SPARTA
System Performance, Availability and Reliability Trend Analysis

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Portfolio Review 2019/20

Sponsors Comments

As the industrial chair for the SPARTA benchmarking system, I am pleased, on behalf of our members, to present the 2019/2020 Portfolio Review.

It is a pleasure for me once again, on behalf of the SPARTA group, to present the annual Portfolio Review. This is an in-depth analysis of trends and performances across the industry and gives insight to operations of offshore windfarms across UK.

This has been an extreme abnormal year due to the Covid19 pandemic, but due to the portfolio review covering the financial year (April 2019 to April 2020), the consequences of the pandemic will first be visible in next year's report. It is during periods such as this where being a member of SPARTA provides massive advantage. SPARTA provides a means to be able to reach out to discuss and align protocols and to share experience, for the benefit of everyone.

As well as benchmarking, SPARTA provides each member with a monthly report of individual wind farm performance. A report such as this provides additional information, as it gives a holistic and aggregated picture of how the industry performance varies across windfarms. These trends tell that there is a lot of additional value hidden in the data, providing an opportunity to search and find additional improvement proposals for all of industry.

This year's report delivers high level trends for the most important metrics, as well as a deep dive into potential factors that can cause variations in these metrics. A brand-new topic this year is a deep dive into how turbine alarms are used and analysed by the industry. This is an interesting read and as well as providing interesting insight, should also prove a valuable negotiation point towards turbine suppliers when it comes to standardisation of data streams and making data available for additional usage.

SPARTA is continuously seeking to improve and this year the focus has been towards centralisation of calculations – transforming raw data to measurable KPIs. By calculating metrics via a centralised and heavily validated script (instead of individual scripts for each member) the reliability in the resulting benchmarks is only increased. Centralisation rules out any errors caused by misunderstanding how the metrics should be calculated or individual mistakes made during the calculation process. I am sure this will raise the quality of the benchmarks produced.

As always, the value of benchmarking increases with the number of participants. Over the years the number of members slowly increases other owners of wind farms are encouraged to join SPARTA and gain the value it can deliver. We are currently working actively to expand outside of the UK and start benchmarking European farms, as well as farms further afield. It is expected that next year we will see the result of this and be able to present the European market along with the UK market.

Being a member in SPARTA not only gives access to benchmarking tools but also presents networking opportunities across the industry at several levels. Sharing knowledge, experience and lessons learned is vital if we are to continually improve operations, performance and Health & Safety at out sites.

I hope you enjoy reading the following report and the insights it presents and my thanks to the Offshore Renewable Energy (ORE) Catapult for producing this comprehensive Portfolio Review.

Covid Comments

As well as encouraging data sharing, SPARTA offers an excellent means for industry to work together in the offshore wind sector.

One element that no one planned for was the emergence of Covid-19 and the repercussions this would bring. By bringing SPARTA members together, some useful insights and comments have been raised around how the industry have dealt with the pandemic. Unfortunately this review does not cover a period where assessments around how the industry has performed can be made, although future review's should provide an opportunity to reflect on the industry performance during the pandemic.

> On the operations side, site teams on site are doing very well, keeping performance high and availability high. A reduction on planned non-critical activities will create a backlog for later in the year.

> There has been some conflict between the company and investors on what work can go ahead and what can't, which is driving scrutiny of processes and procedures.

> O&M approach has changed quickly to accommodate social distancing and has quickly become 'business as usual' on CTVs and in office environments.

> The priority has been to balance between ensuring asset integrity and safety. This has been particularly challenging on sites with high numbers of turbines.

> Office based employees were sent to home working quickly and this has been efficient and has raised IT competence. Productivity has been high.

Introduction

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 2019 – April 2020) 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?

The 2019/20 portfolio review is broken down into three main sections. Firstly SPARTA Trends details some of the high level trends that can be observed from the data to date, showing metrics such as production based availability (PBA) variation, the continuing trend in number of transfers and how capacity factor and PBA relate together, as well as more. The second section undertakes a deep dive that investigates the potential factors that cause some sites to have poor PBA, particularly in the summer months. The final section is somewhat different to portfolio reviews before and provides an insight piece questioning how turbine alarms are analysed by the industry, a highly important aspect of turbine analysis that SPARTA continues to work on, helping the industry move forwards together.

What is SPARTA?

SPARTA is an offshore wind farm performance benchmarking tool, run by industry for industry. SPARTA, an acronym for 'System Performance, Availability and Reliability Trend Analysis', allows owner/operators of offshore wind farms to compare key performance indicators (KPIs) for their farms against aggregated and anonymised industry 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**

Sponsors Comments

Who is Involved?

All major owner/operators with offshore wind farms in UK waters are participating in the 2019/20 SPARTA Portfolio Review. A future goal of SPARTA is to secure participation from offshore wind farms from around the world, strengthening the benchmarking process.

Sponsoring Organisations

Participating Owner Operators

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 output is 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.

Key Numbers

See below for the current SPARTA population figures. Showing the size of the reporting fleet and some high level KPIs.

5255 MW Installed Capacity

54% of UK Installed Capacity

1347 Turbines

62% of UK Turbines

20 Wind Farms

61% of UK Wind Farms

17,192,488 MWh of generation

95.39% Average PBA

42.22% Average Capacity Factor

52,536 Transfers

9,504 Crew Transfer Vessel Days

Key Numbers

Figure 2 - SPARTA Wind Farms (bubble size = installed capacity)

Sparta Trends

Production Based Availability

SPARTA started recording production based availability (PBA) after an internal audit by DNV-GL in June 2016, the SPARTA calculation follows IEC standard 61400-26-2, system owners view. Since 2016 PBA values have been ever increasing, as is shown by Figure 3, and the most recent financial year experienced the highest average PBA recorded to date, at 95.39%.

This is particularly encouraging for the offshore wind sector as it shows that the wind farms are becoming more efficient at capturing energy from the wind and turning it into electricity. This could be due to more efficient turbine technology or improved O&M procedures and technologies. As with other years a seasonality can be noted in the reported values over the year, as can be observed in Figure 3 and Figure 4. Higher PBA values are recorded in the spring and autumn periods where lower amounts of work are being undertaken on the turbines (in comparison to summer) and the winds are not yet so strong as to curtail turbines (as in winter).

Figure 3 - Production Based Availability Trends (top = last year monthly, bottom = yearly average)

Sparta Trends

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 penalise 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 states the turbine should be generating 1000kW but the turbine is only producing 700kW. This would give the turbine a PBA of 70%.

700kW / 1000kW = 70%

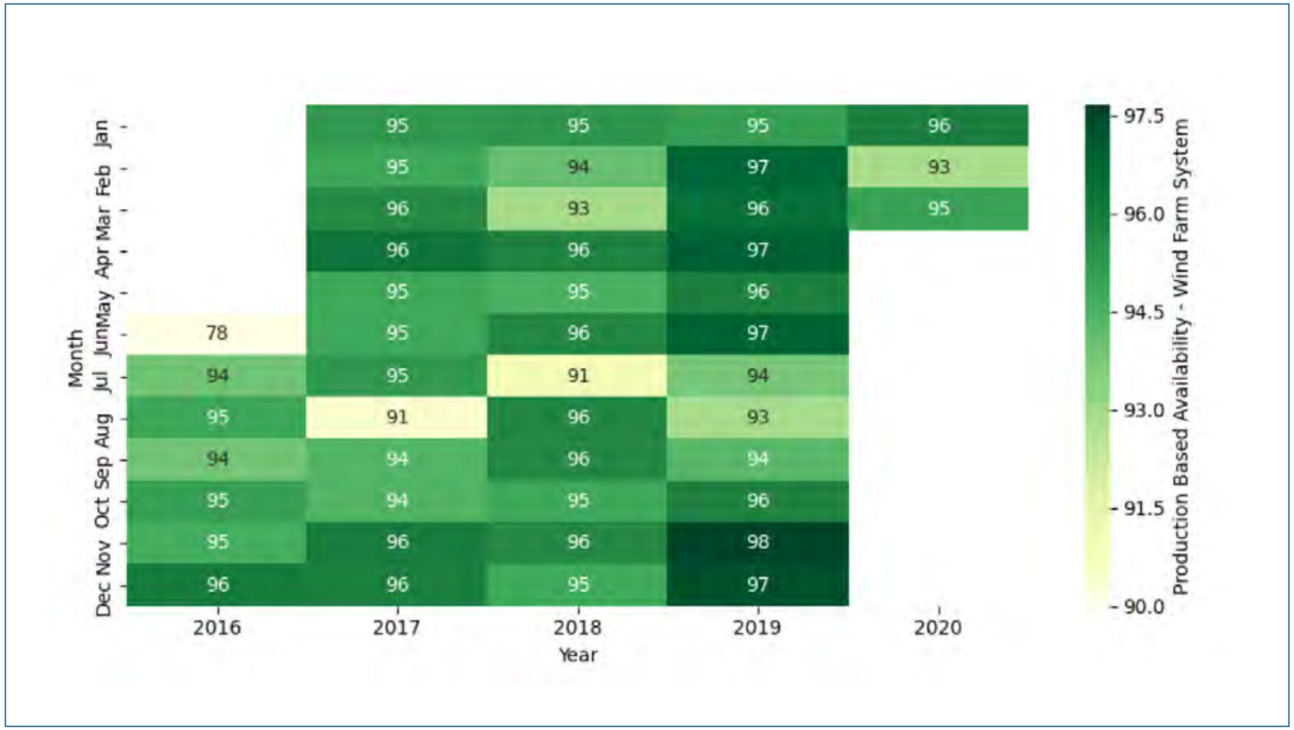


Figure 4 - Production Based Availability Monthly Average Values Heatmap

Sparta Trends

Capacity Factor

Unlike PBA, capacity factor is largely driven by the available resource (primarily wind speed) and so varies much more throughout the years, see Figure 6. This makes it much more difficult to say if the portfolio was performing well solely by looking at capacity factor values.

