Client discretion

# Bermuda offshore wind:
# Key publications review and priority actions

For Greenrock

April 2022

# Document history

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# Executive summary

The purpose of this document is to help progress offshore wind as a key potential element of a sustainable, low carbon energy system for Bermuda by reviewing two key publications relating to offshore wind in Bermuda, providing guidance to stakeholders as to their reliability and how they can be used, and summarising suggested next steps.

Both documents provide a spatial and cost of energy assessment for offshore wind in Bermuda. These are important areas for early work in establishing the viability of offshore wind for Bermuda.

## Spatial assessment

The spatial assessments derive different suggested locations due to:

- Different assumptions regarding environmental and topographical considerations (Ricardo considered a large seasonal Marine Protected Area as available and excluded areas of complex seabed terrain), and
- Different geographical scope (University of California did not consider opportunities beyond the Bermuda Platform).

Both reports considered the use only of relatively small turbines that will be obsolete by the time a project is installed. Using larger turbines will significantly reduce cost of energy, whilst changing visual considerations.

Both give only partial confidence as various potentially important considerations are not included and only some input layers are presented, so it is not clear which consideration drives exclusion at each location

Of the six sites suggested, we believe three are realistically possible, based on information provided and industry good practice. Other possible sites may also exist.

Both reports provide content that can be used as a basis for further work.

## Wind resource assessment

The Ricardo analysis extracted wind speed predictions from a reliable global source of modelled wind data indicating a mean annual wind speed of 7.8m/s at 100m above sea level. This wind speed is lower than in most established and emerging offshore wind markets, but still offers the possibility of a viable offshore wind project.

The energy yield predictions in both assessments were based on non-standard offshore wind turbines and employed non-standard methodologies, so offer little reliable insight into energy production values. There is little in the two reports that can be used as a basis for future work.

## Technology and cost of energy assessment

Neither assessment provides much accuracy as they use generic cost data for relatively small turbines on large projects, as they do not consider:

- Relevant size turbines, with costs relevant to installation in 2028
- The very small project scale and logistics of installing turbines off Bermuda, and
- Foundation designs suitable for the uncertain ground conditions.

There is little that can be drawn from either of the reports as a basis for decisions or future work.

# Priority actions for building on these reports

Key for making decisions about offshore wind in Bermuda is to establish:

1. Whether offshore wind makes sense for Bermuda, then
2. How best to progress offshore wind, if it makes sense.

In order to address whether offshore wind makes sense, three key uncertainties need to be addressed:

- Uncertainty in cost of energy from offshore wind. Currently, this is driven most by uncertainty in capital and operational cost, rather than uncertainty in wind resource.
- Uncertainties in energy system design to provide sufficient stability and flexibility, with significant offshore wind capacity and considering other options.
- Uncertainty in availability of environmentally and socially acceptable, economically viable locations for offshore wind.

## Whether offshore wind makes sense for Bermuda

Based on our assessment of technical work done to date, we recommend the following early roadmap activities, in priority order:

1. A cost of energy assessment that considers the key factors not covered in the studies to date, including project scale and installation logistics
2. A preliminary energy system model to explore system stability with the incorporation of 60MW of variable offshore wind capacity, potentially via four large turbines
3. A more robust, transparent and complete spatial assessment that considers a range of relevant turbine sizes and potential foundation types, and
4. An independent wind speed and energy yield analysis using modelled data from a specialist provider and relevant-scale turbines, including a model validation exercise should suitable local wind data be available

## How best to progress offshore wind, if it makes sense

Assuming positive results from the above and based on our understanding of the regulatory and market environment in Bermuda, we recommend the following next roadmap activities, again in priority order:

5. Establishment of a practical roadmap specifically for Bermuda with actionable steps to support timely progress to decisions (and potentially installation) of offshore wind, including consideration of a procurement route that will work for Bermuda and the offshore wind industry for a small amount of capacity and stakeholder engagement, and
6. Design and implementation of a long-term wind speed data collection campaign, followed by robust wind climate and energy production analysis, both applying good industry practices.

In order to be able to meet potential 2028 installation timescales, it will be important to progress these enabling actions with urgency.

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# 1. Introduction

## 1.1. Background

Greenrock is seeking to support the decarbonisation of Bermuda's electricity supplies within a timeframe that remains within a 1.5C carbon budget.

Based on previous renewable energy resource and technology assessments, offshore wind has consistently been identified as the most critical mature renewable energy technology to achieve decarbonisation of the electricity sector.

Greenrock has welcomed the progress made by the Bermuda Government to date considering offshore wind (offshore wind) as a key potential element of a sustainable, low carbon energy system for Bermuda. It seeks now to help accelerate progress through bringing in global experience of the technology, costs and practicalities of offshore wind, recognising that:

- Offshore wind costs have been falling rapidly and are projected to continue falling, in relative terms compared to traditional forms of electricity generation
- The scale of technology and market continues to grow
- Bermuda has specific characteristics (in terms of size of market, location and available facilities) that need to be addressed, and
- Knowledge about how to progress offshore wind in Bermuda is naturally limited.

## 1.2. Purpose

The purpose of this document is to help progress offshore wind as a key potential element of a sustainable, low carbon energy system for Bermuda by reviewing two key publications relating to offshore wind in Bermuda, providing guidance to stakeholders as to their reliability and how they can be used, and summarising suggested next steps.

