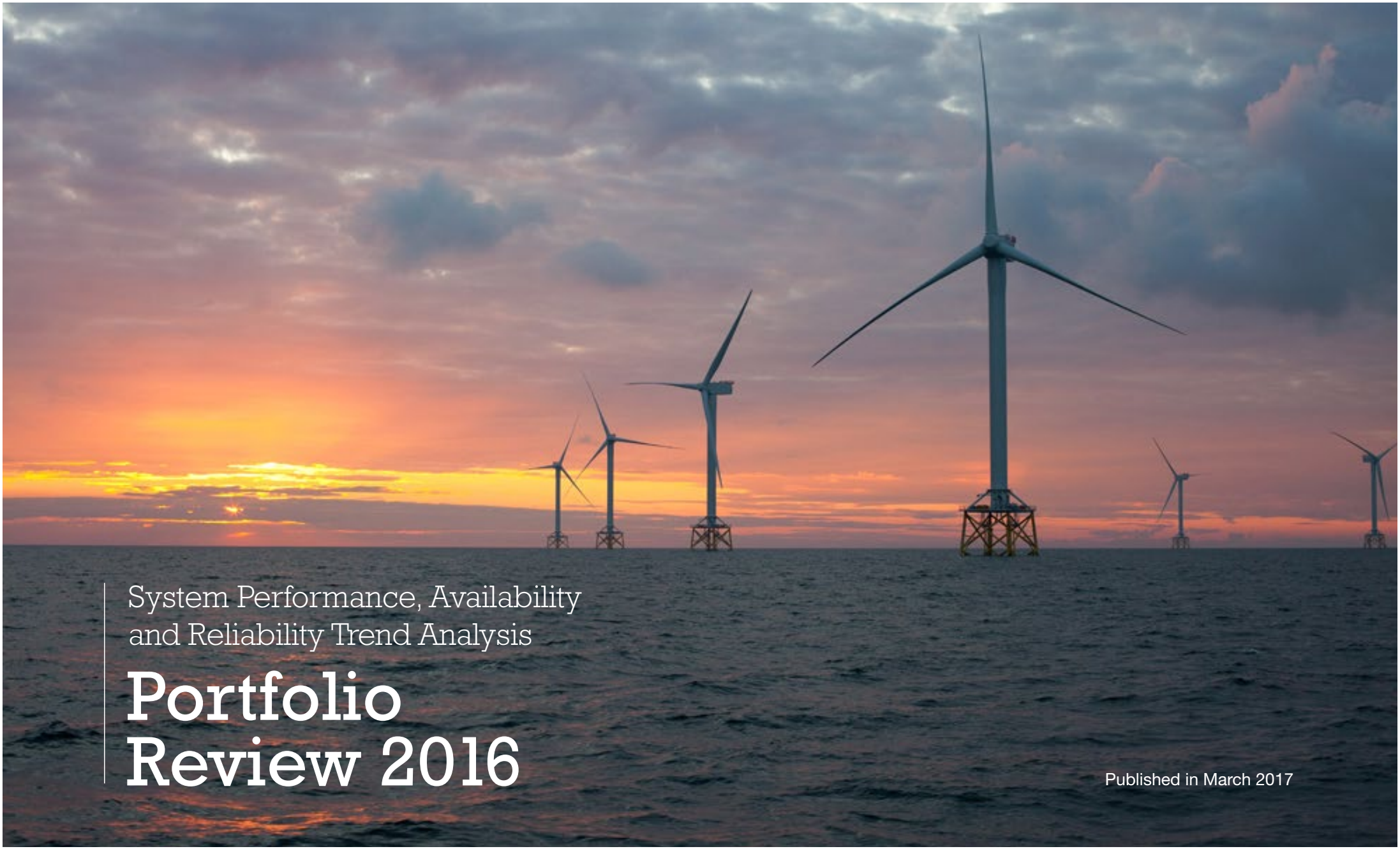
SPARTA
System Performance, Availability and Reliability Trend Analysis