One point of notice is that the last year, 2019 – 2020, obtained the highest average capacity factor to date, a staggering 42.2%, see Figure 5. This will have been largely driven by the extremely windy February where the portfolio of wind farms achieved an average capacity factor of 68.6%, with one wind farm achieving an average capacity factor of 78.4%. In fact, the month of February 2020 was the most productive (in terms of portfolio capacity factor) since records began, with the next highest month coming in at 63.5%.

As mentioned, this large capacity factor will be largely driven by the extremely high average wind speeds that were recorded in the year but other factors, such as wind farms being placed further from shore (in windier locations) and being more efficient at capturing the wind's energy, will also have a large effect.

Figure 5 - Capacity Factor Trends (top = 2018-2019 monthly with average wind speed shown, bottom = yearly average)

Sparta Trends

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, resulting in a capacity factor of 60%.

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

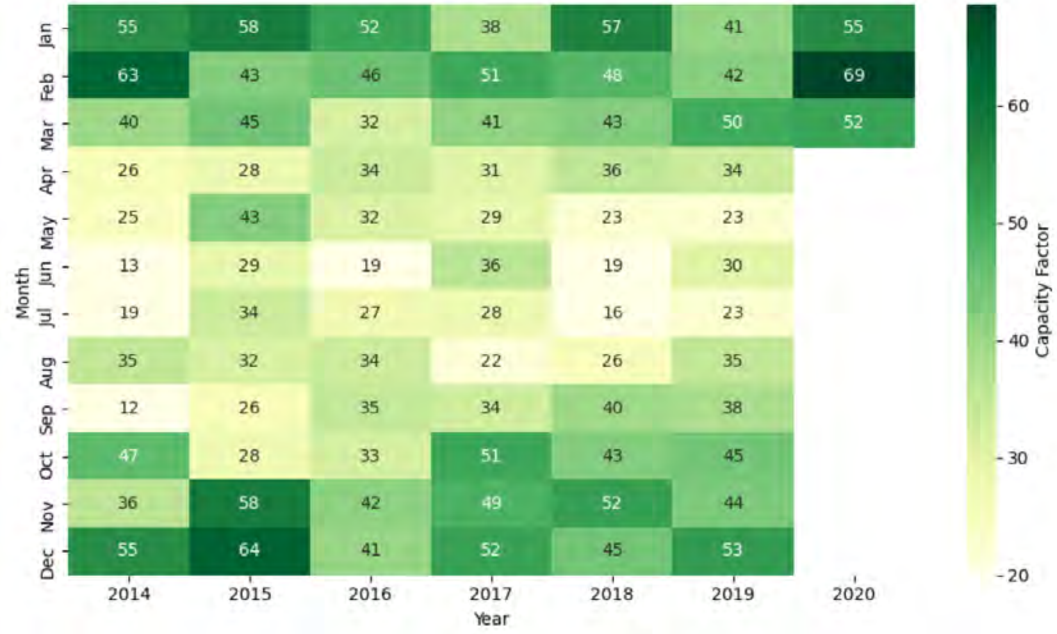


Figure 6 - Capacity Factor Monthly Average Values Heatmap

CF & PBA

As discussed previously in this report, production based availability gives a good indication of how well a farm is capturing the energy resource available and capacity factor gives a good indication of the wind resource available at a particular site. Comparing these values together can indicate which farms are the most effective, as a high PBA and capacity factor may say that the farm is both well positioned to capture high amounts of energy and is doing so well. It can be theorised that aiming to increase capacity factor alone may reduce PBA as the operator may be reducing the amount of maintenance performed at the site. Operators may also not be curtailing turbines as much in potentially damaging (high wind or turbulent) conditions, putting excessive loads on the turbine. This makes balancing these two elements challenging as operators should aim to operate their turbines efficiently but also be looking to obtain as much energy from the wind as possible.

Figure 7 shows how the density of reported values lie on a scale of PBA and capacity factor. This figure gives a good indication as to where most farms should be aiming for their PBA and capacity factors to lie. As can be noted from this figure, there appears to be an outlier group with a lower PBA value. This is likely explained by farms undertaking maintenance over months with good wind resource, driving the PBA down whilst the capacity factor remains high.

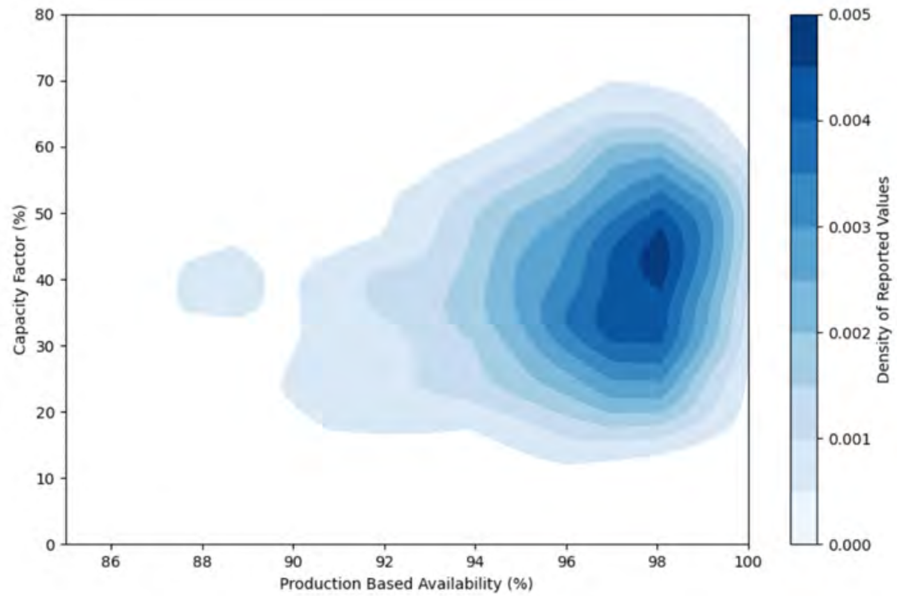


Figure 7 - Production Based Availability and Capacity Factor Density Heatmap

Sparta Trends

Most Effective Reporting Months

To understand some of the “best” reporting months, the months with high PBA and capacity factor were identified, shown in Figure 8. To find these months, first the average PBA and capacity factor were found for each month, from July 2016 (46 months). The capacity factor and PBA values were then independently normalised between 0 and 1, to allow capacity factor and PBA to be directly compared. Multiplying these normalised values together gives an indication as to how effective each month was with respect to capturing available wind resource and high average winds, allowing the “most effective” months to be determined.

As can be seen, the most effective month falls within this reporting year; February 2020, where the average PBA was only 92.96% but the capacity factor was a staggeringly high 68.59%. It is particularly encouraging that the industry was able to maintain such a high PBA when the capacity factor (and so wind resource) was so high. Additionally, 4 out of the top 10 months were in the last financial year, leading to this year having the highest average PBA as well as the highest average capacity factor. This shows that not only were the farms effective at capturing the wind resource available to them (high PBA), but there was also a large amount of wind resource available (high capacity factor).

This is promising for the industry as it shows the wind farms are still able to efficiently capture the energy, even when there are large amounts of wind resource.

