# Offshore Wind - Preliminary Feasibility

## Final Report

**States Of Guernsey**

**Assignment Number:** L500042-S00
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# 1 INTRODUCTION

## 1.1 General

This is the final report of a techno-economic study performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility of a proposed 30MW offshore wind project.

It is important to understand that the design, ownership and other features of a potential wind farm have not yet been finalised. Therefore, the views in this report are preliminary and subject to change.

## 1.2 Objectives

Guernsey is heavily reliant on imported electricity from France and back-up electricity from local diesel generators. RET and GEL are seeking to improve security of electricity supply, long term sustainability and price certainty by diversifying into locally generated low carbon energy in the form of offshore wind turbines.

## 1.3 Scope

The scope of the study was to provide a high level overview of the technical and economic options, and to consider the wider opportunities and impacts associated with such a project. It was also to establish a wind resource monitoring strategy since this needs to be performed in advance of a detailed project assessment.

The study is based on the current state of the offshore wind industry and expected changes for projects currently under development.

In parallel to this study further work to progress a seabed leasing strategy and stakeholder engagement strategy has been performed by Xodus Group and Exeter University respectively. This work does not form part of this report.

## 1.4 Shortlisted sites

The study identified 8 potential sites, from which the following 3 have be shortlisted as the preferred options:

1. North Coast (Option 2)
2. West of Schole Bank (Option 4)
3. Offshore floating (12 nautical miles) (Option 8)

These are shown on the map in Figure 1.1. The map is to scale showing the most likely layout of five 6MW turbines (based primarily on seabed constraints and prevailing wind direction) and the approximate area of construction and possibly operational exclusion zones. Notes that Options 7 and 8 use floating turbines and the exact locations can be altered to avoid existing subsea cables or other micro-siting issues.

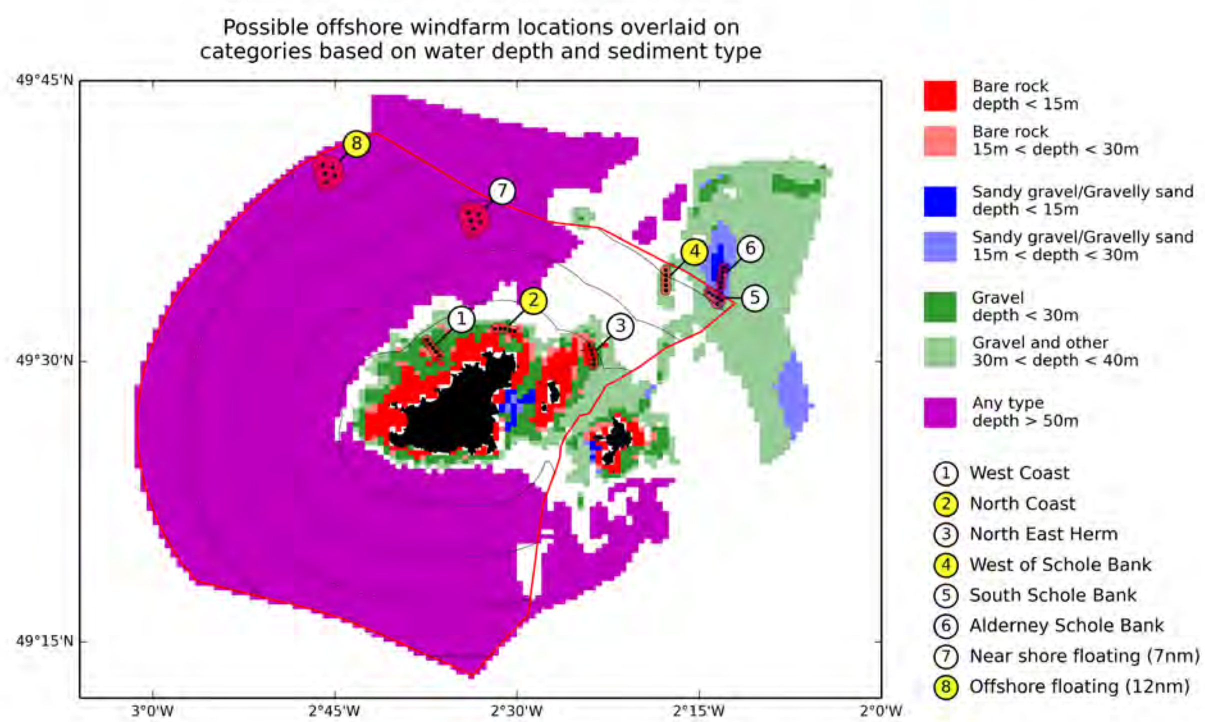


**Figure 1.1 Offshore wind farm sites (shortlist in yellow)**

# 2 CONCEPT OUTLINE

## 2.1 Turbines

There are several wind turbine manufacturers who specialise in offshore wind and European market statistics – the largest international market - are presented annually by the European Wind Turbine Association (http://www.ewea.org/fileadmin/files/library/publications/statistics/EWEA-European-Offshore-Statistics-2015.pdf).

The key players are Siemens, MHI-Vestas (joint venture), Senvion, Adwen (joint venture Areva and Gamesa) and GE Renewables (recently part of Alstom). The average single offshore wind turbine is currently just over 4MW in capacity (ranging from 2MW in early projects to 6MW more common now). However, the size is constantly increasing in a drive to reduce overall costs of energy, and the associated race for original equipment manufacturers (OEMs) to increase their market share (see Figure 2.1). Production machines will soon exceed 8MW but for now we have assumed 6MW turbines will be widely available and proven for the Project. Therefore, a 30MW project will only require 5 or fewer turbines.

These turbine OEMs specialise in horizontal axis turbines mounted on fixed structures. However, they are all now seriously looking at the floating wind market potential. Leading floating foundation designs adopt a fairly conservative approach and basically produce a very stable foundation that is relatively easy to accommodate horizontal axis turbines with little adaptation. Therefore, it is reasonable to assume that floating turbines will also be of the order 6MW/turbine, although possibly with more than one turbine on a single structure.

The exceptions are novel floating wind solutions that take maximum advantage of the benefits of a floating foundation. These turbines are often vertical axis, and demonstration machines are smaller than current market leading horizontal axis but with projections to be far bigger ultimately. These new machines have not been considered specifically for this study, but if a floating wind demonstration project is taken forward then these new machines should be considered.

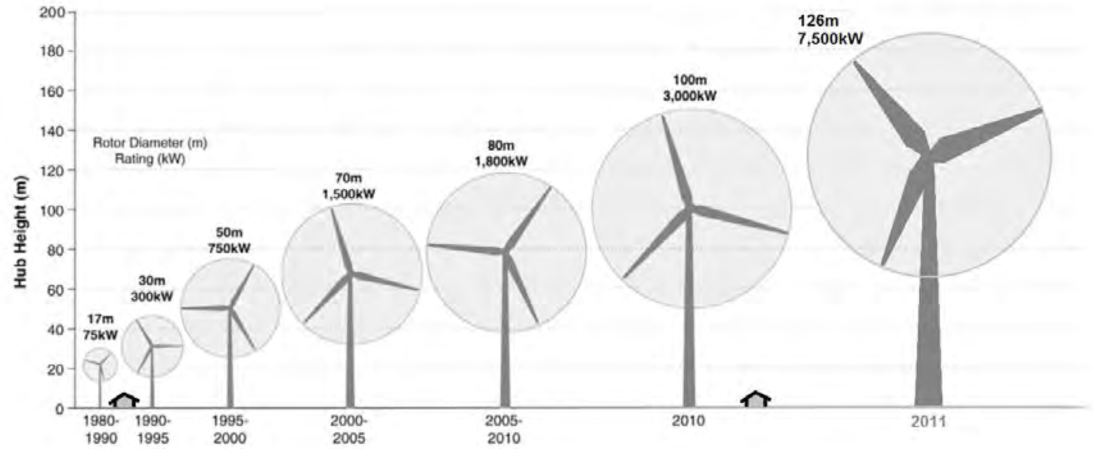


Figure 2.1 Evolution and Scale of Modern Horizontal Axis Turbines

(Source: https://commons.wikimedia.org/wiki/File:Wind_turbine_size_increase_1980-2011.png)

## 2.2 Support Structures

The type of support structure (sometimes referred to as foundation, although this term often only refers to the section below the seabed) is decided during conceptual and detailed design, and is primarily driven by water depth and seabed geotechnics. There are many variations and hybrid combinations made from steel and/or reinforced concrete and either fixed or floating.

Given the relatively small scale of this project it is unlikely that concrete gravity structures (using their mass for stability) will be a viable option because of the set-up costs in a fabrication yard. Also, the high tidal currents around Guernsey would make handling such enormous structures challenging and therefore costly. Concrete floating structures may be viable because they could be the same as structures for other sites and therefore low volume would not be an issue.

Figure 2.2 Example Concrete Gravity Foundations/Structures – Thornton Bank project

(© Hans Hillewaert/licence details: https://commons.wikimedia.org/wiki/File:Windmill_bases_(Oostende_-_from_northwest).jpg)

For the range of sites being considered around Guernsey we only need to consider three types of foundations:

- Large diameter mono-piles for shallow water sites (less than 40m water depth, several meters in diameter);
- “Jackets” (steel lattice structures with either small diameter, say 2m, multi-piled legs or some other form of anchor such as suction anchors). Suitable for generally >30m and < 50m water depth;
- Floating vessels with a fixed mooring system. Many options being tested and some are challenging jacket costs in waters > 50m deep.

Figure 2.3 Examples of Mono-pile Foundations (a single pile into the seabed)

(Source: https://commons.wikimedia.org/wiki/File:Prinses_Amalia_Windpark.jpg)

Figure 2.4 Examples of Turbines on a Jacket Structure

(© Martina Nolte/licence details: https://commons.wikimedia.org/wiki/File:2012-05-13_Nordsee-Luftbilder_DSCF8886.jpg)

Figure 2.5 Example of Floating Wind Turbine - Windfloat by Principle Power

(© Principle Power Inc/licence details: https://commons.wikimedia.org/wiki/File:Agucadoura_WindFloat_Prototype.jpg)

Mono-piles are the simplest of structures and rely on their diameter and wall thickness to overcome the bending forces from the turbine (and waves and currents). The limit of size is governed by the ability to fabricate and install them. Very thick steel is costly to roll and challenging to weld, and the large diameter and weight makes it difficult to handle, transport and drive or drill into the seabed.

The transition to a more complex jacket structure is mainly a cost analysis. Jackets are very structurally efficient structures that can be used in very deep water (>>100m in some oil & gas facilities), however their costs increase significantly with depth. This is why the sector is now exploring floating structures with relatively low cost mooring lines.

The choice of structure for each site is discussed further in Section 2.3.2.

## 2.3 Site Screening and Selection

After identifying the eight potential project site locations shown in Figure 1.1 it was necessary to produce a short list to focus further work. We used Xodus in-house decision making software (VDRM – Value, Decision, Risk Management) to screen and then select three sites for further analysis. The VDRM software uses quantitative analysis to compare qualitative and quantitative information. An overview and results of the analysis are presented in this section and the full analysis is given in Appendix A.

## 2.3.1 Site Selection Drivers

The first step of the analysis is to decide upon the key drivers for site selection and then determine a weighting for each driver. The VDRM software uses an analytical hierarchy methodology to perform a pairwise comparison of each driver to calculate an overall weighting for each one – refer to Table 7.2 in Appendix A to see the scoring of each driver relative to all the other drivers (pairwise comparison). A description of each chosen driver is presented in Table 7.1 in the appendix.

The weightings were discussed and agreed with RET and GEL and are presented in Table 2.1 below, and the analysis is shown in Table 7.2 in the appendix. There is no right or wrong exact weighting for each driver because it depends on the associated scoring system (presented in Table 7.4). But they do provide an initial insight into the likely main factors from a purely site selection perspective, which is discussed further in the following section.

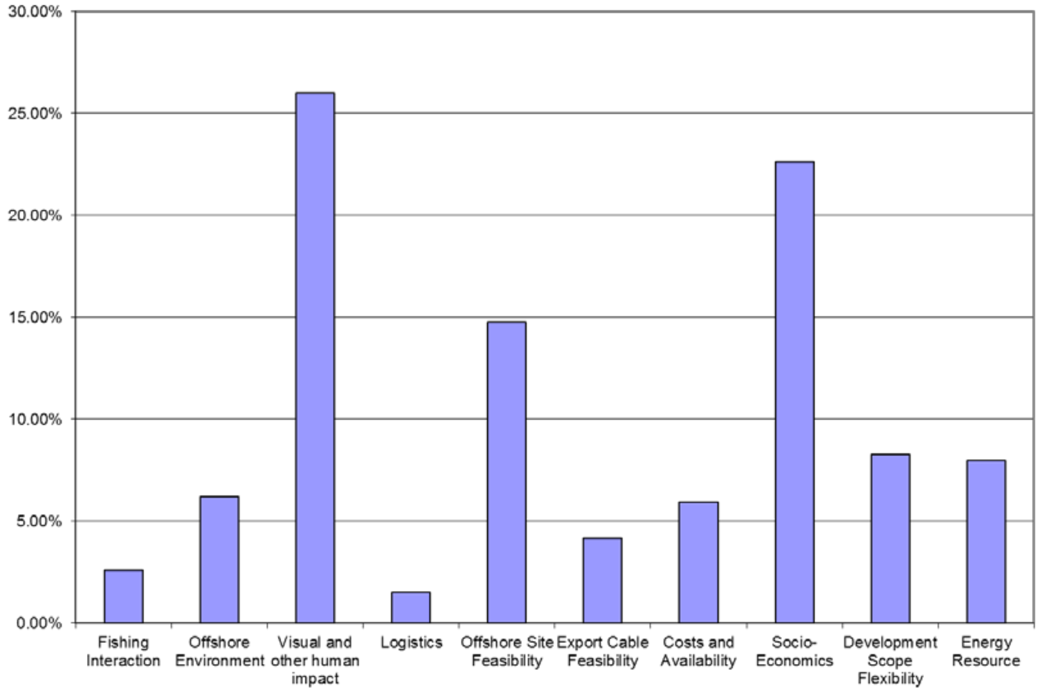


Table 2.1 Weighting of Project Drivers

A summary of the scoring of the top three drivers (as highlighted in grey) is presented in Table 2.2 and a discussion of how the sites were ultimately shortlisted from all 8 sites is given in Section 2.3.2.

| Key Driver/Site | Scoring System for Key Drivers and Shortlisted Scores & Logic | | | | | | |
|---|---|---|---|---|---|---|---|
| | -3 | -2 | -1 | 0 | +1 | +2 | +3 |
| **Visual and other human impact** | **Minority general acceptance with many specific objections.** | | | **Strong general acceptance but with some focused objections.** | | | **Very strong acceptance from all stakeholders. No specific objections.** |
| Site 1 West Coast | Visual impact alone scores -3. | | | | | | |
| Site 4 West of Schole Bank | | | | Main concern is radar but possibly less than sites 1, 2 and 3 because further offshore - although mitigation still required. | | | |
| Site 8 Offshore floating (12nm) | | | | | | This area should be fairly well accepted. | |
| **Offshore Site Feasibility** | **Technically very challenging, but not necessarily a complete show-stopper. Significant technology risks or uncertainties.** | | | **Typical state of the art development issues.** | | | **Technically very low risk with proven solutions..** |
| Site 1 West Coast | Main concern is hard rock. Gravity base solutions could be an option but at very high cost for only a few units. Also considerable depth (20m) for gravity base units. | | | | | | |
| Site 4 West of Schole Bank | | | Unknown exact water depths and thickness of sediment cover over bedrock. Assume jacket type foundation is required that may need small diameter drilling in some cases. | | | | |
| Site 8 Offshore floating (12nm) | | Depends on the timing of the project. Offshore floating wind is currently in pilot project phase but the technology is generally proven and it is likely to progressing rapidly to commercial projects. | | | | | |
| **Socio-Economics** | **Robust business plan unlikely with potential for severe impacts to the local economic and social environment primarily through increased cost of energy and little or no direct project benefit.** | | | **Risks balance the opportunities. A robust long term flexible business model acceptable to policy makers.** | | | **Significant direct and indirect opportunities to Guernsey. Strong business case for both the short and longer term.** |
| Site 1 West Coast | | | Little opportunity but with significant potential for cost escalation or overrun. | | | | |
| Site 4 West of Schole Bank | | | Little opportunity but with significant potential for cost escalation or overrun. | | | | |
| Site 8 Offshore floating (12nm) | | | | It is likely that floating projects will facilitate a phase development approach. | | | |

Table 2.2 Summary of Top 3 Drivers and Shortlisted 3 sites

### 2.3.2 Site Selection Ranking & Discussion

The sites can be grouped into the following three areas of interest:

- Close to Shore: West & North Coast and NE Herm – lowest overall rankings mainly due to close proximity to the coast (VDRM scores -160 to -203).
- Schole Bank Area – West of Schole Bank has good potential (VDRM score -60) but the actual Bank is screened out because of potential risk to an important fishing area and high risk of showstoppers.
- Floating Wind Sites – highest ranking option because of the great flexibility to select a site that is not significantly constrained by water depth and seabed geology. However, also the most costly option at this time. (VDRM scores +30 to +60)

Each group of sites are discussed further below with the detailed results in Table 7.5. Note that although the VDRM software provides a quantitative score for each site these should only be considered as a guide. The objective of the analysis is to see if there is "clear water" between any of the options, and there certainly is with the best scores for floating at +30/60 being considerably better than the other scores.

### 2.3.2.1 Close to Shore: West & North Coast and NE Herm

With reference to Figure 1.1 and Appendix A, we have investigated three sites that are very close to the shore: sites 1, 2 and 3. There are benefits from being close to the shore such as shorter cables to onshore substations and shorter distance to travel for maintenance. However, the main reason that offshore wind projects actually started out being close to shore was the shallow water and associated smaller, lower cost, foundations. These selected sites are very close to the shore because off the coast of Guernsey the water depth increases rapidly after only a few miles.

The lowest cost foundations in shallow water are mono-piles, driven into the sediment with large hydraulic hammers. Unfortunately, there is little or no sediment covering the bedrock at these sites on Guernsey and therefore alternative, more costly, alternatives would need to be considered. The usual method for overcoming seabed that is difficult to pile is to drill. Special large diameter drills have been designed for this purpose, but there are only a few globally that have sufficient diameter for wind turbines. The added challenge at Guernsey is that the coastal rock is very hard (a form of granite at these sites), the reason why Guernsey has not been eroded away!

We have contacted one firm, Fugro GeoServices Ltd, and they have advised that drilling is likely to be technically possible. They have informed us that they have experience drilling in the region and that the cost should not be prohibitive. This is clearly a very important fact to establish before the rocky coastal sites can be fully evaluated. It is important to take into consideration the risks, and risk allocation, associated with drilling before it is possible to get a firm understanding of the costs. Main contractors will certainly want to add a significant safety margin to their price if they are asked to take the risk of slow drilling and/or weather downtime. It may be lower cost to contract directly with the likes of Fugro or other companies that own their drilling rig and vessel, but they would not typically take the same level of risk as a main contractor.

It is possible that a jacket or tripod structures could be used, utilising more drilled holes but smaller diameter and widening the market supply chain. However, this would certainly increase the cost compared to a piled mono-pile.

It may also be possible to use gravity based concrete structures that don't require drilling but may require seabed levelling using rock dump. However, it is unlikely that this would be cost effective for a small project given the initial investment requirements, and also the high currents that would make handling more difficult and needing powerful and costly vessels. That said, there are a number of concrete gravity based foundation ideas being proposed (and certainly a few deployed) and these should be carefully evaluated if a rocky site is taken forward to design. The Carbon Trust has been reviewing the options recently and their findings are reported on their website (e.g. 2015 report: https://www.carbontrust.com/media/672062/ctc844-offshore-wind-industry-review-gbs-gravity-base-foundations.pdf).

If the potentially high costs of the foundations (and possibly cable protection over rock) can be overcome then these shallow sites could be the lowest cost of all the sites being considered. However, cost and feasibility (construction risks) are not the only important considerations.

Visual and other human impacts and associated socio-economics are each weighted as highly as the combined cost and feasibility, and the corresponding scores are all poor in these two categories. With reference to Table 2.2 and Table 7.5, the West Coast is the worst scoring site but the other two are also poor.

It is important to know that modern 6MW wind turbines are huge structures with rotor diameters of 150m+ (more than twice the size of jumbo jets). They will dominate the skyline if positioned close to the shore and this is a major reason why projects are now generally moving further offshore and even into deeper water (e.g. in the UK compare The Crown Estate's offshore wind leasing rounds 1 and 2 with round 3 locations: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/49540/4122-r27-map-of-crown-estate-interest.pdf).

If there were plenty of options to consider then all of these sites would be screened out. However, since two mono-pile options at Schole Bank needed to be screened out (see 2.3.2.2 below) it was decided to keep the North Coast site (the highest VDRM ranked coastal site) on the shortlist to provide a comparison with the other options. It is also important to recognise that although these are not currently preferred sites it is possible that future, more detailed, work could identify problems with the other sites that changes the relative ranking and/or public perception of large turbines could change and this option could become favourable.

### 2.3.2.2 Schole Bank Area

Three sites have been investigated on and around the Schole Bank area: sites 4, 5 and 6. RET and GEL decided that because Schole Bank was such an important area, for example for fishing, that sites 5 and 6 (on the Bank) should be excluded from further consideration because of the high risk of showstoppers. In Table 7.5 these sites have been scored as -999 under fishing interaction to highlight the showstopper.

Site 4, West of Schole Bank, scored well compared with sites 1, 2 and 3. The main drawback is the fairly deep water with much of the site expected to be in 40m (and with a large tidal range). This water depth will require a steel jacket solution (unless the industry makes significant advances with gravity concrete solutions or shallow water floating is developed). Regardless of the exact final technical solution the costs will be higher than a simple mono-pile in good seabed conditions, and indeed there is currently significant uncertainty regarding the seabed geotechnics and some drilling may be required.

There are no other seriously negative scores for each of the site selection drivers, but equally no particularly good scores. So this site certainly makes the short list but still well behind the top ranking floating sites.

### 2.3.2.3 Floating Wind Sites

Floating wind has the potential to transform offshore wind development. Although this study has used a selection of key site drivers to aid in short listing sites for further study, in reality there a numerous issues that influence the siting of wind projects. Often the technical constraints of fixed structures have resulted in poor initial site selection and ultimately project abandonment after tens of millions of pounds have been spent trying to overcome problems and/or objections. But floating foundations dramatically reduce the water depth and geotechnical "ground risks" thus allowing developers to prioritise other issues which should increase the likelihood of successful planning and approval.

We have selected two potential sites: Near shore floating (7nm) and Offshore Floating (12nm), sites 7 and 8 respectively. Both these site scored equally well compared to the other options although site 8 scored best overall (primarily because the extra distance offshore reduces the visual and other human impacts) and was chosen to represent floating in the shortlist for further analysis. It was not necessary to put both sites in the shortlist because the exact location is subject to change and any further work will need to consider all reasonable floating site options in the region of these two sites.

With reference to Table 2.2 and Table 7.5, both sites scored well for visual and other human impacts because they are further offshore, away from radar and flexible regarding micro siting (not reliant on water depth or seabed features) – the only sites to score positively using this system. The socio-economics score for both sites is zero (on a scale of -3 to +3). This score reflected a balance between some small negative and small positive impacts, and the potential for a phased development that introduces flexibility.

Project flexibility is considered valuable not only because of the potential scale of investment for a full project but also because of the impact on overall cost of electricity on Guernsey because offshore wind is more costly than current alternatives. Flexibility also enables new technology to be considered at relatively short notice because the main infrastructure would be pre-installed. This is less of an option for fixed support structure projects because the costs of re-mobilising heavy lift construction vessels (and to some extent fabrication yards) could dramatically increase the overall costs.