System Performance, Availability and Reliability Trend Analysis

Portfolio Review 2016

Published in March 2017

SPARTA by numbers

20 TWh
Produced by portfolio in reporting period

Number one
First benchmarking platform for Offshore Wind assets

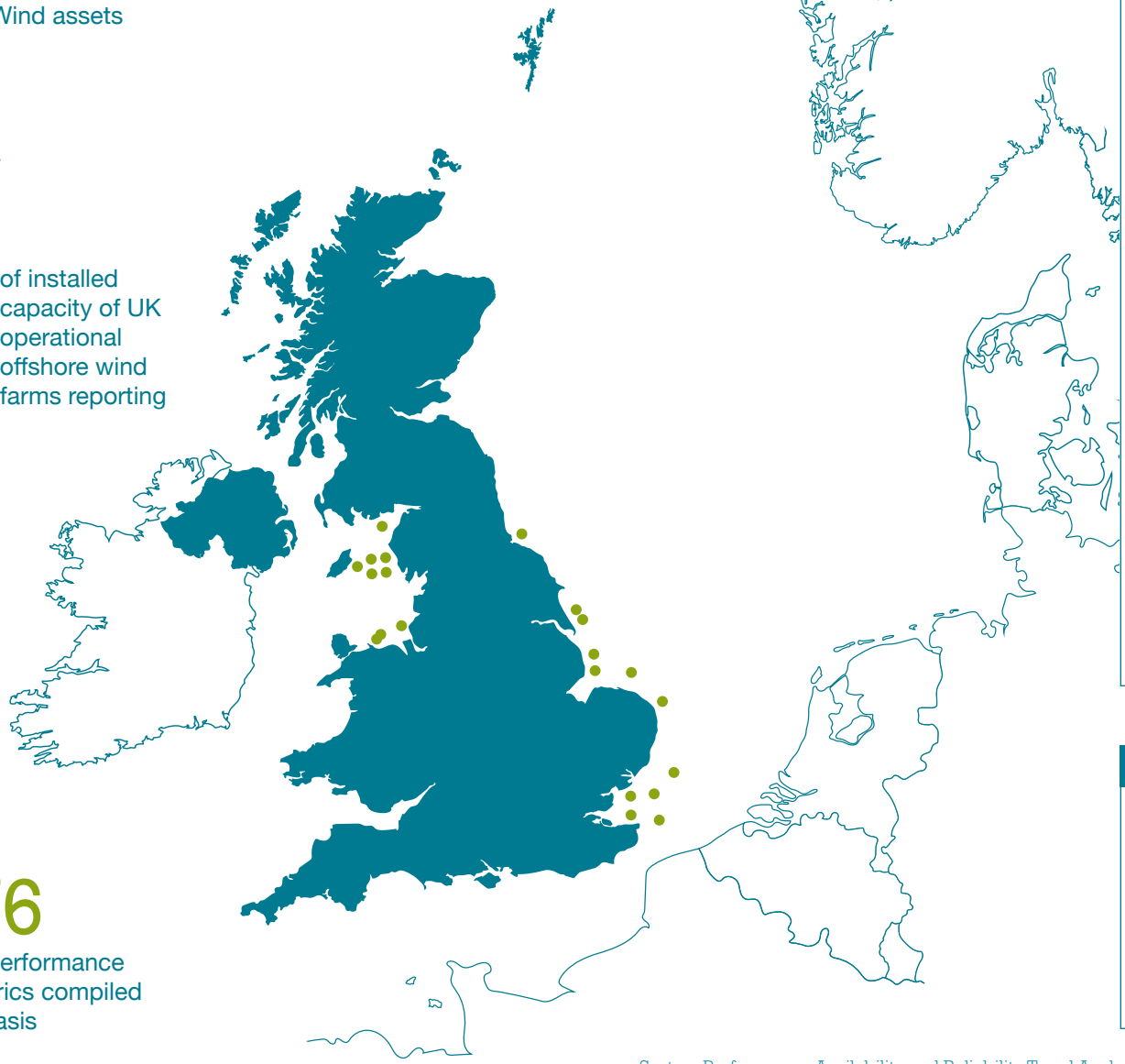
39.4%
Capacity factor achieved by portfolio in reporting period

93.7%
of installed capacity of UK operational offshore wind farms reporting

1,378
Wind Turbines monitored

19,465
Data points reported in year

76
Unique Key Performance Indicator metrics compiled on monthly basis



SPARTA members

centrica
DONG energy
EDF ENERGY RENEWABLES
e·on
innogy
SCOTTISHPOWER
SSE
Statkraft
Statoil
VATTENFALL

Sponsoring organisations

THE CROWN ESTATE
CATAPULT Offshore Renewable Energy

Introduction

Formed in 2013 in the UK, the SPARTA initiative brings together the leading companies operating offshore wind power plants. With over 5GW of capacity installed in the UK already and a growth plan to double by 2020, the industry makes a material contribution to the UK's electricity supply.