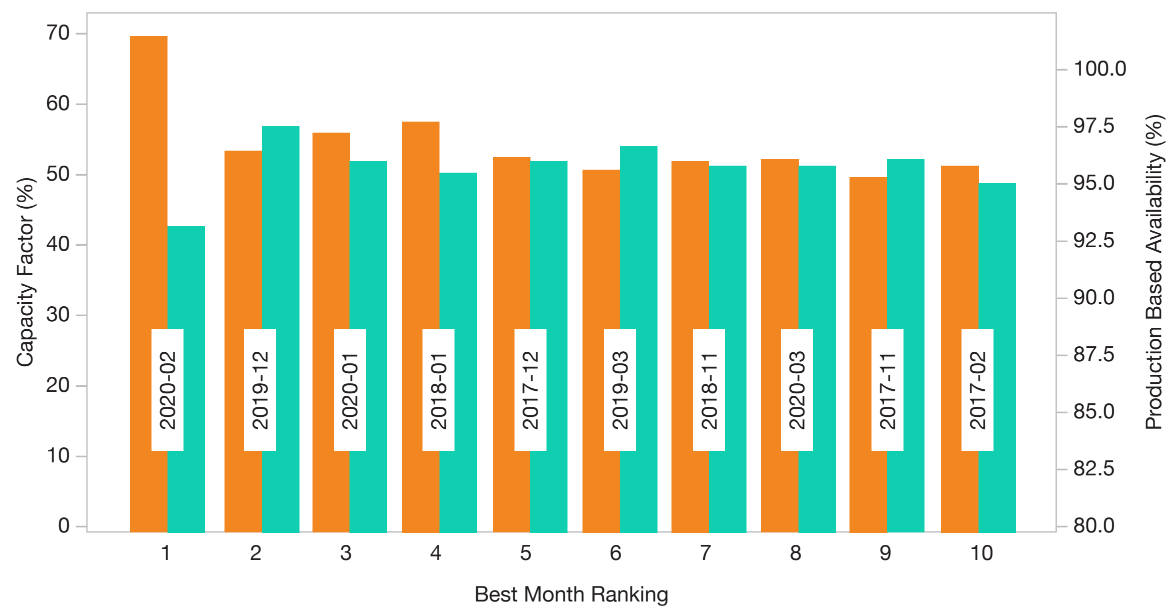


Figure 8 - Best Reporting Months Ranked

Month	Rank	Capacity Factor (%)	Production Based Availability (%)	CF score	PBA score	Score
01/02/2020	1	68.59	92.96	1	0.762	0.762
01/12/2019	2	53.01	97.39	0.706	0.986	0.696
01/01/2020	3	55.44	95.89	0.752	0.911	0.685
01/01/2018	4	56.72	95.33	0.776	0.882	0.684
01/12/2017	5	52.01	95.92	0.687	0.912	0.627
01/03/2019	6	50.19	96.45	0.653	0.939	0.613
01/11/2018	7	51.36	95.60	0.675	0.896	0.605
01/03/2020	8	51.55	95.02	0.679	0.866	0.588
01/11/2017	9	49.13	95.96	0.633	0.914	0.579
01/02/2017	10	50.83	94.89	0.665	0.860	0.572

Table 1 - Best Reporting Months With Scores

Figure 9 - Combined Normalised Production Based Availability and Capacity Factor Scores Monthly Heatmap

Seasonality

Another way of analysing the capacity factor and PBA combination is by looking at the different seasons and how the distribution of values vary. Figure 10 shows this with a distribution plot, with the density plot shown for both PBA and Capacity Factor.

Here it can be seen how the winter months have the highest probability of a high PBA as well as having a high probability of having a high capacity factor. This is likely driven by operators looking to capture all the potential wind resource possible, so making sure all assets are operating well leading into this period. As expected, the summer periods have the highest probability of achieving a low capacity factor. This then leads operators to concentrate maintenance for this period, reducing the PBA over summer. Interestingly, whilst autumn has a higher probability of a high capacity factor, compared to spring, it achieves a lower probability of a high PBA. If operations teams were able to start their annual maintenance earlier in the year, then they may be able to capitalise on the higher capacity factors seen over the autumn period.

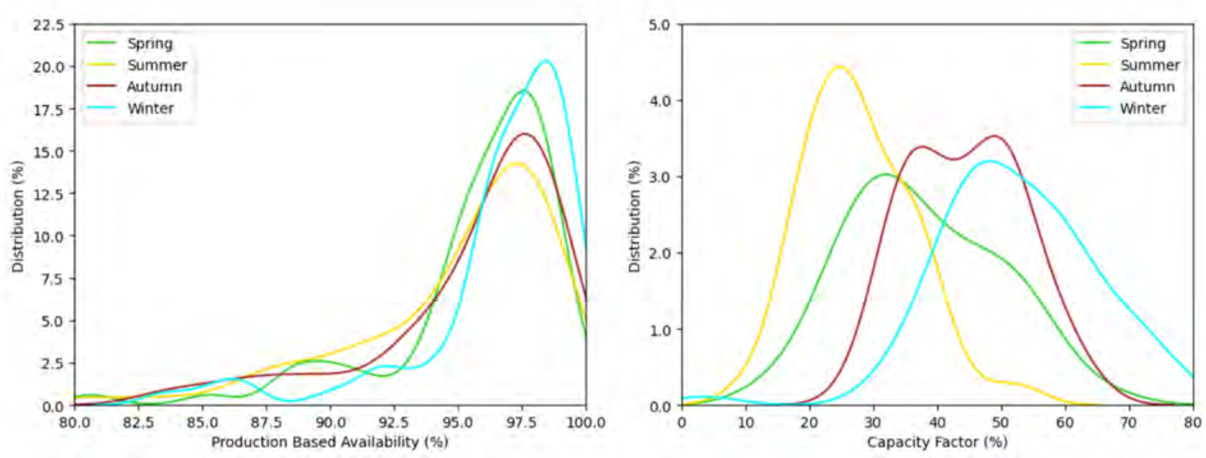


Figure 10 - Production Based Availability (top) and Capacity Factor (right) Seasonal Densities

OEM Breakdown

Although SPARTA cannot comment on specific OEMs, it is still interesting to draw comparisons between them, while keeping the names anonymised. For the purposes of this analysis the differences between OEM 1 and OEM2 is investigated, the two OEMs with the highest population in SPARTA.

When looking at PBA, it seems there is little difference between the two OEMs, with both achieving average PBA values around 95%. The left of Figure 11 shows the average values for the two OEMs whilst the right of Figure 11 shows the probability of the two OEMs achieving PBA values.

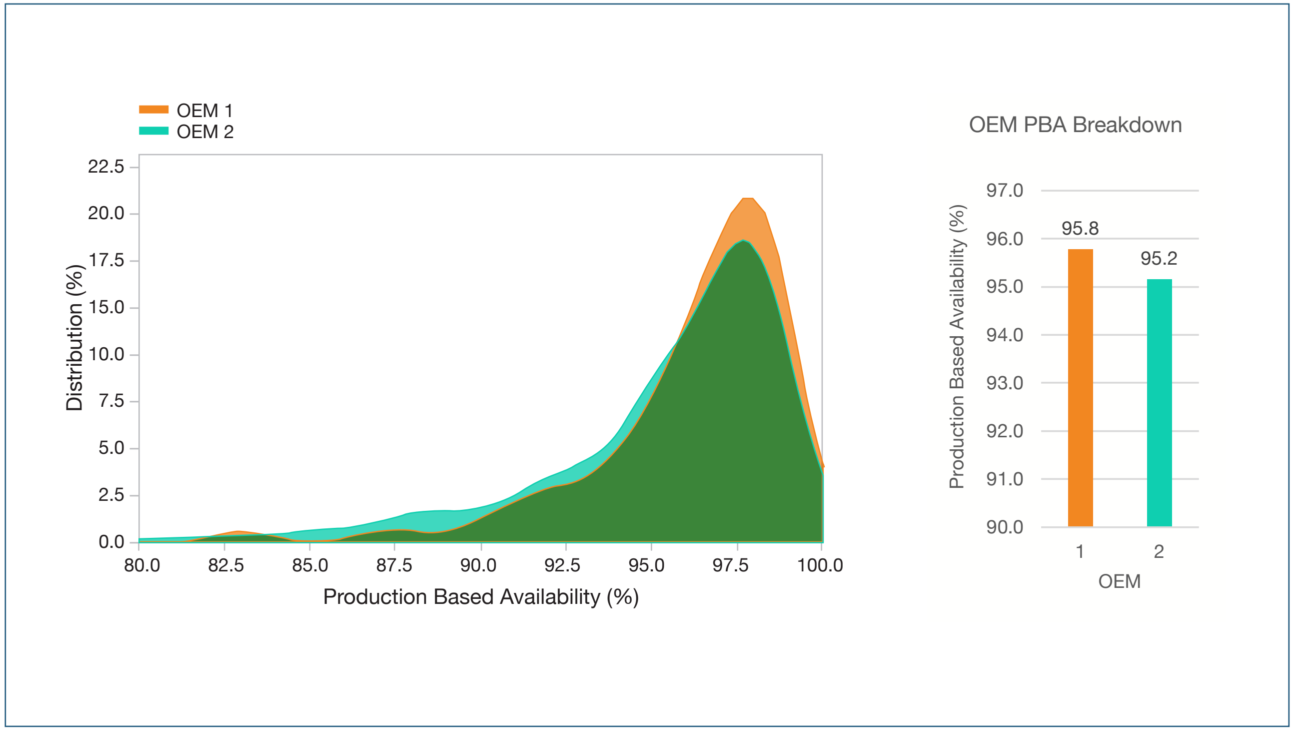


Figure 11 - OEM Production Based Availability Breakdown (left = average values, right = density distribution)

When looking at capacity factor the biggest differences between the two OEMs are noted, with OEM 1 achieving an average value of 35.96% whilst OEM 2 achieves a much higher average value of 39.75%. As mentioned in section 0, capacity factor is largely driven by the wind resource at the site in question but when looking at the average wind speed it can be seen that OEM 1 has a slightly higher average wind speed, despite achieving a lower capacity factor. This could indicate that OEM 1 is not managing to fully capture the potential energy given to it. This can be further seen in the distribution of reported values, with OEM 1 having reported more lower capacity factor values, as seen in Figure 12.