It is also worth noting that France is taking the initiative in floating wind. The French Government announced a pilot programme last year with 3 sites proposed for the Mediterranean and a site off Brittany (Ile de Groix). The latest news is available of this and other wind news sites: http://www.offshorewind.biz/2016/04/12/race-to-build-floaters-heating-up-in-france/. It was also suggested at a recent marine renewables conference in France that the seas around Guernsey would be a target area for large scale floating wind projects (this is not official French policy).

A review of the current technology status prepared by The Carbon Trust in 2015 is available at their website: https://www.carbontrust.com/resources/reports/technology/floating-offshore-wind-market-technology-review/.

## 2.4 Cables, Landfall and Substation

The grid connection to Guernsey for a 30MW project is relatively straightforward. Given the location of the shortlisted sites then the most likely cable landfall will be along the North Coast. GEL suggest that a substation at Le Murier switching station could be a potential location, and this site also avoids planned new infrastructure connecting with the French network.

The wind farm naturally produces intermittent power and this needs to be managed by GEL. This issue is outside the scope of this study but will need to be investigated further.

An important consideration will be the export voltage from the site. We have assumed that projects close to shore could operate at 33kV which is the network transmission voltage on Guernsey. However, projects at 12nm may require to increase the voltage to avoid high electrical losses in the cable. It would be possible to increase the voltage to 66kV without adding much complexity offshore, and this would simply require a 66/33kV step down transformer onshore (possibly located at Le Murier).

There is a large range of engineering options to accommodate even the most challenging landfalls at cliff locations. However, the North coast should provide for a relative low cost and technically low risk cable pull-in and burial landfall solution. The bigger risk is likely to be stability and protection of the cable in shallow waters before it can be effectively buried in bottom sediments. We have made an allowance for rock dump burial in the economic modelling. This will be a key design issue as the project progresses to mitigate the risk of cable failure, especially in rocky areas subject to high wave and current loading at the seabed.

## 2.5 Development & Construction

### 2.5.1 Outline Plan & Schedule

The tasks and schedule for the development phase of a typical 30MW project is presented below. This is actually based on a floating wind project where the technology is not very mature. A more conventional project could probably reduce the design and build stages a little. This 5 year schedule assumes the actions presented in this report are implemented and this will require significant effort and political and public support. Note that cables are long lead items and these would need to be ordered as soon as planning is consented.

| **Project Activity** | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Feasibility Studies (see 2.5.2.1) | | | | | | | | | | |
| Consenting (see 2.5.2.2) | | | | | | | | | | |
| Stakeholder consultation & engagement | | | | | | | | | | |
| Final investment decision (*)<br>Approx. £5 million spend to this point | | | | | * | | | | | |
| Design | | | | | | | | | | |
| - Support structures | | | | | | | | | | |
| - Turbines & Electrical | | | | | | | | | | |
| Procurement & Fabrication | | | | | | | | | | |
| - Support structures | | | | | | | | | | |
| - Turbines | | | | | | | | | | |
| - Infield cables | | | | | | | | | | |
| - Export to Guernsey cable | | | | | | | | | | |
| Offshore installation | | | | | | | | | | |
| Onshore facilities design and build | | | | | | | | | | |

Table 2.3 Outline Indicative Development Schedule

The estimated capital costs (CAPEX) for the project is presented in the following table:

| | North Coast (site 2) £m | West of Schole Bank (site 4) £m | Floating (12nm) (site 8) £m |
|---|---|---|---|
| Project Development & Consenting | 5.00 | 5.00 | 5.00 |
| WTG supply and installation | 38.50 | 38.50 | 38.50 |
| Substructures | 9.35 | 21.76 | 50.00 |
| Foundations | 5.5 | 3.79 | 0.00 |
| Offshore cables | 3.56 | 5.08 | 6.60 |
| Onshore electrical infrastructure | 3.20 | 3.20 | 3.20 |
| Project management and insurance | 3.12 | 3.65 | 4.88 |
| Total | £ 68.23m | £ 80.98m | £ 108.18m |

**Table 2.4 Estimated CAPEX cost (see Appendix D)**

The cost differences are driven by water depth and associated foundation and support structure type. The cost of floating wind structures is expected to fall dramatically as the technology develops.

### 2.5.2 Typical Activities during Development & Consenting

The approximate budget of £5m would be spread fairly uniformly across the 2.5 year period. The engineering studies should start first to provide guidance for initial scoping and stakeholder engagement. The latter activities then feed back into the engineering to influence the concept and design. Onshore and offshore surveys are required for both engineering and consenting and where possible they should be combined for maximum efficiency. Wind and wave measurements should be performed as early as possible because of the lead times to gather sufficient data (refer to Section 5 for further details).

#### *2.5.2.1 Feasibility Studies*

The early engineering on the project is where the value is created. A very wide range of options need to be considered and quickly filtered to create focus on the best opportunities, uncertainties and risks. Ideally only a couple of concepts should make it into the front end engineering design (FEED) stage. FEED should be performed in close collaboration with the supply chain (and sometimes performed by main contractors) to ensure that costs are as accurate as can be (subject to contract), and key risks are well understood. If main contractors perform aspects of FEED then their contract should include incentives to reduce risks and/or costs.

- Site Surveys and Development of Basis of Design
- Conceptual Engineering and Detailed Site Optioneering
- Front End Engineering Design (costs to +/- 20% to 30%)
- Final Site Selection
- Main contract tendering and award (refine costs +/- 10% to 15%) - subject to financial close

#### *2.5.2.2 Consenting Activities*

Achieving the necessary consents is often on the project critical path before financial close and before major contract can be awarded. Activities should start as soon as concepts are defined, and consenting risks and opportunities should be fed into the design teams as quickly as possible to influence design as necessary. Activities would typically be:

- Environmental impact assessment scoping
- Stakeholder consultation
- Environmental baseline characterisation surveys
- Environmental impact assessment and Environmental Statement write up (offshore and onshore)
- Licence / consent / planning applications

### 2.5.3 Equipment & Logistics

Offshore wind turbines are huge structures, and very tall compared to offshore oil & gas structures. They need to be installed very efficiently to minimise costs and maximise speed. For these reasons special purpose construction vessels are used to install the foundations, structures and turbines. The vessels typically operate all over the world and cost of the order £100,000/day to £300,000/day. The same crane vessels are required to remove the rotor and nacelle (housing the generator etc.) if there is a major failure requiring repair. Floating wind turbines can overcome the high cost and uncertain availability of crane vessels because they can be assembled in port using an onshore crane, and later returned to port for maintenance and/or repair. The tug boats required to transport the floating turbines are much lower cost and readily available for hire at relatively short notice.

**Figure 2.6 Example Construction Vessel (Jackup Barge)**

(© Harald Pettersen/Statoil/ licence details: https://commons.wikimedia.org/wiki/File:Havvindparken_Sheringham_Shoal.jpg)

In addition to heavy lift vessels, special purpose maintenance crew transfer vessels have been developed to rapidly transport and ensure safe transfer of crews to turbines for minor maintenance activities. For a relatively small project, where high speed it not essential, it may be possible to utilise other vessels if they can be adapted to ensure safe transfer.


**Figure 2.7 Example Crew Transfer Vessel (fast, often multi-hull vessels)**

(Source: https://commons.wikimedia.org/wiki/File:Ship_Njord_Curlew.jpg)

## 2.6 Operation and Maintenance

Maintaining the offshore turbines safely and efficiently is critical to the success of the project. As mentioned in the previous section, major intervention will either require a large crane ship or, in the case of floating turbines, a return to port. In either case this activity would not involve Guernsey ports because they are too small to accommodate the vessels. However, more routine activity using smaller crew transfer vessels (such as shown in Figure 2.7) could, and probably should, be based from Guernsey.

The maintenance requirements of turbines and the associated performance of vessels has been analysed in detailed to estimate the overall project availability that is required for the cost of energy analysis. The full analysis is presented in Appendix C and the conclusions are given below:

- A central estimate for turbine availability of around 91% has been derived, but with significant sensitivities.
- The turbine availability is expected to vary slightly between the down-selected sites, but isn't significant compared to other sensitivities.
- The turbine availability is very sensitive to lead times for vessels to undertake turbine repairs. A pessimistic scenario for vessel lead times reduces the turbine availability to below 85%.
- The vessel sensitivities are;
  - How quickly a work boat can respond
  - How quickly construction support vessels can be available
  - How quickly and at what cost a jack-up can be available (for fixed foundation turbines)
  - How quickly a tow vessel and a crane in port can be available (for floating turbines)
- Market forces will dictate the vessel availability and cost for the vessels needed for major repairs. Jack-ups for fixed foundation turbines are expected to be the most problematic, as the other vessel types are more readily available. It is impossible to predict these market forces at this time.
- Formulating the best strategy for operating a work boat is not currently possible. It may be justifiable to base a work boat and competent crew of technicians in Guernsey, but alternatives need to be considered (for example, collaborating with a nearby French wind farm) and the optimum strategy will depend on the expected need – i.e. the expected turbine failure rate (following discussion with the selected turbine OEM). The best strategy will need to be developed in collaboration with the turbine OEM since contracting the vessel and crew will form part of the turbine warranty agreement. It is important to try and minimise the number of exclusions an OEM may try to impose as a result of vessel availability and performance. Safety, cost, socio-economics and risk management are all key drivers in this strategic decision.
- The turbine availability is very sensitive to the failure rates assumed for different types of failures. The expected sensitivity of availability based on turbine reliability is of the order 3% (between 91% to over 94% of our nominal case). This represents significant revenue and as such this is a key discussion point with turbine OEMs during tendering.
- It has been assumed that either Le Havre or Plymouth could accommodate floating turbines and the required large onshore cranes – given the port size. The suitability of these or other ports should be investigated at an early stage of the project. Cherbourg is a potential option, especially if it is developed into a wind energy hub as currently planned.

# 3 OBJECTIVES, RISKS AND OPPORTUNITIES

## 3.1 Objectives

The objective of an offshore wind project is simply to produce electricity to complement existing sources of power from on-island generation and imported power via submarine cable interconnectors to mainland Europe. Main reasons for this diversification are to improve security of supply, with less reliance on imported power, lock into a fixed price of energy for 25 years and reduced carbon emissions from decreased use of oil based on-island generation.

A detailed risk and opportunity register has been developed for this stage of the project and has been issued as a spreadsheet (ref. to Appendix G). The key findings are summarised below (refer to the appendix for the scoring system).

## 3.2 Risks

### 3.2.1 Potential Show Stoppers

The following risks are all potential showstoppers and all considered high risk even after reasonable mitigations actions are taken. As such they must be addressed with a high priority before the project can progress much further.

| ID | Risk description | Likelihood | Impact | Risk | Consequence | Category | Mitigating actions | Contingency | Comments | Likelihood | Impact | Risk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre-mitigation | | | | | | | | Post-mitigation | | |
| 1 | Ongoing volatile energy market and/or low cost of oil or alternatives | 5 | 5 | H | Difficult to plan and design value adding project | Political | Introduce flexibility where possible. Have a long term low carbon energy policy incorporating security of supply. | Introduce/maintain flexibility in alternative solutions for electricty supply. | Residual risk depends on policy statements. | 4 | 5 | H |
| 3 | Small scale and first of a kind in Guernsey waters makes project unattractive to the industry | 4 | 5 | H | Lack of interest in supply chain, and no economies of scale drive up costs | Financial | Consider pilot project or collaboration with larger projects. Early engagement with key suppliers. Establish robust permitting pathway. | Prepare for higher costs and give preference to technical solutions that favour small scale. | Residual risk depends on progress of nearby fixed and floating projects and potential of collaboration. | 3 | 5 | H |
| 8 | Lack of detailed information from supply chain | 4 | 5 | H | High risk of cost overruns or cancelling a feasible project | Financial (technical) | Make project look attractive and real (even 1 GW projects have this problem!). Consider pilot stage technology and strategic partnering. | Maintain options. | Risk could be reduced if successful with strategic partnerships. | 3 | 5 | H |
| 10 | Not obtaining seabed rights from the Crown | 3 | 5 | H | Unlikely to find suitable site within 3nm limit. | Political | Keep the pressure on to maintain schedule. | Introduce/maintain flexibility in alternative solutions for electricty supply. | To be reviewed at an early stage. Other risks could be generated depending on agreements. | 3 | 5 | H |
| 10b | Not obtaining territorial seas 3nm to 12nm | 3 | 5 | H | No Guernsey project | Political | Keep the pressure on to maintain schedule. | Introduce/maintain flexibility in alternative solutions for electricty supply. | To be reviewed at an early stage. Other risks could be generated depending on agreements. | 3 | 5 | H |

Table 3.1 High Risks Post Mitigation

## 3.2.2 Key Risk Mitigation Actions

In addition to removing potential show stoppers, the risk register also highlights other key risks that could develop into show stoppers without appropriate mitigation. The following table presents the risks that require (or are currently receiving) action to reduce the risk, and the post mitigation scores clearly highlight the value of taking action. See the detailed register for the residual risks.

| ID | Risk description | Likelihood | Impact | Risk | Consequence | Category | Mitigating actions | Contingency | Comments | Likelihood | Impact | Risk |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pre-mitigation | | | | | | | | Post-mitigation | | |
| 2 | Complex risk profile of the project not fully understood by decision makers | 3 | 5 | H | Incorrect early decision making (either for or against) | Political | Education, a clear stage gate approach and well defined triggers | Introduce/maintain flexibility in alternative solutions for electricty supply. | | 2 | 4 | M |
| 4 | Small scale and first of a kind in Guernsey waters makes project unattractive to external financiers | 4 | 5 | H | Lack of interest in financial markets, high interest rates, increasing cost of energy. | Financial | Establish robust permitting pathway. Minimise external finance requirements. | Prepare for higher costs and give preference to financial solutions that favour small scale. | | 2 | 5 | M |
| 5 | Ongoing evolving supply chain and technology | 4 | 4 | H | Delayed or incorrect decision making | Financial (technical) | Education and introduce strong decision making procedures | Introduce/maintain flexibility in alternative solutions to enable a stop/start approach to offshore wind | Likelihood could increase if floating is adopted. | 2 | 4 | M |
| 6 | Insuffient technical data to inform feasibility studies | 4 | 4 | H | High risk of cost overruns or cancelling a feasible project | Financial (technical) | Well structured feasibility stage with focused surveying | Maintain a few options until budget approval of necessary surveying. | Note this is feasibility stage. Needs to be re-assessed during design stage. | 1 | 4 | L |
| 7 | Insuffient environmental data to inform feasibility studies | 4 | 4 | H | Long consenting delays or show stoppers | Environmental | Well structured feasibility stage with focused surveying | Maintain a few options until budget approval of necessary surveying. | Note this is feasibility stage. Needs to be re-assessed during design stage. | 1 | 4 | L |
| 9 | Inappropriate feasibility project processes due to early stage budget constraints | 3 | 5 | H | Difficulty maintaining flexibility or making the wrong choices | Political | Seek early funding to establish a well structured and skilled project team | Maintain a few options until budget approval. | | 2 | 4 | M |
| 14 | Organised local opposition to the project causes constrained consent or significant resource commitment to overcome | 4 | 4 | H | Delays, sub-optimal design or increased costs | Environmental | Continue public engagement and education | Maintain options | | 4 | 3 | M |
| 19 | Technology solutions are insufficiently proven to gain the confidence of investors | 4 | 4 | H | Increased cost of energy for unproven technology. | Financial | Engage the finance markets early and keep proven technology options open. | Develop trigger points (such as certification, pilot deployment) for new technology options and maintain proven technology options. | Unlikely to be a problem for fixed structures. A higher risk for floating. A higher risk for new turbine models. | 2 | 4 | M |
| 20 | Wind measurement campaign does not conform to requirements of banks resulting in loss of project funding | 3 | 5 | H | Limited availability or increased cost of 3rd party finance. | Financial | Identify an appropriate campaign recognsing scale and phased development options. | Proceed with a higher cost of finance or delayed project. | A low risk because a wind data strategy has been developed and there is time to gather the data. (see Xodus report : L-500042-S00-TECH-002 Feb 2016) | 1 | 4 | L |
| 21 | Small scale of project results in reduced negotiating power with WTG suppliers | 4 | 4 | H | Increased costs and weaker warranties | Financial | Consider pilot stage technology and strategic partnering. | Maintain at least 2 design options until all key uncertainties are resolved. | Residual risk depends on progress of nearby fixed and floating projects and potential of collaboration. | 3 | 4 | M |
| 22 | Exchange rate fluctuations result in unfavorable project economics - (for example we have wind revenue in UK pounds, oil/diesel in US$, French electricity in Euro). | 4 | 4 | H | Project does not meet cost of energy objectives | Financial | Obtain forecasts and consider hedging strategies | Maintain options until main supply contracts are agreed | | 3 | 4 | M |
| 26 | Errors in wind yield assessment leading to incorrect WTG design | 4 | 4 | H | Failure to achieve predicted energy output | Financial (technical) | Perform detailed long term wind analysis and sensitivity analysis. Use 3rd party verification and certification. | Engage Owner's Engineers to ensure certified designs are fit for purpose. | 3rd parties often give different results - hence medium rather than low risk. | 2 | 4 | M |

Table 3.2 Key Risk Mitigating Actions

## 3.3 Opportunities

The good opportunities (Good (“G”) as defined in the opportunities register) are presented in the following table - where necessary following post development action. Most importantly it is agreed that the project will deliver the main objectives of the project as stated in Section 3.1. However, there are several other potential spin-off opportunities and these have been discussed further primarily in the socio-economics technical note (Appendix F).

| ID | Opportunity description | Likelihood | Impact | Opportunity | Consequence | Category | Development actions | Contingency | Comments | Likelihood | Impact | Opportunity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pre- | | | | | | | | Post- | |
| 1 | Security (with diversity of supply) - lower reliance on imported energy | 3 | 4 | G | Less reliance on imports and long cables | Political | Progress the project with a focus on reliability and consider energy storage | Consider altnernative ways of achieving security of supply | Consider network integration requirements. Focus on storage. | 4 | 4 | G |
| 2 | Fixed price or certainty of energy price | 4 | 3 | G | Price will be fairly constant for the life of the project. | Political | Establish acceptable price and scale and design project accordingly. Consider a phased development. | Consider altnernative ways of achieving price certainty. | | 4 | 4 | G |
| 3 | Lower carbon emissions than oil | 5 | 3 | G | Lower carbon emissions. Especially important given COP 21 Agreement on climate change. Improves Guernsey's international reputation and relationships. | Political | Establish the importance of lower carbon emissions | Consider low carbon inter-connectors | | 5 | 4 | G |
| 4 | Reduced CAPEX of replacing diesel generating equipment | 3 | 3 | F | Reduction in net cost of project | Financial | Detailed planning of capacity management | Don't factor in the cost reduction when assessing project | Some diesel generation could be reduced. | 4 | 3 | G |
| 6 | Large scale commercial export | 1 | 5 | F | Very large scale project | Financial and political | Establish if commercially viable (via French or UK subsidy) and seek public interest. | Progress appropriate scale project | The likelihood of this could incease if France develops projects nearby. | 2 | 5 | G |
| 7 | Additional cable connection to Alderney from the project (assuming FAB link goes ahead) | 3 | 3 | F | Increased redundancy and potential import/export | Political | Promote advantages of security of supply, price stability and less diesel backup. | Continue project without the extra cable link. | Need to establish the viability of connecting into the FAB link HVDC system. It could be a showstopper. | 3 | 4 | G |
| 10 | Floating wind centre of excellence - adding a test site using project infrastructure | 2 | 4 | F | Increased local business activity an international reputation. | Financial | Consider during the design process and inform the public of the potential. | Consider in parallel to the project. | | 3 | 4 | G |
| 12 | Creation of a marine reserve/protected area in an exclusion zone | 4 | 3 | G | Excluding large fishing vessels benefits the marine environment. | Political | Promote advantages of potential improved angling (as seen on other wind projects) and overall benefits to marine environment. | Establish exclusion zone requirements during constrcution and operation for both floating and fixed foundation options at an early stage. | Most likely for floating project that will probably require an exclusion zone during operation. | 4 | 3 | G |
| 14 | Local vessel use during construction and O&M | 4 | 3 | G | Local business opportunities and skills development | Financial | Supply chain engagement and education | Prepare to use other vessels | The impact could grow if France develops other projects locally. | 4 | 3 | G |
| 16 | Harbour use during construction and O&M | 4 | 3 | G | Local business opportunities (sufficiently small scale not to impact tourism) | Financial | Supply chain engagement and education | Consider alteratives at an early stage | The impact could grow if France develops other projects locally. | 4 | 3 | G |
| 19 | Partnering with French offshore wind developers. | 3 | 4 | G | Benefit from economies of scale and use of Guernsey as a logistics hub. | Financial | Early discussions with French developers and the French Dept. of Renewable Energy (considering both fixed and floating projects and their 2030 targets). | Consider in parallel to the project. | Waters very near and to the west of Guernsey are considered favourable for floating wind by the French authorities. | 3 | 4 | G |

Table 3.3 Good Opportunity Register

Note that opportunity no. 6 would not apply for a 30MW project but should be considered when finalising the project size.

# 4 COST OF ENERGY

Electricity is an essential utility that for most people is not optional, and as such the cost of electricity is of major socio-economical importance. At these early stages of the project it was not deemed the most important driver from a site selection perspective (ref. Table 2.1), however it is understood that it is a potential show stopper and it could certainly influence the scale and timing of the project. It will most likely influence the choice of project Sponsor and as the project progresses, and the weighting of the site selection drivers evolve, it could ultimately dominate the final choice of site.

With this in mind it is essential to evaluate the key factors governing the cost:

- Wind resource;
- Turbine availability;
- Capital (and a lesser extent operational) costs; and
- Cost of finance.

Guernsey has a strong wind resource that is ideal for wind energy development. The highest scoring floating wind sites are particularly good because they received uninterrupted prevailing winds (although this would need to be re-considered if the French build large projects nearby). Comments on the wind resource and strategy to obtain further data are presented in the technical note in Appendix B.

A high turbine availability is critical to a successful project. It will totally depend on turbine failure rates and the operation and maintenance strategy. Various scenarios and sensitivity cases are presented in the technical in Appendix C, and our cost of energy analysis is based on an availability close to 90% for all shortlisted sites. It is common for developers to target an availability of 95% but this will require far more detailed analysis before it can be assumed for a relatively small project off Guernsey (the small number of turbines makes it less likely to have maintenance equipment on standby because of the cost). Clearly if this can be achieved then the cost of energy will fall.

The CAPEX and OPEX costs for the three shortlisted sites have been calculated in some detail, and based on present costs. The CAPEX is show in Table 2.4 (between £68 and £108 million) and the OPEX is relatively similar for all the sites (approximately £4 million/year +/-10%) – refer to Appendix D for the full analysis.

The resulting levelized cost of energy (LCOE) for each site is governed by the cost of finance (presented as discount rate in Figure 4.1).