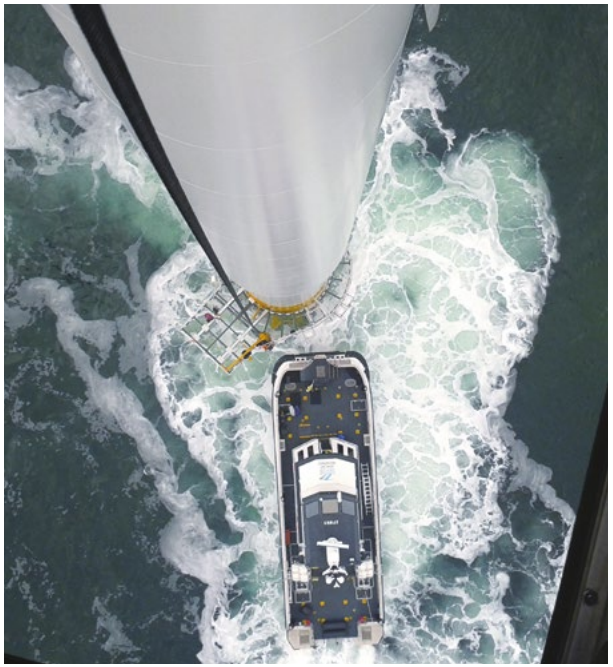
Producing clean, low carbon energy as efficiently as possible has become a key target for owner operators and collaboration on benchmarking and the setting of Key Performance Indicators (KPI) for plant performance is the fastest way of achieving rapid continuous improvement.

The SPARTA project aims to support improvements in the availability, reliability and performance of offshore wind assets. Operational data is collected at system level (from blade to onshore substation), analysed and reported upon in the form of benchmarks, allowing relative performance to be understood and acted upon by members. Benefits will be in the form of operational change, sector innovation, investment and development, and result in efficiency improvements, cost reduction and reduced risk to both employees and deployed assets.

Enabled by the sponsorship of The Crown Estate and Offshore Renewable Energy (ORE) Catapult, SPARTA has achieved a successful pilot phase and a further year of enduring operations under the leadership of its industry steering group. With new performance metrics being introduced into the system in 2016 and other system enhancements planned by members this review looks back on the successful implementation of this essential industry enterprise and takes a look at development plans going forward.

Long term success of the offshore wind industry will be built firmly on operational excellence and reliable services and SPARTA aims to raise the bar to achieve industry-wide superior performance.

Adrian Fox
Chair, on behalf of the SPARTA Steering Group



As co-sponsor, the ORE Catapult is delighted to be working collaboratively alongside the industry members and is looking forward to progressing the key priorities in the year ahead by:

- Moving the focus from gathering metrics to meaningful actions.
- Extending our geographic reach.
- Enabling greater disclosure and dissemination.

Chris Hill
ORE Catapult

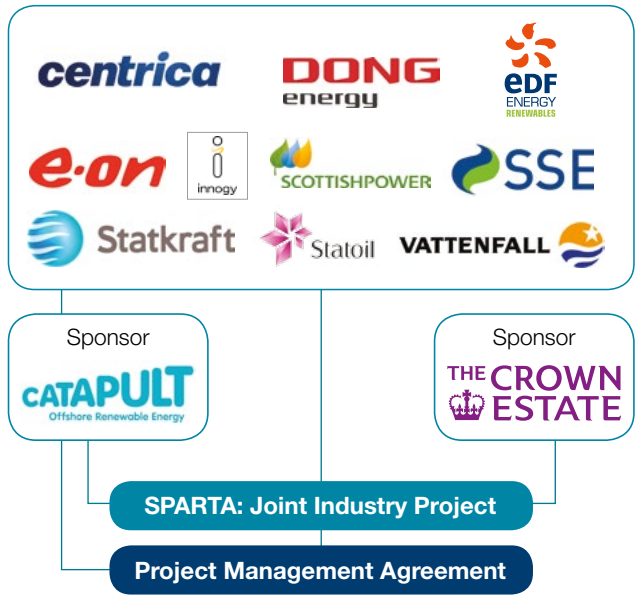
Who we are

SPARTA is a Joint Industry Project designed to be "by owner /operators, for owner/operators" that has successfully delivered a bespoke database for sharing anonymised offshore windfarm performance and maintenance data.

Through the Members Common Interest Agreement (MCIA), participants are provided with:

- a web-based database for the collection and presentation of operational data, reported at wind farm system level;
- systematic processes for quality assurance of the data and metric definition;
- collaborative initiatives to develop new measurements and KPIs to allow the system to evolve to suit members needs;
- monthly benchmark outputs allowing site and portfolio performance to be assessed against industry averages and acted upon.