OEM	Average PBA (%)	Average Capacity Factor (%)	Average Hub Height Wind Speed (m/s)
1	95.8	36.0	8.2
2	95.2	39.8	7.9

Table 2 - OEM Summary

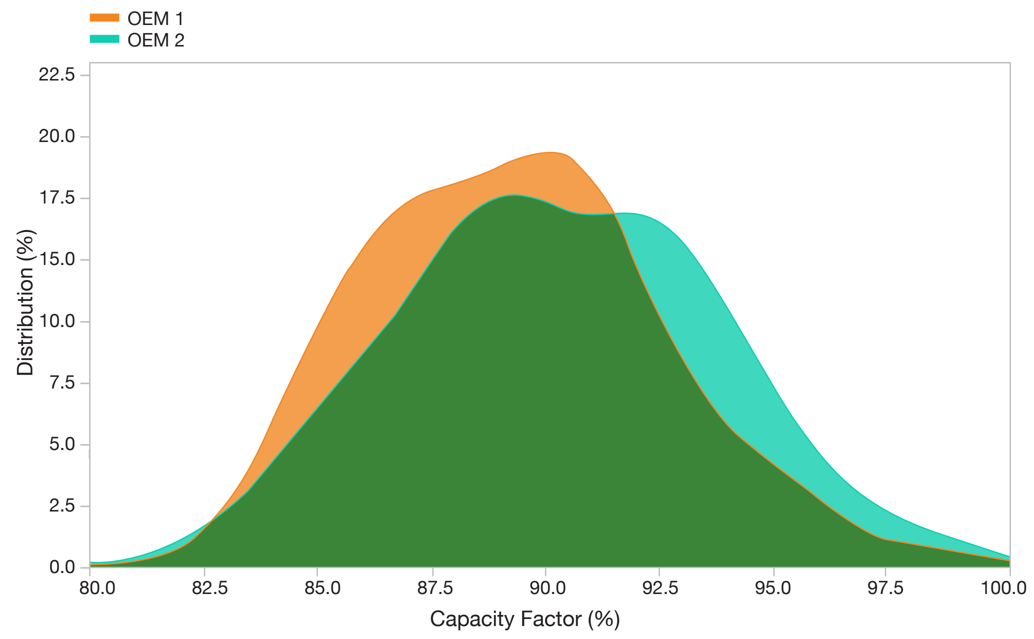


Figure 12 - OEM Capacity Factor Density Distribution Breakdown

Sparta Trends

This is also visible in the breakdown of lost energy production between the two OEMs, with OEM 1 achieving a much higher level of lost energy production per MW, this can be seen in Figure 13. It seems OEM 1 is not as able to effectively capture the wind resource given to it, compared to OEM 2.

An item to note about the different OEMs is how the reporting farms differ, shown in the summary Table 3. As can be seen, OEM 2 has a higher number of farms reporting data compared to OEM 1. OEM 1 can also said to be characterised by smaller wind farms, with a lower average installed capacity and number of wind turbines per farm. This will of course influence the results but it is impossible to say how much by.

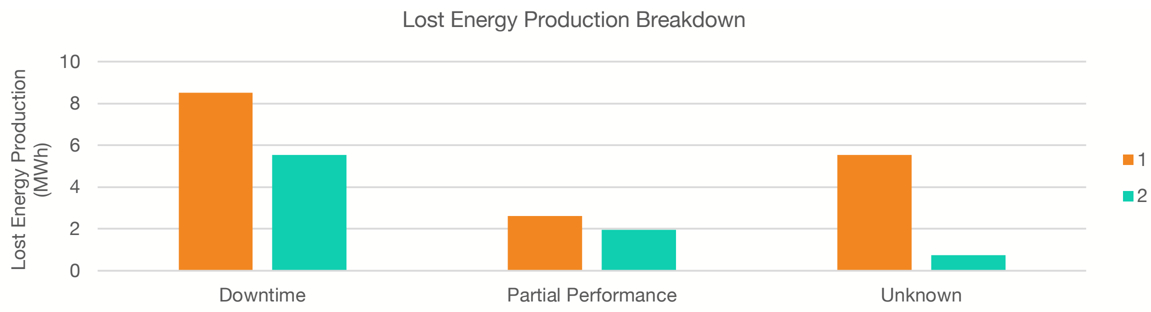


Figure 13 - OEM Lost Energy Production Breakdown

OEM	Number of Wind Farms	Average Installed Capacity (MW)	Average Turbine Rated Power (kW)	Average Number of Turbines per Wind Farm
1	7	183.53	3679	59
2	12	318.39	4175	75

Table 3 - OEM Meta Data

Transfers

As reported in the previous two annual portfolio reviews, the number of transfers per turbine has been steadily declining over the years and this year was no exception. The most recent portfolio year saw the lowest value yet, at an average of 6.49 transfers per turbine per month, this trend can be identified in Figure **14**, Figure **15** and Figure **16**.

This is a very positive sign for the industry as a higher number of transfers will cost sites more and increases the potential for incidents to occur. A key goal for the industry should be to reduce the amount of times personnel transfer onto a turbine, thus reducing risk to personnel.

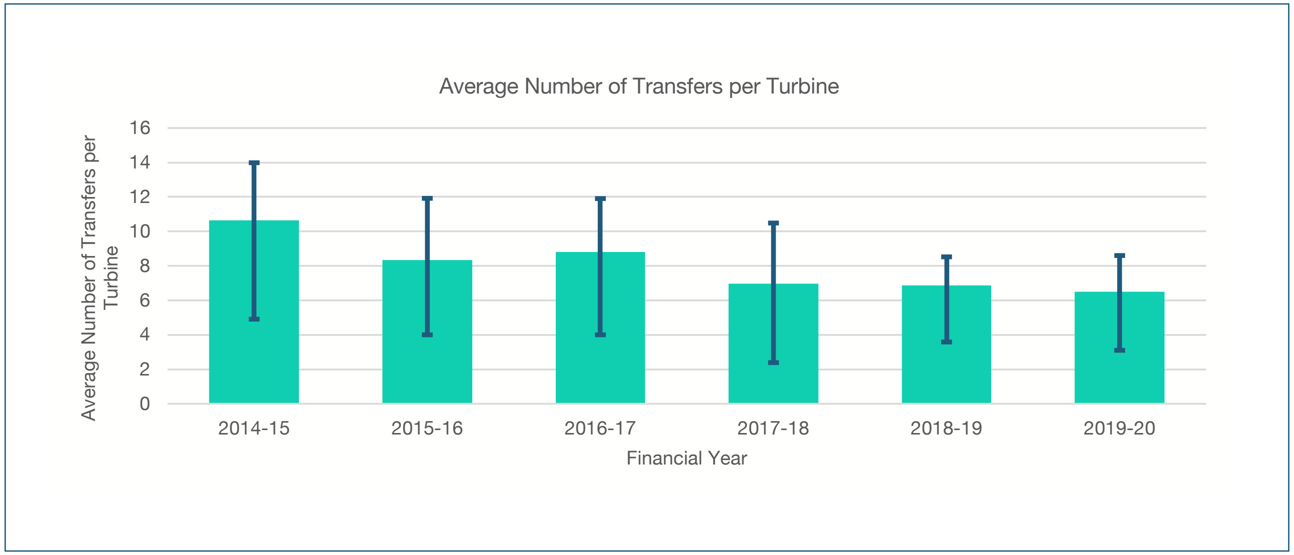


Figure 14 - Average Number of Transfers per Turbine (p25 and P75 shown by error bars)