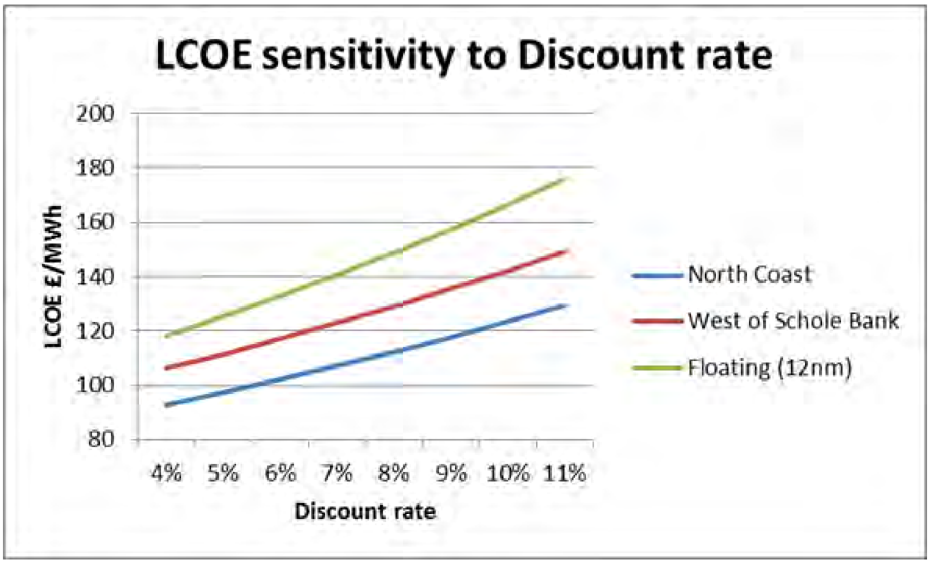


Figure 4.1 Levelized Cost of Energy Projections (from Appendix D)

Figure 4.1 and Table 4.1 clearly show the dramatic impact of the cost of finance on the overall cost of energy. The range of 4% to 10% represents the best case Government funding scenario and a more typical market rate for equity funding of a floating wind project today (immature technology in pilot phase). These and other project Sponsor scenarios are discussed further in the technical note presented in Appendix E. We recommend that the project is funded by the States of Guernsey as far as possible, to reduce the cost of financing and thus reduce the cost of electricity generated by the project.

| | North Coast £/MWh | West of Schole Bank £/MWh | Floating (12nm) £/MWh |
|---|---|---|---|
| 10% Target IRR | 124 | 142 | 167 |
| 4% Target IRR | 93 | 106 | 118 |

**Table 4.1 Approximate LCOE by site and IRR**

# 5 WIND AND WAVE DATA GATHERING STRATEGY

Although the wind data currently collected on Guernsey (namely at Chouet) is suitable for understanding the feasibility of an offshore wind project, it will be deficient for engineering purposes and refining resource estimates. In addition an offshore wind project will also require wider metocean parameters such as waves, currents and water levels. While some data is thought to exist for these parameters, further measurement will be required – especially for offshore waves.

The following table sets out a summary of our recommendations and our full report is presented in Appendix B.

| **Recommendation** | **Timeframe** | **Reasoning** | **Importance for the project** |
|---|---|---|---|
| Employ LIDAR at Chouet to obtain vertical profile data for winds<br><br>*Estimated cost: £140k* | Two years ahead of the expected financial sign off for a project | Vertical profile wind data will be required for engineering and improved resource assessment | High – Engineering data will be seriously deficient without it, increasing cost due to necessary conservatism in design |
| Identify an additional site for wind measurement, with complementary offshore wind exposure to Chouet<br><br>*Minimal cost, if utilising experts available on Guernsey* | Three years ahead of the expected financial sign off for a project – or sooner | Chouet wind data needs to be corrected for land influence for some directions. Engineering data will be less accurate without a further site. | Medium – A LIDAR at Chouet may be sufficient but data will need post-processing and will be less accurate |
| Employ LIDAR at the additional wind measurement site (as identified above)<br><br>*Estimated cost: £160k* | Two years ahead of the expected financial sign off for a project | As above | Medium – As above. Also the LIDAR at Chouet could be moved between sites but would imply a sooner start date for deploying LIDAR |
| Monitor the cost and capability of LIDAR technologies<br><br>*Minimal cost, if undertaken by existing staff or through university collaboration* | Ongoing | Scanning LIDAR may become more affordable ahead of a project going ahead. This would allow direct measurement of winds offshore from Chouet | Medium |
| Scope the deployment of a wave buoy for wider purposes for Guernsey<br><br>*Minimal cost, through using existing staff time* | Ongoing | It is understood such discussions are underway. A wave buoy to the north of Guernsey would be of considerable use to a wind project. | High – wave buoy data will be needed for engineering purposes. If the deployment could be managed from Guernsey, it could allow cost saving and local benefit |

| | | | |
|---|---|---|---|
| Have a wave buoy deployed for at least a winter season<br><br>*Estimated cost: £60k* | One year ahead of the expected financial sign off for a project | An important input to the design basis | High – as above |
| Review all available metocean data (beyond wind and waves) for the project, identifying gaps and uncertainties<br><br>*Estimate cost: £5k (possibly sponsoring a masters student)* | Two years ahead of the expected financial sign off for a project – or sooner | Data for parameters like water levels and currents will be needed. Ascertain if existing data is sufficient for the particular chosen site. | High – it may be possible to progress this with collaborative partners to reduce costs |
| Engage with potential collaborative partners on modelling activities<br><br>*Minimal cost, if using existing staff time* | Ongoing | Further modelling will very likely be needed, for example hydrodynamics, waves, high resolution atmospheric models | Low – it may be possible to utilise (at least in part) collaborative partners for any required modelling studies |
| Cross compare methods for correcting wind data, for example those used in previous reports<br><br>*Estimate cost: £10k (possibly sponsoring a research masters student)* | Ongoing | Average wind estimates and resource estimates differ considerably between the different studies. The best practice should be determined. | Medium – the best method to reduce uncertainty in resource estimates for the longer term is with further wind measurement at heights above 10m. A wide range of resource estimates have been generated, and these need refining for robust financial modelling. |

**Table 5.1 Summary of Wind and Wave Data Gathering Strategy (see Appendix B)**

# 6 DEVELOPMENT PLAN & SCHEDULE CONSIDERATIONS

This study is based on the current market status of offshore wind and therefore assumes a fairly immediate start to the project (i.e. within a year). The schedule presented in Table 2.3 is indicative of a typical project of this size driven by normal market forces. However, there are alternative development scenarios that the States of Guernsey could consider such as:

> Immediate Start (Base Case for this study)

> Delayed Start

> Extended Development Phase

Any deviation from an immediate start will require a thorough review of the findings of this study, and key issues are presented in the following sections.

## 6.1 Delayed Start

A delayed start essentially involves freezing the project now. In this case it would be very valuable at this stage to make a few important strategic decisions and develop a plan for re-starting. Ideally a decision should be made regarding the project Sponsor and also a decision on key factors that will trigger re-assessment and possible re-start of the project. The choice of project Sponsor is likely to influence the triggers and hence deciding this now will be valuable.

If an offshore wind project does not progress for several years then clearly all the findings in this study will need to be reviewed and updated as necessary. The following list provides some examples of changes to expect:

- In say 10 years we expect floating wind to be well established and so there may be less opportunity to establish a centre of excellence using offshore Guernsey as a test site. However the costs of floating wind should also have reduced dramatically in a well-established industry.
- While turbine rotors are unlikely to grow significantly we could see multiple rotors on a single structure become common. This will change the concept layout due to fewer structures and should also reduce the overall cost.
- The cost of energy of all types of offshore wind should continue to fall generally as the technology continues to mature.

## 6.2 Extended Development Phase

Table 2.3 presents a 2.5 year development programme. This programme could be extended to allow for more detailed studies based on enhanced surveys, data gathering and market assessment. Some wind and wave data would certainly benefit from a slightly longer schedule and a revised plan is presented below.

### 6.2.1 Wind and Wave Data Gathering Strategy

For wind data, the longer the time history that can collected, the better the future analysis will be (for example for estimating the expected wind resource and calculating extreme winds for design). Note, it will take many decades for wind data to start to become invalid, namely at a point when it is suspected that the wind climate has systematically changed – maybe exhibiting increased storminess with climate change. It is a similar situation with waves, as waves are driven by the winds over a wider area. So it is not a concern if the project becomes frozen for a period after gathering new data.

Considering the recommendations in the strategy for wind and wave data collection, the following points should be considered for a delayed project start or extended development phase:

> The measurement of wind data at Chouet at 10m height should continue uninterrupted. Although this data is not representative of hub height and exhibits land influences from certain wind directions, it will be a valuable resource for a future wind project – even given some adjustments to the data will be necessary.

- The main uncertainty regarding wind data is the lack of data near hub height. It is recommended that a LIDAR be deployed at Chouet to collect wind data at hub height at an early stage (see suggestions and likely costs in Section 5 and Table 5.1 above). This data will be valuable in narrowing the range of estimates of wind resource and hence will refine estimates of revenue from a future wind project. A future wind project will significantly benefit from many years of wind data at hub height.
- After several years of wind data collection by LIDAR at Chouet, the possibility of an additional LIDAR deployment should be reconsidered (see suggestions and likely costs in Section 5 and Table 5.1 above). The decision will depend on the status of the project, the preferred site option at the time and the performance of the instrument at Chouet. This additional deployment will mostly help in reducing uncertainty in land influences in the wind data.
- Having a long history of wave data will be valuable for a future wind project, but not critical. For example a short wave buoy deployment can be used to calibrate bespoke local wave models. If a wave buoy can be deployed off Guernsey for multiple uses, this should be encouraged for its benefit to a future wind energy project. However a dedicated wave buoy deployment for a wind project could wait until a few years before the wind project is expected to go ahead.
- A delayed project start provides an opportunity to undertake further analysis and modelling to support a future wind project, without undue time pressure. Cost effective routes to undertaking this analysis should be considered as soon as possible, for example University collaborations, building in house expertise or negotiating long term engagement of experts at preferential rates. If handled appropriately, the costs of modelling and analysis for a future wind project could be cut considerably, for example by removing the need to engage consultants at short notice.

# 7 CONCLUSIONS

This preliminary feasibility study has demonstrated two key points:

1. There are a range of technically feasible options to develop an offshore wind project off Guernsey.
2. Developing a modest project, of the order 30MW, will achieve the fundamental objectives associated with energy diversification namely: security; price certainty; sustainability and lower carbon.

However, this comes at a price higher than current French importing and on-island generation. To mitigate the higher cost we recommend that the majority of the project is funded by the States of Guernsey to secure the lowest cost of finance.

At this early stage of analysis the preferred site is far offshore towards the 12nm boundary. This location is in relatively deep water and most suited to the new floating wind turbine structures. However this is currently the most costly option, although the costs are expected to fall dramatically as the floating wind industry matures.

At the present time the lowest cost site is likely to be in the shallow waters off the North Coast (or any coastal site). However, this near shore location has a very high visual and other human impact and so may not be accepted by the public.

Offshore wind projects are strongly influenced by the environmental conditions offshore (wind, sea and seabed) and local stakeholder engagement. Therefore, it is essential to build a strong and experienced project team and understand the detail from the earliest opportunity, especially given the rapid pace of change in the industry. This study includes a risk and opportunity register that highlights potential project showstoppers and mitigating actions that will reduce risks. It also identifies opportunities that can be exploited if action is taken now.

If the project is significantly delayed for any reason then it is important to check that the findings of this study remain valid because it is a rapidly changing industry. Also consider pursuing an extended wave and wind data gathering programme that could be relatively low cost but high value for the future. Wind and wave data gathering (in addition to that already underway (e.g. Chouet)) will need to start very soon if the project is not delayed.

# APPENDIX A SITE SELECTION

The following tables present the details of the site selection analysis using Xodus in-house software.

| Key Driver | Scope | Notes |
|---|---|---|
| Fishing Interaction | Exclusion zones<br>Commercial and leasure<br>Floating and fixed foundation issues<br>Shellfish and aquaculture | Any factors that could directly and indirectly impact fisheries and fishing activity. The life cycle of the project should be considered but recognising that construction and decommissioning are relatively short term activities. |
| Offshore Environment | Environmental Impact Risk.<br>Marine ecology<br>Mitigation Requirements - cost / schedule implications | Consider the impact of the offshore elements that may be acceptable from a legislative perspective but are unacceptable / unwelcome to the local population. |
| Visual and other human impact | Location and distance from coast<br>Sound<br>Boating and navigation<br>Radar | The impact of the offshore elements that are acceptable from a legislative perspective but are unacceptable / unwelcome to the local population. Also factors that will require active intervention/mitigation (such as radar) to avoid unacceptable impact. |
| Logistics | Construction port requirements<br>O&M port requirements | Strongly driven by foundation type and O&M strategy. Floating and fixed structures to be considered. |
| Offshore Site Feasibility | Seabed gradient, bathymetry, geology, sediment type and depth.<br>Presence of other offshore infrastructure.<br>Construction and operation inc metocean constraints and technology risks<br>Seabed territory | The Offshore Feasibility driver covers the suitability of the seabed to installation with consideration given to bathymetry, geology, sediment, roughness, etc.<br><br>The area that Offshore Feasibility is being applied to is 'local' to the onshore site being assessed. This definition of 'local' is fluid and shall be elaborated upon in the 'Record of Discussion'.<br><br>Further consideration will be given to any existing offshore infrastructure that is in the vicinity of this 'local' area.<br><br>Consideration should also be given to the location of the 'local' offshore site, w.r.t. the local port in terms of both construction and support activities. |
| Export Cable Feasibility | Cable installation method<br>Sediment depth and type along route<br>Landfall options<br>Route to grid connection.<br>Length of cable<br>Cable fishing and anchor interaction<br>Voltage (consider under cost) | The project export cable to Guernsey driver deals specifically with issues relating to the interconnection between the offshore elements and the connection back to the onshore facility. Since the exact project location and landfall locations are not yet fixed, only general issues need be considered. |
| Costs and Availability | CAPEX<br>OPEX and Availability<br>LCOE | Key CAPEX differentiators include foundation risks, water depth, cables lengths and export voltage, turbine size, procurement strategy for "small" project.<br><br>Key OPEX differentiators include major intervention methods (floating vs fixed), O&M strategy (inc. responsiveness of OEM) and subsequent turbine availability. |
| Socio-Economics | Risk and opportunities<br>Business model (inc phased development)<br>Political impact and opportunity | The socio-economics driver covers a broard spectrum of possible direct and indirect impacts. It is important to consider the whole life cycle of the project for example a short term construction nuisance is likely to be less important to a long term change in energy costs. See also Development Scope Flexibility. |
| Development Scope Flexibility | Gravity base fabrication and installation (requires min order size)<br>Offshore site size potential<br>Link to other Islands<br>Combine with other technology | Due to oil price and energy price volatility it is difficult to predict the optimum scale of the project. With such energy market instability it is valuable to consider projects that present flexibility and the possibility of a phased development. Consider both the offshore site and also the constuction logistics (e.g. it is not realistic to purchase a single gravity foundation because yard set up costs would make it prohibitively expensive). |
| Energy Resource | Island wake effects<br>Turbine height<br>Layout | Small changes in energy resource can have a large cumulative impact on project economics. A few % change in energy yield can significantly impacty the overall cost of energy. |

Table 7.1 Site Selection Differentiators ("Drivers")

| Key Drivers | Fishing Interaction | Offshore Environment | Visual and other human impact | Logistics | Offshore Site Feasibility | Export Cable Feasibility | Costs and Availability | Socio-Economics | Development Scope Flexibility | Energy Resource | Weighting |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fishing Interaction | N | W | MW | W | MW | W | W | N | W | W | 2.57% |
| Offshore Environment | S | N | MW | VMS | W | MS | S | MW | W | MW | 6.20% |
| Visual and other human impact | MS | MS | N | VMS | N | MS | MS | N | MS | MS | 26.00% |
| Logistics | S | VMW | VMW | N | VMW | MW | MW | VMW | VMW | VMW | 1.49% |
| Offshore Site Feasibility | MS | S | N | VMS | N | MS | N | MW | S | S | 14.76% |
| Export Cable Feasibility | S | MW | MW | MS | MW | N | N | VMW | S | MW | 4.16% |
| Costs and Availability | S | W | MW | MS | N | N | N | MW | N | N | 5.95% |
| Socio-Economics | N | MS | N | VMS | MS | VMS | MS | N | N | MS | 22.63% |
| Development Scope Flexibility | S | S | MW | VMS | W | W | N | N | N | S | 8.28% |
| Energy Resource | S | MS | MW | VMS | W | MS | N | MW | W | N | 7.95% |

**Legend**

Very Much Stronger **(VMS)**
Much Stronger **(MS)**
Stronger **(S)**
Neutral **(N)**
Weaker **(W)**
Much Weaker **(MW)**
Very Much Weaker **(VMW)**

Table 7.2 Pairwise Comparison of Drivers to Calculate Weighting

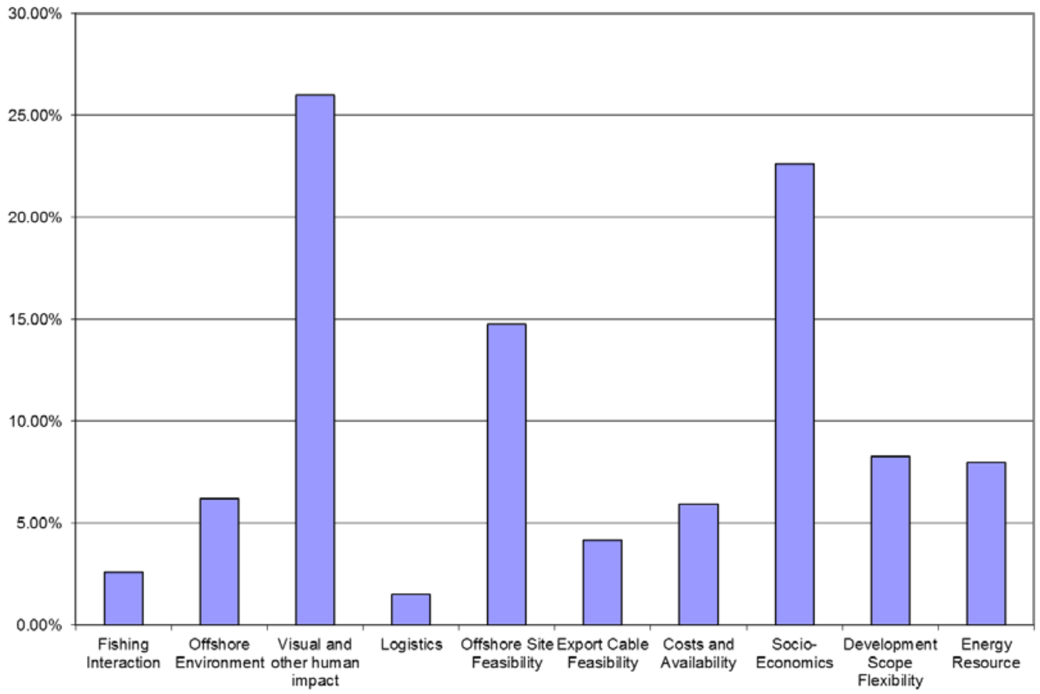


Table 7.3 Weighting of Project Drivers (same as Table 2.1)

| Key Driver | Classification of Contribution | | |
|---|---|---|---|
| | -3 | 0 | +3 |
| **Fishing Interaction** | Exclusion zones and navigation risks | No impact. | Major enhancement of fisheries |
| **Offshore Environment** | Severe environmental impact, potentially a show stopper w ith consent conditions unacceptable to the project or uneconomical, and may include suspensive conditions that investors may consider potentially unachievable. Severe impact on schedule and overall concerns leading to active opposition | Moderate or minor environmental impact, generic conditions expected w hich could result in a minor cost to the project, around 1 - 2 months delay in project consenting, and limited specific stakeholder concern. | Represents an opportunity for environmental enhancement, no risks for permitting or schedule implicaitons and w ill result in an overal benefit to stakeholder issues and interests. |
| **Visual and other human impact** | Minority general acceptance w ith many specific objections. | Stong general acceptance but w ith some focused objections. | Very strong acceptance from all stakeholders. No specific objections. |
| **Logistics** | Challenging and long distance to ports. Significant investment required to enable project. | No significant project investment required. Reasonable distances to ports. | Short distance to ports. Maximises opportunities for Guernsey ports. |
| **Offshore Site Feasibility** | Technically very challenging, but not necessarily a complete show-stopper. Significant technology risks or uncertainties. | Typical state of the art development issues. | Technically very low risk with proven solutions.. |
| **Export Cable Feasibility** | Technically very challenging, but not necessarily a complete show-stopper. Significant cable protection costs. | Typical state of the art development issues. | Technically very low risk with low cost cable burial options and low cable damage risks. |
| **Costs and Availability** | High cost and significant risk of cost overruns. Potential for much low er revenues. | Comparable to state of the art 2016 LCOE projections (using UK Rd as guide at £120/MWh) | Potential for low er costs and low er risk of overruns w ith strong venue. |
| **Socio-Economics** | Robust business plan unlikely w ith potential for severe impacts to the local economic and social environment primarily through increased cost of energy and little or no direct project benefit. | Risks balance the opportunities. A robust long term flexible business model acceptable to policy makers. | Significant direct and indirect opportunities to Guernsey. Strong business case for both the short and longer term. |
| **Development Scope Flexibility** | Highly constrained site w ith little scope for phased or additional development. | Flexibility to develop a small project circa. 30 MW but limited larger development scope. | Very strong scope for phased development, including increasing project size, inter-island collaboration and adding other technologies. |
| **Energy Resource** | Potential for significant island w ake effects, and/or significant height and layout constraints. | Close to maximum unobstructed offshore w ind advantage, w ith few layout or height constraints. | Utlise maximum unobstructed offshore w ind advantage, w ith no layout or height constraints. |

