in Figure 9. The CDF shows the cumulative share of points contained up to a value – for example, Figure 9 shows that around 40% of uploads in 2020/21 had PBA at 95% or less.

While the previous years had been consistent in the spread of PBA – particularly between the majority of windfarm months that were reported to have above 96% PBA – 2020/21 was less consistent and had a more disparate distribution. A greater number of months with performance in the lower bracket of PBA, between 85% and 95%, has resulted in a larger spread and lower average performance.

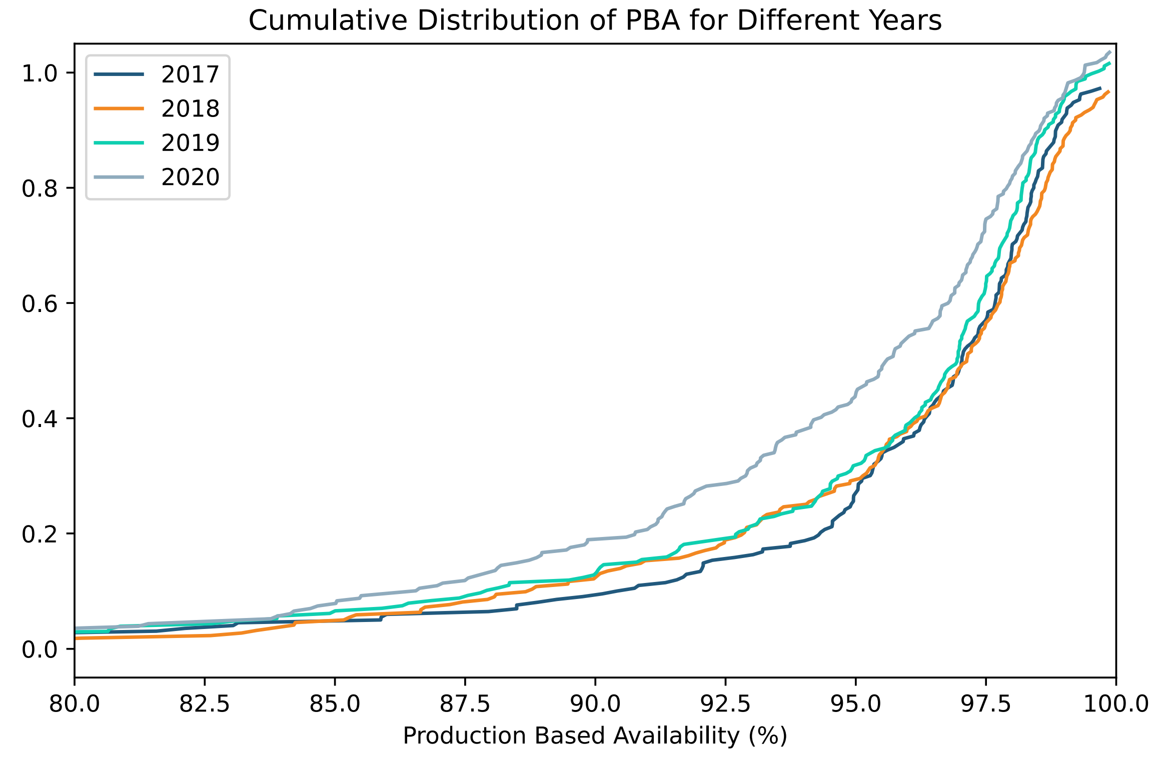


Figure 9 - Cumulative distribution of monthly organizational production based availability over the financial year, by year.

Transfers

The number of transfers hit a new minimum but has been similar to recent years.

Social distancing and work-from-home orders were two of the main ways which the pandemic affected work patterns. Despite the essential nature of much work in the offshore wind industry, this had a major impact on operations as organisations tried to limit social contact within day-to-day practices. In the data, one way such practices can be measured is by turbine transfers – the number of people who move on and off the turbine.

Since records began in 2014 this number has been dropping as organisations have tried to limit the number of staff on turbines in the interest of health, safety, the environment (in terms of vessel use) and operational efficiency. In 2020/21, this number did hit a new low again – particularly in May and June, in the height of the first lockdown, and later in August and October.

Despite the record low transfers – averaging 6.29 transfers per turbine each month - it is worth noting that the numbers were not radically different from the low numbers (averaging 6.78) already set in the previous 3 years, as demonstrated in Figure 10. It is possible that there are a certain number of essential transfers that are difficult to avoid if operations are to be maintained. If this is the case, one way to maintain a similar number of transfers while maintaining social distancing is charter more vessels to take staff to turbines.

These transfer figures are significantly lower than those observed in the set before 2017 which reached averaged 9.36 monthly transfers per turbine.

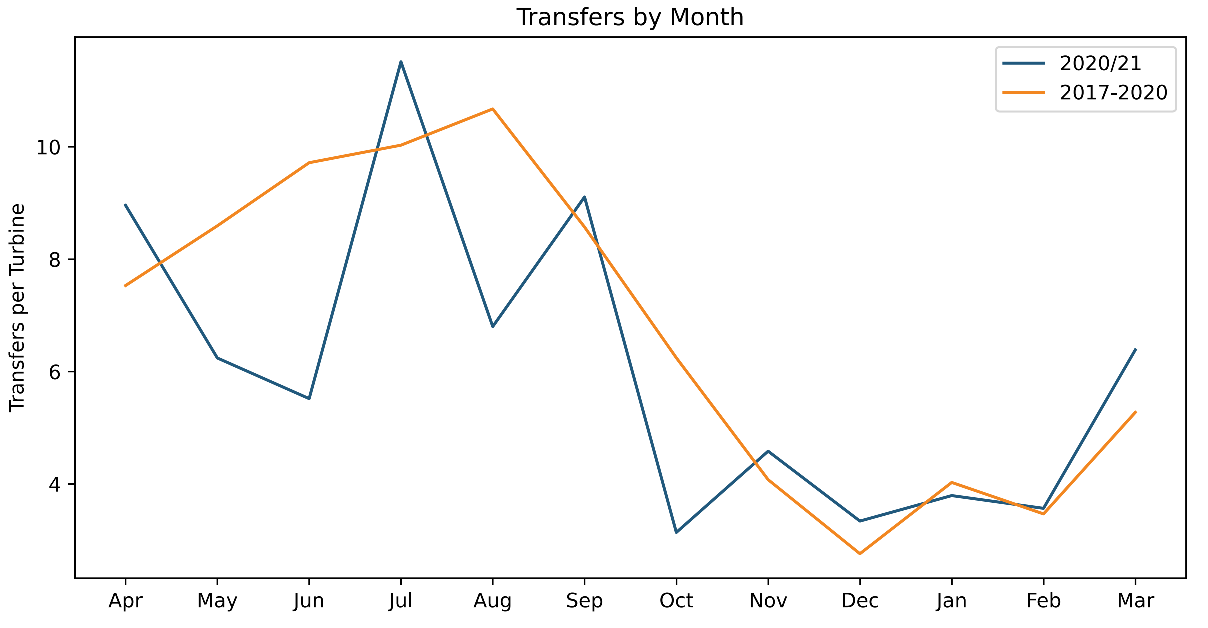


Figure 10 - Number of transfers per turbine over the year, in 2020/21 and on average in the 3 previous financial years.

Vessels

The number of chartered vessels reached a new high after already increasing in 2019.

For the second year in a row, vessel usage reached a new maximum with record numbers of vessels chartered for use in windfarms. On average, windfarms chartered 19 vessel days per turbine in the year – up from 18 the previous year and 13.87 in general in the set.

Vessel use was uncharacteristically high throughout 2020, in contrast to the usual seasonal trend that is visible in the set. Furthermore, a new maximum number of vessel days was set in March 2021 – a month which usually has lower numbers of vessels days. This could indicate that organisations are in general moving to charter more vessels, and it could be that we will see yet another high in 2021/22.

If social distancing did play a role it seems that windfarm operators had been well prepared after having already chartered a high number of vessels in 2019/20.

What is a Vessel Day?

The number of vessel days in a month is the total number of available vessels multiplied by how many days those vessels were available for. SPARTA collects this metric for CTVs, SOVs and helicopters but for the purposes of this report, only CTV vessel days are analysed.

If additional CTVs are chartered in for only part of the month then these are included.

Figure 11 - Number of crew transfer vessel days over time (top) and on average by year and time of year.

Vessel Occupancy

The number of people on vessels was limited, which would have been more problematic depending on the location of farm.

When social distancing was becoming a common part of life, vessel occupancy hit an all-time low in the dataset, but did not need to fall far thanks to the high number of vessels and already-low occupancy observed in 2019/20. Before 2020/21 the average number of transfers per vessel days was 6.21, dropping to 3.9 this year. This means that each chartered vessel facilitated on average 3.9 turbine transfers per day.

Limiting vessel occupancy and maintaining distancing might have been harder for some windfarms than others. One factor impacting vessel occupancy is the distance from the windfarm to shore. As displayed in Figure 11, windfarms that are further away from shore are more likely to have fuller vessels.