SPARTA structure



Realised Benefits

Since the initial conceptualisation of SPARTA, the collaboration has successfully developed a secure, stable working system, realising the following benefits:

- agreed set of standard key performance metrics;
- consistency of reporting at project, portfolio and sector level;
- quality assurance through targeted auditing,
- monthly aggregation of metrics and comprehensive data sets, allowing members to benchmark and analyse for trends and insights to aid performance improvements;
- peer group professional networks at strategic and technical levels;
- monthly reporting at both detailed technical levels in the form of data sets and "at a glance" graphical representations.

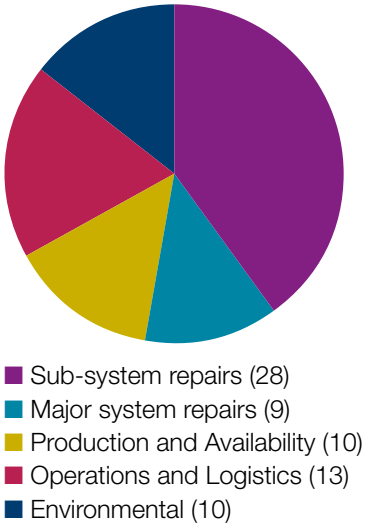
In addition, the project management services provided to the group enables future development through formal yearly business planning and fore-sighting processes to support decision making.

Data Processing and Metrics

Key Performance Indicator (KPI), or metric, specifications are developed by a Technical Advisory Group (TAG) drawn from members and approved by the Steering Group (SG).

The metric definitions are curated by the Project Manager into a metrics handbook. Based on this framework each participant submits monthly metrics to a secure server for each of its wind farms for the previous month. The SG and TAG teams have worked with their respective site based operational teams to validate the value of each metric, and to continuously improve the standardisation of the collection and calculation methods. This has resulted in a standard set of metric reporting which can be broken down in to the categories shown below.

SPARTA KPIs



"The consistency of the input data has been ensured by the collaborative work of the TAG to make the output benchmarks a valuable resource."
Dr Natalie Barratt,
Innogy Renewables UK Ltd

Key Performance Indicators, a first look

The following analysis is based on all wind farms that were operational and reporting to SPARTA throughout the year leading to May 2016. This includes 19 wind farms; 3.55GW; 1,045 wind turbines.

The site characteristics involved in this investigation are as follows:

Wind Farm Age *(number of years since commissioning date)*	**Mean Wind Farm size** *(MW)*	
Old (> 8 years)	83	4 farms
Medium (5-8 years)	155	7 farms
Young (< 5 years)	266	8 farms

Distance to Port *(measured between wind farm centre and O&M base, as the crow flies)*	**Mean Wind Farm size** *(MW)*	
Close (< 15 km)	90	6 farms
Medium (15-24 km)	219	6 farms
Far (> 24 km)	241	7 farms

Distance to Shore *(measured between wind farm centre and shoreline, as the crow flies)*	**Mean Wind Farm size** *(MW)*	
Near (< 9 km)	97	6 farms
Medium (9-15 km)	156	7 farms
Far (> 15 km)	313	6 farms

Wind Farm Location	
UK East Coast	11 farms
UK West Coast	8 farms

A: Impact of Site Characteristics on KPIs

To understand how the overall portfolio of assets is performing, it is important to understand how different site characteristics are impacting critical KPIs, such as wind farm availability and capacity factor.

The charts shown combine characteristics. The size of each bubble indicates the average size (in installed capacity) of the wind farms in that corresponding group. Older, smaller assets are generally sited closer to shore whilst younger, larger arrays tend to be further from shore.

Figures A1 and A2: On average, younger, large farms, further from shore are currently achieving lower wind farm availabilities than older projects sited closer to shore with their inherent quicker transit times for maintenance teams. The younger wind farms appear, on average, to be reporting lower availabilities, whilst the older assets are achieving higher wind farm availabilities. Other metrics would suggest that as the wind farms mature, the associated maintenance experience and work process improvements lead to higher availabilities being achieved.

Figure A3: Although further from shore sites currently exhibit lower availability, the capacity factors achieved are higher, being generally attributed to increased windspeed and more modern turbines. As noted above, as these assets mature and availability increases (as observed in the older assets) it is likely the potential for higher production levels will be unlocked.