**Table 7.4 Scoring Logic for Drivers**

| Option | TOTALS | Fishing Interaction | Offshore Environment | Visual and other human impact | Logistics | Offshore Site Feasibility | Export Cable Feasibility | Costs and Availability | Socio-Economics | Development Scope Flexibility | Energy Resource |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2.57% | 6.20% | 26.00% | 1.49% | 14.76% | 4.16% | 5.95% | 22.63% | 8.28% | 7.95% |
| Site 1 West Coast | **-203.13** | -1 | -2 | -3 | -3 | -3 | -2 | -1 | -1 | -2 | -1 |
| | | Close to shore disruption to coastal fisheries. No exclusion zones in the longer term. | Shallow water site close to coast will be highly inhabited. Gravity bases or drilling will be highly disruptive. See also Doc593 "Wind Site Selection Analysis", by GRT. | Visual impact alone scores -3. | Construction logistics are likely to be very poor. Transporting gavity bases in a high tidal current is challenging and drilling hard rock has very limited supply chain with high costs. | Main concern is hard rock. Gravity base solutions could be an option but at very high cost for only a few units. Also considerable depth (20m) for gravity base units. | Wave activity is likely to create a very mobile seabed where it is not exposed to bedrock. High cable protection costs in some areas. | Potential high costs of foundations due to rock, with high risk of overrun and limited supply chain. Potential reduced revenue due to height constraints. | Little opportunity but with significant potential for cost escalation or overrun. | Gravity bases or drilling most likely to be required as a single operation. Visual impacts would limit growth beyond 30 MW. | Resource limited by height constraints. Some scope to optimise layout and little island wake effects. |
| Site 2 North Coast | **-160.21** | -1 | -2 | -2 | -3 | -2 | -1 | 0 | -1 | -2 | -2 |
| | | as above | as above | ref. Exeter University PhD Bouke Wiersma 2015, "Public acceptability of offshore renewable energy in Guernsey". The North is regarded by some as being the most "industrial" and the best coast for modern technology. | as above | Slightly shallower water than Site 1 which will be better for gravity base foundations. | Less wave activity than Site 1 and closer to substation. | Slightly better than Site 1 because of smaller gravity base option in shallower water. | as above | as above | Contrained field layout introducing in-field wake effects. |
| Site 3 North East Herm | **-166.41** | -1 | -3 | -2 | -3 | -2 | -1 | 0 | -1 | -2 | -2 |
| | | as above | as above. Also Herm has been identified as a breeding ground for birds. This could be a show stopper. | Slightly further offshore Guernsey than sites 1 and 2 but clearly close to Herm. Like sites 1 and 2, radar is a concern. | As above. Also very shallow water in places could limit size of construction vessels operating in the area - especially with the strong tides. | as above | as above | as above | as above | Very limited shallow water. | Worst island wake effects but optimsal field layout. |
| Site 4 West of Schole Bank | **-57.32** | 0 | -1 | 0 | -1 | -1 | 0 | -2 | -1 | -1 | 1 |
| | | only minor impact during construction phase. | Main concern is likely to be short term piling or drilling noise. | Main concern is radar but possibly less than sites 1, 2 and 3 because further offshore - although mitigation still required. | Main concern is the tidal stream strength reducing the operating wind of vessels. | Unknown exact water depths and thickness of sediment cover over bedrock. Assume jacket type foundation is required that may need small diameter drilling in some cases. | It should be possible to avoid shallow rocky sections. | Fairly deep water for a fixed foundation solution. | as above | More flexibility to phase jacket supply. May be area constraints due to water depth. | Layout or height may be constrained by radar. |
| Site 5 South Schole Bank | **-2666.77** | -999 | -1 | 0 | -1 | -2 | -1 | -1 | -1 | -2 | -1 |
| | | Important fishing grounds (after joint meeting with Alderney it was decided this was a show stopper) | as above | as above | as above | Seabed mobility is a concern. Charts refer to changing bathymetry and sediment types. | as above, but concern about sediment mobility on bank. | as above | as above | Very constained with water depth. | Layout constrained by water depth. Major infield wake effects. |
| Site 6 Alderney Schole Bank | **-2660.75** | -999 | -1 | -1 | 0 | -1 | -1 | 0 | -2 | 0 | 1 |
| | | Important fishing grounds (after joint meeting with Alderney it was decided this was a show stopper) | as above | as above | Advantage is sheltering from waves however strong currents could be a concern. | Sediment type and mobility could be problematic. | as above | No major concerns other than unknown ground conditions. | as above | Some constraint due to water depth. | Layout or height may be constrained by radar. |
| Site 7 Near shore floating (7nm) | **27.93** | -3 | 1 | 1 | -1 | -2 | 0 | -1 | 0 | 2 | 3 |
| | | Compared to fixed structures the mooring present a major navigation risk. This will almost certainly require an exclusion zone. | Floating has very little negative impact on the marine environment. | This area should be fairly well accepted. | The main concern is the availability of a local port to facilitate major maintenance. | Depends on the timing of the project. Offshore floating wind is currently in pilot project phase but the technology is generally proven and it is likely to progressing rapidly to commercial projects. | as above | Depends on the timing of the project. Offshore floating wind is currently in pilot project phase but projects are projected to be cost competitive in 50m water. Score -1 to reflect present uncertianty and more costly than a monopile in 20m of sand. | It is likely that floating projects will facilitate a phase development approach. | It is likely that floating projects will facilitate a phase development approach easier than fixed foundations. Heavy lift vessels are not required and gravity based foundations will require a minimum order size to be competative. | This is a perfect location that will benefit from clean air (no island wake) from the prevailing direction, and no constraints on practical hub heights and field layout. |
| Site 8 Offshore floating (12nm) | **58.83** | -2 | 1 | 2 | -1 | -2 | 0 | -2 | 0 | 3 | 3 |
| | | as above | as above | As above but further offshore. | as above | as above | as above | as above but with additional export cable length. This could increase the voltage of a 30MW project to 66kV and clearly extra cable too. | as above | as above | as above |

**Table 7.5 Site Selection Scores**

# APPENDIX B STRATEGY FOR WIND AND WAVE DATA

Refer to Xodus Group Report “Offshore Wind - Strategy for Wind and Wave Data Collection and Analysis (L-500042-S00-TECH-002-R03)”

# Offshore Wind - Preliminary Feasibility

## Strategy for Wind Data Collection and Analysis

**States Of Guernsey**

**Assignment Number:** L500042-S00
**Document Number:** L-500042-S00-TECH-002

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# Strategy for Wind Data Collection and Analysis

**L500042-S00**

**Client:** States Of Guernsey
**Document Type:** Technical Note
**Document Number:** L-500042-S00-TECH-002

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| R03 | 13/3/16 | With Minor Amendments | SP | JI | JI | |
| R02 | 26/2/16 | Client comments addressed | SP | JI | JI | |
| R01 | 27/1/16 | Issued for Review | SP | JI | JI | - |
| **Rev** | **Date** | **Description** | **Issued By** | **Checked By** | **Approved By** | **Client Approval** |

# CONTENTS

# 1 INTRODUCTION

This technical note forms part of a wider study being performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility study of the proposed 30MW offshore wind project.

# 2 AIMS

This technical report presents a 'Strategy for Wind Data Collection and Analysis' (SWDCA) based on the expected needs of an offshore wind project in Guernsey. As described in the initial project proposal, Xodus have considered a number of key principles;

- ***Making the most of available data, and supplementing it with a cost effective measurement campaign(s).*** Existing wind datasets have kindly been provided by Martin Crozier (Senior Met Officer at Guernsey Airport) to give context to understanding the need to gather further wind data. Additional existing datasets have been considered, and are discussed in the following sections of this technical note. The need for wind data for a range of purposes throughout a Guernsey offshore wind project have been considered, including how further measurement campaigns will fit with a schedule for scoping and developing a wind energy project for Guernsey. Past analysis of the Guernsey wind data has been considered, and limitations of the past analysis have been highlighted where possible.

- ***Alongside deriving a strategy for wind data collection, consider the requirement for wider metocean parameters.*** In addition to wind, other metocean data will be essential for a Guernsey offshore wind project, for example currents and waves. This requirement has also been considered as part of the wind data collection strategy, as there may be synergies with collecting wind data.

- ***Consider a range of options for gathering wind data.*** While many large offshore wind projects have installed offshore meteorological masts to collect wind data over prolonged time periods, this is not the only option. New measurement technologies such as LIDAR can (and are) being employed, while the whole premise of needing dedicated site wind measurements is being challenged on some projects.

- ***Consider the unique nature of the Project.*** An offshore wind project in Guernsey will be considerably different in nature to the large purely commercial offshore wind developments happening elsewhere. The States of Guernsey Government has sought collaboration with the University sector and has been exploiting existing measurements and commissioning new onshore wind measurements in support of developing an offshore wind project. However other project constraints will be as real as for entirely commercial developments, such as the engagement with turbine manufacturers and the need for certification of the design basis.

As well as considering the above key principles, it has been assumed that the site of an offshore wind project would be in an exposed location – so unlikely to be significantly influenced by sheltering effects from land or having a wind boundary layer profile associated with the roughness of the wind blowing over land. While this was not assumed initially when proposing this strategy development, the down selection of sites using the VDRM tool (see main report - CTR 110) has favoured floating wind to the north of Guernsey and fixed installation to the north east of Guernsey (towards or on the Banc de la Schole). Both options are some way from land (10's of kilometres), and are exposed to the prevailing wind directions blowing over the sea.

# 3 WIND DATA FOR RESOURCE ASSESSMENT

So far, the emphasis has been on obtaining suitable wind data to assess the expected wind resource for power generation. This is understandable, as assessing the expected electricity generation is key in justifying the economics of developing an offshore wind project. To undertake a resource assessment, wind data representative of the hub height of wind turbines is needed, which is representative of the offshore location at which the turbines will be installed. This requirement leads to a number of gaps in the wind information available for Project Wind Isle;

1. ***The location of the turbines is yet to be finalised and will not be until further into the development of a project.*** However (as stated in the aims section), the site down selection is favouring sites that will be exposed to winds off the sea from the prevailing wind directions. It can hence be assumed that land influences on the winds will be minimal, but may need to be quantified at a later stage of project development. This is discussed in the conclusions section. For resource assessment at this stage of assessing project feasibility, it is most appropriate to derive winds typical of locations offshore from Guernsey that experience minimal influence of land.

2. ***Wind data is only available for 10m above ground (following meteorological convention) with no data above this height.*** Turbine hub heights will be typically approaching 100m, and will experience considerably strong winds than at 10m height. The reduction in wind speed near the surface is a function of surface roughness, so wind velocity profiles are quite different for different terrain types and between sea and land. The variation of wind speed with height can be approximated, using power law and logarithmic profiles. Previous reports have used such methods, for example [2] use a logarithmic profile – but they employ a simplifying assumption of neutral atmospheric stability which will introduce errors and uncertainties.

3. ***The 10m height wind data includes land influences.*** The dataset at Chouet is most appropriate to capture winds coming off the open sea (being right at the coast) – however this is only true for certain wind directions. Wind data from Alderney Airport appears to be sufficiently far from the coastal cliffs to be influenced by the surface roughness of the surrounding land – even though the airport is located at the south west tip of the island facing the prevailing winds.

To address point 2 above, there is a need to make wind measurements at heights above 10m, and ideally as close to the expected turbine hub height as possible. As mentioned in the aims section, large offshore wind projects often install offshore meteorological masts to conduct such measurements. However such installations are expensive (of the order £10M), take time to plan and install, and can be logistically challenging. A previous report [1] has suggested a cost of many millions of pounds. As the Guernsey project is small, this cost may represent a significant percent of the overall CAPEX – and hence should be avoided if possible. A previous project report has suggested alternative options to a met mast – of which LIDAR is the one most commonly being adopted by the wind energy industry. Until wind measurements are made above 10m height, wind speeds at hub height can be inferred using standard formulae, as described in previous reports, e.g.[2,3]. An alternative approach using weather forecast model output is described in Appendix B.

Utilising standard vertical profiles for wind speed will always be an approximation, as any formula will not capture all the dynamic processes that are at work. Profiles should be dependent on the atmospheric stability, but past work has employed the simplifying assumption of neutral atmospheric stability. The analysis in Appendix B attempts to capture more of the variation in vertical wind profiles, by inferring them from an atmospheric forecast model. This analysis suggests that previous analysis has slightly overestimated the wind climate. It is recommended that further analysis is undertaken to understand the sensitivity of the wind resource to assumptions about vertical profiles, and implement a suitably rigorous approach for further resource assessment.

To address point 3 above, there is firstly a need to correct the existing 10m data to be representative of conditions offshore and uninfluenced by land. Previous project work has undertaken such analysis, and an alternative simple approach is presented in Appendix A, utilising wind measurements from satellite scatterometer instruments. As well as correcting existing data for land influences, there is a requirement to ensure any new measurements are representative of offshore conditions, while balancing cost – as offshore measurement is generally much more costly and logistically challenging than onshore measurement. Chouet is a promising site for deploying LIDAR, as it has been shown from the 10m wind measurements to be uninfluenced by land for a number of wind directions. However it would be advantageous to deploy a second LIDAR which would complement a Chouet LIDAR instrument, to provide wind data uninfluenced by land for a complementary set wind of directions. Alderney Airport could be a possible site, but the instrument would need to be deployed much closer to the sea than the present 10m wind measurement instrument. There may exist alternative sites on the south coast of Guernsey. Any such site should have a suitable exposure to (ideally) winds over the sea from the east, south-east, south and south-west. As the south coast of Guernsey has cliffs, there may be compromise on getting data close to sea level, and a possible requirement to correct for local terrain effects.

In summary, to better estimate the expected energy resource yielded from an offshore wind development off Guernsey, additional wind measurement is required. It is recommended that;

- An offshore met mast be discounted on the grounds of cost. In fact offshore wind measurement is not considered vital for the purposes of resource assessment, as the Chouet coastal site has been shown to be a good proxy for offshore measurement (for certain wind directions).

- An additional site be identified to supplement the Chouet site, with complementary exposure to offshore winds. A site on the Guernsey south coast may be suitable, as may Alderney Airport (but with instrumentation sited closer to the immediate coast, than the exiting 10m wind instrumentation).

- A LIDAR system be used to obtain wind measurements up to the expected turbine hub height. LIDAR is being adopted by the wind industry as a cost effective and logistically simpler alternative to met masts. A LIDAR system could be deployed for many years, with a minimal physical footprint and relative ease of maintenance. Two LIDARs are suggested for deployment at complementary sites, as discussed above. Purchase of a second hand LIDAR from the manufacturer could be considered, if some warranty and quality assurance of the data is offered.

- If two LIDAR sites are employed, ideally this would be using two LIDAR instruments making observations concurrently. To save cost, it would be feasible to utilise one LIDAR instrument and move it between sites – potentially being one year at one site, followed by the next year at the other. This solution would require a longer deployment time overall, and would be a compromise as data post processing will be required to give a continuous estimate of offshore winds at hub height.

Leosphere have been approached to ascertain costs of LIDAR systems. They are a leading supplier of LIDAR systems and offer some innovative technology, for example scanning LIDAR that can measure winds away from the coast from a coastal deployment site. The most relevant instrumentation they offer cost the following for purchase;

- WINDCUBE v2 vertical profiler is 135,000€. This should be a suitable instrument for the deployments suggested above.
- WINDCUBE 100S scanning LIDAR which can measure out to 3.5km from the coast is 250,000€.
- WINDCUBE 200S scanning LIDAR which can measure out to 6km from the coast is 395,000€.
- WINDCUBE 400S scanning LIDAR which can measure out to 10km from the coast is 550,000€.

The WINDCUBE 100S scanning LIDAR is an alternative solution to the WINDCUBE v2 vertical profiler, as only one instrument may need to be deployed (at Chouet) to capture offshore wind conditions. However the expected performance of the scanning LIDAR would need further investigation, as such technology is only just being employed by offshore wind. Leosphere indicated there can be issues of reduced data returns from the scanning LIDAR, which is understandable as it is making measurements some way from the sensor and seeing through a substantial amount of the atmosphere. A scanning LIDAR has the potential benefit of obtaining data from multiple sites of interest, given a suitable location for deployment. Purchase costs have been considered, as long multi-year deployments will be required and it is expected that the expertise in the Guernsey Met Office could be utilised to manage a LIDAR deployment. Rental is possible, but may be more costly for a long deployment. For a 1 year rental, costs are expected to be around £60,000. For an offshore deployment, these costs for 1 year will exceed £300,000.

It is not expected for there to be any significant difference in wind resource between the down selected sites, which are at least 10km from shore. The wind strategy is seeking to determine the wind climate beyond any coastal influences, but a more cost effective strategy is being suggested of land based measurements.

The requirement for further wind measurement is not immediate, and the timing is discussed in the final section of this report. In the interim ahead of making profile wind measurements, the 10m wind data collected at Chouet is sufficient for estimating resource, given it should be corrected to represent offshore conditions and extrapolated suitably to the expected turbine hub height. The uncertainties in these corrections could be quantified, to yield uncertainties in the estimated resource. A preliminary uncertainty analysis is presented in Appendix C.

As the requirement for LIDAR wind measurement is not immediate, the exact technical solution can be left open. LIDAR instruments have been reducing in cost, and the price differential between the vertical profiling and the scanning LIDAR may well reduce with time. This could potentially make a scanning LIDAR (measuring offshore wind directly from shore) the most appropriate and cost effective wind measurement solution.

# 4 WIDER REQUIREMENT FOR WIND DATA

While wind data is clearly needed to estimate the expected wind resource, wind data will also be vital at various stages through the development of an offshore wind energy project. These uses for wind data are listed in the following table;

| Wind data requirement | Stage of the project when it is required | Suggested source of appropriate data |
|---|---|---|
| Extreme wind statistics for design purposes | Preliminary and detailed design | Multiple years (at least 2 years) of wind measurement at hub height, synthesised with lower level data and/or weather hindcast model data to generate multi-decade time histories |
| Correlation statistics between wind and waves | Preliminary and detailed design | Ideally coincident measurement of wind and wave parameters offshore. Wave measurements may be correlated with winds from a more distant site. |
| Wind shear and wind turbulence parameters | Preliminary and detailed design | At least 1 year of wind measurement at several heights, i.e. from a met mast or LIDAR |
| Time history of wind data for planning construction and O&M activities | From feasibility studies, through to detailed design. The data will likely be needed for input to stochastic simulations of construction and O&M activities. | Ideally multiple years of wind measurement, but could be a synthesis of measurement and weather model data. 10m and hub height winds will likely be required. Data quality will need to improve as a project progresses. |

The above list is not exhaustive, but illustrates that the wind measurements made for a project must be appropriate for a number of uses. These requirements for wind data can be satisfied with multiple years (at least 2 years) of wind measurements made at multiple heights with a LIDAR, as suggested in the previous section. While these measurements are not required immediately, they will need to have taken place by the time financial approval has been given for a project development.

The basis of design document, which will contain details of site wind statistics for design purposes, will need to be certified before use for detailed design. This requirement for certification should be considered closely before embarking on a wind measurement campaign. While the use of coastal LIDAR has been suggested as a cost effective method for collecting the wind data needed for an offshore wind project, further investigation would be required to ensure the resulting wind data can be justified as fit for design purposes.

# 5 REQUIREMENT FOR OTHER METOCEAN DATA

As well as wind data, other metocean data will be required to support the development of an offshore wind project. The key metocean parameters will be waves and currents, which are important for most projects and especially so for Guernsey given the strong tidal currents and the exposure to sizeable waves from the west. These uses for wider metocean data are listed in the following table;

| **Wave and/or current data requirement** | **Stage of the project when it is required** | **Suggested source of appropriate data** |
|---|---|---|
| Extreme and fatigue wave statistics for design purposes | Preliminary and detailed design | Months of data during winter (at least 3 months), synthesised with hindcast model data to generate multi-decade time histories |
| Extreme current statistics for design purposes | Preliminary and detailed design | At least a month of data, synthesised with hindcast model data to generate multi-decade time histories |
| Correlation statistics between wind and waves | Preliminary and detailed design | Ideally coincident measurement of wind and wave parameters offshore. Wave measurements may be correlated with winds from a more distant site. |
| Water levels, both tidal and non-tidal (surge) | Preliminary and detailed design. Planning e.g. cable installation at the landfall. | Tide gauge data, supplemented by models and site measurement |
| Time history of waves and currents for planning construction and O&M activities | From feasibility studies, through to detailed design. The data will likely be needed for input to stochastic simulations of construction and O&M activities. | Data from models, validated against observations (as required for design purposes) |

The above should be considered as important for the site of the wind turbines and the cable route, for example scour by waves and currents will be important for planning cable protection.
The Renewable Energy Team (States of Guernesy) has kindly pointed out a number of possible wave data sources for Guernsey, including;

- Channel Light Vessel
- Jersey buoy south of Jersey
- French wave buoys deployed in surrounding waters, for example as stored in the CANDHIS archive
- Wave modelling (with the SWAN model) through Plymouth University assessing wave energy potential
- Wave modelling (with the MIKE21 model) by Royal Haskoning to support flood risk assessment

The buoy data listed above could all be useful for the validation of wave modelling to support a wind development, however it will not be sufficiently close to be useable directly (e.g. for design purposes). A wave buoy deployed for at least one winter season would be needed, at a site with representative wave conditions of the wind development (i.e. in the vicinity of the proposed development). Such a deployment will be potentially costly, but costs could be reduced by;

- Tying deploying a ‘Guernsey wave buoy’ to potential wind development locations. It is understood that such a wave buoy deployment is being investigated by the States of Guernsey.
- Utilising Guernsey based capability and vessels to operate a wave buoy deployment. Costs for a wave buoy deployment can be expected to be around £10,000 per month. Once a deployment reaches 6 months, it is expected to be cheaper to have purchased a wave buoy.

Further wave modelling will also be required – for example to simulate the impact of a wind development on waves for consenting purposes and to generate time histories of waves for design purposes. Given the commercial nature of Royal Haskoning's work and uncertainty if the Plymouth University wave modellers are still at the university, thought should be given to establishing collaborative wave modelling – priming for future needs. One of the senior researchers is still at Plymouth, but it is not clear if he would still have the various configuration files and outputs from the wave model.

Universities are often keen to collaborate with end users of their research, but it is the onus of the end user to try to set up a collaboration that can have longevity and direct access to project outcomes – such as model configurations and raw output data. The project has so far worked well with various Universities to undertake useful analysis for the project. As the project progresses, there will be a need to engage with more specialist researchers, and to do so in a way that allows the project access to research outcomes that will be useful through project development (and not require repeating at a later stage).

Measurement and modelling of currents and water levels may also be needed to support a wind development project. It is beyond the scope of this study to review all available data sources, but once plans for a wind development are sufficiently advanced, such a review should be undertaken.

# 6 CONCLUSIONS, RECOMMENDATIONS AND TIMEFRAMES

The overall conclusion from this report is that although the wind data currently collected on Guernsey (namely at Chouet) is suitable for understanding the feasibility of an offshore wind project, it will be deficient for engineering purposes and refining resource estimates. In addition an offshore wind project will also require wider metocean parameters such as waves, currents and water levels. While some data is thought to exist for these parameters, further measurement will be required – especially for offshore waves.

The following table sets out the more detailed recommendations coming from this 'Strategy for Wind Data Collection and Analysis (SWDCA)' report;

| **Recommendation** | **Timeframe** | **Reasoning** | **Importance for the project** |
|---|---|---|---|
| Employ LIDAR at Chouet to obtain vertical profile data for winds<br><br>*Estimated cost: £140k* | Two years ahead of the expected financial sign off for a project | Vertical profile wind data will be required for engineering and improved resource assessment | High – Engineering data will be seriously deficient without it, increasing cost due to necessary conservatism in design |
| Identify an additional site for wind measurement, with complementary offshore wind exposure to Chouet<br><br>*Minimal cost, if utilising experts available on Guernsey* | Three years ahead of the expected financial sign off for a project – or sooner | Chouet wind data needs to be corrected for land influence for some directions. Engineering data will be less accurate without a further site. | Medium – A LIDAR at Chouet may be sufficient but data will need post-processing and will be less accurate |
| Employ LIDAR at the additional wind measurement site (as identified above)<br><br>*Estimated cost: £160k* | Two years ahead of the expected financial sign off for a project | As above | Medium – As above. Also the LIDAR at Chouet could be moved between sites but would imply a sooner start date for deploying LIDAR |
| Monitor the cost and capability of LIDAR technologies<br><br>*Minimal cost, if undertaken by existing staff or through university collaboration* | Ongoing | Scanning LIDAR may become more affordable ahead of a project going ahead. This would allow direct measurement of winds offshore from Chouet | Medium |
| Scope the deployment of a wave buoy for wider purposes for Guernsey<br><br>*Minimal cost, through using existing staff time* | Ongoing | It is understood such discussions are underway. A wave buoy to the north of Guernsey would be of considerable use to a wind project. | High – wave buoy data will be needed for engineering purposes. If the deployment could be managed from Guernsey, it could allow cost saving and local benefit |
| Have a wave buoy deployed for at least a winter season<br><br>*Estimated cost: £60k* | One year ahead of the expected financial sign off for a project | An important input to the design basis | High – as above |

| | | | |
|---|---|---|---|
| Review all available metocean data (beyond wind and waves) for the project, identifying gaps and uncertainties<br><br>*Estimate cost: £5k (possibly sponsoring a masters student)* | Two years ahead of the expected financial sign off for a project – or sooner | Data for parameters like water levels and currents will be needed. Ascertain if existing data is sufficient for the particular chosen site. | High – it may be possible to progress this with collaborative partners to reduce costs |
| Engage with potential collaborative partners on modelling activities<br><br>*Minimal cost, if using existing staff time* | Ongoing | Further modelling will very likely be needed, for example hydrodynamics, waves, high resolution atmospheric models | Low – it may be possible to utilise (at least in part) collaborative partners for any required modelling studies |
| Cross compare methods for correcting wind data, for example those used in previous reports<br><br>*Estimate cost: £10k (possibly sponsoring a research masters student)* | Ongoing | Average wind estimates and resource estimates differ considerably between the different studies. The best practice should be determined. | Medium – the best method to reduce uncertainty in resource estimates for the longer term is with further wind measurement at heights above 10m. A wide range of resource estimates have been generated, and these need refining for robust financial modelling. |

The final point in the above table is suggesting further analysis of the existing wind data, to establish the most appropriate wind resource estimate to employ – which is important for robust financial modelling. Such a study would;

- Utilise all available data for Chouet (and other sites as appropriate).
- Compare techniques for removing land based effects from the Chouet data (and suggest other methods as appropriate), and suggest a best practice.
- Compare techniques for extrapolating from 10m height winds, to hub height winds. This should in particular consider how atmospheric stability impacts the vertical profile, and suggest a best practice.
- Utilise atmospheric model data to extrapolate wind data back to before Chouet data is available, ideally for at least a decade.
- Generate a best estimate of wind resource, with an estimate of associated errors and inter-annual variability.