Since it takes longer and costs more to get to the windfarm, it is logical that vessels would take more engineers in a single trip and/or deal with maintenance on multiple turbines in one trip (registering as separate turbine transfers). Moreover, windfarms that are further away are much more likely to experience non-access days due to bad weather conditions, meaning that the maintenance may be grouped together while it is possible. Such organisations will likely have found social distancing more challenging than others.

What is Vessel Occupancy?

Vessel occupancy serves as an estimate of how many people are involved in a crew transfer or, more specifically, in a vessel day. It is calculated by dividing the number of transfers by the number of crew transfer vessel days.

While it estimates the occupancy of a transfer, it does not account for the fact that a vessel may make multiple turbine trips in 1 day, so a vessel could transfer a low number of staff to multiple turbines and it would appear to have a high occupancy.

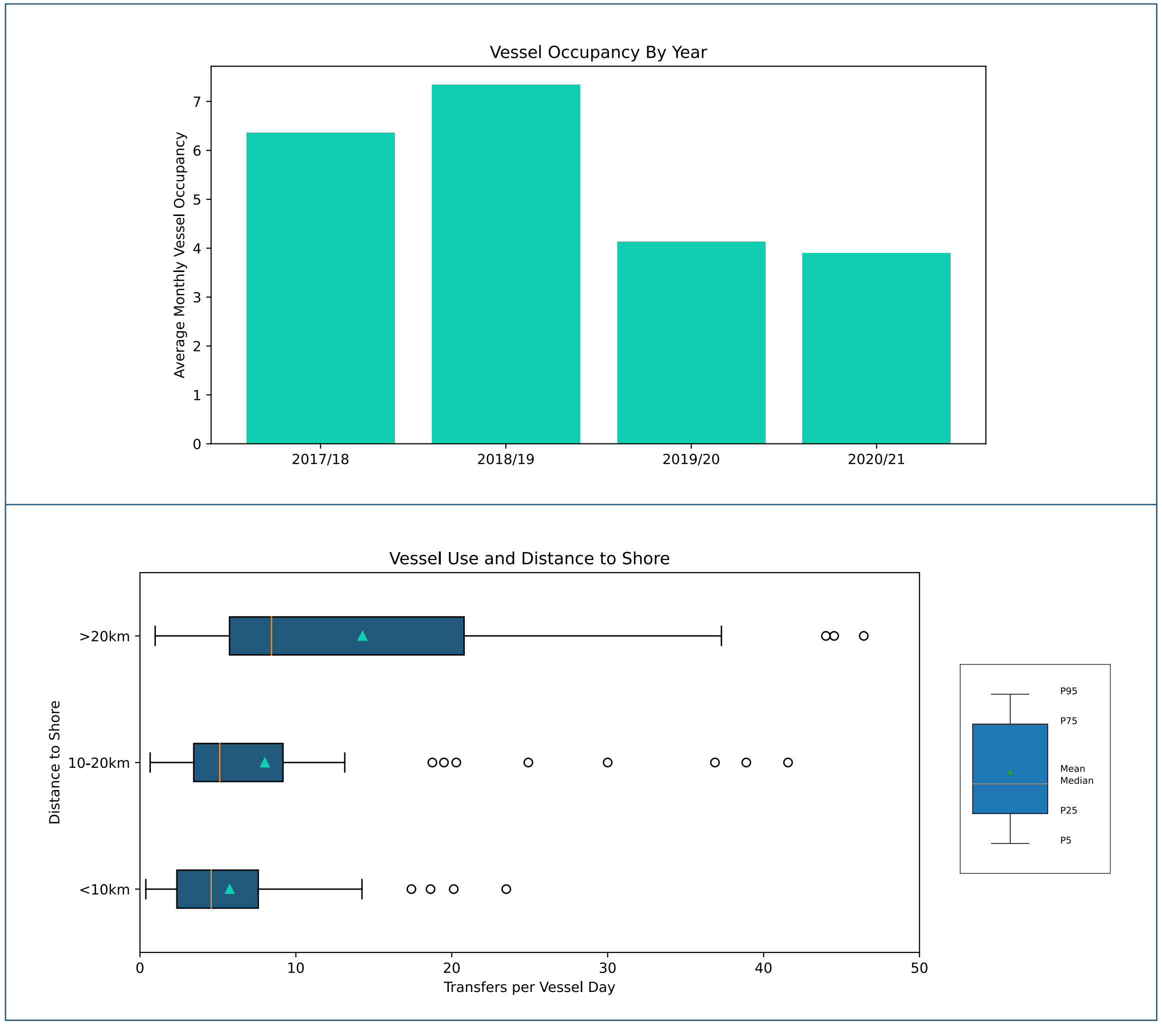


Figure 12 - Average transfers per vessel day by financial year (top) and the distribution of transfers per vessel day grouped by distances from the windfarm to shore.

Summary

In spite of major disruption to the supply chain, many windfarms in the SPARTA set continued to operate at a high level throughout the first year of the pandemic. However, there were also instances of below-average availability throughout the year, and it turned out to be the lowest average availability of any year in the set. Social distancing on crew transfers could have played a role in this, with transfers being limited while vessel-use increased. This would have been most difficult for farms that are further from shore, as measures for vessel occupancy imply. The full effect of the pandemic on industry does not lie solely in this first year, and the disruption will likely continue to impact industry in unforeseen ways.

Forced Outages and Major Repairs

Investigating Failure Data from Offshore Wind Turbines

Forced Outage Data Quality

How are Forced Outages Noticed and Classified?

Alarm logs accompany SCADA data with alarm codes which can be classified through alarm mapping - the process of using an alarm code to determine which operative state the turbine is in and which physical component an alarm relates to.

The Root Cause Assumption

The primary assumption of the SPARTA definition for forced outages is that given a cluster of alarms, the first alarm signifies the root cause of the outage. This assumption is required so that the benchmarks can be easily calculated and kept consistent across farms and turbines. However, this assumption is likely not true in all cases.

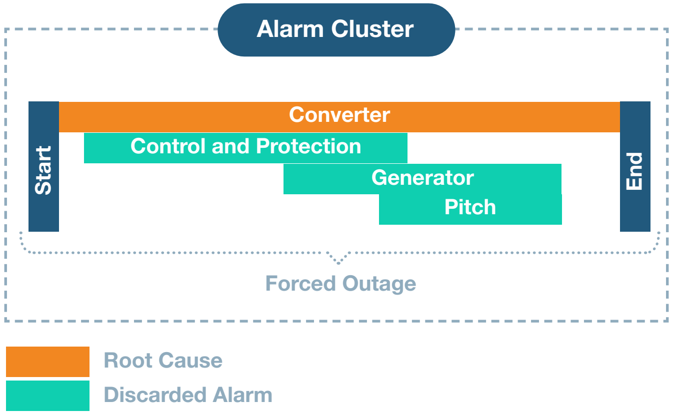


Figure 13 - Classification of a root cause from a cluster of alarms.

Challenges with the Alarm System Methodology

Analysing alarm maps has highlighted four limitations that, if resolved, could enhance operations and maintenance for wind farm owners, OEMs and operations and maintenance teams.

1. Alarms do not seem to come with any notion of severity. Would it be more accurate to attribute root cause to the most serious of alarms and how would severity be measured and consistency achieved across the industry?
2. The RDS-PP component "control and protection system" is particularly vague in what it relates to. It is somewhat equivalent to the human nervous system in that it has sensors across the turbine. For the purpose of component analysis in this report, alarms attributed to the control and protection system were not included in analysis.
3. A growing area of interest is in relation to curtailments and the reason for those curtailments. Particularly with older turbines, it seems that it is not always possible from the alarm logs to determine why a turbine has been de-rated or de-graded.

Forced Outage:

When an immediate action to disable the generating function of the wind turbine generator (WTG) is required as unforeseen damage, faults, failures or alarms are detected.

Ways to improve forced outage methodology

The SPARTA group continues to work to improve the methodology for forced outage analysis and a discussion in the 2019/20 portfolio review identified ways in which practices could potentially be improved:

Cluster analysis could serve to identify the most severe alarm triggered from a cluster of alarms and identify that as the most likely root cause.

Using machine learning methods to compare alarm clusters to a 'true' training set could be a good way to classify alarms but would require a large dataset with sound maintenance logs attached.

Types of Forced Outages

The transmission system alarm was triggered most, followed by the yaw and rotor systems.

On average a windfarm logs 2.83 forced outages per turbine each month. Out of the failures that are registered in the system, failures in the transmission system are the most common that are flagged by alarms, followed by those in the yaw system and the rotor system. There are 13 total components that failures are logged for, but most – such as the balance of plant system and ancillary system – log very few forced outages and are grouped into ‘other’ in Figure 14.

Different component failures may have different impacts on the turbine, with certain component failures accounting for a disproportionate amount of downtime for the frequency of outage (such as in the drive train and generator). Meanwhile, the yaw system accounts for many outages but relatively little downtime.