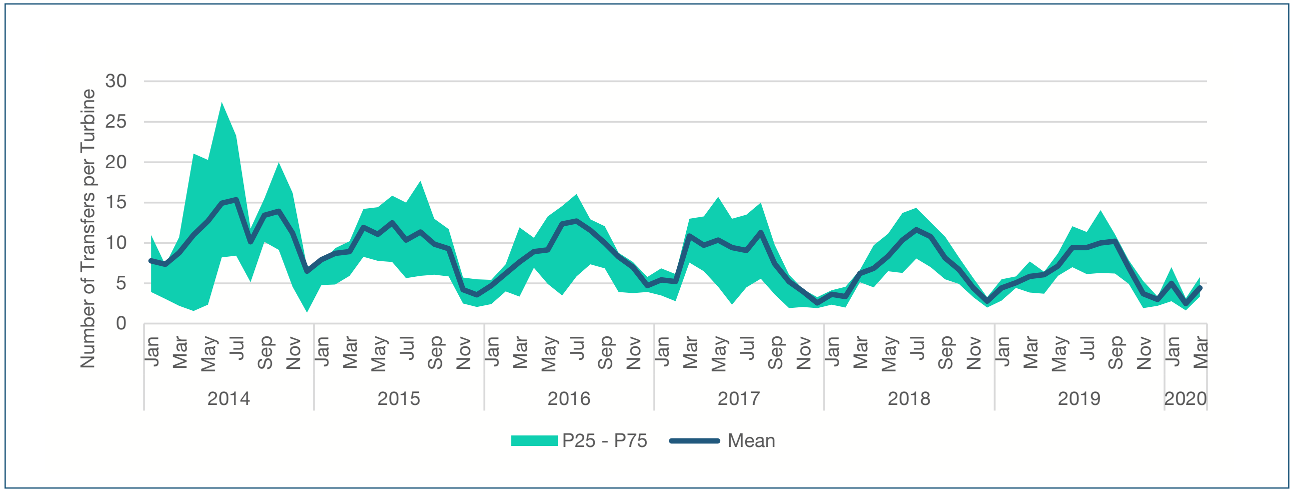


Figure 15 - Number of Transfer per Turbine Monthly Trend (p25 and p75 shown by shaded area)

What is a turbine transfer?

Turbine transfers 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 transfer several technicians onto a singular turbine.

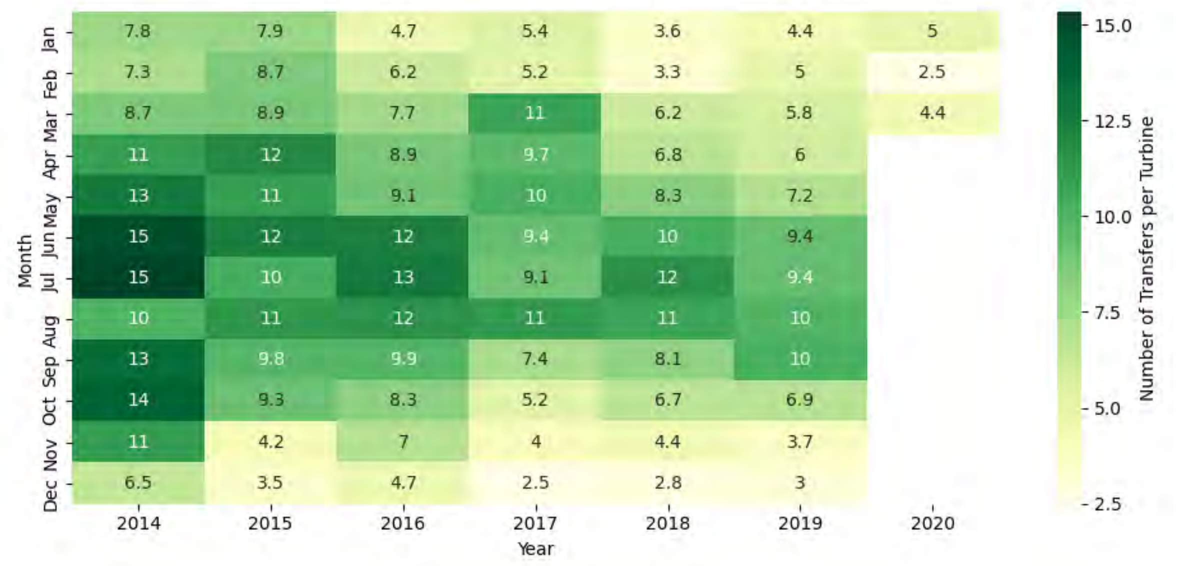


Figure 16 - Number of Transfers per Turbine Monthly Heatmap

Operations

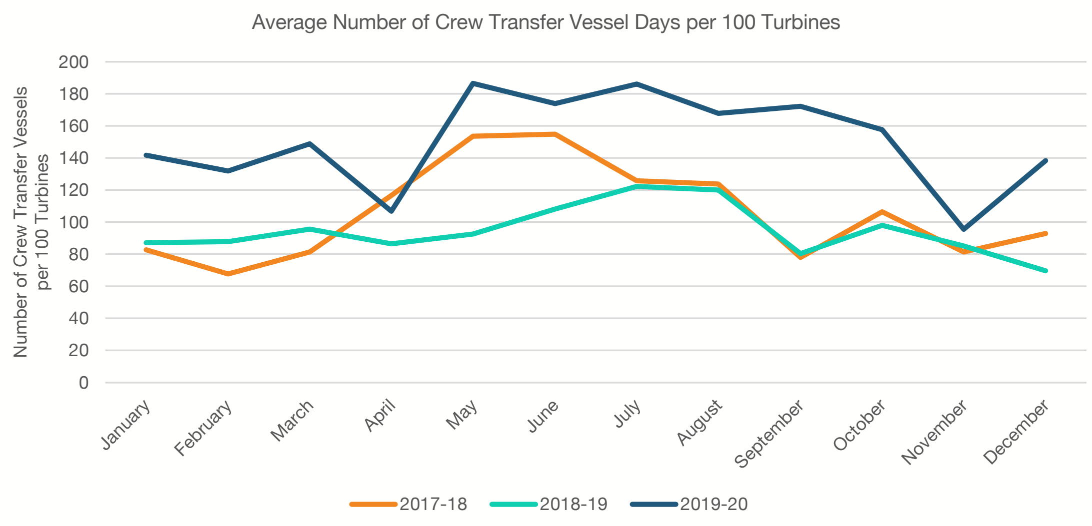
Vessel Days

Looking at the average number of vessel days per turbine reported to SPARTA it seems the last reporting year had significantly more than the years before, with a particularly large value over the summer periods, this increase can be seen in Figure 17. Perhaps this could be representative of the industry doing more O&M work over the summer period in anticipation of the winter period. By looking at a normalised value (per turbine) then comparing this over a "standard wind farm" of 100 turbines, an approximation for the number of vessels a site generally has can be gained. As can be seen 2019 - 2020 saw values over 180, indicating on average 6 CTVs were at the site during the month.

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.



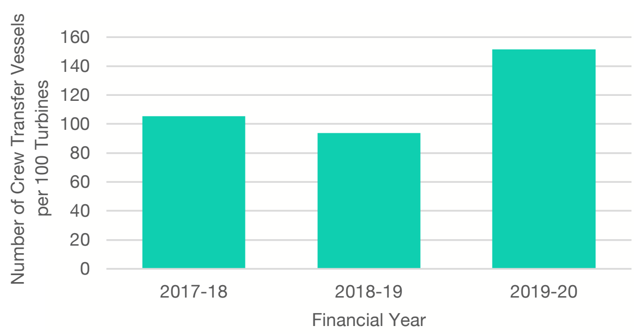


Figure 17 - Number of Crew Transfer Vessel Days per 100 Turbines Trends (top = monthly values, bottom = yearly values)

Operations

An insightful way of looking at the number of vessel days is by looking at the number of transfers made, divided by the number of vessel days. This gives an indication as to how "full" the vessels are. Higher numbers may indicate more work being done in parallel, with larger numbers of technicians being transported out at once, whereas lower numbers may indicate more reactive work with technicians going out when work is required, with less proactive scheduling. Figure 18 shows the median value for each month with the P25 to P75 range displayed around the median. The general downwards trend in this graph shows that less transfers are happening with every vessel day. This could be explained by less technicians being present on each vessel or more vessels being chartered to provide more redundancy, in the case that a large amount of work needs undertaken.