Finally, it should be noted that French developers are progressing offshore wind projects in the region. Early engagement with these developers is recommended in general to explore potential collaboration opportunities. There may be scope for wind data exchange and this should be explored, however this will not change the data gathering and analysis requirements listed above.

# 7 REFERENCES

[1] Guernsey Offshore Wind: A Data Acquisition Strategy (2015) Mr Marc Staddon, MEng Renewable Energy Thesis, University of Exeter

[2] Feasibility of offshore wind in Guernsey Waters (2012) Oliver Lee, MSc Renewable Energy Technology Thesis, Cranfield University

[3] Guernsey Energy Analysis and Strategy Recommendations to 2050 (2013) Report by Renewable Energy Third Year Students, University of Exeter

[4] Guernsey Renewable Energy Feasibility Report (2012) Report by Renewable Energy Third Year Students, University of Exeter

# APPENDIX A CORRECTING LAND INFLUENCES ON 10M WIND OBSERVATIONS USING SCATTEROMETER DATA

In this appendix, a method is used to give a preliminary correction to the Chouet wind data (at 10m height) to account for the fact that the Chouet data will not always capture the winds being experienced offshore. The basis for the correction is utilising satellite scatterometer data. Satellite scatterometers provide wind speed and direction data based on the scattered return from a satellite based radar. For this analysis, the ASCAT scatterometer is used which flies on two satellites – Metop-A and Metop-B. An example of a set of wind vectors from a scatterometer swath are shown in Figure 1. The satellite scatterometer data is averaged over an area west of Guernsey (shown in Figure 1), to capture wind speeds far from the coast.

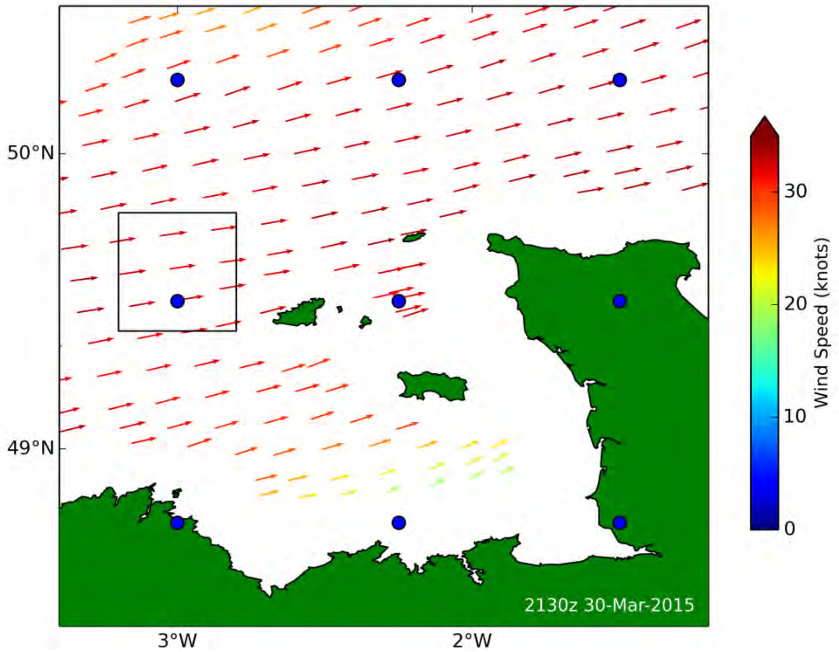


**Figure 1 - An example of wind vectors derived from the ASCAT satellite scatterometer. Also shown are the locations of modelled hindcast wind data from ECMWF (blue circles) and the area used for averaging the scatterometer data for analysis (black box)**

Figure 2 compares a number of wind datasets for 1 month. The scatterometer data is always at the higher end of the range of data, as it will be capturing offshore winds. The hindcast model (ECMWF – European Centre for Medium-range Weather Forecasting) compares well to the scatterometer, which may be expected as the scatterometer data will have been assimilated into the ECMWF model to constrain it. At times the scatterometer and Chouet data compare well, while at other times the Chouet data shows weaker winds than the scatterometer.

While scatterometer data is available several times a day, this is not enough to provide a comprehensive wind dataset – for example for estimating wind resource. However it can be used to suggest corrections to the coastal Chouet data. Figure 3 shows the correlation between the scatterometer and the Chouet data. For a number of directions the correlation is close to one to one, as these are the directions for which Chouet is exposed to winds from offshore. Figure 3 can be used to crudely correct the Chouet data, but multiplying the Chouet data by the given gradient correction factor for winds in that particular directional sector.

The result of applying these correction factors to the Chouet data for wind resource estimates is presented in Appendix C.

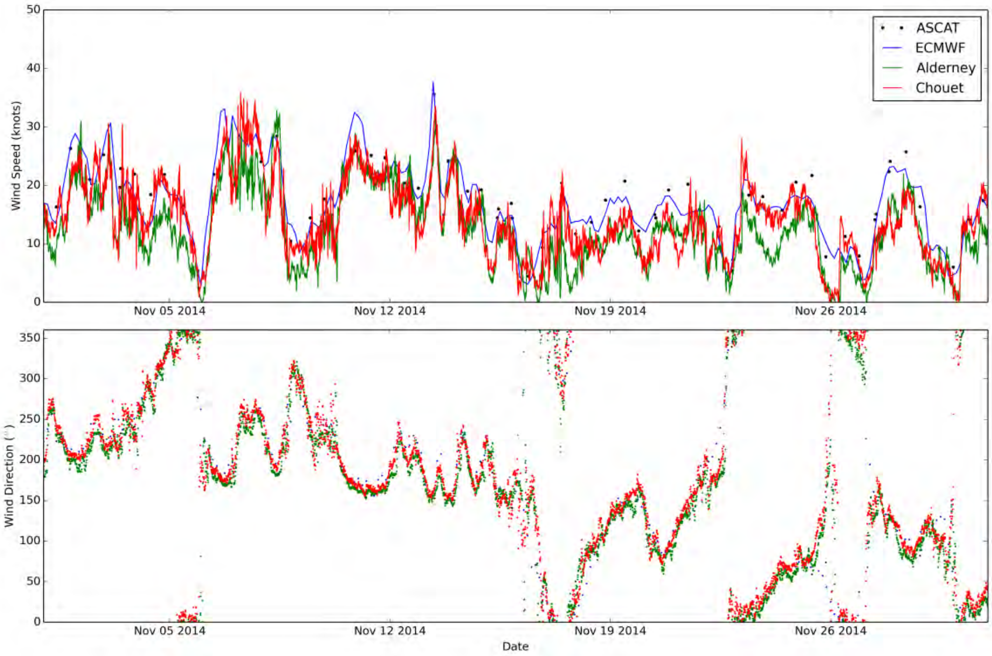


**Figure 2 - Wind speed (top) and direction (bottom) for one month, from a range of data sources (see legend).**

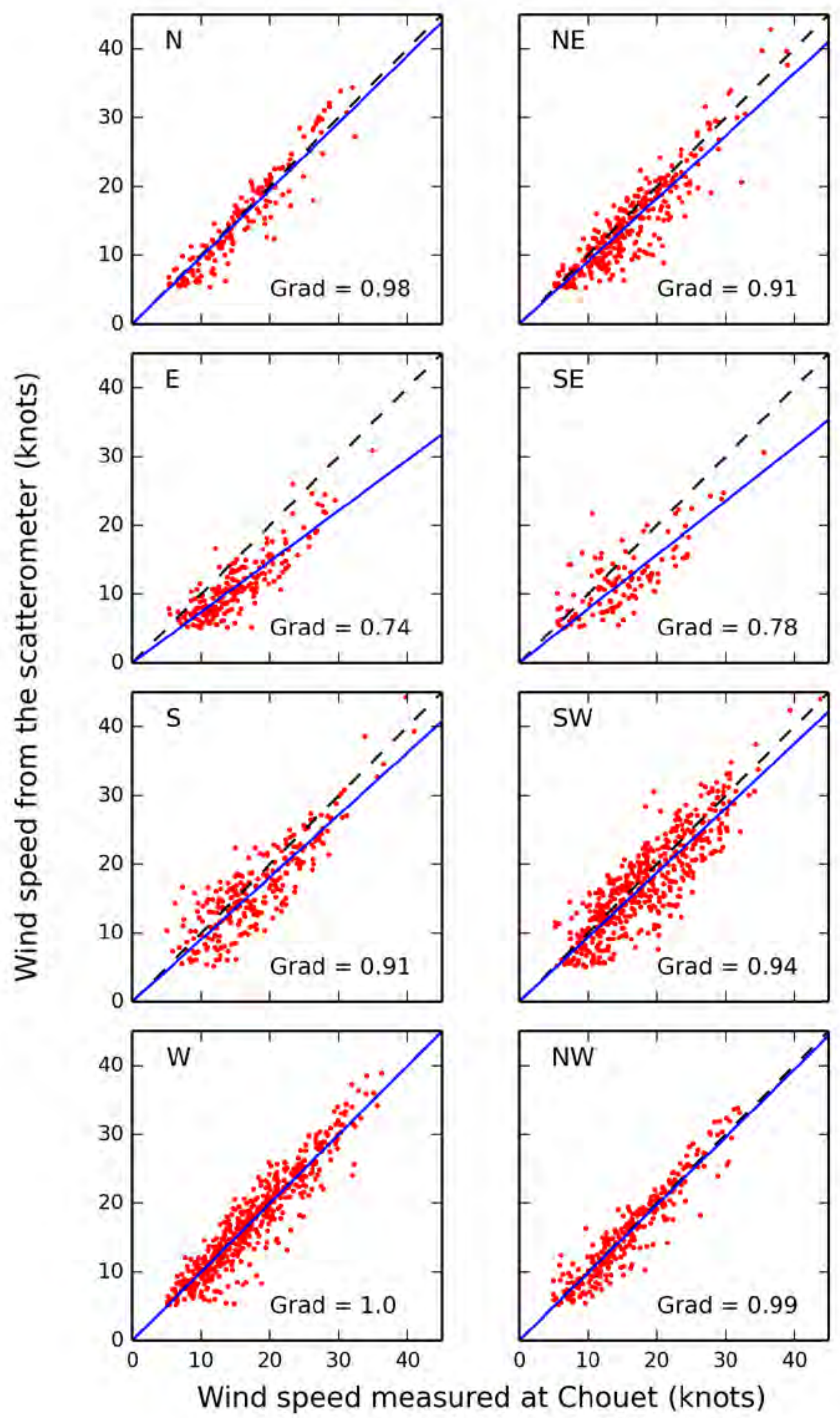


**Figure 3 - Scatter plots of winds from Chouet compared to winds from the ASCAT scatterometer, for 8 directional sectors. The 1-1 line is shown as black dashes, and the best fit line (passing through the origin) is shown as a blue line (with the gradient shown).**

# APPENDIX B ESTABLISHING A WIND TIME HISTORY AT APPROXIMATE HUB HEIGHT

Once a time history of 10m wind speed has been derived, as suggested in Appendix A, it must be extrapolated to a wind speed at turbine hub height to be useful for resource analysis. Standard logarithmic or power law formulae can be used for this purpose, but the vertical gradient of wind will vary depending on atmospheric conditions (stable, unstable and neutral). To estimate the impact of the uncertainty in the vertical profile of wind, two methods have been used to estimate winds at 100m height based on the winds at 10m height. The first is a constant factor based on a surface roughness associated with water, and a vertical profile associated with neutral conditions. The second method utilises an atmospheric forecasting model (the US GFS model). This model provides data for 10m and 100m winds at 3 hourly intervals (examples are shown in Figure 4), and the ratio of 100m to 10m winds will depend on the complexities of the model simulation of the atmospheric boundary layer. An example of this ratio is also shown in Figure 4, and these ratios can be used to extrapolate the Chouet data to 100m height (by time interpolating from the 3 hourly GFS model data). For the period shown the simpler logarithmic profile it is an overestimate – however at other times it may be an underestimate and overall the impact of using the more complex modelled wind profile is to reduce the estimated wind resource.

Appendix C examines the impact on resource assessment of the choice of method for deriving hub height winds. As discussed in the main text, ultimately wind measurements will be made at hub height to reduce uncertainty.

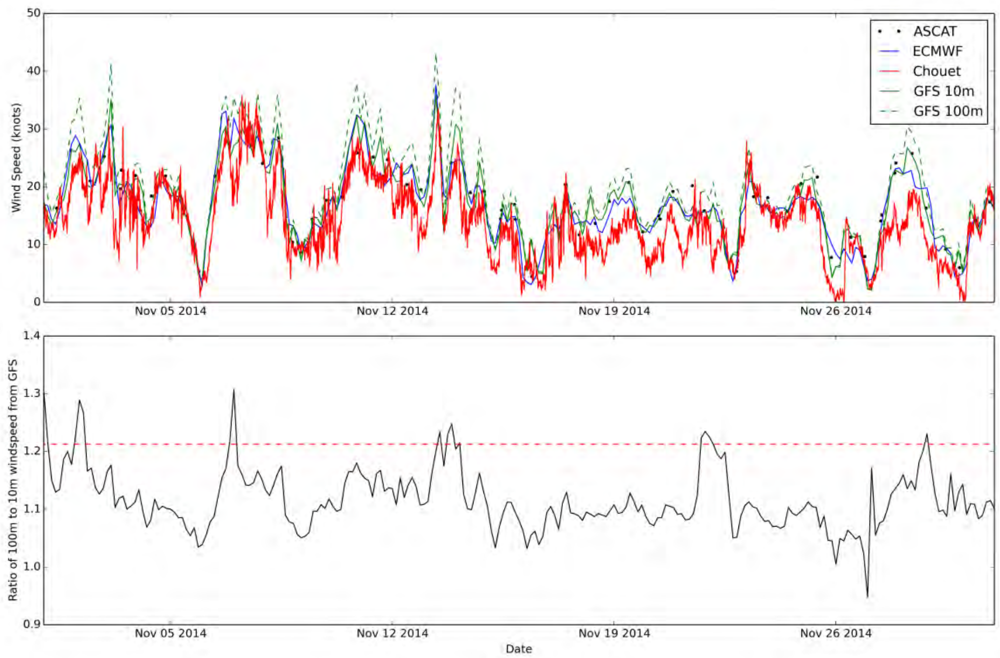


**Figure 4 - Wind speed from a range of sources (top), including the US GFS forecasting model at 10m and 100m height (see legend). The bottom plot shows the ratio of 100m wind speed to the 10m wind speed from the US GFS forecasting model – with a constant ratio shown (red dashed line) for comparison (associated with neutral atmospheric conditions over water).**

# APPENDIX C ESTIMATING THE WIND RESOURCE IN GUERNSEY WATERS IN SUPPORT OF THE ECONOMIC ANALYSIS

To estimate the wind resource for an offshore location in Guernsey waters, several time histories of winds have been generated based on the 10m wind measurements made at Chouet. These are;

- The Chouet winds at 10m, extrapolated to 100m using a constant vertical scaling
- The Chouet winds at 10m corrected for land influences (see Appendix A), and extrapolated to 100m using a constant vertical scaling
- The Chouet winds at 10m corrected for land influences, and extrapolated to 100m using the time varying ratio derived from the US GFS forecasting model (see Appendix B)

For the final method, the US GFS 100m height wind data is only available for mid-2012 onwards, hence this method has not been used for Chouet wind data from before this time.
A wind turbine power curve representative of a 6MW REpower has been used to derive resource estimates. These estimates have not included wake loses as it is too early to determine a definite layout for the turbines, although for the small Guernsey development wake loses can be minimised. The following table shows the estimated average wind speed at 100m height and the turbine capacity factor (the % of the rated power generation than can be achieved).

| Comment | Average 100m wind speed (m/s) | | | Turbine capacity factor (%) | | |
|---|---|---|---|---|---|---|
| | **2012** | **2013** | **2014** | **2012** | **2013** | **2014** |
| Unadjusted for land effects, constant vertical scaling | *8.87* | *8.59* | *8.53* | *41.7%* | *39.2%* | *38.2%* |
| Linear adjustment for land effects, constant vertical scaling | *9.50* | *9.30* | *9.17* | *46.3%* | *44.4%* | *43.0%* |
| Linear adjustment for land effects, weather model vertical scaling | | *8.98* | *8.81* | | *41.7%* | *40.2%* |

There is considerable variation between years of wind data, but much greater differences depending on the method for obtaining the 100m wind data time history. Correcting for land influences significantly increases the estimate of resource to well above 40% capacity factor. However using the more sophisticated method for estimating vertical wind gradients (from the GFS atmospheric model) reduces the resource estimate, compared to assuming a constant profile. Ahead of obtaining vertical profile wind data with minimal land influence (as suggested in the main text), it is prudent to use the estimates in the final row of the above table – as the method is more justifiable in terms of correcting for various unknowns and it provides a mid-range estimate for wind resource.

Further resource statistics have been generated using the methods described here, and are used in the 'Project Economics Assessment' work stream.

The average wind speed estimates generated here are slightly lower than previous estimates in the various study reports (although similar to [4]), however different years of data have been used in the previous studies, as well as different correction and analysis methods. It is difficult as this stage to determine the most appropriate method, and a consistent cross comparison of methods would be useful to narrow the uncertainty in resource estimates.

# APPENDIX C O&M AND TURBINE AVAILABILITY ASSESSMENT

Refer to Xodus Group Report “Offshore Wind - O&M and Turbine Availability Assessment (L-500042-S00-TECH-003-R03)”

# Offshore Wind - Preliminary Feasibility

## O&M and Turbine Availability Assessment

**States Of Guernsey**

**Assignment Number:** L500042-S00
**Document Number:** L-500042-S00-TECH-003


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# O&M and Turbine Availability Assessment

**L500042-S00**

**Client:** States Of Guernsey
**Document Type:** Technical Note
**Document Number:** L-500042-S00-TECH-003

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| R02 | 15/3/16 | Incorporating client comments | JI | SS | JI | - |
| R01 | 25/2/16 | Issued for Review | SS | JJ | JI | - |
| **Rev** | **Date** | **Description** | **Issued By** | **Checked By** | **Approved By** | **Client Approval** |

# CONTENTS

# 1 AIMS

The risk assessment and financial modelling has highlighted that turbine availability is a critical unknown factor, and influences the risk profile of the project and the projected cost of energy. This report examines the metocean conditions and performs preliminary O&M constraints modelling (using Xodus in-house software).

The aim is to differentiate the shortlisted sites from a turbine accessibility and resultant availability perspective. This is particularly important for a small project – where waiting on large vessels and weather could be a major concern, and there may be reduced availability guarantees on offer from turbine OEMs. This in turn could significantly influence financing options and limit turbine options.

# 2 INTRODUCTION

This technical note forms part of a wider study being performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility study of the proposed 30MW offshore wind project. It should be read in conjunction with the other reports.

Once turbines are installed, they will require maintenance – both with planned interventions (routine inspection and servicing – preventative maintenance) and dealing with unplanned failures (corrective maintenance). Planned maintenance can be scheduled for the summer months, when metocean conditions for accessing the turbines will be more favourable. Typically 2 visits per turbine are required that cover the inspection and serving or maintenance of known wear components and oil changes – heavy lifting equipment/vessels are not typically required and the details are turbine/OEM specific. Inspections will also cover the primary and secondary structures (the details of which are defined by the design safety factors and the extent of motion and stress monitoring equipment used to assess fatigue damage). Also turbine downtime associated with scheduled maintenance can be minimised to the duration of the actual work, and the resulting reduction in turbine availability can be accounted for in financial models with a reasonable level of accuracy.

Unplanned failures are far harder to allow for, for a number of reasons;

- Once a failure occurs, energy production is being lost until the turbine is repaired
- Failures can occur any time of the year, and hence metocean conditions may be less favourable
- Failure rates are not well known (because it is commercially sensitive and guarded information)
- Turbines may or may not be under warranty with performance guarantees
- The right O&M resources are needed to deal with problems, e.g. numbers and types of vessels, availability of crew, spare parts etc

Given that a Guernsey offshore wind project would be small (with a current working assumption of 30MW but this could increase), probably with around 5 turbines at most, there are added issues;

- Having access to the right O&M resources (vessels and technicians) at the desired time (resources that a larger project could financially justify having exclusive access to)
- Being susceptible to the randomness of the failure process, e.g. a project may be lucky with few failures or unlucky with many (on a large project the randomness will average out)
- One failure represents a much greater proportion of lost generating capacity compared to a large project

Guernsey also has a relatively severe wave climate (for example in comparison to the east coast of England), with waves propagating from the open Atlantic to the west. This will limit the ability to respond rapidly to failures, and may lead to lengthy periods of turbine downtime – especially in the winter months. It is important to take this factor into consideration when selecting the turbine, type of foundation (floating or fixed) and intervention vessels. It is not possible to eliminate this risk (as with any offshore location) but it can certainly be planned for and our modelling presented in this technical note takes this into account. It should also be noted that the planned floating wind project off Portugal (Windfloat Atlantic) is located in a more hostile environment (similar extreme waves but more frequent high waves – based on our preliminary analysis of location specific wave data from the ECMWF wave model).

# 3 SCENARIOS

To quantify the turbine availability that may be expected for a Guernsey offshore wind project, several scenarios have been considered – based on the down-selected sites, their associated engineering concept, the distance to O&M ports and the exposure to limiting metocean conditions. Offshore intervention is assessed based on planned (scheduled service and preventative maintenance – approx. 2 visits/year/turbine) and unplanned reactive maintenance due to turbine failures. Cable failures are also an important consideration but they are excluded from this analysis. It is very important to mitigate the risk of cable failure as much as possible, primarily by adopting a risk based cable burial and protection approach. Cable failures should be very infrequent and it would not be statistically meaningful to model the failure rate for a single project. To manage this risk appropriate insurance and contingency plans should be in place to ensure a very fast response to a failure.

For our modelling purposes turbine failures are split into two categories, namely minor failures that require intervention with a workboat (potentially based out of Guernsey ports), and major failures that require handling of major parts, the use of much larger vessels or jack-ups, and operation out of a more distant port (or towing to a distant port in the case of floating wind).

Note that the failure rates we assume in our analysis our based on our experience working in the sector for several years (since 2001), working with developers, turbine suppliers and research institutes, Turbines almost certainly exhibited failure rate profiles similar to a bath tub curve – high failure rates during the “burn in” period followed by several years of stability before entering the “burn out” phase at the end of the economic life. For this reason is it essential to have a strong warranty with the OEM at the start of the project life for at least 5 years. There is not yet strong consensus that higher failure rates occur in winter (as might be expected). It is very difficult to predict future turbine failure rates that may be applicable to the Project. The industry is starting to collect failure rate data in an anonymous fashion which should provide “offshore” wind specific data (much existing data is from onshore turbines which are nothing like the modern offshore machines). The industry states that reliability is improving and it probably is, although turbine OEMs will be promoting this position. But technology is also constantly changing and new turbines have little chance to develop into highly reliable machines before the next model is produced.

Firstly minor repairs are considered.

## 3.1 Minor repairs

For a wind turbine, a number of unplanned minor failures must be expected. These may include SCADA (supervisory control and data acquisition) failures, and electrical faults on various systems. Such repairs can be handled with a relatively small work boat and a small (but experienced) crew of technicians. Using Xodus Group’s in-house knowledge, it has been assumed that 8 minor repairs can be expected per turbine per year. This failure rate is very uncertain, and 8 per year can be considered an upper estimate. As estimates of turbine availability will be very sensitive to this choice of failure rate, a more optimistic rate of 4 failures per turbine per year has also been considered.