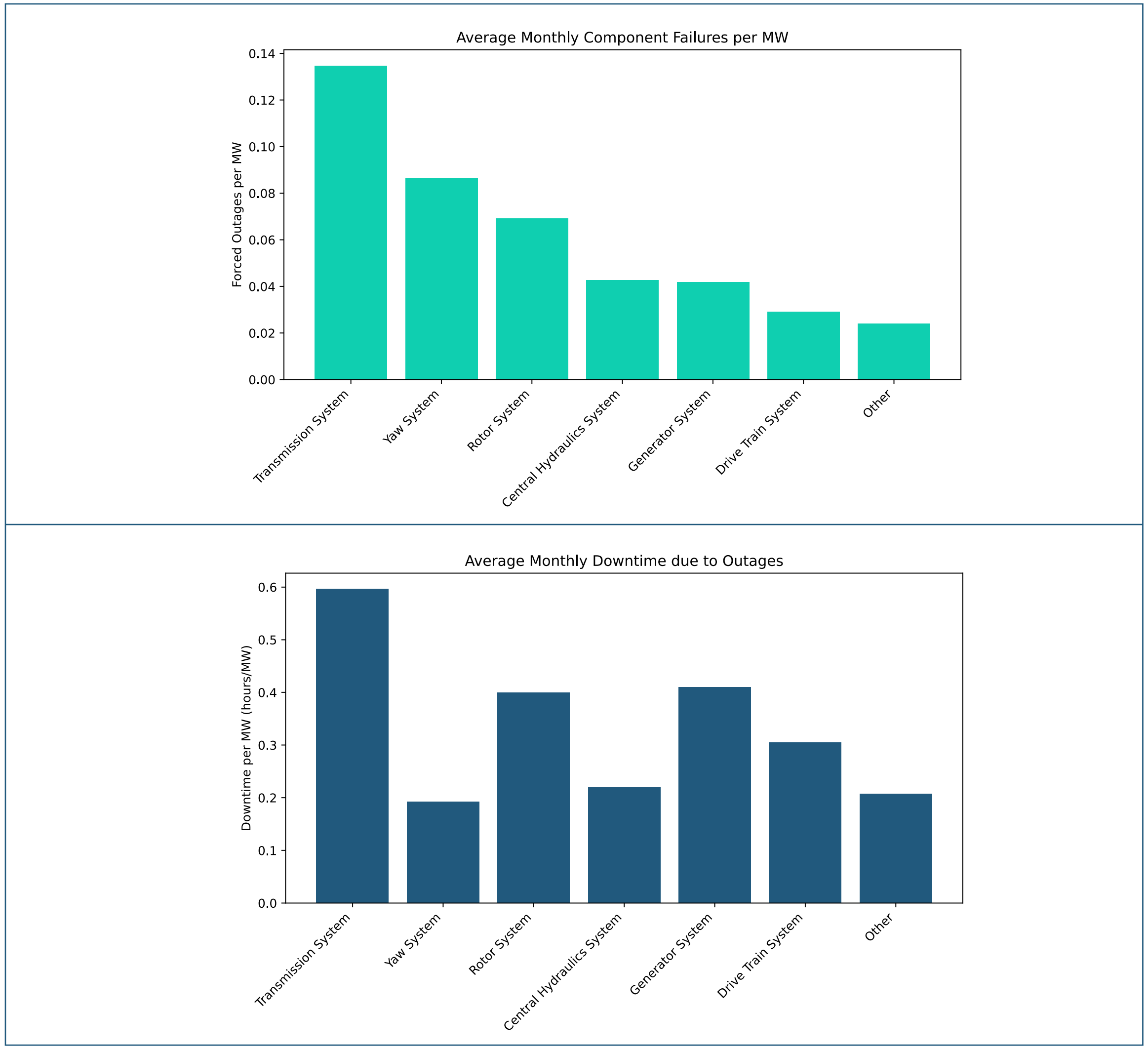


Figure 14 - Average monthly forced outages per MW installed (top), split by component, and related downtime per MW (bottom). Graphs do not include less reliable data such as alarms for control and protection system or unknown alarms.

Failure and Age

Turbine failures are especially common in the first year of life and in the 7-8 year age range, after the usual warranty period.

The likelihood of failure changes with the age of the turbine and the components within it. Forced outages generally follow a ‘bathtub’ relationship over time since there are usually a lot of failures at the start of a component’s lifespan and a lot at the end. As components might get fixed and replaced, this trend is slightly different for the turbine in general.

Figure 15 shows that in addition to the expected high number of failures at the start of life, a high number of failures have been reported to occur in the 7-8 year age period. This number may be significant as many farms will come to the end of warranty agreements and maintenance procedures will change. The end of warranty is also likely to precede the end of some components’ life cycles. This cycles appears to continue with another peak in failures 6 years after this point.

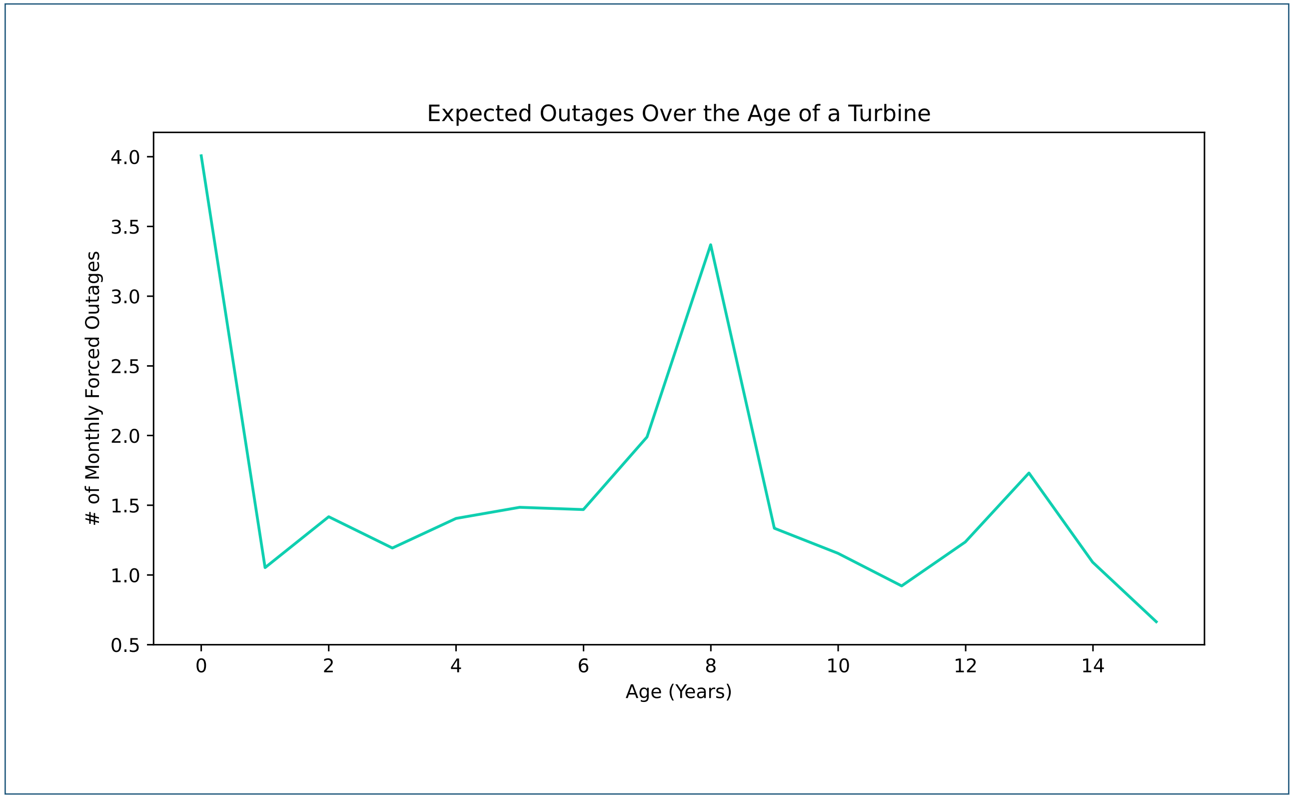


Figure 15 - Average monthly forced outages per turbine by age of the windfarm, grouped into years.

Failure and Age

Different components seem to have different lifespans, with failures occurring periodically at different stages of life.

Looking at the same trend by component, there are similar breakage cycles for some of the subsystems in the turbine. For example, Figure 16 shows that rotor system has failed most around the 5-year and the 12-year mark, and the hydraulics system has roughly seen peaks in failures every 4 years.

The transmission system seems to have had consistent issues throughout the first stretch of turbine life in the set, while the generator system has only seen failures peak in older turbines.