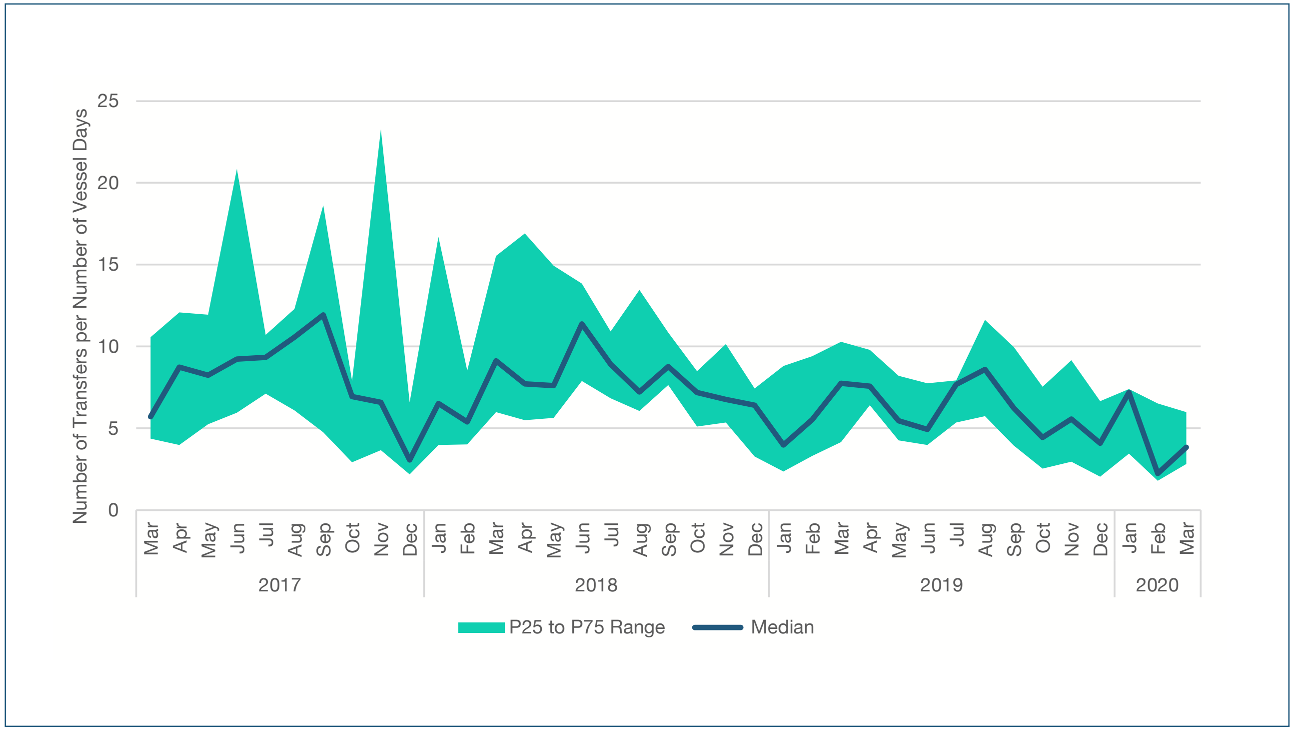


Figure 18 - Number of Transfers per Number of Vessel Days

Non-Access Days

It is imperative to reduce the number of non-access days as these reduce the number of days that are available to undertake maintenance on a wind farm, which can in turn lead to reduced production for the wind farm.

As can be seen from the below graphs (Figure 19), the average number of non-access days reduced dramatically during the early period of SPARTA data collection (representative to the start of the offshore wind industry) but has since levelled off. With the growing adoption of SOV use, as opposed to CTVs, it is likely that this value will decline again, as SOVs are able to access turbines in higher sea states.

One notable insight that can be gained from these charts is how high the numbers are. For the last four reporting years the average number of non-access days has been sitting at around 8 days per month, this equates 96 days per year. This means that over a quarter of the year vessels are not able to access the site to complete O&M. This will have a large detrimental impact to work being undertaken at site.

What is a Non-Access Day?

The number of non-access days in a month can be defined as the number of days in the month where regular maintenance work offshore cannot be performed, or is restricted, due to weather.

This includes any day that work cannot be undertaken, irrespective of whether work was planned to occur or not. Any site access limitations other than weather, such as health and safety or vessel mechanical issues, are not counted.

Figure 19 - Number of Non-Access Days Trends (top = monthly, bottom = yearly)

Deep Dive

Drivers of Low PBA Performance

For some months in Figure 3, the distribution of PBA is skewed towards lower values.

This deep dive discusses what may be the cause of this skewed distribution; could it be that some sites consistently struggle with their PBA and if so why?

Deep Dive – Drivers of Low PBA Performance

PBA performance groups

To investigate the drivers of low PBA performance, sites were firstly split into 3 performance groups based on their average PBA for the financial year 2019-2020; top performers (sites in the top quartile), low performers (sites in bottom quartile) and average performers (those sites between the top and bottom quartiles). Table 4 shows sites which were in the bottom quartile for PBA in 2019 – 2020 and if they were in the bottom quarter in previous years. It is shown that over half of the sites in the low performance group generally perform poorly in terms of PBA, when looking back over 4 financial years.

Sites with consistently and significantly lower PBA were investigated, to understand their impact on the industry average, seen in Figure 3, and if this could translate to financial losses. Figure 20 shows the comparison of PBA between the low, average and top performers over time from January 2017 up to March 2020. During the summer months, low performers as a group consistently have dips in PBA, whilst top and average performers have PBAs comparable with the winter months. In February 2020, the average PBA for low, average and top performers was 89.27%, 92.36% and 96.79% respectively. 3-4% between the groups may not seem like a significant difference, however when translated to financial impact the difference is stark. For an average 400MW windfarm with a capacity factor of 40%, the site would expect to achieve 107,520 MWh of production for the month of February, using the below equation.

Predicted Generation (MWh) = Rated power of site (MW) × Days in the month × Hours in a day × Capacity Factor

By rearranging the equation for PBA (actual generation / predicted generation), a drop in PBA of 96.79% to 92.36% results in a loss of £476,313. A drop from 92.36% to 89.27% would result in a loss of £332,237. Whilst a drop in PBA from 96.79% to 89.27% would cost £808,550, a staggeringly high value considering this is only a drop of ~6% in PBA.

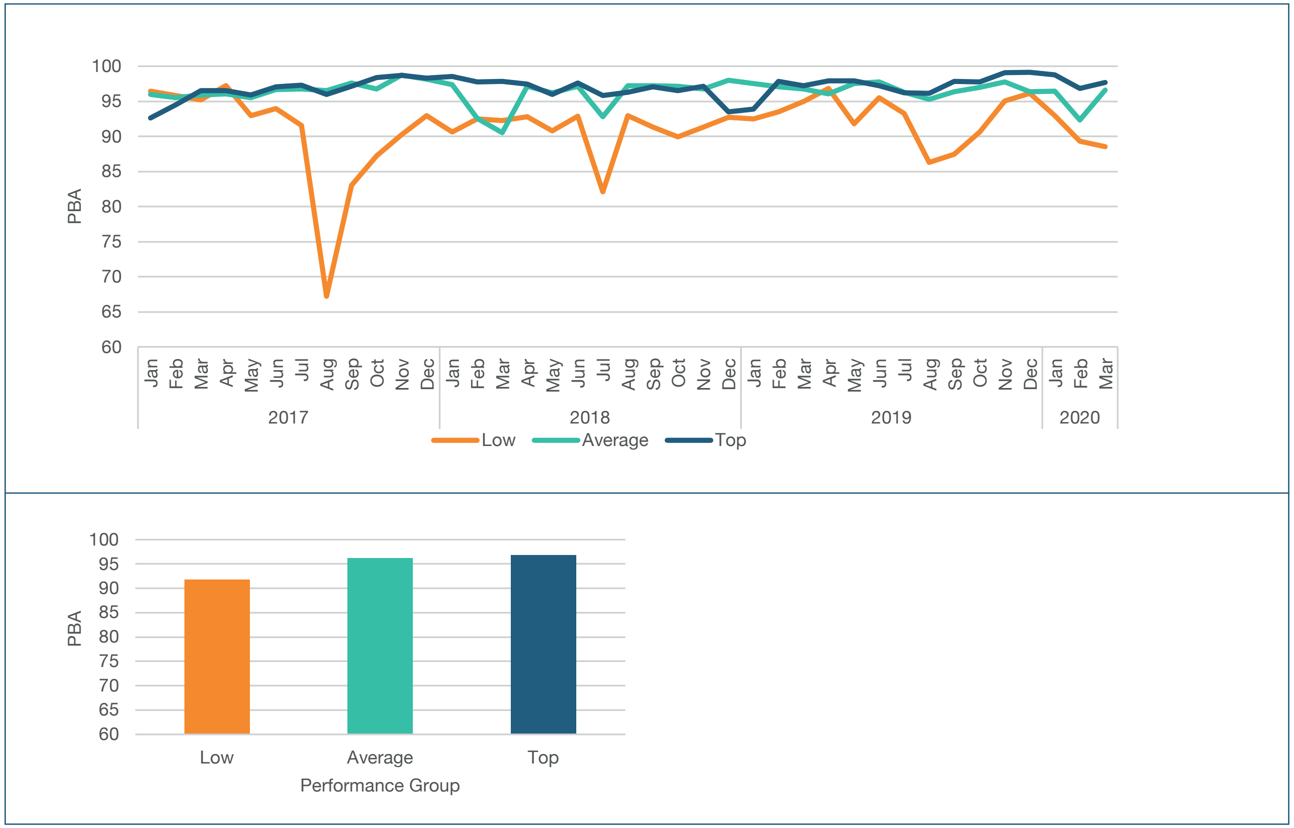


Figure 20 - PBA Over Time Split by Performance Group (top) and Mean PBA (bottom)

Site	FY16-17	FY17-18	FY18-19	FY19-20
1	Y	N	Y	Y
2	Y	Y	Y	Y
3	N	N	N	Y
4	N	Y	Y	Y
5	N	N	N	Y

Table 4 - Sites Consistently in Bottom PBA Quartile (Y = in the bottom quarter, N = not in bottom quarter).