## 1.3. BVG Associates

BVGA provides strategy consulting in renewable energy. We help our clients to do new things, think in new ways and solve tough problems. Our practical thinking integrates the business, economics and technology of renewable energy generation systems. We combine deep wind industry knowledge with skills gained in the world of business consulting. Our purpose is to help our clients succeed in a sustainable global electricity generation mix founded on renewables.

- BVGA was formed in 2006 at the start of the offshore wind industry
- We have a global client base, including customers of all sizes in Europe, North America, South America, Asia and Australia
- Our highly experienced team has an average of over 10 years' experience in renewable energy
- Most of our work is advising private clients investing in manufacturing, technology and renewable energy projects, and
- We've also published many landmark reports on the future of the industry, cost of energy and supply chain.

### Specifically of relevance to supporting offshore wind in Bermuda

BVGA is a leading consultancy for offshore wind industry building, globally:

- Leaders in BVGA have been involved in offshore wind in the UK since 2004
- We have helped shape the development of the market ever since, with Government, industry bodies and key stakeholders as clients

- We developed the World Bank's first roadmap for offshore wind, for the Government of Vietnam, and continue to support Government and industry there, as the market develops
- We co-authored World Bank's *Key factors for successful development of offshore wind in emerging markets* report, a cornerstone for plans for offshore wind, globally
- We are soon to complete further roadmaps for the Philippines and Azerbaijan (a market, like Bermuda, with distinct logistics challenges)
- We have helped shape industry development in multiple US states and we remain active in that market.
- We work for industry as well as Governments, so understand how industry thinks and what it needs to see to get involved in markets.
- We have dynamic models and processes set up to be able to evaluate and shape new markets, and
- We have a firm belief that each market is different, so needs carefully chosen solutions that work for it, even if based on experience from elsewhere.

# 2. Review of recent publications

The two key publications reviewed are:

1. *Offshore wind energy in the context of multiple ocean uses on the Bermuda platform*, dated March 2014, authored for Government of Bermuda by MSc Students at University of California, Santa Barbara (the "*UoC report*")[1]
2. *Assessment of the Offshore Wind Potential in Bermuda*, dated August 2021, authored for Regulatory Authority of Bermuda by Ricardo (the "Ricardo report")[2]

These are compared in the sections below. The later publication does not seem to refer to the earlier publication, though it does use some of the same data. We also refer to *Offshore Wind Suitability in Bermuda*, dated June 2019, authored by Adam Meyer, Tufts University ("*Tufts paper*").[3]

We consider:

- Purpose
- Scope
- Spatial assessment
- Wind resource assessment, and
- Technology and cost of energy assessment.

In each of the assessment areas, we consider each report's method, then results. We then draw our conclusions and provide recommendations.

## 2.1. Purpose

The purpose of the two reports is summarised in Table 2.1.

**Table 2.1 Purpose of the two reports, compared.**

| 1. *UoC report* | 2. *Ricardo report* |
|---|---|
| To determine economic viability of offshore wind with respect to Bermuda's energy context, identify and characterize potential conflicts with ocean uses and ecological features, and develop a spatial analysis model to identify potential locations for offshore wind farms with acceptable risk of impacts | To carry out desk-based environmental, technical and financial pre-feasibility assessments of offshore wind in Bermuda in response to the 2019 *Integrated Resource Plan* published by the Regulatory Authority of Bermuda which envisaged 60MW of offshore wind being installed in the waters off Bermuda by 2027 |

## 2.2. Scope

A comparison of report scope, compared to what might be expected in a full roadmap for offshore wind in a potentially large-scale market, is shown in Table 2.2.

The structure of this table is developed from World Bank Group's report *Key Factors for Successful Development of Offshore Wind in Emerging Markets* (*Key Factors* report)[4] and *Offshore Wind Roadmap for Vietnam*[5]. We recognise that it was not the purpose of either report to provide full roadmap scope. The table is intended to show what elements of an eventual roadmap have been covered or are still to be covered. Empty table entries signify no substantive content in this area.

Table 2.2 Comparison of scope of reports to typical roadmap.

| Typical roadmap scope | 1. *UoC report* | 2. *Ricardo report* |
|---|---|---|
| Energy strategy | | |
| How offshore wind fits as part of an energy strategy, considering security of supply, cost-effective energy for consumers, local jobs and economic benefit, climate and environmental benefits, attracting foreign investment | Brief summary, with pointer to 2011 Government Energy White Paper – no mention of local jobs or attracting foreign investment | |
| Energy system modelling to address supply and demand balance, including storage and curtailment | (Not discussed – but a key consideration, especially in a small market with planned high penetration of variable renewable energy sources (wind and solar)) | |
| Energy policy | | |
| Key policies to deliver offshore wind, considering volume and timescales, cost of energy, local jobs and economic benefit and environmental and social sustainability | (Not discussed – Bermuda is small market and likely only a single project is needed, so little policy input required, except to provide bankability to enable industry investment – likely that in time, policy/delivery decisions regarding local jobs and environmental and social sustainability will be required) | |
| Frameworks for offshore wind | | |
| Marine spatial planning | Preliminary site screening using subset of GIS-based considerations, prioritising and combining considerations | Preliminary site screening using subset of GIS-based considerations |
| Leasing | (Not discussed - Bermuda is small market and likely only a single project is needed, so no significant frameworks need to be put in place to manage a pipeline of projects, but bankable leases, permits and power purchase agreements and good international industry practice (GIIP) [i] in environmental and social impact assessment (ESIA) are needed to enable investment and financing of activity.<br>Also, Government does have to decide how to progress the opportunity, following a number of possible procurement routes, including:<br>• Invest in developing site using good international industry practice, then running a competition for offshore wind development companies to bid for the lease, permits and power purchase contract to enable construction and operation of a project (as in established markets such as Denmark and Netherlands), or<br>• Design an alternative arrangement that puts all development cost and much of the risk to an offshore wind development company (as | |
| Permitting | | |