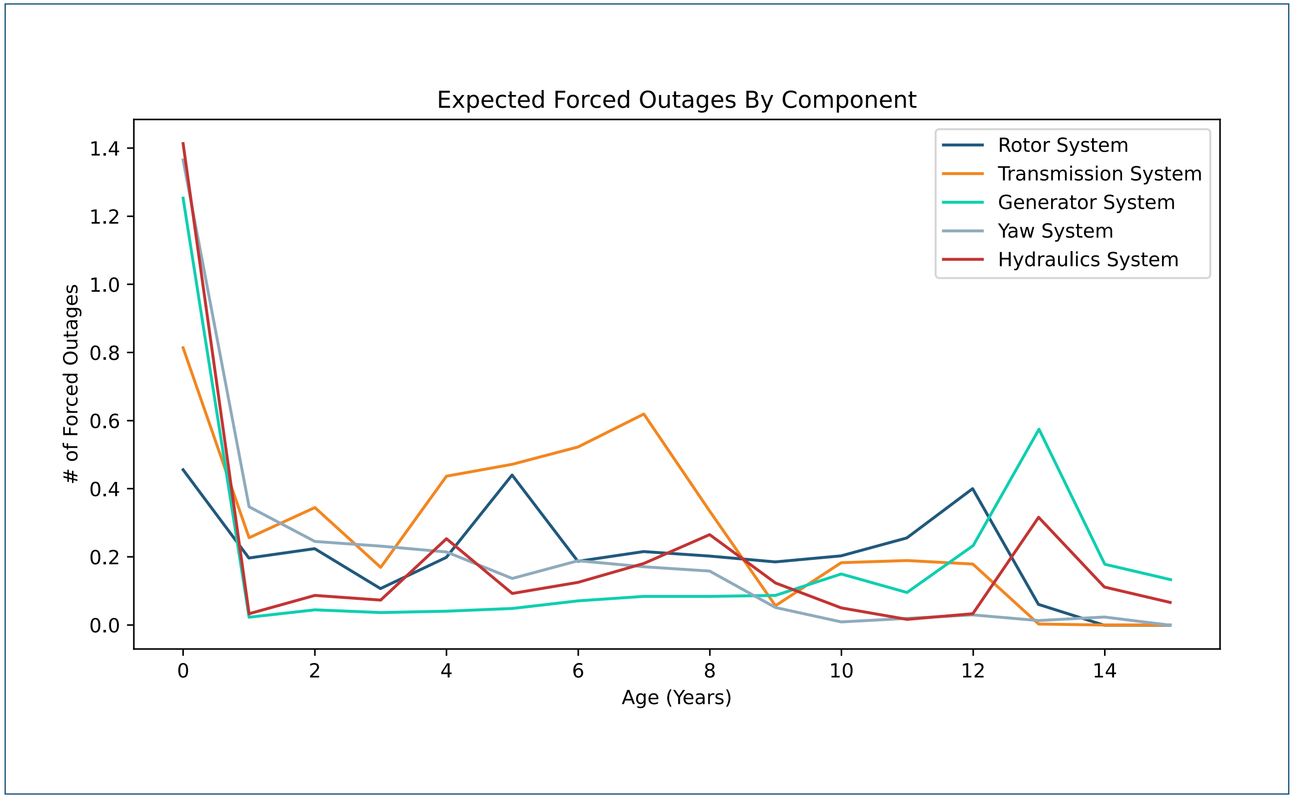


Figure 16 - Average monthly forced outages per turbine by age of the windfarm and by component, grouped into years.

Impacting Factors

Factors such as OEM and wave height impact failure rates. Higher rated turbines have had more failures per turbine so far.

There are many factors that impact failure rates of turbines and components, and all types of turbine are likely to have a different experience. Separating by original equipment manufacturer (OEM), one can see that turbines from one manufacturer have a higher failure rate than the other.

In Figure 18, the component failure rate is compared for these 2 OEMs, showing that the spread of component failure is similar, but failures are slightly more diverse for OEM 2.

Comparing different generations of turbine, the highest rated turbines (>=5MW) have the highest number of recorded failures per turbine. These turbines are also more likely to be younger, so it is worth considering that this number is likely to decrease. Even though they log more failures per turbine, the failures per MW are still comparable. While the generation from these turbines is higher, the percentage of production lost is similar.

Weather will also play a role in causing turbine failures, if conditions are particularly bad. Investigating locations with high wave height for the month shows that there is a correlation between high waves and turbine failures. This could be a result of extreme conditions placed on the turbines, but also because preventative maintenance is more difficult to perform.

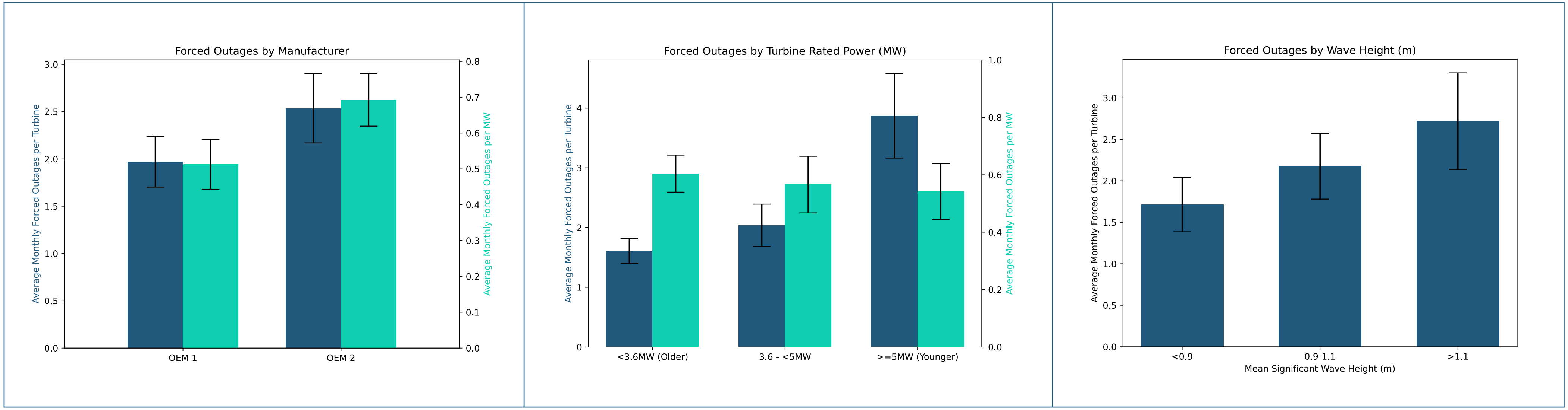
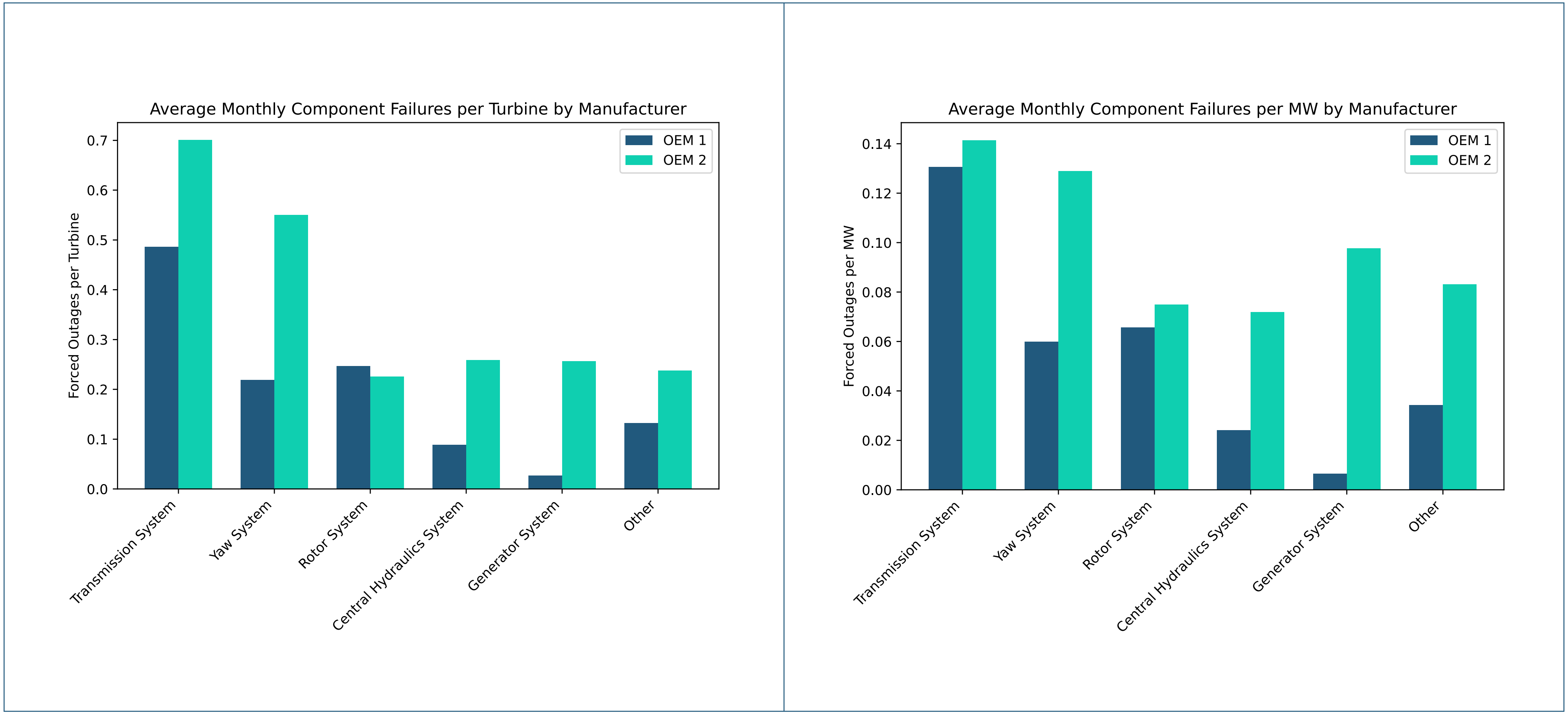


Figure 17 - Average monthly forced outages per turbine and per MW when grouped by OEM (left) and rated power (middle), and per turbine when grouped by mean significant wave height for the month (right).