Deep Dive – Drivers of Low PBA Performance

Trends relating to PBA performance

Locale

The potential causes for low PBA performance were investigated. Figure 21 shows how the three performance groups compare when analysing the static dimensions; age, region, size and OEM maintenance strategy. The regional comparisons show that all of the top performers are located on the East Coast, whilst the majority of the low performers are located on the West Coast and the average performers have a 50/50 split between regions. Whilst there are no significant differences or trends in age or size between performance groups, the maintenance provider comparison shows that low performers have a higher population of contracts where the OEM undertakes all the maintenance (Full OEM), compared to the top performers, this could indicate that in-house maintenance helps sites achieve a higher PBA.

Figure 21 - Region, OEM Maintenance, Size and Age Breakdown Per Performance Group

Deep Dive – Drivers of Low PBA Performance

Operational strategy

The strategy of how a farm is operated and maintained may be affecting its PBA performance. Focusing on the operational metrics such as number of transfers per turbine, number of vessel days per turbine and non-access days due to the weather reveals the level of site activity going on. This may indicate how efficient the operational strategy is, i.e. are too many or not enough visits being made to site or does the weather impact the ability to make vital repairs.

Figure 22 shows the number of transfers per turbine for each of the performance groups over time and as an average. Overall, low performers have the highest number of transfers, whilst the top performers make the least transfers. This could indicate that low performing sites have more issues with turbines or potentially an inefficient maintenance strategy, meaning they are making unnecessary visits to site when they could be combining tasks and improve efficiency of their time on site.

Figure 22 - Number of transfers per turbine (Jan 2017 - Mar 2020)

Deep Dive – Drivers of Low PBA Performance

Figure 23 shows how the number of crew transfer vessel days differs between the three performance groups. Top performers are spreading their crew transfer vessel days throughout the year, whilst low and average performers are deploying their vessels primarily in the summer months. Having constant access to a crew transfer vessel throughout the year could be a factor in the success of top performing sites. Another factor in this could be the ability to plan/ carry out work that requires a longer period of time such as major system repairs; i.e. if a major repair takes 3-4 days to complete, weather or resource scheduling may or may not permit consecutive days to carry out the work, top performers may be able to take an advantage of increased CTV availability over low performing sites in achieving more effective operational strategy.

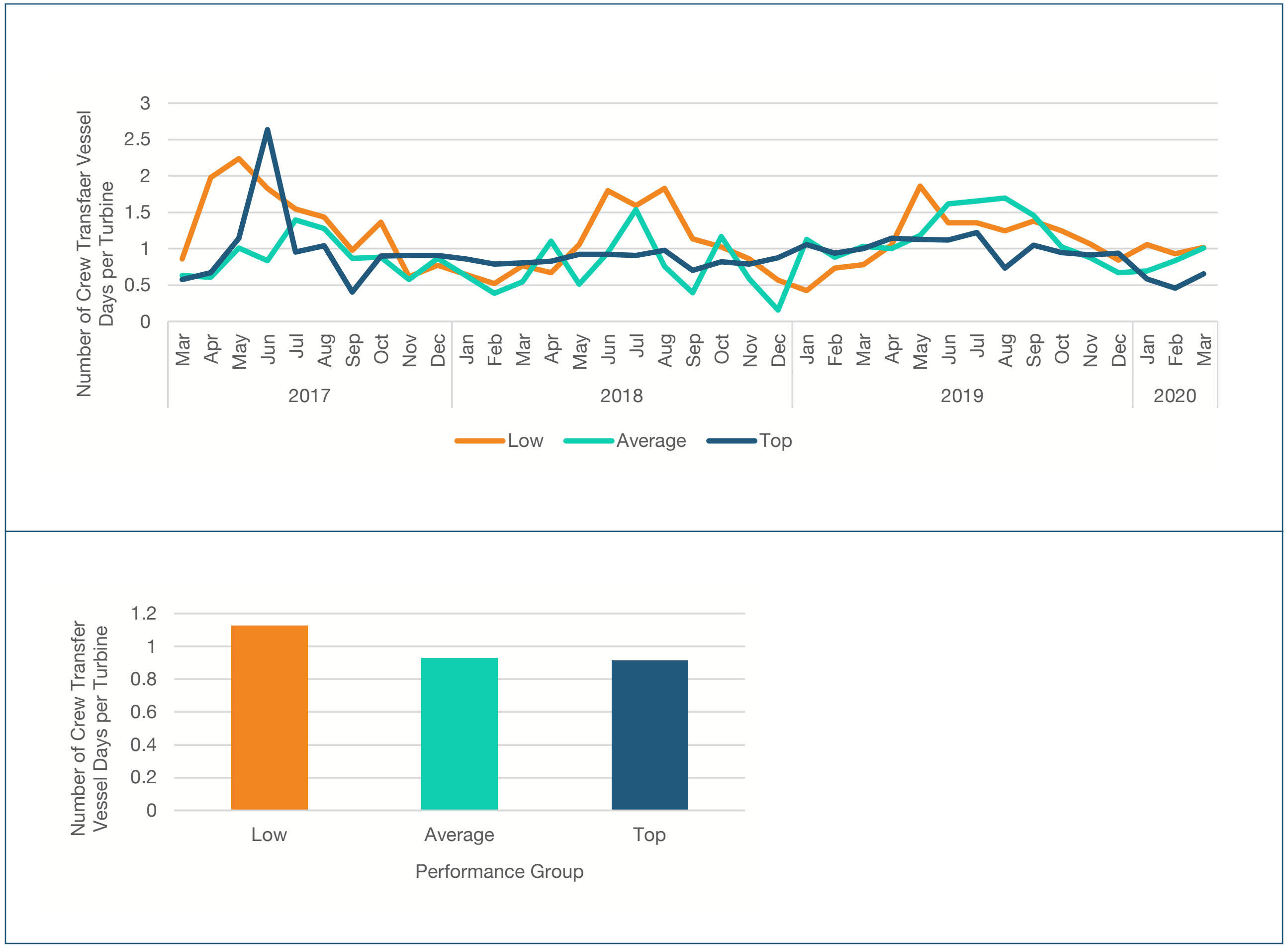


Figure 23 - Number of crew transfer vessel days per turbine (Jan 2017 - Mar 2020)

Deep Dive – Drivers of Low PBA Performance

Site accessibility

The ability to access a wind farm and its turbines may be a key factor in the farm's PBA performance. Figure 24 shows the number of non-access days due to weather. In the bar chart, the average significant wave height is also included to determine a sites ability to handle tougher environmental conditions. While the low and average performing sites have significantly more non access days than top performing sites, they also have lower mean significant wave heights. This could suggest that top performers are able to handle rougher sea conditions either by using vessels able to sail in higher waves or a difference in technology used to transfer personnel. What drives the differences in these operational metrics is multi-factored and can be influenced by site location as well as how modern the vessels are. Whilst improving vessels and vessel technology is a significant investment, if the PBA of a site rises by a few per cent, using the figures stated previously in this section, the site could increase its income by approximately £400,000 over one month and approximately £5M over a year.

Figure 24 - Top = Number of non-access days split by performance group (Jan 2017 - Mar 2020)
Bottom = Average number of non-access days and significant wave height (Jan 2017 - Mar 2020)

Deep Dive – Drivers of Low PBA Performance

Lost Production

Finally, Figure 25 shows the lost energy production breakdown between the three performance groups. The majority of lost production is due to downtime across all groups however low performing sites have on average four times more downtime than top performing sites. This could indicate that low performing sites suffer with more repairs, corrective maintenance and/or maintenance than top performing sites. Perhaps, by improving operational strategy such as combining maintenance tasks whilst on site, as an example, the number of transfers can be reduced therefore reducing the amount of downtime and hence lost production which would in turn increase PBA, making the windfarm more profitable.

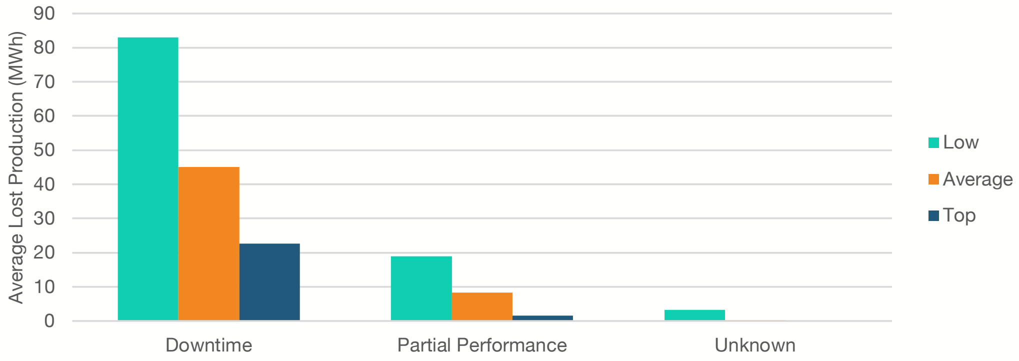


Figure 25 - Lost energy production breakdown split by performance group. (Jan 2017 - Mar 2020)

Conclusion

This section investigated a number of possible drivers as to why some sites perform poorly in terms of PBA. Whilst PBA is influenced by a variety of factors, this deep dive has compared static dimensions and operational metrics of the sites in SPARTA to shed some light on why some sites perform poorly in comparison to others and how a small increase in PBA could dramatically improve site revenue.