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[i] GIIP, as defined by International Finance Corporation Performance Standard 3 (PS3), is the exercise of professional skill, diligence, prudence, and foresight that would reasonably be expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances, globally or regionally.

| | | |
|---|---|---|
| | in established markets such as UK, but with different challenges as no pipeline of projects in Bermuda) | |
| Procurement / power purchase | | A half-page, simplified process is presented, as used for the recently solar PV plant, but it is unclear how procurement fits with the permitting process |
| Health and safety | (Not discussed – important later consideration that is likely to be addressed differently to other markets as likely only a single project is needed) | |
| Certification | | |
| Delivery | | |
| Roadmap timelines and recommendations | Recommended next steps only | Four simple recommendations, without timing |
| Levelized cost of energy (LCOE)[ii] | Simplified, generic analysis of costs, combined with simplified wind resource assessment | Highly simplified, generic analysis of costs, combined with simplified wind resource assessment |
| Supply chain | (Not discussed – important later consideration that is likely to be addressed differently to other markets as minimal supply likely during construction; small amount of labour and support during project development, construction and operation) | |
| Jobs and economic benefit | | |
| Environmental and social considerations | Yes – mainly via desk work, applicable at this stage, with more to do later | Yes – mainly via desk work, applicable at this stage, with more to do later |
| Transmission infrastructure | (Not discussed – important consideration when considering location of potential sites – links also to energy system modelling) | |
| Port infrastructure | (Not discussed – typically, unrestricted access to a long quay with deep-water access and large areas for storage and pre-assembly are required to support construction of an offshore wind project, but due to the scale of project under consideration and the location of Bermuda, different logistics solutions could be used. It may be possible for a large vessel to bring foundations and turbines with it, in one journey, or to transfer in protected waters from a feeder vessel, thereby not needing port space in Bermuda (as has been done for offshore wind elsewhere)for any heavy activity during construction.) | |
| Risk and bankability | (Not discussed – important consideration that is different to other markets as likely only a single project is needed – likely will want to access concessional finance to support project development and delivery) | |
| Finance | | |
| Stakeholders | Some work done, but list of key stakeholders not documented | Some work done, but list of key stakeholders not documented |

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[ii] Levelized cost of energy is a commonly used measure of the cost of electricity production. It is defined as the revenue required (from whatever source) to earn a rate of return on investment equal to the cost of capital over the life of the wind farm.

# 2.3. Spatial assessment

## 2.3.1 Method

Both GIS-based assessments apply a process to exclude locations based on a range of considerations, then choose suggested wind farm locations based other criteria afterwards.

Table 2.3 summarises use of spatial assessment criteria against those typically used now. We recognise different levels of availability of data in different markets. Empty cells signify no mention of consideration in the report, recognising that the authoring team may have considered it, and some considerations may not be relevant. Neither study combined technical factors to develop a spatial LCOE layer, often used in this sort of analysis in order to prioritise the most economically attractive areas.

### *UoC* report

The *UoC report* does this in a structured way, well-documented way, excluding areas where:

- The impact of a given consideration immediately leads to an exclusion, for example a shipping lane, and
- A set threshold level is reached relating to a given consideration, for example high levels of coral cover or fishing activity in a given location (250m x 250m cell)(thresholds set by the project team and presented in the results; could be adjusted later, in stakeholder discussion).

This leads to a layer of suitable locations. It then uses a rather complex process to find potential site locations by exploring where an array of turbines can be placed close together in suitable locations, without considering LCOE.

Finally, some further (post-hoc) assessment of additional considerations was applied once potential wind farm areas were defined, but this assessment did not change outcome.

For viewshed, airport and radar considerations and wind farm designs, a turbine height of 160 m was considered, relating to a 5 MW wind turbine with rotor diameter 120 m. Wind farm designs were for 100 MW, consisting of 20 turbines.

Although the process is well documented, only a subset of layers are presented, so it is not clear which consideration drive immediate exclusion or exclusion via a threshold at each location.

### *Ricardo report*

The *Ricardo report* is less transparent and seems to take a less structured approach, presenting a single picture of Marine Protected Areas, then describing a range of other considerations before collating a subset of these on to a map showing suggested sites. It does not clearly differentiate the impact of different types of consideration.

For viewshed and airport considerations and wind farm designs, a turbine height of 134 m was considered, relating to a 3.6 MW wind turbine with rotor diameter 107 m. Wind farm designs were for 61 MW, consisting of 17 turbines.