Impacting Factors

The distribution of failures across components is broadly similar between the 2 OEMS.



Average Monthly Component Failures per Turbine by Manufacturer

Average Monthly Component Failures per MW by Manufacturer

Figure 18 - Failure rates for turbine components for OEMs 1 and 2.

Downtime per Outage

Reducing the downtime associated with an outage is one way to limit lost production.

Looking at outages in an alternative way, we can investigate how much downtime was cause per outage by dividing the total downtime by the number of forced outages. This value has a strong correlation with the number of non-access days in the year, since an inability to get engineers to the turbine inhibits operators' ability to deal with the issue effectively. Limiting this value is a clear way to minimise lost production and boost performance.

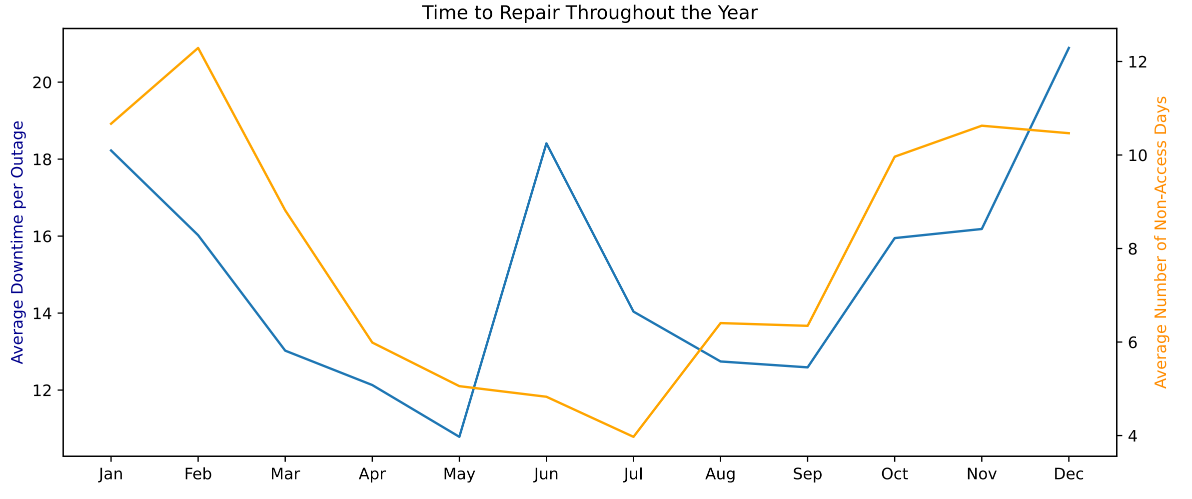


Figure 19 - Downtime per outage each month against the average number of non-access days across the year.

Major System Repairs

Major repairs are most common on blades and gearboxes.

Major repairs do not occur often in a turbine's life, but when they do, they take a significant toll on windfarm operations. In the set there has been 122 recorded months in which major repairs have been undertaken.

The most common object requiring major repair are the blades. When blades are replaced, they are often changed for multiple wind turbines across the farm for operational efficiency. Blade repairs do not necessarily get done as a result of failure but may be carried out on-mass as a planned campaign for upgrade or to resolve a manufacturing issue. In fact, 95% of reported months with blade repairs occurred in clusters with other months of repair, meaning they are likely to be part of a planned campaign.

It is also common for multiple component replacements to get carried out in the same campaign to save costs on jack-up barges. Other common objects of repair are the gearbox (where it applies) and generator.

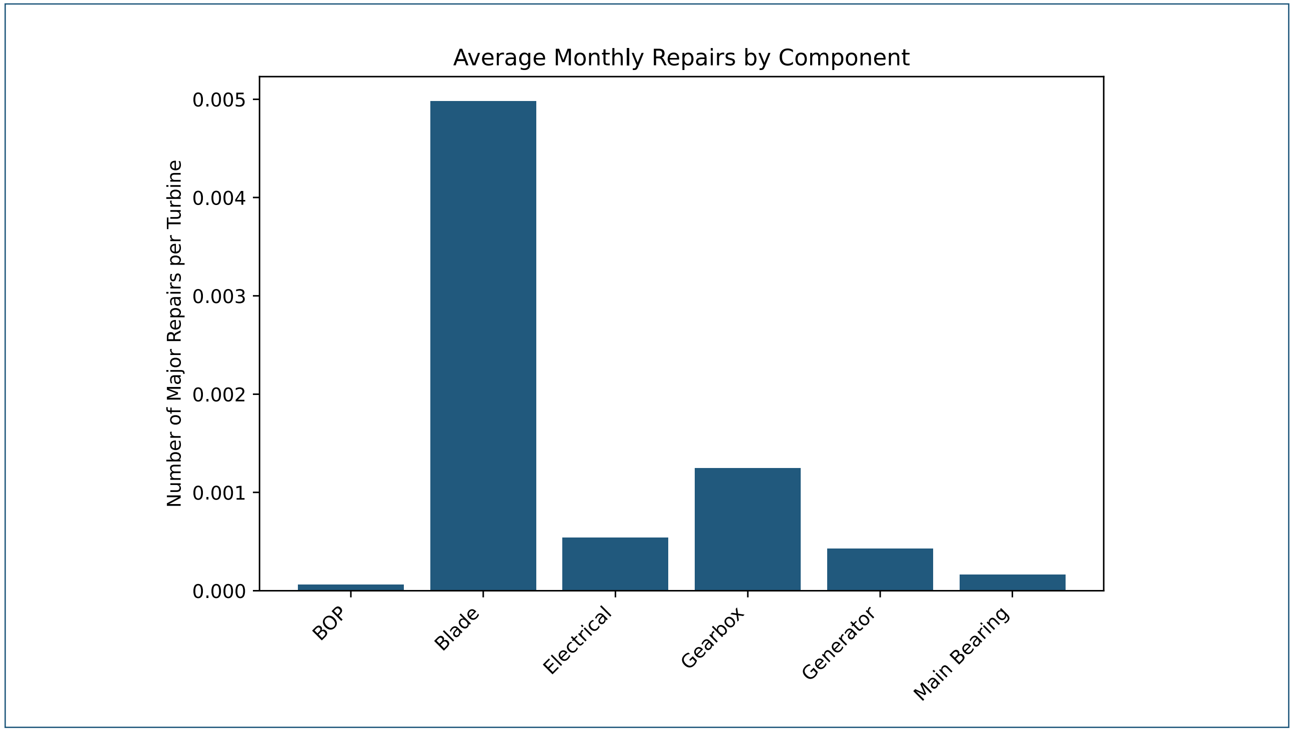


Figure 20 - Major system repairs per turbine by component.

What are major system repairs?

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

0.013
Average Days of Jack-Up Activity per Turbine

11.1%
Windfarm Months with Recorded Major Repairs

743
MWh
Average Lost Production per Major Repair

464
Hours
Average Downtime per Major Repair

81%
Windfarms that have reported Major Repairs

Major Repairs and Age

Rates of repair vary between the 2 OEMs in the set.

Splitting the windfarms into 3 age brackets, it can be seen how these different age brackets were impacted in terms of component, with the main differences being more gearbox repairs for younger windfarms and vice versa for blades.

The maintenance strategy for the 2 OEMs seems to be quite different in the set, with OEM 2 replacing/repairing more blades than the other. While OEM 2 seems to have spent more time replacing blades, OEM 1 has registered more varied types of repairs.