Fig A1: Impact of distance to port on WF availability

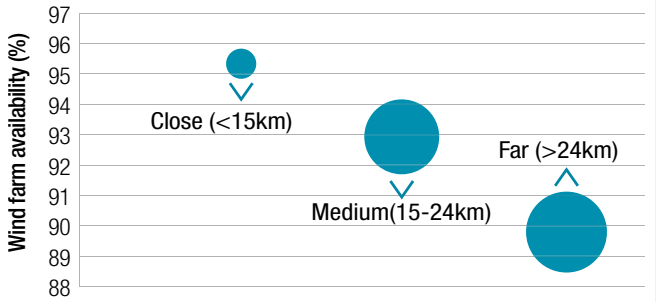


Fig A2: Impact of age on WF availability

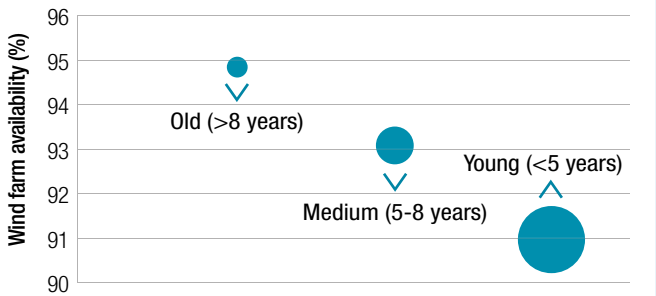
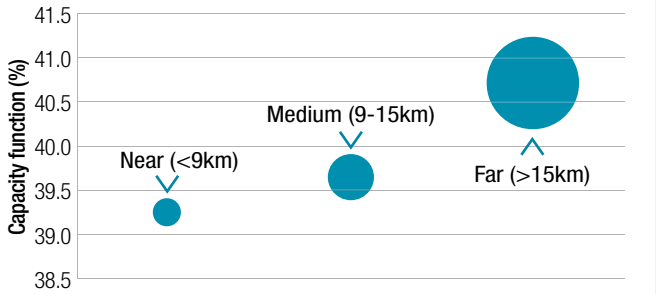