Table 2.3 Use of typical early spatial assessment criteria.

| Typical early-stage considerations | 1. *UoC report* | 2. *Ricardo report* |
|---|---|---|
| Area considered | Bermuda Platform only | Bermuda Platform and other local shallow areas |
| Environmental considerations | | |
| Marine Protected Areas | Yes – as an exclusion | Yes – with seasonally protected areas considered as available (which is reasonable at this stage) |
| Critical Habitats | | |
| Alliance for Zero Extinction sites | | |
| Important Bird Areas | Yes – as an exclusion | Yes |
| Bird migration routes | | |
| Ramsar sites | Yes – as an exclusion | |
| Important Marine Mammal Areas | Yes – as part of post-hoc assessment, via local expert, considering humpback whale locations | |
| UNESCO World Heritage Natural Sites | | |
| UNESCO-MAB Biosphere Reserves | | |
| Coral | Yes – stony corals as an exclusion above a given threshold and soft corals as part of post-hoc assessment | Yes |
| Seagrass beds | Yes – as an exclusion above a given threshold | Yes |
| Mangrove forests | | |
| Locally Managed Marine Protected Areas | Yes – relating to birds, at least, as an exclusion | |
| Ecologically or Biologically Significant Marine Areas | | |
| Cartilaginous Fish | | |
| Endemic Bird Areas (EBAs) | | |
| Social and technical considerations | | |
| Landscape and seascape | A range of viewshed analyses explored visual considerations – not included in spatial assessment | Yes – minimum distance imposed that varies around the coast, but distance not stated and derivation unclear |
| Aggregate and material extraction areas | | |

| | | |
|---|---|---|
| Airports | Yes – as an exclusion | Yes, using detailed information, though exclusion looks small |
| Radar | Yes – as part of post-hoc assessment | Yes, using detailed information, though exclusion looks small |
| Fishing | Yes – as an exclusion above a given threshold, with different forms of fishing considered | Yes |
| Exclusive Economic Zones (EEZ) | (200 nautical miles radius, so effectively irrelevant for Bermuda) | |
| Extreme wind speeds | | Only in text |
| Ground conditions | | Only in text |
| Marine aquaculture | | |
| Mean wind speed | Only after site selection | Only after site selection |
| Wind direction | | The derivation of prevailing wind direction, used for initial layout design, is simplistic but likely to be reasonable |
| Military areas | | |
| Offshore disposal sites | | |
| Offshore oil and gas activity | | |
| Ports | | |
| Seismic activity | | |
| Shipping | Yes – channels treated as exclusions, with 1.8km buffer zone | Yes – but with no buffer zone |
| Tourism areas[iii] | Only in text | Only in text |
| Undersea cables | | Yes |
| UNESCO World Heritage Sites | | |
| Water depth | Yes, limiting to area of search to area on the Bermuda Platform, defined as inside a 20m depth contour; did not consider local topography | Yes, including the impact of irregular local topography on foundation siting<br>Challenger and Plantagenet banks are identified as potentially suitable for floating foundations, though water depths are quoted at only 50m - this would suggest the opportunity still to used fixed foundations |
| Wrecks and historic offshore sites. | Yes – as an exclusion | Yes |

### 2.3.2 Results

Both reports suggest three potential sites. None of the suggested sites are suggested in both reports – indeed each study excludes consideration of the suggested sites in the other study. The spatial assessments derive different suggested locations due to:

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[iii] Note that offshore wind farms can bring positive impacts regarding tourism. As well as being a powerful ‘green’ symbol, a visitors centre and boat trips to wind farms are often established, providing positive impact to the local economy.

- Different assumptions regarding environmental and topographical considerations (Ricardo considered a large seasonal Marine Protected Area as available and excluded areas of complex seabed terrain), and
- Different geographical scope (UoC did not consider opportunities beyond the Bermuda Platform).

The six chosen sites are shown in Figure 2.1 and discussed in Table 2.4.

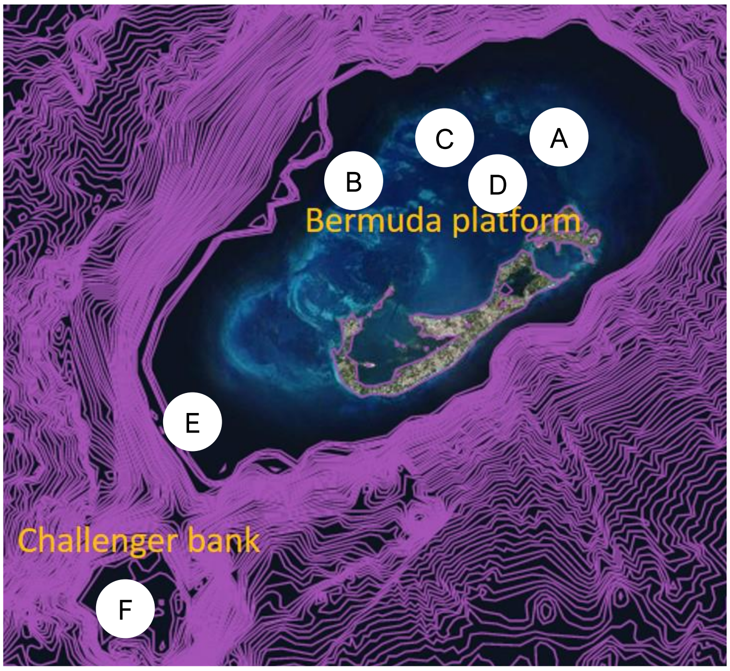

***Figure 2.1 Approximate location of suggested wind farm sites, based on map from Ricardo report.***

**Table 2.4 Summary of six suggested sites.**

| 1. *UoC suggested sites* | | | |
|---|---|---|---|
| Suggested site | 1. *UoC report* assessment | Our interpretation of what 2. *Ricardo report* says about site | Our assessment of site |
| A. Scenario 1: Rim, north of George Island (closest 4km from shore) | Preferred, along with scenario 3 | Not considered suitable due to topographical and undefined environmental constraints | Suggest needs care regarding visual impact due to proximity to shore |
| B. Scenario 2: Rim, west of Bermuda Platform (closest 5km from shore) | Least preferred as wind farm distributed over fair distance, between restrictions | Not considered suitable due to undefined environmental constraints | Suggest needs care regarding visual impact due to proximity to shore – current layout using small turbines not preferred, but use of fewer, larger turbines could improve |
| C. Scenario 3: Rim, northwest of George Island (closest 8km from shore) | Preferred, along with scenario 1 | Not considered suitable due to undefined environmental constraints | Possible site |