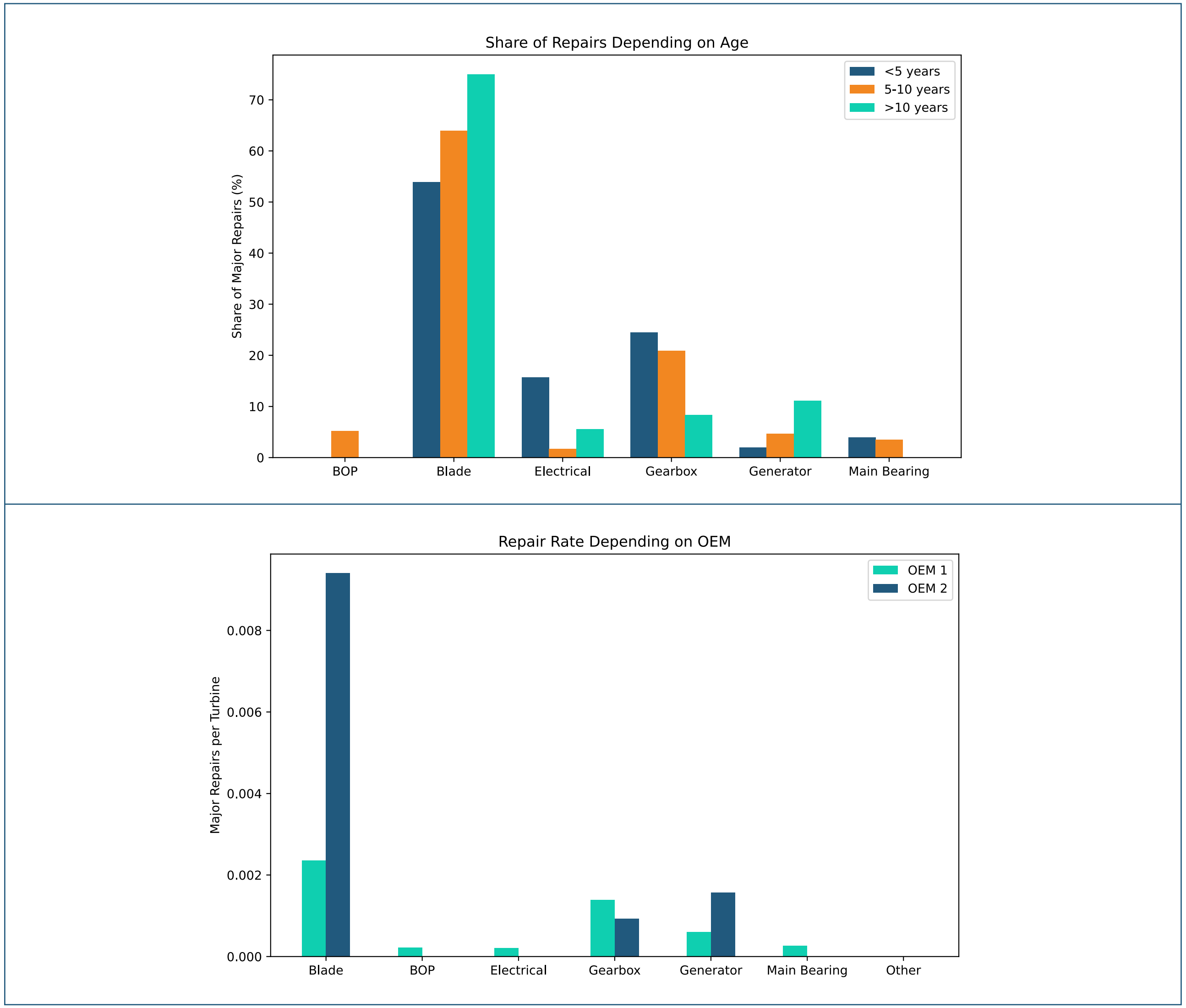


Figure 21 - Major system repairs per turbine over the age of the turbine (top), and by component and age bracket (bottom).

Cable Outages

Subsea cable failures are the biggest insurance cost for the industry, accounting for 75-80% of claims in the UK. The cost implications of even a single cable failure can be enormous, taking an average of two months to repair and having the potential to exceed the £20 million mark in costs and lost power generation.

SPARTA data confirms that this is a pressing issue for the industry – with over 7% of months including a cable failure and around 2/3 of reporting windfarms having experienced issues. Comparing the average lost production from a single cable outage day to that of a forced outage in Figure 19, cable outages are generally more consequential.

Over time, there is no clear trend to cable outages. We can also see that the number of outage days can be attributed equally between inter-array and export cable.

What are 'cable outage days'?

This is defined as the number of days cables are down and not able to transmit power. The number is calculated by adding together the downtime from every cable to get a final figure for the wind farm.

If multiple cables are down at the same time, the downtime of each cable is reported (i.e. 2 cables down for the same day = 2 cable outage days). However, time is not recorded for cables that are unused due to reduced capacity or only down due to other BOP or external grid related issues.

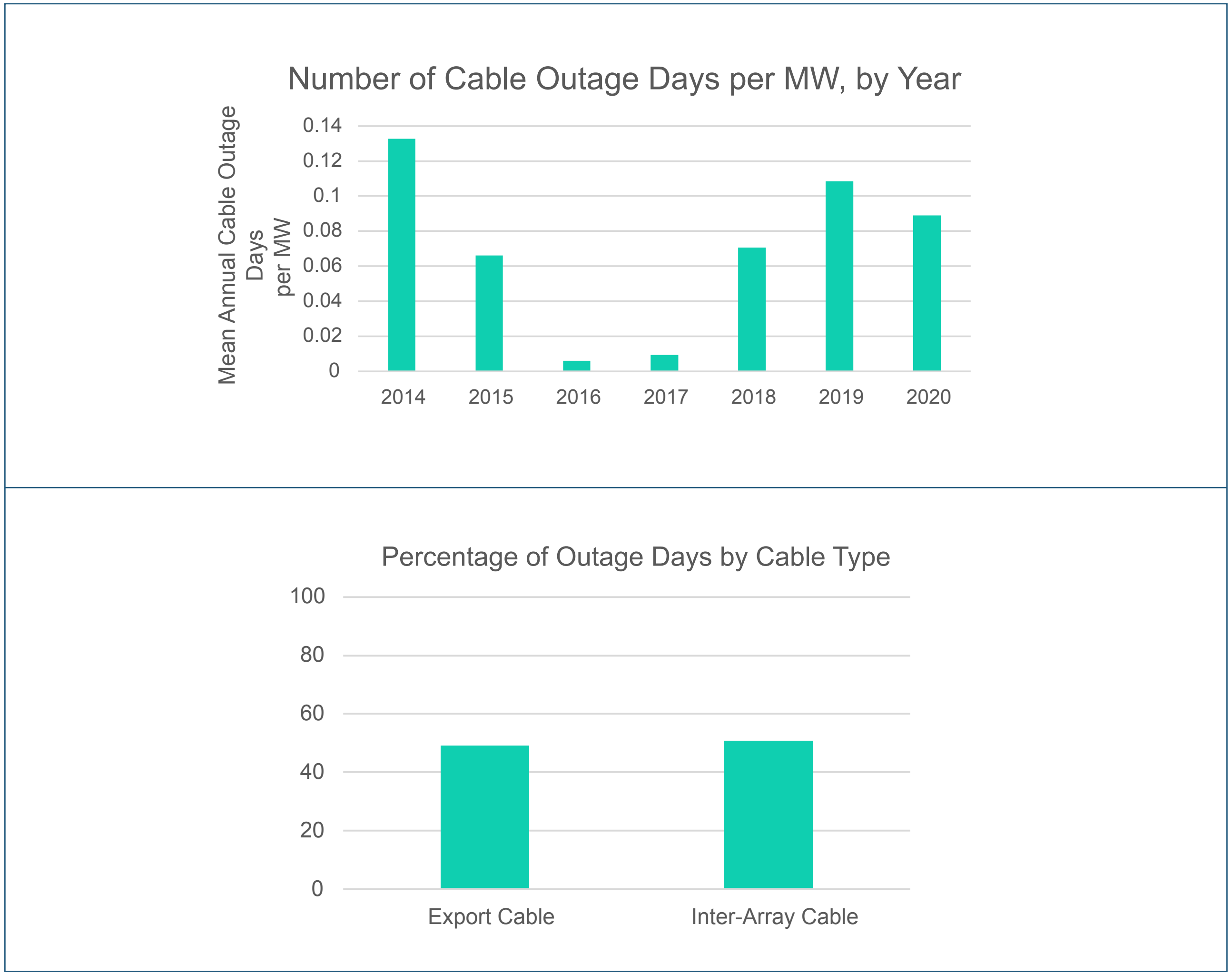


Figure 22 - Average annual number of cable outage days per MW by year (top) and percentage of outages split by type (bottom).

Cable Outages

While cable outages have been observed at the infant stage of life and at the end of the typical warranty period, many cable outages have also been observed in the older turbines in the set.

They are also more likely in farms that are further from shore – which is no surprise due to the extra cable length needed to get the electricity onshore.