Metocean conditions will impact the ability to access turbines to carry out repairs, with the most significant being: the impact of rough seas on the technicians making the transit to site; waves (and winds) limiting the safe transfer of technicians from the vessel to a turbine landing stage, and; winds limiting the ability to work on the turbine. Currents can also be a limiting factor for using a workboat to achieve safe transfer of technicians to a turbine, but it is assumed here that the predictable tides can be planned around – although they may delay repair operations by a few hours. To simulate the likely impact of metocean conditions on the ability to undertake minor repairs on a Guernsey offshore wind farm, a number of assumptions have been made. These assumptions regarding repair tasks, their duration and metocean limits, are set out in the Table 1.

| Task | Duration (mins) | Wave limit (Hs in m) | Wind limit (in m/s) |
|---|---|---|---|
| *Transit to turbines* | 60 | 2.5 | No practical limit |
| *Transfer crew to turbine* | 30 | 2 (2.5 for North Coast) | 14.4 |

| | | | |
|---|---|---|---|
| *Carry out work (vessel on stand by)* | 300 | 2.5 | 14.4 |
| *Retrieve crew from turbine* | 30 | 2 (2.5 for North Coast) | 14.4 |
| *Transit back* | 60 | 2.5 | No practical limit |

**Table 1 - Tasks assumed when simulating minor repairs to turbines**

The task information in Table 1 assumes that turbines may be up to 35 kilometres from a Guernsey port – hence 60 minutes should be enough time to transit to a turbine. The transit time to a coastal site like North Coast may be shorter, but the results will be insensitive to such a difference. Transfer of crew onto a turbine will be the most metocean sensitive operation with the strictest wave limit. At North Coast, the wave climate around the turbines is expected to be more benign as a result of sheltering and shallower water – compared to the more open waters at the other sites. It has not been possible to assess how the coastal location may reduce wave heights, hence (as a proxy for lower waves at North Coast) the “transfer” wave limit is set at a higher level such that the transfer from vessel to turbine is equally impacted by waves as the transit from shore. The average duration of the repair task is set at 5 hours, and this will ultimately depend on the nature of the failure and the experience of the technicians. Slightly longer repairs would be feasible without seriously impacting the statistics for availability presented below. It is assumed that the workboat and technicians are available during daylight hours – hence no multiple and night time shifts.

Note that the wind sector has developed a range of special purpose vessels and access systems in an attempt to optimise vessel access. This is very important for large projects that are a long way offshore, however not necessarily the case for Guernsey’s relatively small scale project that is relatively close to shore even at 12nm. Using existing local vessels (with the necessary modifications if necessary) or new multi-purpose vessels that could have a wider application should be considered in consultation with the selected turbine OEM. It the vessel is not contracted by the OEM then the availability and performance of the vessel may limit the strength of the turbine availability warranty.

The tasks set out in Table 1 are evaluated against a long time history (1979 - present) of wind and waves, from an ECMWF hindcast weather model. It is hence possible to assess how many repairs could be carried out by a single workboat and crew, how long a turbine typically takes to repair, and how these statistics compare between good and bad years of weather. Figure 1 shows the number of repairs that could be carried out by a single workboat.

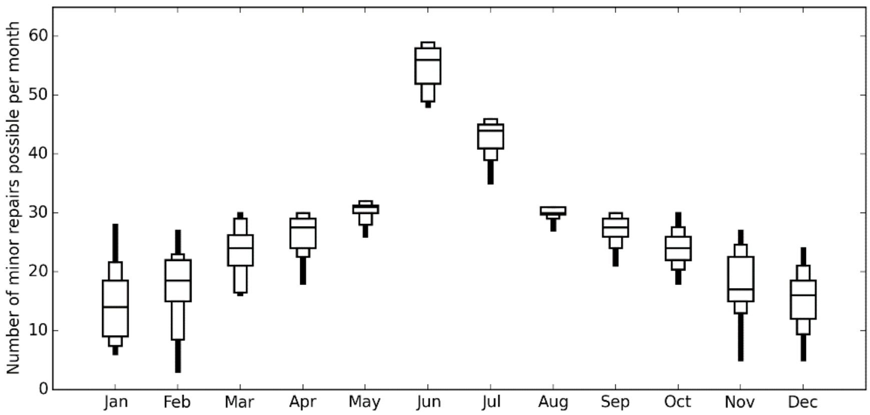


**Figure 1 - A 'box and whiskers' plot showing the number of minor repairs that could be carried out by a single workboat operating out of Guernsey. The boxes and whiskers indicate the range of values over the 35 years of simulation. The widest box shows the P25 to P75 percentiles (with a horizontal bar for the median), the narrower box shows out to the P10 and P90, and the narrow ‘whisker’ shows the most extreme values.**

Figure 1 highlights that typically more than 10 minor repairs can be carried out in a month, even in the winter. In the summer it is possible to double up repairs with long daylight hours – although this may not be needed. Given we may expect 40 failures over an entire year, the use of a single workboat is sufficient, with significant excess capacity to carry out planned maintenance. The most extreme winter conditions may limit repairs to less than 5/month, and could cause some significant downtime – however this is expected to occur in less than 1 year in 10. Figure 1 also suggests that backlogs of minor repairs will be unlikely, as a minor repair can be dealt with long before another is expected – even in winter.

For North Coast with a less limiting wave climate, the number of minor repairs that can be achieved is slightly improved over the more exposed sites (see Figure 2).

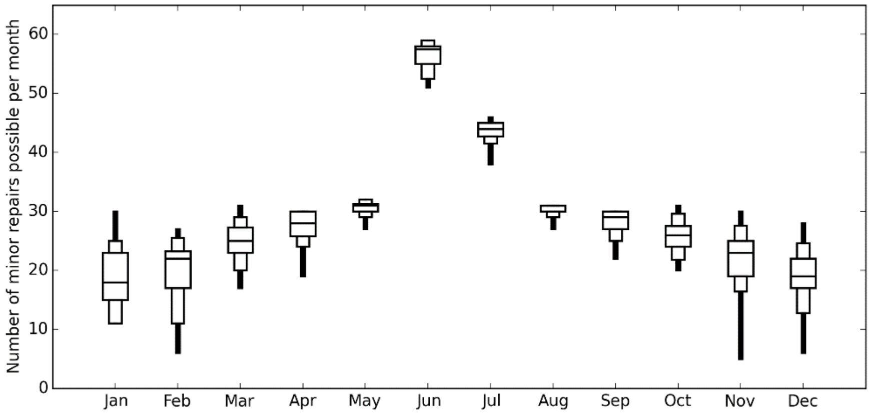


**Figure 2 - As Figure 1, but for North Coast with improved wave conditions for transfer of personnel to turbines.**

For the financial modelling, the most useful outcome of the O&M simulations is an estimate of the expected turbine downtime to give the turbine availability. Table 2 gives the average time by month for a minor repair on a turbine to be addressed, i.e. from the moment of the failure to the turbine being operable again. This includes waiting for the next daylight shift to begin for the workboat, the crew and workboat waiting for suitable metocean conditions, and the time to get to the turbine and carry out the repair.

| Time to repair (days) | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** | **Oct** | **Nov** | **Dec** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **More exposed sites** | 3.24 | 2.47 | 1.44 | 0.97 | 0.70 | 0.61 | 0.61 | 0.66 | 0.89 | 1.49 | 2.15 | 3.47 |
| **North Coast** | 2.29 | 1.70 | 1.05 | 0.77 | 0.63 | 0.58 | 0.58 | 0.63 | 0.76 | 1.09 | 1.43 | 2.24 |

**Table 2 – The expected time for minor repairs to be completed on a turbine (in days)**

These statistics can be converted to a turbine availability by estimating the overall downtime by month, i.e.

expected downtime = expected number of failures x time to repair

Once an expected downtime by month has been calculated, the annual turbine availability can be calculated taking an average of the monthly figures, but weighted by the capacity factor – to allow for wintertime failures leading to enhanced generation losses. These annual average turbine availability figures (for minor repairs) are given in Table 3.

Table 3 also shows the sensitivity of the estimate for turbine availability, for both a reduction in the failure rate for minor failures, and for adding additional delays to repairs (outside of metocean influences). The simulation of dealing with minor repairs is optimistic, as it assumes a crew immediately ready to deal with a repair. It may take time to mobilise a crew, especially if expertise is needed that is not available on Guernsey – or shifts may mean a crew is not available every day. To examine the sensitivity, an additional day of delay is assumed in calculating the availability.

| | More exposed sites | North Coast |
|---|---|---|
| *Standard simulation with 8 failures per turbine per year* | 96.1% | 97.2% |
| *Simulation with 8 failures per turbine per year, and 1 day additional delay for repairs* | 93.9% | 95.0% |
| *Simulation with 4 failures per turbine per year, and 1 day additional delay for repairs* | 97.0% | 97.5% |

**Table 3 - Estimates of turbine availability, from the simulation of the handling of minor repairs to turbines.**

Table 3 shows that the North Coast site will likely provide very slightly enhanced turbine availability, and this can be considered in the financial modelling of the revenue from the different site options. Clearly this is not a strong differentiator between sites.

## 3.2 Major repairs

In addition to minor repairs, wind turbines will occasionally require more major interventions – for example to replace the gearbox, generator, blades, yaw and pitch control motors etc. For a fixed foundation turbine, this will require use of a much more capable vessel than a work boat, for example a construction support vessel, multi-purpose jack-up or heavy lift vessel. For floating wind, the current thinking is that a turbine will be towed to a suitable port where cranes can be used to assist a major repair. Some less serious of the major repairs may be handled in situ, using the nacelle crane and a construction support vessel.

The less serious of the major repairs can be treated as a special case of the minor repairs, and may include replacement of the pitch/yaw mechanisms, replacing brakes or rectifier/inverter failures. The main differences will be;

- Waiting for a chartered construction support vessel, and its mobilisation (assumed to be 14 days)
- Waiting for the arrival of spare parts
- A longer time for transfer of personnel and equipment to/from the turbine (assumed 60 minutes)
- A longer time for the repair to be carried out (assumed to be 16 hours)
- No daylight limitation to working – the vessel would operate as soon as mobilised
- Lower rate of failure for this type of failure (assumed as 1 per turbine per year)

The expected time waiting on weather for these less serious of the major repairs is shown in Table 4, but not including the time waiting for mobilisation of the vessel (and the arrival of spare parts).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **More exposed sites** | 3.36 | 2.50 | 1.67 | 1.22 | 0.99 | 0.92 | 0.89 | 0.91 | 1.11 | 1.56 | 2.28 | 3.38 |
| **North Coast** | 2.51 | 1.88 | 1.33 | 1.03 | 0.92 | 0.88 | 0.86 | 0.87 | 0.96 | 1.26 | 1.48 | 2.47 |

**Table 4 - The expected time for the less serious of the major repairs to be completed on a turbine (in days) – not including mobilisation time for the construction support vessel.**

Table 4 shows that the time to undertake the repair, including any weather downtime, is much shorter than the expected time needed to charter and mobilise a suitable vessel. This is also reflected in the resulting turbine availability (see Table 5) where any difference between sites is minimal. The major sensitivity is the lead time for obtaining a suitable vessel and the reliability of the turbines. Doubling the lead time for obtaining a suitable vessel reduces availability from 96% to 92%. A halving of the failure rate – assuming an inherently more reliable turbine – increase availability from 96% to 98%.

| | More exposed sites | North Coast |
|---|---|---|
| *Standard simulation with 1 failure per turbine per year and 14 days for vessel mobilisation* | 95.6% | 95.8% |
| *Simulation with 1 failure per turbine per year and 28 days for vessel mobilisation* | 91.8% | 91.9% |
| *Simulation with 1 failure per turbine per 2 years and 14 days for vessel mobilisation* | 97.8% | 97.9% |

**Table 5 - Estimates of turbine availability, from the simulation of the handling of the less serious major repairs to turbines.**

For the most serious of the major repairs – such as blade, gearbox, generator or rotor bearing replacement – the approach between fixed foundation turbines and floating turbines will be very different. For fixed foundation turbines, there will be a requirement for a jack-up vessel (see Table 6). While large projects may have a contract to retain the services of a jack up, the sporadic requirement on a Guernsey project will make this infeasible. Instead the services of a jack-up will need to be contracted on a case by case basis – which will severe limit the responsiveness, and potentially be costly. For the purposes of simulating the use of a jack-up for major repairs, a 28 day lead time is assumed but a more pessimistic scenario of 56 days lead time is also considered. This lead time will also include collecting large spare parts and the transit to site. Clearly the latter case should be avoided if possible, perhaps by collaborating with other projects in the vicinity.

For simulating the most serious of major repairs for floating turbines, it is assumed the turbines will be towed to a suitable port (see Table 7 for an indicative process). Two ports have been identified, namely Le Havre and Plymouth (clearly nearer ports like Cherbourg would be preferable but more distance ports have been selected as conservative options at this stage until more detailed port assessments are completed). The transit to Plymouth is approximately 150 kilometres, while the transit to Le Havre is approximately 240 kilometres. A transit to Plymouth will likely experience slightly worse wave conditions, and this has been factored into the simulations. In simulating the most serious major repairs for floating wind, there are two lead times that will be significant – the wait for a suitable towing vessel and the wait for a suitable crane in port. Neither of these lead times is expected to be as onerous as the wait for a jack-up for fixed foundation turbines. It is assumed that the towing speed is 7 knots for specially designed vessels. However, this is not a critical parameter and we have performed a sensitivity analysis at 3.5 knots (and doubling the duration of the disconnect and reconnect of moorings in Table 7). The results only changed by 0.2% - insignificant at this stage of analysis.

The failure rates for the most serious major repairs is not well constrained. Previous work by Xodus has suggested one failure per three years per turbine, while other reports have suggested one per 5 years per turbine, down to one per 20 years per turbine. For this study we have assumed a rate of one per 5 years per turbine, and a more optimistic rate of one per 10 years per turbine. With only around 5 turbines, a Guernsey project will be subject to the randomness of the failure process (and the randomness of the weather at the time of failure). To illustrate how this will impact the turbine availability, Monte Carlo simulations have been used to illustrate the variation between 'fortunate' and 'unfortunate' random failures over the first 10 years of a project. An example of the output of a Monte Carlo simulation is show in Figure 3.

As the lead times for various vessels and cranes will dominate the availability associated with the most serious major failures, we have not considered any minor differences in metocean conditions between North Coast and the other sites.

| Task | Duration | Wave limit (Hs in m) | Wind limit (in m/s) |
|---|---|---|---|
| *Lead time* | 28 or 56 days | No limit | No limit |

| | | | |
|---|---|---|---|
| *Jack down legs* | 12 hrs | 2 | 25 |
| *Remove broken components* | 24 hrs | 2.5 | 12 |
| *Replace broken components* | 24 hrs | 2.5 | 14.4 |
| *Jack up legs and jack-up leaves* | *Not on critical path for turbine availability* | | |

**Table 6 - Tasks associated with using a jack-up to carry out a major repair on a fixed foundation turbine.**

| Task | Duration | Wave limit (Hs in m) | Wind limit (in m/s) |
|---|---|---|---|
| *Lead time for towing vessel* | 3 or 6 days | No limit | No limit |
| *Disconnect turbine from mooring* | 6 hrs | 2 | 14.4 |
| *Tow to port (Plymouth or Le Havre)* | 11½ hrs or 18½ hrs | 2.5 | 14.4 |
| *Carry out repair* | 10 or 20 days | No limit | No limit |
| *Tow back to Guernsey* | 11½ hrs or 18½ hrs | 2.5 | 14.4 |
| *Reconnect turbine to the mooring* | 6 hrs | 2 | 14.4 |

**Table 7 – Tasks associated with towing a floating turbine back to port for a major repair.**

The resulting estimates of availability for the various strategies for major repairs are given in Table 8. For the fixed foundation turbines, there is a strong sensitivity to the lead time for obtaining a jack-up. For more pessimistic lead times, availability is below 97%. For floating turbines, the availability is somewhat better than for the fixed foundation turbines, as a result of the lead times for a towing vessel and a crane in port being expected to be both much less than for a jack-up. Towing a floating turbine to either Le Havre or Plymouth makes little difference to the turbine availability, in part due to the offset between Le Havre being further to travel but the tow will experience slightly more favourable wave conditions (our analysis calculates delayed towing to port until there is a sufficient weather window to disconnect and tow – see Table 7). Also the turbine availability is not greatly impacted by metocean conditions and towing speeds/distances – but is more sensitive to the lead time for the towing vessel and crane in port and the failure rates.  Table 8 also illustrates that the 'fortune' of the project can significantly impact the turbine availability due to the most serious major repairs.

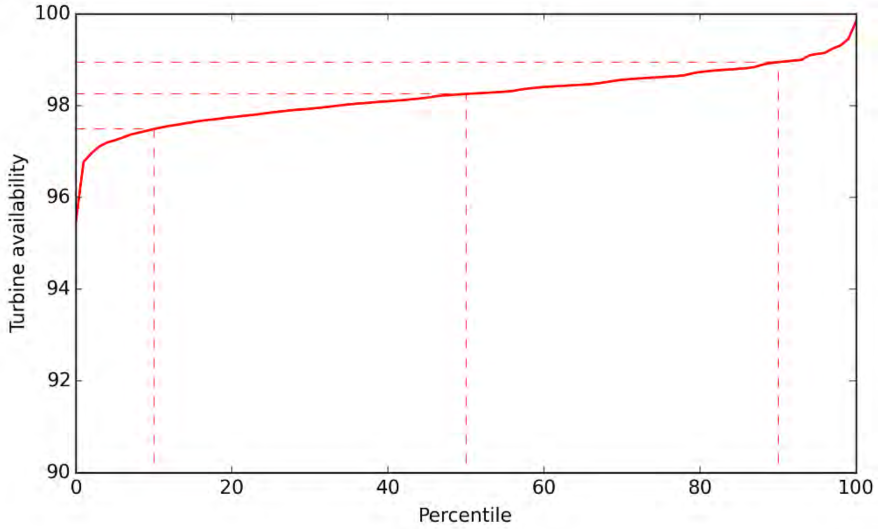


**Figure 3 – The distribution of turbine availability for 5000 Monte Carlo simulations of randomly timed major failures – for the standard simulation for fixed foundation turbines (repaired using a jack-up). The 10th percentile is used to indicate an unfortunate project, the 50th percentile (median) as an average project, and the 90th percentile as a fortunate project.**

| | | Fixed foundation turbines | Floating turbines (to Plymouth) | Floating turbines (to Le Havre) |
|---|---|---|---|---|
| *Standard simulation with 1 failure per turbine per 5 years and optimistic lead times* | *Fortunate*<br>*Average*<br>*Unfortunate* | 98.9%<br>98.3%<br>97.5% | 99.4%<br>99.1%<br>98.7% | 99.4%<br>99.1%<br>98.7% |
| *Simulation with 1 failure per turbine per 5 years and pessimistic lead times* | *Fortunate*<br>*Average*<br>*Unfortunate* | 98.0%<br>96.7%<br>95.3% | 99.0%<br>98.4%<br>97.7% | 99.0%<br>98.4%<br>97.7% |
| *Simulation with 1 failure per turbine per 10 years and optimistic lead times* | *Fortunate*<br>*Average*<br>*Unfortunate* | 99.6%<br>99.1%<br>98.6% | 99.8%<br>99.6%<br>98.3% | 99.8%<br>99.6%<br>98.3% |

**Table 8 -- Estimates of turbine availability, from the simulation of the handling of the most serious major repairs to turbines. Monte Carlo simulations are used to assess fortunate and unfortunate random failures over the initial 10 years of a project.**

# 4 OVERALL TURBINE AVAILABILITY ESTIMATES

The availability estimates presented in the previous section can be combined together (multiplicatively) to give an overall estimate of the turbine availability (using the 'standard' simulations as the benchmark), and its sensitivities (see Table 9). The choice of site makes a small difference to turbine availability – with North Coast and the floating sites having similar turbine availability and slightly improved over the deep water fixed foundation site west of Schole Bank. The sensitivity to vessel lead times is far greater than the difference between sites. If we are pessimistic about how responsive the O&M activities can be, the turbine availability reduces from around 91% to around 84%. Conversely the turbine availability is also sensitive to how reliable the turbines will be, with optimistic failures rates improving the turbine availability from around 91% to over 94%.

| | **North Coast (fixed foundation)** | **West of Schole Bank (fixed foundation)** | **Floating sites** |
|---|---|---|---|
| ***Standard simulations*** | 91.4% | 90.1% | 90.9% |
| ***Pessimistic lead times for repair vessels*** | 84.3% | 83.2% | 84.7% |
| ***Improved failure rates*** | 94.4% | 93.8% | 94.3% |

**Table 9 - Overall turbine availability estimates for three wind farm sites. An allowance of 2 visits/year of 8 hours down time is also included to capture scheduled maintenance.**

Given the sensitivities found for the turbine availability, the following section discusses some of the relevant considerations for the logistics and engineering of an O&M strategy.

# 5 LOGISTICAL AND ENGINEERING CONSIDERATIONS

## 5.1 Choice of port and strategy for work boats

For minor repairs, the initial assumption was that a work boat would be based out of Guernsey, operating during day shifts. This provides enough capacity to handle the minor repairs and planned maintenance, and would also yield some economic benefit to the island. However establishing the most cost effective strategy is complex, and would require evaluating the alternatives – such as flying in technicians (qualified to work on the specific turbine) as required (utilising a Guernsey based boat) or using work boats operating in nearby French wind farms. Alternatives would likely yield slower response times and hence reduced turbine availability (as suggested in Table 3), but costs savings may outweigh any additional lost revenue. The most optimised financial scenario may also not be the only consideration. Some project Sponsors may have other socio-economic drivers that take priority and this could encourage the use of local vessels and engineers (perhaps with vessel modifications and engineer training and certification). However, it is important to ensure the turbine OEM accepts the strategy and does not dilute the turbine availability warranty contract.

The choice of work boat strategy will also depend on the reliability of the turbines. If turbines are more reliable and require a small number of visits each month, the case for a Guernsey based work boat and crew may be less financially justifiable unless they can be contracted on a part time basis.

## 5.2 Choice of port for floating wind repairs

A port with sufficient depth and space to accommodate floating wind turbines is required. If the Guernsey project is small scale as currently assumed, it will be unjustifiable to make any significant investment in port facilities – and it is unclear that there will be any wider requirement for servicing floating turbines in the area, unless floating wind takes off in a major way in the western English Channel – a realistic scenario. It has been assumed that either Le Havre or Plymouth could accommodate floating turbines – given the port size. However, the capacity for these ports to service floating wind projects has not been assessed for this study. Given the sensitivity of the turbine availability to the lead times for obtaining vessels, it has been shown the distance to the O&M port, the metocean conditions for the tow and the tow speed are of secondary importance. For this reason there is little difference expected between using Plymouth or Le Havre in terms of the logistics of the tow to port. However, it would clearly be advantageous if closer ports, such as Cherbourg, could be used and a detailed assessment and investigation of the options should be performed at an early stage of the project.

## 5.3 Vessel availability for major repairs to fixed foundation turbines

The biggest unknown in assessing the ability to carry out major repairs to fixed foundation turbines is the ability of a Guernsey project to access construction support vessels or jack-up vessels as needed to minimise turbine downtime following a major failure requiring a heavy (and high) lift. The project is unlikely to be able to afford to contractually guarantee vessel availability, as a large wind farm would. Given this, a Guernsey project will be open to free market forces governing the availability of the desired vessel, and the day rates that will be payable at the time. It is difficult to conceive of ways to mitigate this risk, and financial contingency should be allocated to cover enhanced turbine downtime and the potential for high vessel day rates. For small and remote projects (assuming France does not develop other projects locally) this is a significant risk differentiator between fixed and floating wind turbines, with the latter less exposed to large vessel availability and response times.

## 5.4 Turbine reliability

While vessel availability can have a major downside for turbine availability, enhanced turbine reliability can have a major upside and help mitigate issues with vessel availability. The wind industry is acutely aware of the importance of reliability. However, market forces are driving turbine OEMs to constantly strive for larger turbines that introduce new technology. For this reason it is important to negotiate very long turbine availability warranties (5 years is normal and 10 years has been achieved with new turbines on pilot projects).