| 2. *Ricardo suggested sites* | | | |
|---|---|---|---|
| Suggested site | *2. Ricardo report* assessment | Our interpretation of what *1. UoC report* says about site | BVGA assessment of site |
| D. Site 1: Lagoon, west northwest of George Island (closest 4km from shore) | 1st choice, despite proximity to shore – lowest LCOE; favourable topography and lowest modelled electrical losses | In middle of exclusion zone due to Marine Protected Area / Avian area / shipping channels / airport control area ( report is not clear which) | Likely too close to airport, especially if turbines larger than 3.6MW are used |
| E. Site 2: Outside rim, southwest edge of Bermuda Platform (closest 11km from shore) | 2nd choice – 9% higher LCOE and in seasonally protected fish spawning grounds | Not considered suitable due to high coral reef cover and low/mid-level of fishing | Possible site |
| F. Site 3: Challenger Bank, southwest off Bermuda Platform (closest 20km from shore) | 3rd choice - considered expensive as floating and with cable routing through deep channel | Not considered, as beyond Bermuda Platform | Possible site, which may not need to be floating – cable route and possible offshore substation will add cost |

## 2.3.3 Conclusions

Both assessments assume much smaller turbines than will be routinely available in the market for installation in about 2028. Larger turbines (anticipated to be about 15MW and with rotor diameter about 250m for 2028 installation) help reduce LCOE considerably, but with increased visual impact per turbine (depending on location).

Although it is likely to be possible to use smaller turbines, the practical economic limit is likely to be at around 5-6MW with rotor diameter 150m, still significantly larger than assumed in the reports. This scale of turbine is in production today for onshore use. The turbines considered by the two studies, a 5MW, 120m diameter turbine and a 3.6MW, 107m diameter turbine, are already no longer sold or in series production, and by installation in 2028 will be fully obsolete.

Based on this, we expect that sites A, B and D will need care regarding visual impact due to proximity to shore. Sites C, E and F also remain possible locations for what could be a 4-turbine, 60MW wind farm. Other possible sites may also exist.

We suggest that independent of which offshore wind procurement route Bermuda takes, it conducts a spatial assessment that:

- Builds on the reports discussed above and also the marine spatial planning activity by the Bermuda Ocean Prosperity Programme (not seen by BVGA)
- Provides coverage of all relevant considerations
- Provides full transparency regarding individual data layers and their use in contributing to a spatial assessment
- Considers a range of relevant turbine sizes and potential foundation types
- Establishes areas of exclusion, where a project cannot be built and areas with restrictions, where increased permitting considerations and potential mitigation measures will be required – often in such areas, co-existence of different uses can be established, opening up solutions with ultimate overall benefit

- Introduces increased nuance about co-existence of offshore wind with other ocean uses and a recognition of the economic, climate and local environmental benefit from an offshore wind project
- Uses technical spatial data to evaluate most attractive areas with regard to cost of energy, and
- Uses good international industry practice in early stakeholder engagement.

Such work can build on aspects of each report, as both provide content that can be used as a basis for further work.

# 2.4. Wind resource assessment

## 2.4.1 Method

### Typical methodology

In a feasibility study, the aim is to establish a best estimate of the long-term mean annual wind climate for the region or sites under considerations. For the purposes of wind resource assessment, a valid period for a long-term wind climate is 20 years.

In most early feasibility studies, high-quality and location specific wind data is unlikely to be available. Data collected for other purposes such as aviation operations or weather forecasting are rarely useful for application in wind feasibility studies due to unsuitable measuring equipment and practices, inappropriate siting, or lack of consistency in the measurements.

Established industry practice for such feasibility studies, where no suitable measured data are available, is to use modelled data sets such as the Global Wind Atlas[iv] (GWA), which provide a long-term wind climate and associated statistics for a range of heights above sea for any global onshore or offshore location.

Once a wind climate has been established, annual energy production values are calculated. The wind climate data is then typically used to calculate LCOE for a specified wind farm configuration and timeline, either on a spatial basis or for specific locations.

In Table 2.5, we provide more detail about each stage of this typical methodology, and then summarise how each report has approached that stage.

Table 2.5 Comparison of both reports to typical wind resource assessment methodology as part of a feasibility study.

| Typical methodology | *1. UoC report* | *2. Ricardo report* |
|---|---|---|
| Wind data sources | | |
| Modelled global reanalysis data sets such as GWA or Vortex[v]These datasets provide long-term mean annual, monthly and diurnal wind statistics for any global location and are designed specifically for wind energy applications<br>Measured data may be used for secondary validation if:<br>• Measuring equipment is of a suitable standard and height for wind resource assessment purposes<br>• There is good provenance of data records regarding consistency of exposure, data collection practices, and quality control | Time series of radiosonde wind data, collected twice daily at Bermuda Airport, between 2005 and 2013<br>Time series of wind data from an offshore platform located 28km southwest of Bermuda, collected between 1961 and 1964 - unspecified measuring equipment<br>Data from Commissioners Point in west of Bermuda, between 2005 and 2013 - unspecified measuring equipment | Generalised wind climate data from GWA for the wind farm locations proposed in the report<br>Time series from a coastal location in the north of Bermuda, for the period 2008 to 2019 - unspecified measuring equipment<br>Report indicates data is from a buoy, although National Oceanic and Atmospheric Administration (NOAA) records indicate that it is data from an onshore location |