7.46%

Windfarm Months with Recorded Cable Outages

260 MWh

Average Lost Production per Cable Outage Day

61%

Windfarms that have reported Cable Outages

0.007

Average Monthly Outage Days per MW

0.025

Average Monthly Outage Days per Turbine

0.098

Average Cable Outage days per MW in non-zero Months

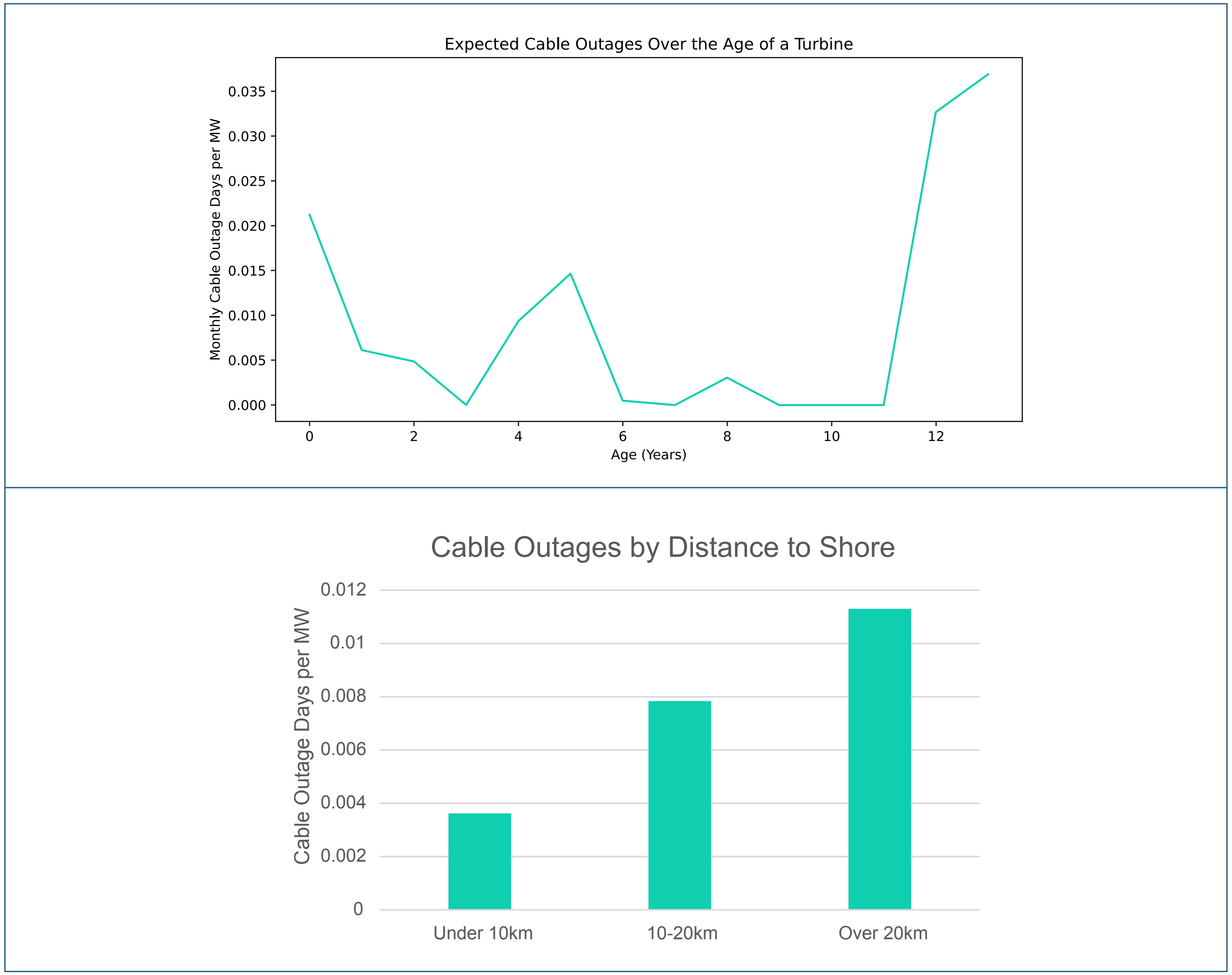
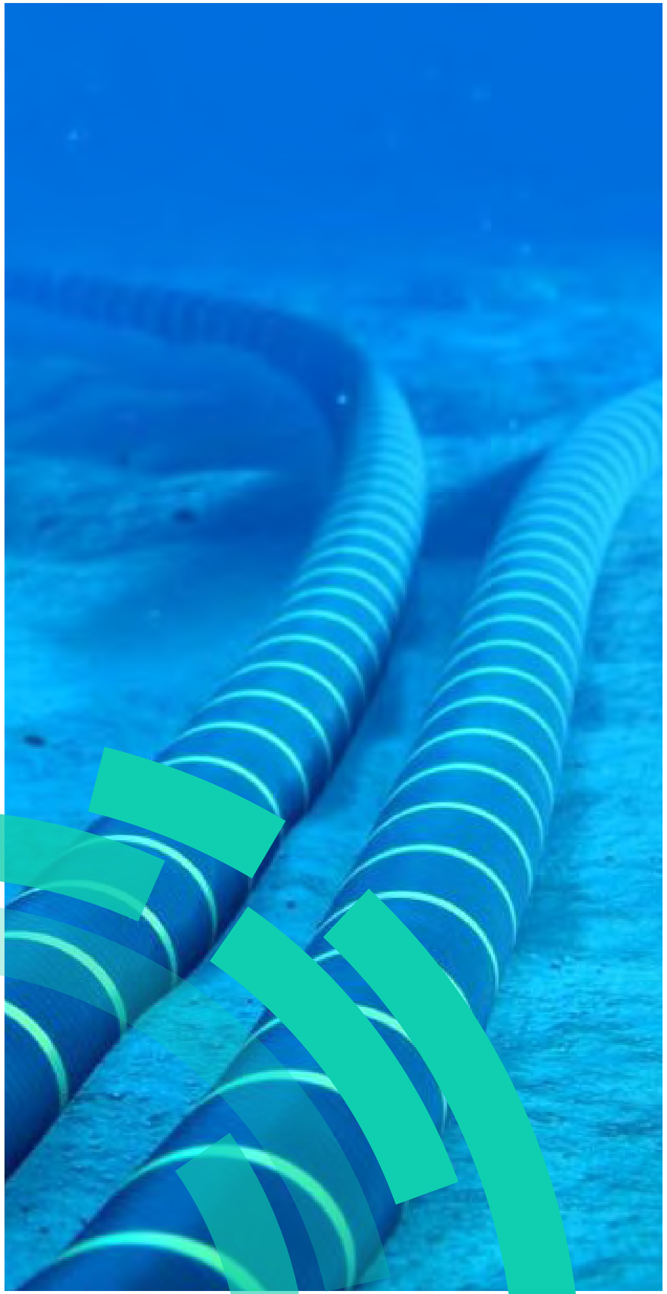


Figure 23 - Expected number of monthly cable outage days per MW, grouped into year of life (top), and average monthly outage days per MW by Distance Shore (bottom).

ELECTRODE



Causing large insurance costs for the industry, cable failures are a significant issue for owner/operators which greater information would help to address. In particular, benchmarking cable outage data in more detail than that within SPARTA will be instrumental in informing industry on the common problem.

Relating specifically to cable outages, ORE Catapult's new ELECTRODE programme will track failures, service downtime, and repair and maintenance metrics. It will be operated in a similar way to the SPARTA model, with anonymity as the core principle of the platform.

ELECTRODE aims to tackle the challenges created by cable failures by:

- Tracking subsea cable failures and identifying trends
- Giving insight to aid maintenance and condition monitoring
- Informing innovation and best use of technology
- Improving efficiency and driving down costs
- Providing evidence for insurers and investors

For more information visit:

ore.catapult.org.uk/stories/electrode

Technology and Performance

Comparing Different Generations of Wind Turbines

Capacity Factor

Direct drive turbines have had consistently higher capacity factor in the set.

The 2020/21 financial year was the first full year that the SPARTA portfolio contained 3 distinct direct drive windfarms. These windfarms have so far demonstrated high performance compared to others. In order to better compare with others we split gearbox turbines into those with less than 3.6MW rated power and those with that and above.

The higher capacity factor of direct drive turbines should be noted with the caveat that these windfarms are situated in location with a higher mean wind speed (9.1 m/s compared to 8.5 m/s).