# 6 CONCLUSIONS

From the analysis of O&M for a Guernsey wind project, the following conclusions can be drawn;

- A central estimate for turbine availability of around 91% has been derived, but with significant sensitivities.
- The turbine availability is expected to vary slightly between the down-selected sites, but isn't significant compared to other sensitivities.
- The turbine availability is very sensitive to lead times for vessels to undertake turbine repairs. A pessimistic scenario for vessel lead times reduces the turbine availability to below 85%.
- The vessel sensitivities are;
    - How quickly a work boat can respond
    - How quickly construction support vessels can be available
    - How quickly and at what cost a jack-up can be available (for fixed foundation turbines)
    - How quickly a tow vessel and a crane in port can be available (for floating turbines)
- Market forces will dictate the vessel availability and cost for the vessels needed for major repairs. Jack-ups for fixed foundation turbines are expected to be the most problematic, as the other vessel types are more readily available. It is impossible to predict these market forces at this time.
- Formulating the best strategy for operating a work boat is not currently possible. It may be justifiable to base a work boat and competent crew of technicians in Guernsey, but alternatives need to be considered (for example, collaborating with a nearby French wind farm) and the optimum strategy will depend on the expected need – i.e. the expected turbine failure rate (following discussion with the selected turbine OEM). The best strategy will need to be developed in collaboration with the turbine OEM since contracting the vessel and crew will form part of the turbine warranty agreement. It is important to try and minimise the number of exclusions an OEM may try to impose as a result of vessel availability and performance. Safety, cost, socio-economics and risk management are all key drivers in this strategic decision.
- The turbine availability is very sensitive to the failure rates assumed for different types of failures. The expected sensitivity of availability based on turbine reliability is of the order 3% (between 91% to over 94% of our nominal case). This represents significant revenue and as such this is a key discussion point with turbine OEMs during tendering.
- It has been assumed that either Le Havre or Plymouth could accommodate floating turbines and the required large onshore cranes – given the port size. The suitability of these or other ports should be investigated at an early stage of the project. Cherbourg is a potential option, especially if it is developed into a wind energy hub.

# APPENDIX D ECONOMICS ASSESSMENT

Refer to Xodus Group Report “Offshore Wind - Project Economics Assessment (L-500042-S00-TECH-004-R02)”

# Offshore Wind - Preliminary Feasibility

## Project Economics Assessment

**States Of Guernsey**

**Assignment Number:** L500042-S00
**Document Number:** L-500042-S00-TECH-004


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# Project Economics Assessment

**L500042-S00**

**Client:** States Of Guernsey
**Document Type:** Technical Note
**Document Number:** L-500042-S00-TECH-004

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| R02 | 17/5/16 | Incorporating further comments | JJ | JI | JI | |
| R01 | 13/3/16 | Incorporating client comments | JJ | JI | JI | |
| R00 | 29/2/16 | Draft for client review | JJ | | | - |
| **Rev** | **Date** | **Description** | **Issued By** | **Checked By** | **Approved By** | **Client Approval** |

# CONTENTS

# 1 INTRODUCTION

This technical note forms part of a wider study being performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility study of the proposed 30MW offshore wind project. It should be read in conjunction with the other reports.

The cost of electricity generated by the offshore windfarm, and the impact on the overall cost of electricity for consumers on Guernsey is a key risk to the project. To assess the cost of electricity from different sites and design options we have created a Levellised Cost of Energy ("LCOE") model. LCOE is effectively the cost of energy generated by the project and is usually quoted in £/MWh.

A LCOE model for an offshore windfarm is a financial model created to assess different options on a consistent basis. It does this by calculating the energy price required to meet the target Internal Rate of Return ("IRR") required by the project funders. It takes into account the amount and timing of Capital Expenditure ("CAPEX"), Operational Expenditure ("OPEX") and decommissioning costs of the windfarm, as well as the amount and timing of electricity generated.

It is therefore a consistent and flexible tool that can be used to assess:

- Different windfarm designs
- Different project sizes
- Impact of phased development
- Sensitivity of results to changes in costs

In addition, by using consistent assumptions it can compare projects with industry norms.

The principal aim of this Technical Note is to describe the LCOE model, the assumptions used, and the estimated LCOE for the 3 different sites being considered. It is also intended to show the sensitivity of the estimated LCOEs to key assumptions, and how these sensitivities could influence decisions about the location, size and timing of the project.

# 2 MODEL OVERVIEW

LCOE models at the feasibility stage generally use high level costs assumptions, annual cashflows and are prepared on a Real basis ie no modelling of inflation. As a project develops more detail is usually added i.e. more detailed assumptions on costs and energy generation, and monthly cashflows to model LCOE more precisely. In addition functionality could be added to the model to allow for different inflation rates on different costs over the life of the project.

An unrestricted copy of the Excel spreadsheet is included at Appendix A (and issued as Excel spreadsheet file), and assumption sheets for each site at Appendix B.

The model covers the years 2015 to 2060 and is set out on a number of separate sheets which are discussed below.

## 2.1 Assumptions

The key assumptions for the model are input on this sheet and are discussed in more detail below.

Cells coloured yellow are input cells and formatted for the inputs required. However there are no validation checks on inputs, although these could be added in future.

### 2.1.1 Wind farm – energy generated and revenue

- Number of WTG installed/(decommissioned) in each year – used to calculate the number of operational WTG for each year
- WTG nominal size (MW) – used to calculate the operational capacity of the windfarm
- WTG capacity factor i.e. average electricity generated per annum as % of the theoretical maximum, from Wind Data Assessment
- WTG availability i.e. average % of time the WTG is generating electricity, from O&M study (issued as a separate Technical Note)
- Transmission electrical losses - after leaving the WTG (Note that there may be other small electrical losses onshore if a step down in voltage is required but this level of detail will not impact the present cost of energy assessment.)

  These assumptions are used to calculate the amount of electricity transmitted to Guernsey each year.
- Energy price – this is split into 2 elements (consumer price and potential government subsidy) to allow flexibility in the calculation of project cashflows. This assumption is only used for calculating the project Net Present Value (“NPV”); it is not used in the calculation of LCOE.

### 2.1.2 CAPEX

- CAPEX by type
  - Project development and consenting
  - WTG supply and installation
  - Substructures
  - Foundations
  - Offshore cables
  - Onshore electrical infrastructure
  - Project management/insurance
  - Contingency

The CAPEX cost assumptions were chosen to match the structure of cost information available from other projects. However the cost categories used can be easily changed.

- Phasing of each type of CAPEX by year – used to spread the overall CAPEX by year from 2015 to 2030. As the project progresses more accurate analysis of projected cashflows should become available.
- Decommissioning costs

### 2.1.3 OPEX

- OPEX by type
    - Insurance
    - Maintenance
    - Operations, including management of the project

The OPEX cost assumptions were chosen to match the structure of cost information available from other projects. However the cost categories used can be easily changed, although it will be necessary to distinguish between costs linked to the number of WTGs, and those linked to the total project.

Once the project is built, OPEX cost should be the key factor for Guernsey Electricity deciding on the merit order of different sources of generation.

### 2.1.4 Funding cost

- Target IRR – is the rate of return required by investors in the project and is used to calculate project NPV and LCOE. This is the overall rate of return and does not take into account the funding structure i.e. split between debt and equity.

## 2.2 Project cashflows

This sheet summarises the yearly project cashflows up to 2060 showing separately:

- Income – using the electricity price on the assumptions sheet
- OPEX
- CAPEX
- Net project cashflow
- Cumulative project cashflow

There are a number of specific outputs:

- Maximum funding – the largest negative value on the cumulative cashflow used to identify how much project funding is required
- NPV as at 31 December 2015 using Target IRR
- Project IRR – actual IRR for the project using the electricity price on the assumption sheet

## 2.3 LCOE

This sheet also summarises the yearly project cashflows from 2015 to 2050 and beyond, but instead of using the electricity price from the assumptions sheet it uses the electricity price (LCOE) in Cell G7 highlighted in green.

The LCOE is calculated by the model using the Goal Seek function, to set the Net Present Value of the project (Cell G29 on the “LCOE” sheet) to zero, by varying the LCOE (Cell G27 on the “LCOE” sheet), when using the assumed Target IRR.

| | | | |
|---|---|---|---|
| Target IRR | | 4.00% | |
| | | | |
| LCOE | | 93.10 | £/MWh |
| | | | |
| NPV | | 0.00 | OK |

Figure 2-1 LCOE Model output

## 2.4 CAPEX

This is a working sheet to show the actual CAPEX by category and by year.

## 2.5 OPEX

This is a working sheet to show the actual OPEX by category and by year.

# 3 SITES AND ASSUMPTIONS

## 3.1 Selected sites

During Site Selection we have identified 3 sites for offshore windfarms for further assessment. These are:

> North Coast (Option 2) – selected after Schole Bank was screened out

> West of Schole Bank (Option 4)

> Offshore floating (12 nautical miles) (Option 8)

These are shown on the map below:

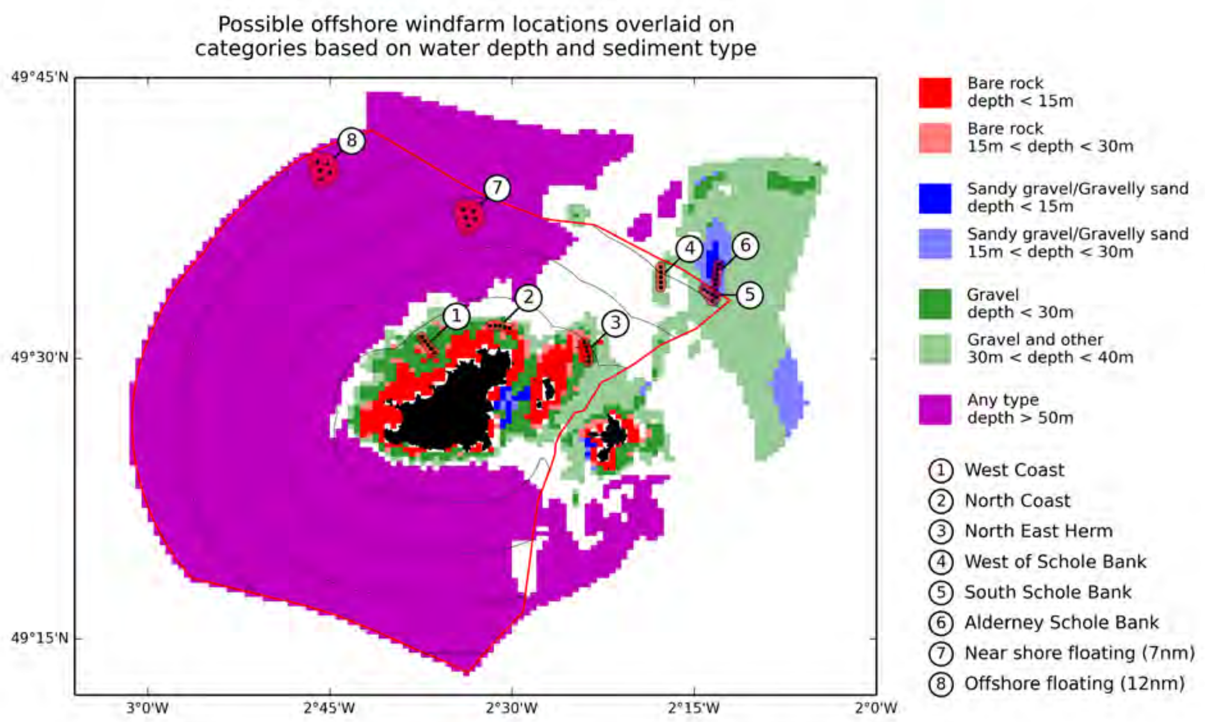


**Figure 3-1 Offshore wind farm sites**

For each of the 3 sites we have identified the key technical components required using information on water depths, distance from shore, seabed bottom type, metocean conditions etc. This information is set out in detail in the site selection work and is summarised below.

For all sites we have assumed 6MW capacity WTG are used with a total site capacity of 30MW, and a beach cable landing on the north side of Guernsey.

### 3.1.1 North Coast

This site is within 5km of the North coast of Guernsey in water depths of less than 15m with a seabed of bare rock. The WTG will be supported on a large diameter (say 6m) monopile which will be lowered into a drilled hole in the seabed and grouted into place. Monopiles have previously been used for offshore WTG, but generally have been piled into seabed sediment rather than drilled into solid rock. Technically it is feasible to drill into rock but the costs are potentially significantly higher than pilling. The costs we have used in this study follow preliminary discussions with a drilling contractor.

### 3.1.2 West of Schole Bank

This site is North East of Guernsey, some 15km from the coast in water depths of c50m with a mainly gravel sea-bottom. Due to the water depth and ground conditions, a steel jacket (a pylon-type structure made up of a network of steel pipes held to the seabed via large diameter piles) will be required to support the WTG. This design is typical of the larger offshore windfarms being currently designed and built around the UK and in the North Sea in this depth of water.

### 3.1.3 Offshore floating

This site is North West of Guernsey, nearly 25km from the coast in water depths of over 50m. This uses a floating platform to support the WTG, which is fixed to the seabed with anchors and chains. This is a new type of design for offshore windfarms with the first prototypes currently being installed, but large floating structures have long been used in the offshore oil and gas industry.

## 3.2 Assumptions

### 3.2.1 CAPEX

For each of the sites we have estimated CAPEX costs based on our knowledge of other windfarms in the design and build phase. At the feasibility stage however there is a high level of uncertainty about the CAPEX cost.  We have estimated the CAPEX to an accuracy of the order +/- 20% around the central estimates given below. This uncertainty is for a number of reasons:

> Information about the site is incomplete e.g. limited information on winds, waves, currents, seabed conditions;

> Detailed design and site optimisation has not yet been carried out, and final design choices have not been made;

> No engagement with the supply chain has taken place (other than preliminary discussion with a drilling contractor), and realistic cost estimates obtained for the final design; and

> Commodity prices and exchange rates may change significantly before the design is finalised.

The CAPEX cost estimates for each site are shown below:

| | North Coast £m | West of Schole Bank £m | Floating (12nm) £m |
|---|---|---|---|
| Project Development & Consenting | 5.00 | 5.00 | 5.00 |
| WTG supply and installation | 38.50 | 38.50 | 38.50 |
| Substructures | 9.35 | 21.76 | 50.00 |
| Foundations | 5.5 | 3.79 | 0.00 |
| Offshore cables | 3.56 | 5.08 | 6.60 |
| Onshore electrical infrastructure | 3.20 | 3.20 | 3.20 |
| Project management and insurance | 3.12 | 3.65 | 4.88 |
| Total | £ 68.23m | £ 80.98m | £ 108.18m |

**Table 3-1 CAPEX costs by site**

Some of the costs eg Project Development and Consenting, WTG Supply and Installation, Onshore Electrical Infrastructure are assumed to be the same for all 3 sites considered, as these costs are primarily driven by the size of the project and not by the site. Note that WTG costs will not vary significantly between floating or fixed structures.

Other costs eg Substructures, Foundations are primarily driven by the design chosen which reflects the water depth and ground conditions at the site. Offshore cable cost is mainly driven by the distance of the site from the shore, and project management and insurance will be linked to the overall cost of the project.

The cost of substructures for the floating option reflects the early stage of development of the industry with the first prototypes currently being installed. It is expected that as more experience is gained then the costs will reduce to c£25m - similar to jacket designs (ie West of Schole Bank) - as the mass of steel used and construction methods are similar (for jackets in approximately 50m water depth).

The LCOE model has been designed to make it easy to vary each of the CAPEX cost estimates to identify the impact on the cost of electricity generated.

### 3.2.2 Decommissioning costs

The decommissioning costs for each site are shown below:

| | North Coast £m | West of Schole Bank £m | Floating (12nm) £m |
|---|---|---|---|
| Decommissioning costs | £5.5m | £9.7m | £4.5m |

Table 3-2 Decommissioning costs by site

These are the costs of removing the WTGs, supporting structures, and cables and restoring the seabed to the extent required by the consent conditions. The difference in costs reflects the complexity of the operation for the different types of supporting structures.

### 3.2.3 OPEX and WTG availability

We have estimated OPEX costs and WTG availability based on the O&M study. Again at the feasibility stage there will be a high level of uncertainty about these estimates.

| | North Coast | West of Schole Bank | Floating (12nm) |
|---|---|---|---|
| Availability | 91.4% | 90.1% | 90.9% |
| OPEX costs (£m pa) | | | |
| Insurance | 0.75 | 0.75 | 0.75 |
| Maintenance | 3.15 | 3.25 | 2.65 |
| Operations | 0.35 | 0.35 | 0.35 |
| Total | £ 4.25m | £ 4.35m | £ 3.75m |

Table 3-3 OPEX costs and Availability by site

Some of the costs eg Insurance and Operations are assumed to be the same across all 3 sites as they are primarily driven by the size of the project and not by the site. There will be differences between floating and fixed foundation technology, with some costs increasing and others decreasing, but this is a suitable assumption for this stage of the project.

The Maintenance cost reflects the cost of the repairs to the WTG. A large proportion of this cost is the cost of the vessels to carry out these repairs, while the Availability reflects how long it takes to get these vessels to the project site and carry out the repairs. The detailed analysis of maintenance is set out in the O&M and Turbine Availability Assessment.

The floating option is expected to have lower maintenance costs and higher availability as it is believed that it will be quicker and cheaper to tow the floating turbines to port for repairs than wait for suitable large maintenance vessels to become available. Better estimates of this advantage will become available in the next few years as prototype floating offshore windfarms become operational.

The LCOE model has been designed to make it easy to vary OPEX cost and availability estimates to identify the impact on the cost of electricity generated.

### 3.2.4 Funding costs

We have not presented any detailed analysis of current funding costs as part of this economics technical note, as this will depend on the design of the windfarm and the project funding structure. Refer to the Sponsor Strategic Overview Technical Note 05 for analysis of potential funding scenarios.

We have used two different funding costs in this report:

- 10% which has generally been used for estimating LCOE for privately funded offshore wind projects in the UK; and
- 4% which would be appropriate if the project was fully government funded.

The LCOE model has been designed to make it easy to vary the funding cost estimates to identify the impact on the cost of electricity generated.

# 4 ASSESSMENT OF SITES

## 4.1 Results

The LCOE for each of the 3 sites using the key assumptions set out above are:

| | North Coast £/MWh | West of Schole Bank £/MWh | Floating (12nm) £/MWh |
|---|---|---|---|
| 10% Target IRR | 123.59 | 142.29 | 166.58 |
| 4% Target IRR | 93.10 | 106.36 | 118.06 |

**Table 4-1 LCOE by site**

As noted above, at the project feasibility stage there will be a high level of uncertainty about the values of all the key assumptions, and so these LCOE estimates should be taken as indicative only.

In addition the Site Selection work done to create a shortlist of sites shows that other factors e.g. Visual and other human impact, and Socio-economics, had a far larger impact on the shortlisting of sites than Costs and availability.

However, during future more detailed analysis of the shortlisted sites it is expected that LCOE will have a significant impact on the final site election and indeed the overall viability of the project.

These results using a funding cost of 10% are in line with expectations of current costs for offshore windfarms currently being developed around the UK. The decrease in LCOE using a 4% funding cost demonstrates the importance of this key assumption.

There are a number of features of the project that will directly affect the LCOE:

> The small size of the project - Project Development and Consenting costs have a large fixed element and so will not vary directly with the size of the project. Therefore this makes smaller projects more expensive than larger ones.

> The location of the project and its size mean than offshore electrical substations will not be required as for larger windfarms so reducing CAPEX and LCOE.

We show the results separately for both 10% and 4% Target IRR assumptions. This is because changes in this key assumption change the relative importance of other assumptions on CAPEX, OPEX, availability etc.

## 4.2 Sensitivities

We set out below an assessment of the sensitivity of the LCOE to changes in key assumptions, to illustrate how changes in the key assumptions might affect decisions on the project's location and design. We have considered each assumption separately, and have not analysed the effect of changing multiple assumptions at the same time.

### 4.2.1 Funding cost

We set out below the sensitivity of the project LCOE to different funding costs:

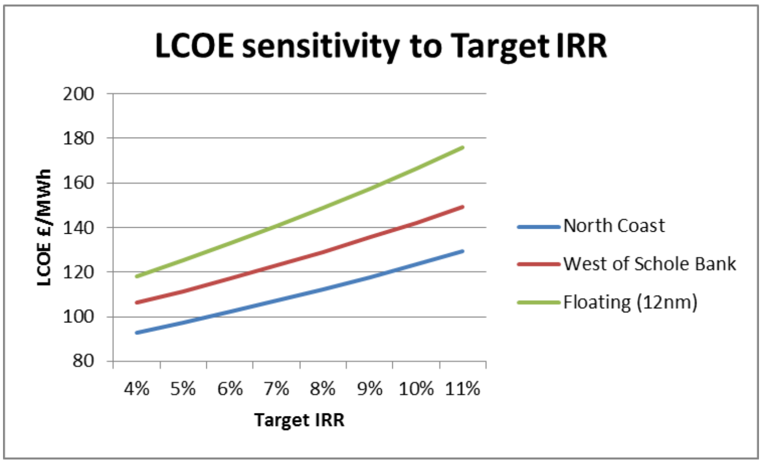


Figure 4-1 LCOE sensitivity to Target IRR

The LCOE of the project decreases as the Target IRR (i.e. the rate of return required by investors in the project) decreases, with a 2% reduction in the nominal IRR reducing LCOE by c10%.

### 4.2.2 CAPEX

We set out below the sensitivity of the project LCOE to changes in the project CAPEX.

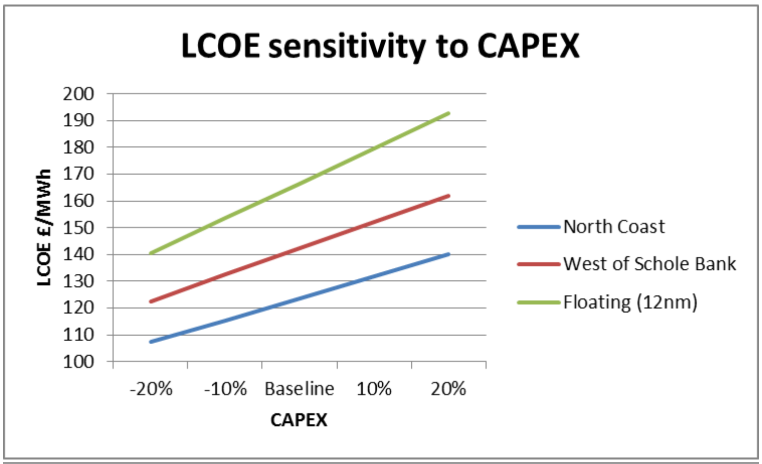


Figure 4-2 LCOE sensitivity to CAPEX (10% Target IRR)

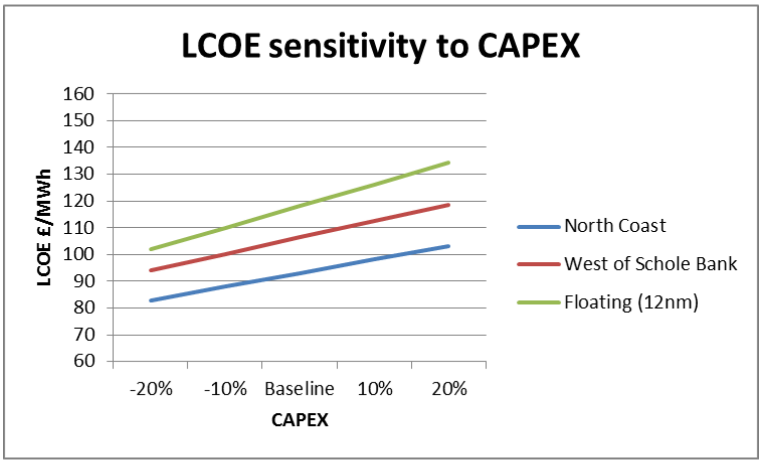


Figure 4-3 LCOE sensitivity to CAPEX (4% Target IRR)

The LCOE of the project decreases as the CAPEX cost decreases with a 20% reduction in CAPEX causing a 10 to 15% decrease in LCOE.