Fig A3: Impact of distance to shore on capacity factor



Key Performance Indicators, a first look continued

Fig A4.1: Mean seasonal capacity factors

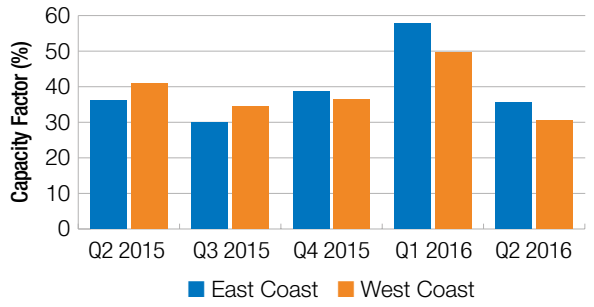


Fig A5.1: Impact of location on capacity factor

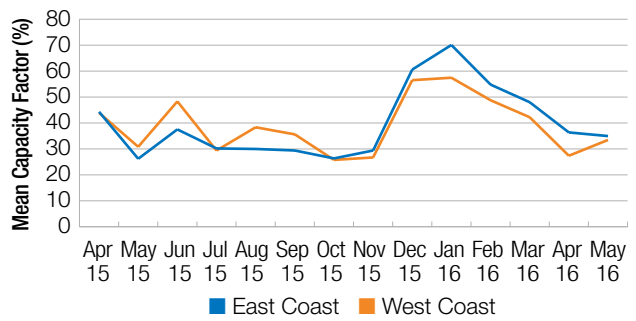


Fig A5.2: Impact of location on mean hub height wind speed

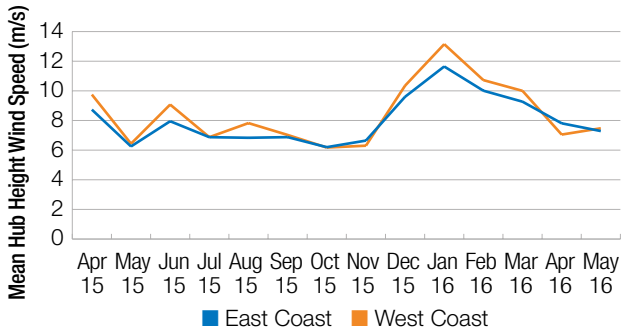


Fig A4.2: Mean seasonal hub height wind speeds

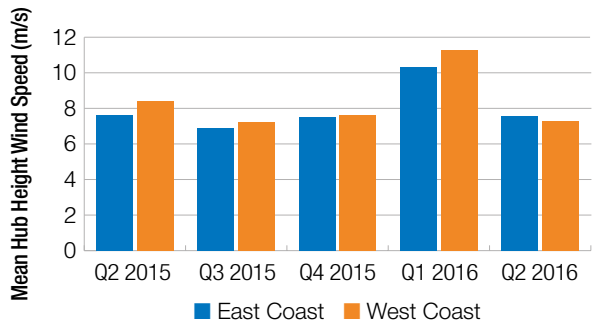


Fig A5.3: Impact of location on mean significant wave height

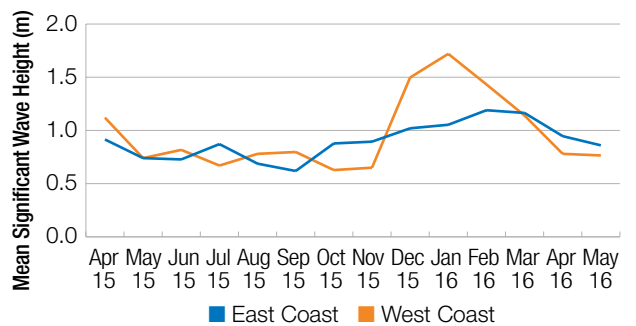


Fig A5.4: Impact of location on number of non-access days

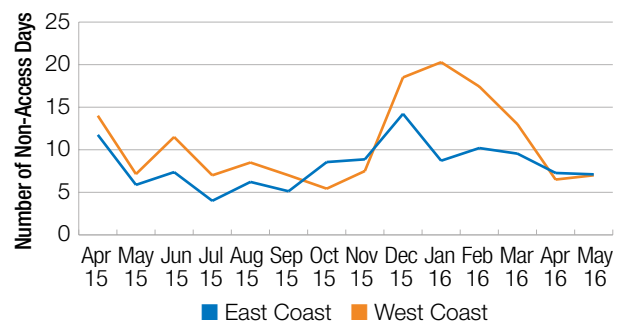


Figure A4 shows how mean capacity factor and mean hub height wind speed were impacted by the location of the wind farms for the different seasons in the year. Typically, wind speed is the main driver of capacity factor and it is shown here that in spring and summer months (Q2 and Q3) the region with the higher wind speed is reporting higher capacity factors (e.g. West in Q2 2015 and East in Q2 2016). However, it can be observed that in the autumn and winter months (Q4 and Q1), despite higher wind speeds in the West, these wind farms reported lower capacity factors.

In an attempt to understand this reversal in the autumn and winter months, Figure A5 shows trends in capacity factor, mean hub height wind speed, mean significant wave height and number of non-access days. Whilst there are a number of factors that could influence this result such as asset age and operator maturity, the number of non-access weather days on the West coast compared with the East seems to be having an impact on the performance of those wind farms in Q4 2015 and Q1 2016.

Fig B1: Correlation between mean significant wave height and number of non-access days per month

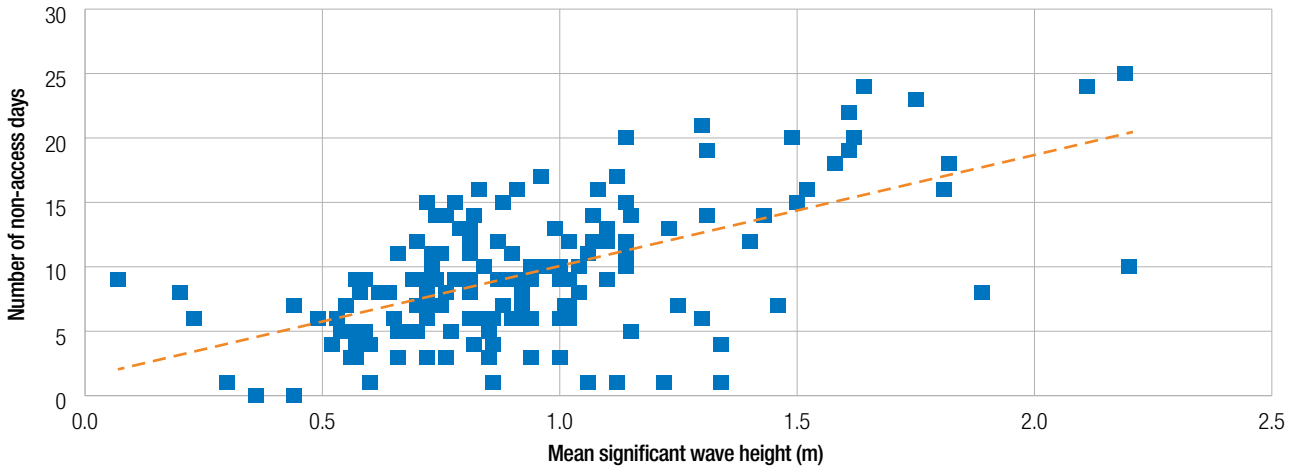
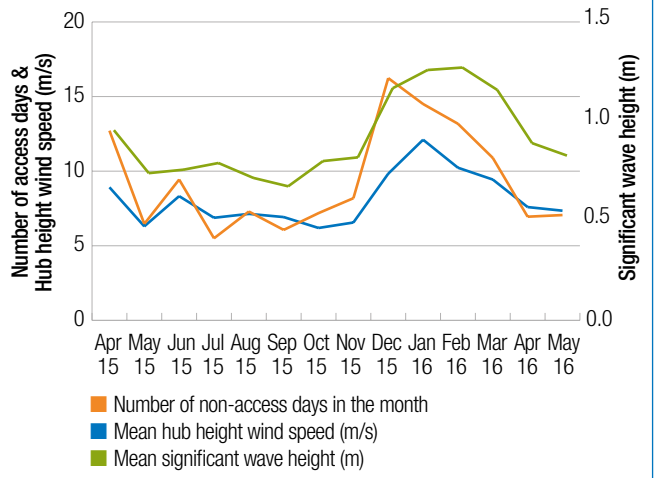