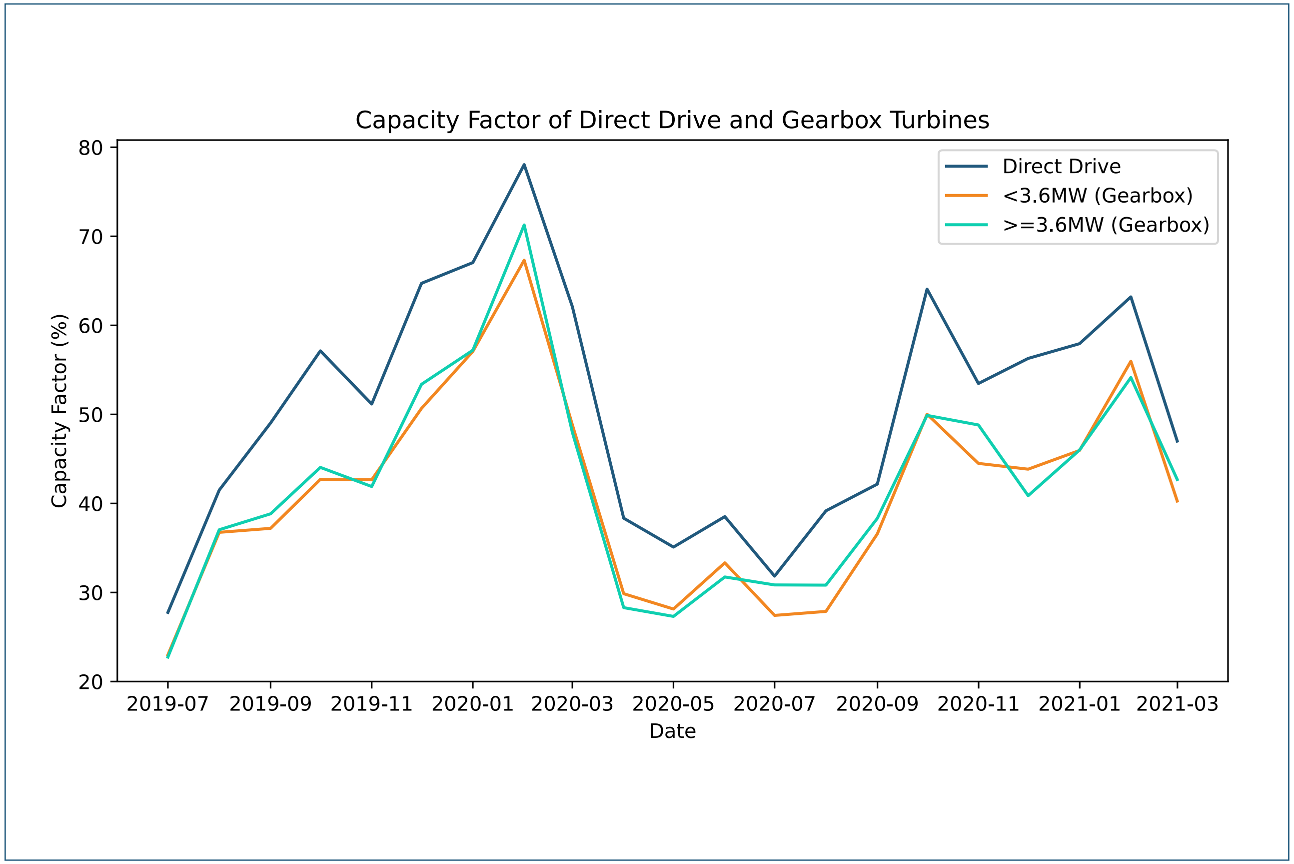


Figure 24 - Average capacity factor over time for different generations of turbines.

Production Based Availability

For the most part direct drive turbines have had significantly higher availability than gearbox turbines.

When high wind speeds are taken into account by PBA, direct drive turbines still performed better than other turbines in most periods, bar a few periods where lost production was uncharacteristically high.

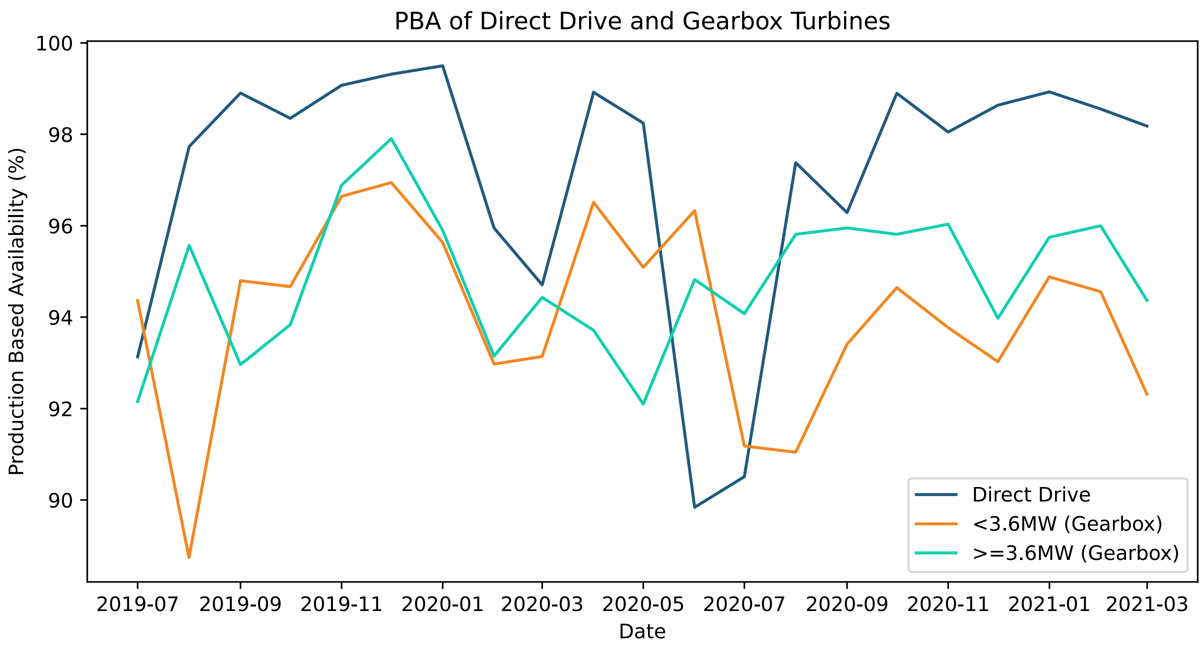


Figure 25 - Average production based availability over time for different generations of turbines.

Failure Rates

Higher rated turbines experience more failures but not necessarily more lost production.

In terms of failure rates, direct drive turbines have seen comparable forced outages per turbine with similar turbines in the 3.6MW and above group. Since the direct drive turbines have on average higher rated power, this translates to a lower number of forced outages per MW and a lower amount of lost production each month. Since these turbines are still young, these failure rates can be expected to decrease in general in the future.

As the technology is a recent advancement, more data is required to create strong insights about the differences between direct drive turbines and turbines with gearboxes.

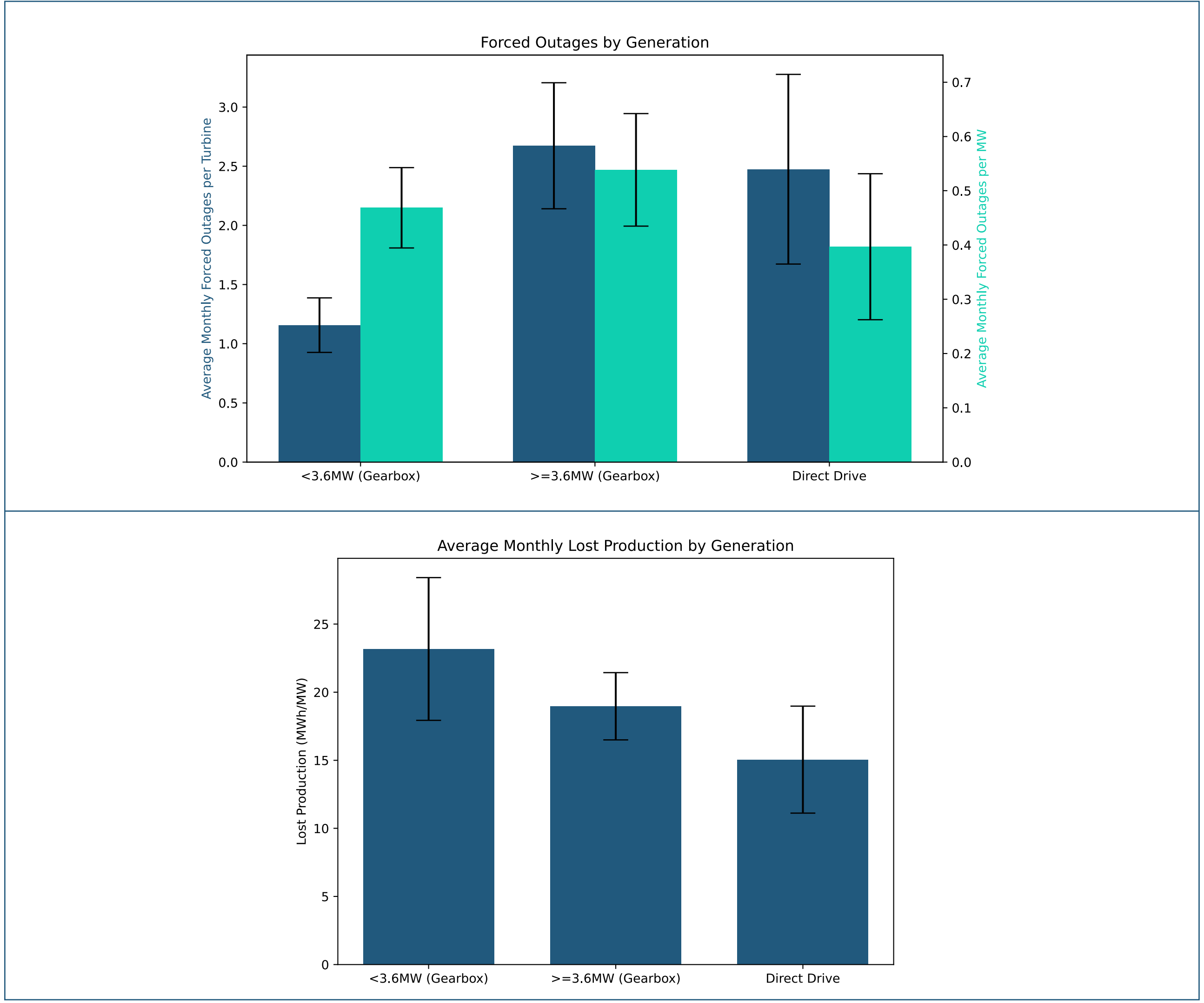


Figure 26 - Forced outages per turbine and MW (top) and lost production per installed MW (bottom) for different generations of turbine.

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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