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[iv] https://globalwindatlas.info/

[v] www.vortexcfd.com

| | | |
|---|---|---|
| **Observations** | The lack of detailed data records make it difficult to assess the suitability of the data sources in detail, although it is reasonable to assume that any results based on these data will have high uncertainty<br>Of the data available, the radiosonde data set from the airport is likely to be the most suitable for use as a very general long-term wind climate for Bermuda due to the height of the data collection, although the low data sampling period (twice daily) and accuracy of the data collection technique reduce its usefulness | The use of data from the GWA meets with established industry practice and normally provides a robust estimate of wind speed suitable for use in a feasibility study<br>The data from NOAA is unlikely to be of suitable quality to provide any meaningful validation due to the height of the wind measurements (about 8m) and uncertainty over its location |
| Data validation | | |
| If high quality wind data at a suitable height and location is available, a validation can be performed on the global reanalysis data | A cross-validation between the three data sets was undertaken, but the results were inconclusive | A validation of the GWA results was undertaken using the NOAA data<br>The results showed significant differences between the predicted monthly wind speeds |
| **Observations** | The validation should be disregarded as the datasets used were not of suitable quality to draw any meaningful conclusions | The validation should be disregarded as the NOAA data is not of a suitable quality to draw any meaningful conclusions, not least due to the difference between the measurement height (8m) and the valid height of the GWA data (100m)<br>The NOAA data was extrapolated to the height of the GWA data but the uncertainty in doing this is considerable and is likely to be at least as large as the wind speed differences observed |
| Wind climate analysis | | |
| Analysis of the source wind data is undertaken to predict:<br>• A long-term mean annual wind speed (MAWS) and wind speed distribution | Calculated a MAWS of 7.7m/s at 100m height with an associated wind speed distribution<br>The prediction applies to the main airport on Bermuda, which was the | Calculated a MAWS of 7.8m/s at 100m height for Site 1, which is located off the western coast of north Bermuda<br>Wind speed not stated for the other two candidate sites |

| | | |
|---|---|---|
| - An annual wind direction distribution<br>- A wind shear exponent that defines how wind speed varies with height<br>- Monthly and diurnal wind patterns, especially where electricity system balance is critical (as in Bermuda)<br>- An assessment of extremes of wind speed for the purposes of wind turbine class selection | location of the principal source of wind data<br>Wind direction, wind shear, monthly and diurnal patterns, and extreme winds not discussed | (We checked the GWA dataset: wind speeds for the other two sites are similar to Site 1, within +/- 0.2m/s)<br>A wind direction rose was extracted from the GWA, showing a predominance of winds from the south-west (but this did not take account of wind speed, so the conclusion is uncertain)<br>Wind shear was calculated using high-level assumptions<br>Mean monthly wind speeds are presented but diurnal wind patterns are not discussed<br>Wind turbine classification is discussed, and the potential impact of hurricanes addressed, but no detailed analysis was undertaken |
| **Observations** | The wind speed prediction is based on non-standard data and has not been robustly validated<br>It does not provide a robust analysis of the potential offshore wind resource | The wind speed prediction and wind direction rose extracted from the GWA for site 1 provides a robust prediction of the offshore wind climate in Bermuda and are suitable for use in a wind feasibility study |
| Spatial variation | | |
| Spatial wind resource models are prepared, or wind resource maps extracted from tools such as the GWA<br>These show how the wind resource varies over the area of interest and at specific potential wind farm locations | No spatial wind resource modelling was undertaken | No spatial wind resource modelling was undertaken<br>Spot values were extracted from the GWA<br>Wind speed is only provided for one location (Site 1) |
| **Observations** | It would have been useful for both reports to have addressed the issue of spatial variation in wind resource, although the GWA shows only modest variation in wind speed (+/- 0.2m/s) across the region that lies with 20km of Bermuda<br>Any differences in LCOE between different potential sites will therefore be mainly as a result of factors other than wind speed | |

### 2.4.2 Results

The *UoC* report predicts a wind speed of 7.7m/s at a height of 100m. No wind direction rose is provided.

The *Ricardo* report predicts a wind speed of 7.8m/s at a height of 100m, with a predominantly south-westerly wind direction rose.

### 2.4.3 Conclusions

The most robust finding of the two reports is the mean wind speed of 7.8m/s extracted from the GWA. The attempts at data validation are not robust enough to provide additional comfort.

The reports use non-standard approaches to assess the energy production potential of offshore wind in Bermuda, with a number of inadequacies in both input data and methodology.

Due to uncertainties in the underlying wind resource calculations, the use of relatively small wind turbines and the non-standard methodologies employed, neither report provides a reliable analysis of the energy production potential.

In the short term, we suggest that other areas contributing to LCOE have greater uncertainty, so we do not recommend any further work. Should more confidence be sought before new wind data collection, then we would suggest commissioning an independent model of the wind climate using a reanalysis data set such as from Vortex, using a smaller geographical scale than applied the GWA, and undertaking a model validation should a suitable data source be identified. Initial research has indicated that addition meteorological records from Bermuda airport may be available that suit this purpose.