Fig B2: Wind and sea-state trends



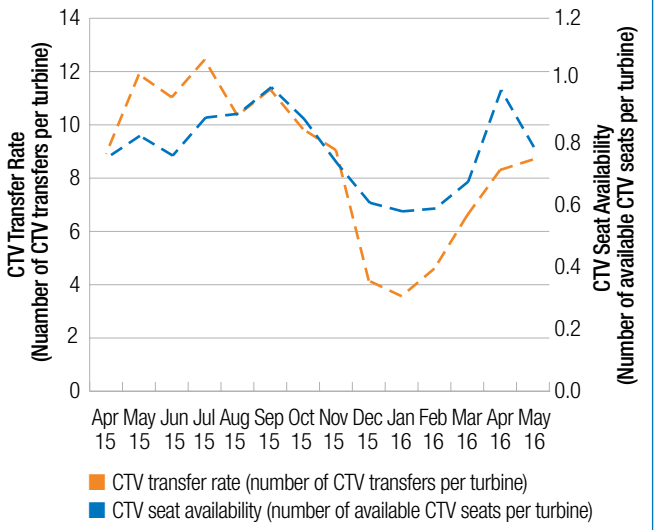
B: Logistics Trends

The days lost due to adverse weather affecting accessibility have a negative impact on the performance that can be achieved for a wind farm. One of the primary drivers of non-access days is mean significant wave height as is demonstrated in Figure B1. The line of best fit through this spread of data suggests that for every additional 0.5m in mean significant wave height recorded at a site, there will be 4.25 more non-access days at that site over a month. New generation service maintenance vessels with a larger wave height operating range, compared with conventional CTVs, would be expected to bring non access days down for sites with higher mean monthly Hs.

Figure B2 displays the average number of non-access days per month, the mean hub height wind speeds and the mean significant wave heights that were reported to SPARTA. It is evident that the high wind speeds and wave heights in the winter months are leading to issues in terms of accessibility for operational wind farms. In December 2015 an average of 16 non-access days were reported across the 19 offshore wind farms included in this study. This is over half of the month that the wind farm was not accessible and is clear evidence that improving wind farm access remains a challenge for the industry.

Figure B3 shows the average trends in access metrics across the 19 wind farms considered in this analysis. The blue dotted line shows CTV transfers per turbine. There is a significant number of transfers recorded in summer with a peak of 12.5 transfers per turbine in the month of July 2015. The orange dotted line shows the available number of CTV seats per turbine. This reveals that offshore wind farm operators are adjusting their vessel strategy to suit the seasonal effects. In September 2015, there was an average 0.98 seats per turbine across the vessel fleet but this was reduced to 0.59 seats per turbine in January 2016.