Figure 25 shows that downtime plays a big role in the amount of lost production on site so by reducing the amount of time turbines are switched off, for whatever reason, this would have a big impact on improving PBA. By investing time and money into improving operational strategy, technology and vessels, sites are able to work more efficiently, enact repairs when needed and allow safer transfers for personnel as well as generating more revenue.

Deep Dive

Interpreting Alarm Logs to Benchmark Unplanned Outages

SPARTA aims to do more than just provide industry standard benchmarks, SPARTA works as a mechanism to bring together the offshore wind industry to solve problems together. This next section aims to highlight that by introducing a discussion to a problem that SPARTA is constantly working on, how best to analyse turbine alarms.

This deep dive aims to highlight the importance of understanding turbine alarm codes to enable accurate and consistent reliability benchmarking and considers how these benchmarks can then be used. It will then explore the root cause assumption, before briefly touching on the limitations of alarm logs and finish with two use cases that could bring insight and cost savings to operations and maintenance.

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."

Alarm Mapping

Forced outages are defined by the British and European adopted IEC standard, BS EN IEC 61400-26-1 as, "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."

Benchmarking these unplanned stops can be used to interrogate the performance and reliability of turbines. For example,

1. **Are particular components failing more often than the industry average?**
   Components could be wearing out and in need of replacement. This may be increasing the demand on maintenance teams and it may be more cost effective to replace the component than frequently repair it.

2. **Are particular infrequent failures resulting in a lot of downtime?**
   Supply chain issues could be preventing the quick replacement of parts, or this might highlight the need for further learning to better diagnose problems related to that component and fixing them more efficiently.

3. **Is a wind farm outperforming the industry average?**
   The operations and maintenance teams might be in a good place to spread their best practice and help the industry and supply chain perform better.

Alarm Mapping is the process of using an alarm code to determine which operative state the turbine is in and which physical component an alarm relates to. If these two aspects are understood, then it is possible to process raw alarms into useful metrics such as forced outages, at a turbine component level. These additional metrics would offer additional valuable insights which could be used to better enhance O&M strategy and planning, for example, being able to associate criticality of component maintenance directly to history of forced outages, hence cost.

Deep Dive – Interpreting Alarm Logs to Benchmark Unplanned Outages

Enhancing Alarm Log Analysis

Wind turbine alarms are designed to protect and support diagnostics for single turbines and were not designed such to be able to support farm level operations and maintenance strategies, how the industry analyse these are therefore not currently optimum. 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. **The distribution of alarms across the components is uneven and not consistent between manufacturers.** In one example 60% of forced outage alarms are mapped to control & protection system. In another the largest grouping is 30% for the blade adjustment system, but in another still, blade adjustment system has only 7.5% of forced outage alarms mapped to it. This uneven distribution of alarms may exaggerate the failure rates for some components.

2. **Alarms are not categorised with any notion of severity.** Accuracy would be improved if records attribute root cause to the most serious alarm, however this would require severity to be consistently measured across the industry.

3. **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. Often it seems to include disparate alarms like software failures, configuration errors, safety alarms, signal errors and miscellaneous alarms related to almost all other components. It would be advantageous to expand this component group to better describe each of these areas.

4. **A growing area of interest is in relation to curtailments and the reason for those curtailments.** Particularly with older turbines, it is not always possible, from the alarm logs, to determine why a turbine has been de-rated or de-graded. Knowing this would allow better benchmarking as the impact of each type of partial performance could be better accounted for.

By enhancing how alarms are analysed and addressing the challenges laid out previously, alarm data could be better utilised to enhance operations and maintenance strategies, decision making, planning and prioritisation.

Deep Dive – Interpreting Alarm Logs to Benchmark Unplanned Outages

Root Cause Assumption

The primary assumption of the SPARTA definition for forced outages is that for a given 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. The following two scenarios highlight this.

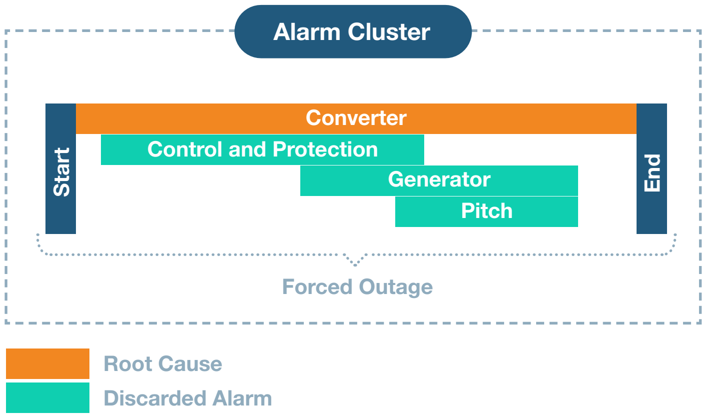
Suppose that the converter fails, it should trigger an alarm and this failure also causes other components to fail and trigger alarms. There may be some conditions within the control and protection system, such as cable distance, that mean the converter alarm is not received first, perhaps only with a delay of milliseconds.

Similarly, suppose that there is an issue with the main bearing and that it is in the process of failing, but this failure could take several hours or days to occur. Due this degradation in performance another component may experience higher stress than normal causing it to fail before the problems with the bearing raise an alarm. This series of events would entirely exclude the bearing from the alarm log.

Potentially, these problems could be overcome with precedence rules, such as: If a converter alarm and a control and protection system alarm occur within 1 second of each other then the converter alarm is considered the primary cause. By introducing precedence and hierarchical relationships to alarm causes, it may be possible to more accurately reflect the assumed root causes, improving the efficiency of diagnosis and therefore offering potential cost savings through enabling more effective maintenance and reduced downtime.

Groups of Alarm – Clusters

Given a set of alarms that occur around the same time, the current focus is to try to determine the single root cause from amongst these alarms. This is extremely difficult to do remotely and often only possible with high accuracy following an inspection by an engineer. However, if these groups of alarms are considered as a single entity, a cluster, then we can begin to create new properties for them that can then be exploited with artificial intelligence. For example, it would be possible to describe the sequence, distributions and overlaps of alarms, using this information to further categorise and 'fingerprint' alarm clusters to specific physical failures. Whilst this could help remotely diagnose problems, it may also lead to a more holistic view of the health of the turbine by considering all alarms rather than discarding many.



*"Given a set of alarms that occur around the same time,… try to **determine** the **single root cause** from amongst these alarms.*

Deep Dive – Interpreting Alarm Logs to Benchmark Unplanned Outages

*“Supervised learning is **artificial intelligence** that aims to determine a label from some data… This relies on having a ground truth to train your model… This would come from combining **maintenance records** with numerical data.”*

Human Labels for Research and Artificial Intelligence

Supervised learning is artificial intelligence that aims to determine a label or a value from some data. For example, you may wish to use SCADA data to determine the operative state of a turbine. A more complex example would be using SCADA and other signals to predict if a component failure is imminent. This relies on having a ground truth to train your model. This ground truth would come from combining maintenance records with your numerical data. This may be difficult if the maintenance records are either not electronic or hard to align with your data. This data may also be more sensitive and the criteria for releasing it stricter.

Alarms could provide an alternative. Rather than trying to predict a component failure, it may be possible to predict the likelihood of an alarm occurring, and as all the alarms are already labelled there is no need for a human to annotate them. Whilst predicting an alarm may not be as valuable as an actual component failure, it may have additional benefits such as highlighting when routine warnings or messages have not occurred within expected timeframes.

Improved labelling of alarms and alarm data could unlock potential value from the data that the industry is currently unaware of. The ability to employ new tools and techniques, not currently used with this data could result in improved insight to support future O&M decision making, improve efficiency and reduce cost.

What is SPARTA Doing?

SPARTA aims to be, and is, the industry standard for transparent offshore wind benchmarks. A key part of this is consistent alarm mappings, without these mappings, forced outage benchmarks cannot be obtained. The SPARTA group continue to work in this area to ensure all alarm maps are generated in a consistent manner, ensuring all workings are transparent. If you are working in the field of turbine alarms and would like to know more, please get in touch with the SPARTA technical lead at the Offshore Renewable Energy Catapult, contact information given at the end of this report.

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 in writing or by contacting either of the project sponsors:

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