In the longer-term, we recommend a wind data collection campaign including the installation of industry standard wind speed data collection equipment. This is likely to be based on the use of wind lidars[vi], potentially deployed:

- At fixed locations for reference purposes, and
- Roving, to assess potential sites.

Once sufficient data has been collected, typically after one to two years, a full wind climate and energy production analysis should be performed using good industry practice. In order to be able to meet potential 2028 installation timescales, it will be important to progress this and other enabling actions with urgency.

## 2.5. Technology and cost of energy assessment

### 2.5.1 Method

Both assessments exhibit a lack of understanding of key cost drivers, especially project size, logistics and site conditions, which are especially relevant due to the specifics of the Bermuda situation.

Table 2.6 summarises the methodology of each against good practice for non-standard sites.

#### ***UoC report***

The *UoC report* provides a brief summary of conventional state-of-the-art offshore wind turbines and foundations, as of 2014. It used generic CAPEX, OPEX, project lifetime and cost of capital estimates from relevant industry sources, which were up-to-date at the time, and an energy production estimate based on its wind resource estimate discussed above.

#### ***Ricardo report***

The *Ricardo report* provides a long but generic discussion of conventional and other wind technology. It then used generic CAPEX, OPEX and cost of capital estimates from an NREL study in 2019, deriving export cable costs for each of the three suggested sites, and an energy production estimate based on its wind resource estimates discussed above, factored with export cable losses derived for each of the three sites.

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[vi] Lidars are remote sensing anemometry devices which use lasers to measure wind speed and direction at heights up to 300m.

Table 2.6 Comparison of cost of energy methodology to current good practice.

| | *1. UoC report* | *2. Ricardo report* | Good practice, especially for non-standard sites |
|---|---|---|---|
| CAPEX | Generic per MW costs for project at less than 25m water depth and 40km from port<br>No visible adjustment for year of installation, project size, logistics or site conditions | Generic per MW costs, with separate calculation of export cable cost showing poor understanding; adjusted for year of installation<br>No visible adjustment for project size, logistics or site conditions | Costs considering turbine rating and year of installation, foundation type, project size, logistics and site conditions and export system arrangement |
| OPEX | Generic per MW per year cost for offshore wind; no adjustment for year of installation<br>No visible adjustment for year of installation, project size, logistics or site conditions | Generic per MW per year cost for offshore wind, with some adjustment for export cable length<br>No visible adjustment for year of installation, project size, logistics or site conditions | As above, also considering operational strategy and the challenge of long distances to:<br>• Holdings of more significant spare parts<br>• Presence of larger vessels for major component exchange<br>• Presence of expert staff for more complex troubleshooting |
| Net annual energy production (AEP) | Gross AEP calculated from power curve of 3.6MW turbine with 120m rotor diameter<br>Estimated aerodynamic, cable and other losses<br>No uncertainty analysis | Gross AEP calculated from power curve of 3.6MW turbine with unclear rotor diameter<br>No visible adjustment for losses (except for export cable losses, with unclear calculation)<br>No uncertainty analysis | Gross AEP calculated from power curve of relevant turbine with stated rotor diameter<br>Adjusted for typical losses, including from export system<br>Uncertainty in energy production calculated for different time periods and probability levels |
| Project lifetime | 20 years | Not stated | Typically at least 30 years for project installed in 2028 |
| Weighted average cost of capital | 10% | 10% | Depends on offtake, currency and other market risks |
| LCOE | No separate LCOE calculated for different sites | LCOE calculated for each site | Spatial calculation of LCOE, producing a GIS layer |

### 2.5.2 Results

The UoC Report derives an LCOE of $261/MWh and the Ricardo report derives an LCOE of $182 to $296/MWh, depending on site. The turbines considered by the two studies, a 5MW, 120m diameter turbine and a 3.6MW, 107m diameter turbine, are already no longer sold or in series production, and by installation in 2028 will be fully obsolete. For comparison, LCOEs in established markets (with higher winds, larger projects and greater competition) are anticipated to be about $60/MWh.

### 2.5.3 Conclusions

Neither assessment provides much accuracy, as they do not consider:

- Relevant size turbines, with costs relevant to installation in 2028. Viable turbine sizes will be between the larger turbines sold for onshore wind today, at 6MW scale, and the standard turbines that will be being installed in projects offshore in 2028, at around 15MW scale. This could reduce LCOE by over 30%.
- Appropriate energy losses.
- The very small project scale planned in Bermuda. This could add over 20% to LCOE.
- The logistics of installing turbines off Bermuda, requiring an installation vessel to steam from US or Europe. It may be possible for a large vessel to bring foundations and turbines with it, in one journey, or to transfer in protected waters from a feeder vessel.
- Foundation designs suitable for the uncertain ground conditions. In firm ground without boulders, monopile foundations typically are the lowest cost solution. In less ideal conditions, jacket or gravity base solutions can be the lowest cost solution. Floating site F has approximately  30% increased CAPEX and OPEX due to floating aspects which is reasonable, but if water depth is about 50m, then It is unlikely that floating foundations offer the best solution for this site.
- The actual water depths and distances to operations port and grid connection for each site.

LCOE is sensitive to a range of factors, as shown in Figure 2.2.