Fig B3: Access trends



Key Performance Indicators, a first look continued

Fig C1: Sub-System Monthly Repair Rate (Total Sub-System Repairs per Turbine)

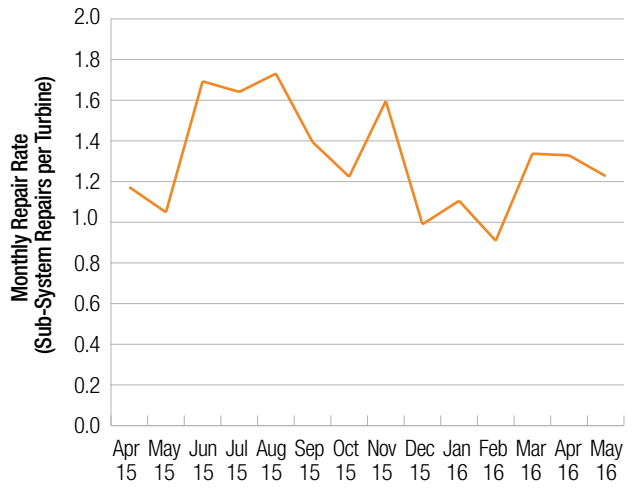
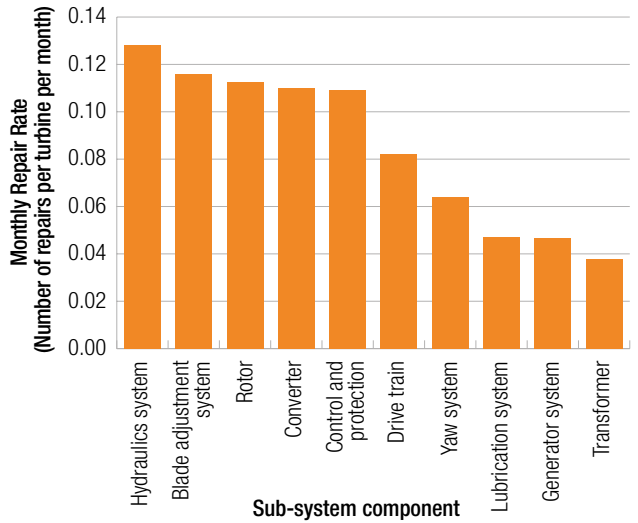


Fig C2: Comparison of Sub-System Monthly Repair Rates



C: Reliability

Increasing reliability has been a feature of recent progress in reducing Levelised Cost of Energy (LCOE) for offshore wind. Higher capacity factors have resulted in a closer correlation between actual and design production levels for new assets. Just as importantly, older assets with lower production expectations can take some advantage from reliability improvements by upgrading systems and processes. Benchmarking of comparative results can show areas for improvement, and identify areas for future, more detailed metric requirements once major gaps have been eliminated or mitigated as far as possible.

Across the SPARTA population the mean monthly repair rate trend is illustrated in Figure C1. As expected, many more repairs are carried out in the summer months. Taking the average over the period considered here, the average monthly repair rate is 1.32 repairs per turbine per month.

The repair data within SPARTA can be broken down to the sub-system level as shown in Figure C2. This indicates the top 10 wind farm sub-components that require the most interventions. The sub-components are ranked indicating the relative repair rate of each.

"The SPARTA Production Based Availability benchmarks, developed by owner/operators for owner/operators, provides us with an independent and trustworthy measure of wind farm performance against our peers."
Martin Stanyon,
Centrica

Looking ahead

SPARTA has a vision to be the hub of essential industry operations and maintenance performance data across the offshore wind sector, enabling owner/operators to continuously improve and deliver the best possible performance, whilst continually driving down life-time costs and maintaining the highest health and safety standards offshore.

Participants are considering further development opportunities to further enhance and accelerate added value to the industry. Next year the group will be evaluating measures to:

- secure 100% of the offshore commercial wind farms on to the system;
- work constructively with owner operators and offshore wind farms in other countries to grow the membership and reporting outside of the UK. This will increase data volumes, and hence the value of the database and highlight performance discrepancies between regulatory environments;
- work with the G+ Global Offshore Wind Health and Safety Organisation to find ways of integrating H&S statistics and performance-related metrics from SPARTA. This should enable incidence data to be cross correlated with frequency of operations, providing a deeper insight into the significance of incidents and their contributory factors;
- build on the successful introduction of production-based availability, investigate other new metrics at system level as well as studying the benefits and means of integrating component level reporting.

These developments will ensure that SPARTA continues to provide increasing levels of benchmark reporting, valuable and up to date metrics, integrated reporting and insightful analysis that will help the offshore wind industry achieve world-class performance in delivering low carbon renewable sourced electricity to consumers.

Membership

Owner/operators not currently involved in the SPARTA project are invited to join the group through the members collaborative agreement, to add to the 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 operations and maintenance performance measurement.

Applications or enquiries for new members may be made at any time in writing or by contacting either:

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