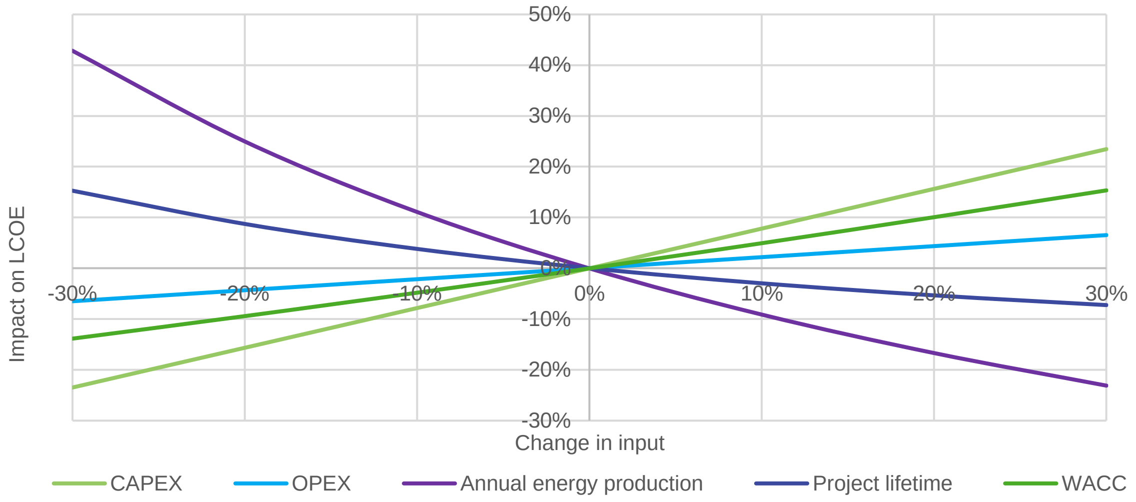

***Figure 2.2 Cost of energy sensitivity analysis for a typical offshore wind project.***

For Bermuda, key uncertainties include:

- Regarding CAPEX and OPEX:
    - How past trends of significant reduction in cost change looking forward
    - What size turbines will be used
    - What foundation designs will be suitable
    - What logistics will be best

    - How will competition in the global supply chain evolve
    - What will be the long-term trends in commodity prices
    - What is the cost of hurricane mitigation
  - Regarding annual energy production:
    - What is the wind resource
    - What will be the impact of a small, remote site on project uptime
  - Regarding Weighted average cost of capital (WACC):
    - How will competition to finance OSW develop
    - How will concessional finance help
    - What appetite will there be for a small project

We suggest that independent of which offshore wind procurement route Bermuda takes, it conducts a better cost assessment that addresses each of the weaknesses and uncertainties described above, giving a more realistic range of anticipated LCOE from offshore wind at preferred sites in Bermuda. There is little that can be drawn from either of the reports as a basis for this.

The other important consideration is how offshore wind will fit within Bermuda's future energy system, with the following aspects:

- Natural variability of wind farm output, year-to year, month by month within a given year, and shorter-term, also recognising the variability of solar output, the ability to forecast both and the ability of thermal generation to fill the gaps in generation.
- The importance of using excess generation above demand, rather than curtailing output. In time, this could come from generating hydrogen at such times, and storing then using this hydrogen as the fuel for generation to fill the gaps in renewable energy generation.
- The potential impact of faults on the wind farm / elsewhere on the grid:
  - In terms of short-term impact on the electricity system (milliseconds to seconds) when a fault occurs and there is immediate loss of supply, whether this fault is on the wind farm or elsewhere
  - In terms of loss of supply from the wind farm for short periods, that could be hours or days (in the event of a fault that can be fixed remotely or by a visit by the local service crew and with spare parts held on the Island), and
  - In terms of loss of supply from the wind farm for longer periods, that could be weeks or months (in the event of a fault on a turbine (or the export system) that needs more major intervention).
- How impacts change using turbines ten 6MW turbines compared to four 15MW turbines and with the incorporation of battery storage to provide short-term support the grid over the period of seconds and hours.

We suggest that these aspects be considered, following good industry practice.

## 2.6. Summary of strengths and weaknesses

Considering solely the scope addressed in each report, we consider the strengths and weaknesses (as relevant to use today) in Table 2.7.

**Table 2.7 Strengths and weaknesses of the two reports.**

| Area | 1. UoC report | 2. Ricardo report |
|---|---|---|
| Spatial assessment | Strengths:<br>• Logical, well-defined process<br>Weaknesses:<br>• Considers what are now relatively small 5MW, 120m diameter turbines<br>• Uses 2014 understanding – much has progressed since then<br>• Only some input layers are presented, so it is not clear which consideration drives exclusion at each location<br>• Can only give partial confidence as various potentially important considerations not included | Weaknesses:<br>• Considers small 3.6MW, 107m diameter turbines<br>• Poorly defined process with poorly documented inputs and output<br>• Can only give partial confidence as various potentially important considerations not included |
| Wind resource assessment | Weaknesses:<br>• Not clear that wind data sources are reliable<br>• Did not address spatial variation of wind resource<br>• Did not address extreme wind speeds | Strengths:<br>• Used robust modelled wind data from Global Wind Atlas<br>• Addressed wind direction<br>Weaknesses:<br>• Did not address spatial variation of wind resource in a useful way<br>• Did not address extreme wind speeds |
| Technology and cost of energy assessment | Weaknesses:<br>• Generic assessment using ‘old’ technology choices and limited data and understanding<br>• Did not address AEP uncertainty | Weaknesses:<br>• Generic assessment using ‘old’ technology choices and limited data and understanding<br>• Did not address AEP uncertainty |

# References

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