If the cost of the floating foundations were reduced to be similar to that of a jacket design, as discussed in 3.2.1 above, then the LCOE of the floating design would be reduced from £166.58/MWh to £138.76/MWh using a 10% discount rate. It would reduce from £118.06/MWh to £99.55/MWh using a 4% discount rate. These LCOEs are lower than the West of Schole Bank site because it is expected that maintenance costs will be lower for floating windfarm designs.

### 4.2.3 WTG Capacity factor

We set out below the sensitivity of the project LCOE to changes in the WTG Capacity factor.

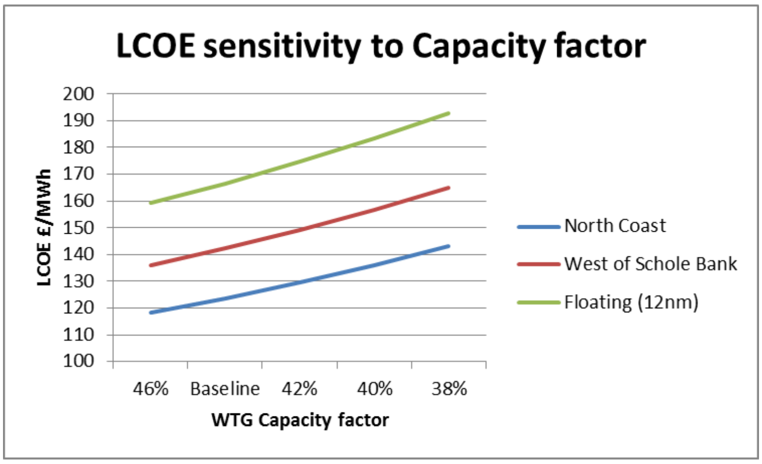


Figure 4-4 LCOE sensitivity to WTG capacity factor (10% Target IRR)

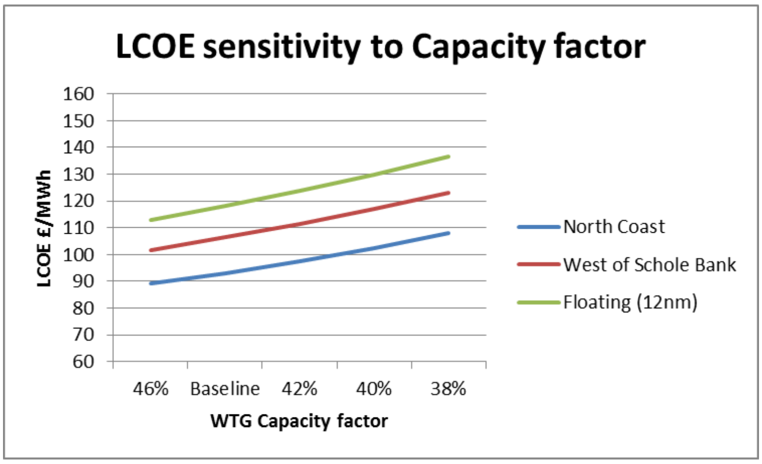


Figure 4-5 LCOE sensitivity to WTG capacity factor (4% Target IRR)

As the WTG capacity factor decreases, the amount of electricity generated over the lifetime of the project reduces. This increases LCOE as the CAPEX costs have to be recovered over a smaller total of MWh produced.

### 4.2.4 WTG Availability

We set out below the sensitivity of the project LCOE to changes in WTG availability. These are changes in the absolute level of availability rather than relative i.e. the '-6%' change for the North Coast site reduces availability from 91.4% to 85.4%.

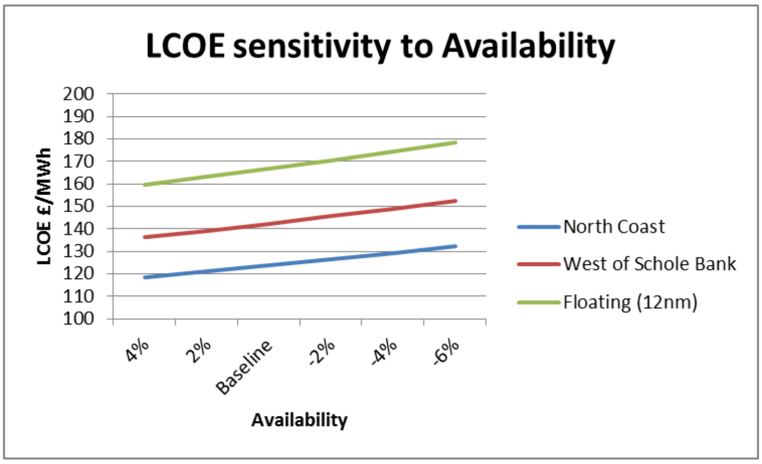


Figure 4-6 LCOE sensitivity to WTG availability (10% Target IRR)

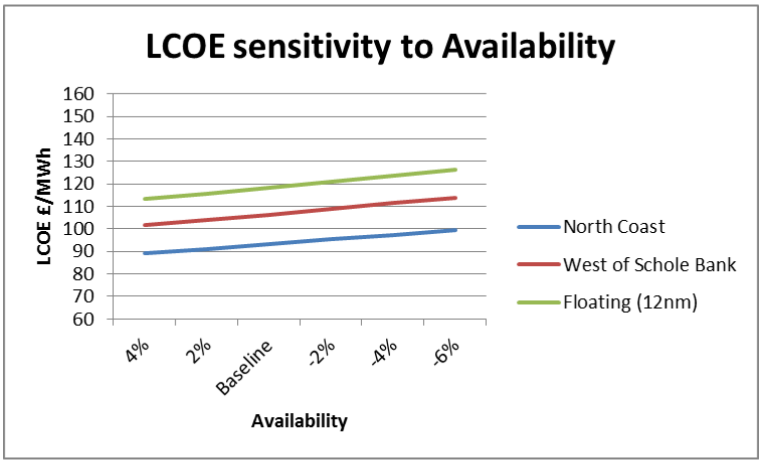


Figure 4-7 LCOE sensitivity to WTG availability (4% Target IRR)

As WTG availability decreases, the amount of electricity generated over the lifetime of the project reduces. This increases LCOE as the CAPEX costs have to be recovered over a smaller total of MWh produced.

### 4.2.5 OPEX

We set out below the sensitivity of the project LCOE to changes in the project OPEX.

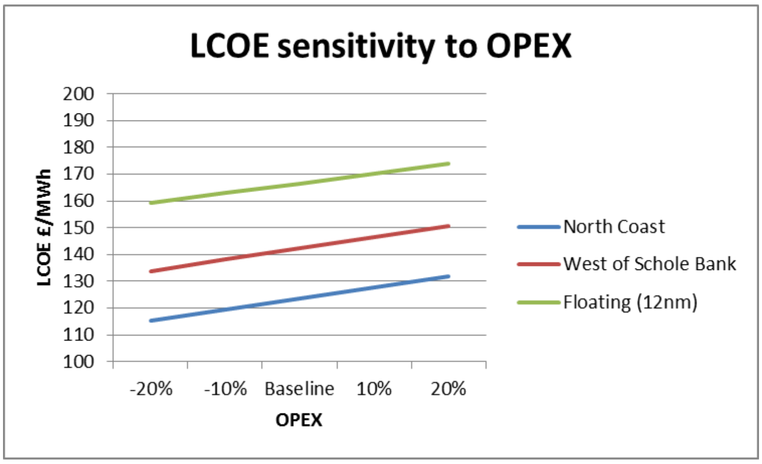


Figure 4-8 LCOE sensitivity to OPEX (10% Target IRR)

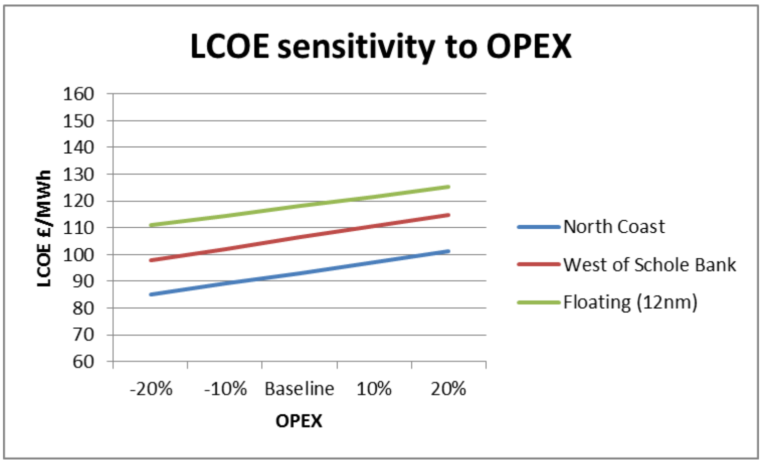


Figure 4-9 LCOE sensitivity to OPEX (4% Target IRR)

The LCOE of the project decreases as the OPEX costs decrease, with a 20% decrease in OPEX reducing LCOE by 5 to 10%. LCOE is less sensitive to OPEX than CAPEX because the OPEX costs are spread over the life of the project and so their impact is reduced by the effect of the discount rate.

# 5 ASSESSMENT OF OTHER FACTORS

We set out below an assessment of some other factors which may affect the overall design of the project.

## 5.1 Phased build out

We have modelled the impact of installing a single WTG every other year at the North Coast site, rather than installing all 5 WTG at the start of the project.

| | Full installation | Phased installation |
|---|---|---|
| **10% Target IRR** | | |
| LCOE £/MWh | 123.59 | 141.70 |
| Maximum funding required £m | 68.2 | 38.3 |
| **4% Target IRR** | | |
| LCOE £/MWh | 93.10 | 108.19 |
| Maximum funding required £m | 68.2 | 38.3 |

Table 5-1 Impact of phased build-out

This assumes that the total project CAPEX does not change, but the phasing of the costs does. This change increases the estimated LCOE as project revenues are delayed while not all the project costs are similarly delayed e.g. the full consenting process will need to be completed to install even a single WTG.

In reality the total CAPEX costs for the project may increase if a phased approach is adopted, as for many of the offshore operations there is a significant fixed cost for mobilising assets irrespective of how much work is done on each visit. If a phased build-out is considered further analysis needs to be done on the most cost-effective approach eg drilling holes for monopile foundations may need to be completed in one mobilisation and the holes capped, rather than having 5 separate mobilisations.

However the delay in installation reduces the overall funding required for the project as the second and subsequent WTGs will be partly funded by revenue from the first WTG.

Whether a phased installation approach would be useful depends on the relative importance of available funding, and the average cost of electricity.

## 5.2 Single WTG demonstration

We have also assessed the impact of planning to install just a single WTG at the North Coast site. This is an extreme version of the case shown above and we have assumed some fixed project costs such as consenting will reduce slightly due to the smaller scale of the project.

| | Full installation | Single WTG |
|---|---|---|
| **10% Target IRR** | | |
| LCOE £/MWh | 123.59 | 180.08 |
| Maximum funding required £m | 68.2 | 19.8 |
| **4% Target IRR** | | |
| LCOE £/MWh | 93.10 | 132.77 |
| Maximum funding required £m | 68.2 | 19.8 |

Table 5-2 Impact of a single WTG installation

Again the LCOE increases, as the fixed project costs become a higher proportion of the total project costs, and the amount of funding required decreases. However this approach loses the benefit of funding later WTG installations from the revenue of earlier ones.

## 5.3 Project life

For this model we have assumed in the base case that the WTG will be installed during 2020 and decommissioned during 2040, as although projects often have a design life of 25 years there is limited experience of long-term operation of offshore windfarms.

The key concern is increased failure rates towards the end of the WTG's expected life as these will both increase OPEX and reduce WTG availability potentially making it uneconomic to repair the WTGs.

We have assessed the impact of an extra 5 years operational life for the project at the North Coast site.

| | Baseline project life | Extended life |
|---|---|---|
| **10% Target IRR** | | |
| LCOE £/MWh | 123.59 | 117.54 |
| **4% Target IRR** | | |
| LCOE £/MWh | 93.10 | 85.55 |

Table 5-3 Impact of extended project life

# 6 CONCLUSIONS

From the analysis of Project Economics for a Guernsey wind project, the following conclusions can be drawn:

- The North Coast site has the lowest LCOE, with the Floating option currently the most expensive;
- There is a large degree of uncertainty about LCOE at this stage of the project due to:
    - Only limited site information being available
    - Lack of detailed design for the project
    - No supply chain engagement
    - Uncertainty about future commodity prices and exchange rates
- LCOE for the Floating option is expected to decrease as the technology matures, and will probably reduce below that of the West of Schole Bank option in the 2020s;
- LCOE is sensitive to changes in the key assumptions:
    - Target IRR – the rate of return expected by investors in the project
    - CAPEX
    - WTG capacity factor
    - WTG availability
    - OPEX
- A phased approach reduces the total amount of funding required significantly, although it increases LCOE for the project.

# APPENDIX A – LCOE MODEL

See spreadsheet provided by Xodus Group. This spreadsheet is the property of Xodus Group. It is provided to RET and GEL under a royalty free licence for the purpose of this Project. Xodus Group accepts no liability for anyone other than Xodus Group using this software.

## APPENDIX B – SITE ASSUMPTIONS

# Assumptions - North Coast

| | | | | | |
|---|---|---|---|---|---|
| **General** | | | | | |
| | Number of turbines | | 5 | | 5 WTG of 6MW each |
| | | | | | Water depth 15m over granite |
| | WTG rated capacity | | 6 | MW | Monopile |
| | | | | | Cable to shore 5km |
| | WTG capacity factor | | 44.0% | | |
| | WTG availability | | 91.4% | | |
| | Transmission electrical losses | | 1.0% | | |
| **Construction costs** | | | | | |
| | Project development & Consenting | | 5.00 | £m | |
| | WTG | | 38.50 | £m | |
| | Substructures | | 9.35 | £m | |
| | Foundations | | 5.50 | £m | |
| | Offshore cables | | 3.56 | £m | |
| | Onshore electricals | | 3.20 | £m | |
| | Project management/insurance | | 3.12 | £m | |
| | Contingency | | | £m | |
| | | | | £m | |
| | | | | £m | |
| | Total | | 68.23 | £m | 13.6452 m per WTG |
| | | | | | 2.27 m per MW |
| **Decommissioning** | | | | | |
| | Decommissioning cost per WTG | | 1.10 | £m | |
| **Operating costs pa** | | Total pa £m | | | |
| | Insurance | 0.75 | 0.15 | £m per WTG | |
| | WTG maintenance | 3.15 | 0.63 | £m per WTG | |
| | Operations | 0.35 | 0.35 | £m | |
| | | 0.00 | | £m | |
| | | 0.00 | | £m | |
| | Total | **4.25** | £m | | |

# Assumptions - West of Schole Bank

| | | | | |
|---|---|---|---|---|
| **General** | | | | |
| | Number of turbines | 5 | | 5 WTG of 6MW each |
| | | | | Water depth 50m |
| | WTG rated capacity | 6 | MW | Jacket c800t |
| | | | | Cable to shore 20km |
| | WTG capacity factor | 44.0% | | |
| | WTG availability | 90.1% | | |
| | Transmission electrical losses | 1.0% | | |
| **Construction costs** | | | | |
| | Project development & Consenting | 5.00 | £m | |
| | WTG | 38.50 | £m | |
| | Substructures | 21.76 | £m | |
| | Foundations | 3.79 | £m | |
| | Offshore cables | 5.08 | £m | |
| | Onshore electricals | 3.20 | £m | |
| | Project management/insurance | 3.65 | £m | |
| | Contingency | | £m | |
| | | | £m | |
| | | | £m | |
| | Total | 80.98 | £m | 16.196 m per WTG |
| | | | | 2.70 m per MW |
| **Decommissioning** | | | | |
| | Decommissioning cost per WTG | 1.94 | £m | |

| | | | | |
|---|---|---|---|---|
| **Operating costs pa** | | Total pa £m | | |
| | Insurance | 0.75 | 0.15 | £m per WTG |
| | WTG maintenance | 3.25 | 0.65 | £m per WTG |
| | Operations | 0.35 | 0.35 | £m |
| | | 0.00 | | £m |
| | | 0.00 | | £m |
| | Total | **4.35** £m | | |

# Assumptions - Floating (12nm)

| | | | | | | |
|---|---|---|---|---|---|---|
| **General** | | | | | | |
| | Number of turbines | | 5 | | | 5 WTG of 6MW each |
| | | | | | | Water depth 50m+ |
| | WTG rated capacity | | 6 | MW | | Floating structure |
| | | | | | | Cable to shore 30km |
| | WTG capacity factor | | 44.0% | | | |
| | WTG availability | | 90.9% | | | |
| | Transmission electrical losses | | 1.0% | | | |
| **Construction costs** | | | | | | |
| | Project development & Consenting | | 5.00 | £m | | |
| | WTG | | 38.50 | £m | | |
| | Substructures | | 50.00 | £m | | |
| | Foundations | | 0.00 | £m | | |
| | Offshore cables | | 6.60 | £m | | |
| | Onshore electricals | | 3.20 | £m | | |
| | Project management/insurance | | 4.88 | £m | | |
| | Contingency | | | £m | | |
| | | | | £m | | |
| | | | | £m | | |
| | Total | | 108.18 | £m | 21.636 | m per WTG |
| | | | | | 3.61 | m per MW |
| **Decommissioning** | | | | | | |
| | Decommissioning cost per WTG | | 0.90 | £m | | |
| **Operating costs pa** | | Total pa £m | | | | |
| | Insurance | 0.75 | 0.15 | £m per WTG | | |
| | WTG maintenance | 2.65 | 0.53 | £m per WTG | | |
| | Operations | 0.35 | 0.35 | £m | | |
| | | 0.00 | | £m | | |
| | | 0.00 | | £m | | |
| | Total | **3.75** | £m | | | |

# APPENDIX E SPONSOR STRATEGIC OVERVIEW

Refer to Xodus Group Report "Offshore Wind - Project Sponsor Strategic Overview (L-500042-S00-TECH-005-R04)"

# Offshore Wind - Preliminary Feasibility

## Project Sponsor Strategic Overview

**States Of Guernsey**

**Assignment Number:** L500042-S00
**Document Number:** L-500042-S00-TECH-005


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# Project Sponsor Strategic Overview

**L500042-S00**

**Client:** States Of Guernsey
**Document Type:** Technical Note
**Document Number:** L-500042-S00-TECH-005

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| R04 | 17/5/16 | Incorporating Comments | JJ | JI | JI | |
| R03 | 3/5/16 | Incorporating Comments | JJ | JI | JI | |
| R02 | 19/4/16 | For review | JJ | JI | JI | |
| R01 | 11/3/16 | Early draft | JJ | JI | JI | - |
| **Rev** | **Date** | **Description** | **Issued By** | **Checked By** | **Approved By** | **Client Approval** |

# CONTENTS

# 1 INTRODUCTION

This technical note forms part of a wider study being performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility study of the proposed 30MW offshore wind project. It should be read in conjunction with the other reports.

Most of these other studies are concerned with the gathering of information on potential sites and selection of the type and location of the windfarm and do not consider the ownership and funding of the windfarm.

The principal aim of this Technical Note is to present different options for:

- Ownership of the windfarm;
- Funding of the different stages of the project
    - Development and consenting
    - Construction
    - Operation

It will also address related questions such as the regulation and subsidy regimes for the offshore wind project. These should be transparent, robust and stable to reduce the risk to any external investors.

# 2 OVERVIEW OF OFFSHORE WIND PROJECTS

We set out below an overview of different elements of an offshore wind project:

- Funding required
- Sources of capital funding
- Sources of operational income
- Regulation

These set out the key characteristics and risks of different elements and options.

## 2.1 Funding required

There are 3 main stages in the development of an offshore wind project:

- Development and consenting
- Construction
- Operation (and subsequent decommissioning)

The characteristics of each stage affect the types of funding which are most appropriate.

### 2.1.1 Development and consenting

This is the initial stage of the project and runs from the first feasibility studies until the project is designed in detail, all required consents have been received, and draft commercial agreements reached.

Funding this stage can be very high risk as there will only be a return to the investors if the project is built and many risks are outside the control of the project. This depends on obtaining all required consents and licences, creating a technical feasible design, reaching agreement on the sale of electricity generated and subsidy arrangements, and obtaining tenders from key contractors and suppliers so that the project provides an adequate return to investors who will fund its construction.

The risks of this phase will be lower if there is good quality wind data and other information available for the proposed site, and general public acceptance of the concept of offshore wind farms.

However, any extra costs or delays in this phase in gathering information or gaining consent will reduce returns to the initial investors. Any restrictions in the consent conditions which reduce income, increase costs or increase risks for the construction or operation phase will also reduce the return for the initial investors. The possibility of reduced returns due to these factors increases the risk to the investor.

### 2.1.2 Construction

This is the second stage of the project which runs from obtaining finance to build the project, until all the WTG are operational and electricity generated.

The funding risks during this stage are due to the possibility of cost or schedule overruns on the project. For example, the risk that weather conditions delay offshore operations so delaying the project and increasing costs. There are also risks of contractor errors or accidents e.g. damaged cables, which can also delay the project.

For offshore wind projects up to 70% of this funding is debt from banks, with the balance from the owners of the project. At this level of debt the lenders will be looking to push risks into the supply chain. In reality the lenders will not take on significant risks themselves, and hence they provide lower cost finance than equity.

Once the windfarm is operational it may be possible to refinance the bank debt and get lower interest rates as the risk profile of the project will have decreased once it is operational and all construction is finished.

### 2.1.3 Operation

As noted above the operation phase of an offshore windfarm should be lower risk once the WTGs are operational, and project cashflow is positive. Therefore further bank debt or institutional funding can be raised at lower interest rates to replace earlier funding. It is not without risk and for this reason developers (and their lenders) often require the WTG suppliers to provide long term warranties (usually at least 5 years) with damages for lost revenue due to failures.

In addition to the turbines an increasing concern is the ongoing uncertainty of operation and maintenance costs associated with primary structure integrity (i.e. damage cause by corrosion and fatigue). The industry is actively developing new approaches, such as condition monitoring, to address this concern.

## 2.2 Sources of capital funding

The main sources of capital funding and their characteristics are set out below:

- Government
- Community
- Supplier/manufacturer
- Developer
- Bank
- Institutional

### 2.2.1 Government

Government funding is potentially the cheapest form of funding as governments can raise long term debt in the international capital markets due to their strong credit ratings. For example the States of Guernsey issued a £330m bond at the end of 2014, maturing in 2046, with an interest rate of 3.375%.

Governments are a good source of finance for long-term or large infrastructure projects for a number of reasons. They generally use lower discount rates than commercial organisations, which increases the relative importance of long-term benefits, consider wider benefits to the community (not just financial returns), and are prepared to invest for longer periods than most commercial organisations.

Governments also have a great deal of flexibility in structuring funding which could be in the form of capital grants, subsidies linked to electricity generated, or long-term loans.

The major risk of government funding is the potential for future changes in policy or legislation as a result of changes in government following elections.

### 2.2.2 Community

Community funding from individuals on Guernsey can come in 2 forms:

- Small scale equity investment i.e. individuals investing small amounts in the share capital of a company developing the project and so becoming part-owners.

  This was used by Swansea Bay Tidal Lagoon who raised some £0.4m in equity from c400 individuals who lived locally to support the development phase of their scheme. As well as raising cash, this may help create strong links with the local community. They also raised further equity from high net worth individuals across the UK under an Enterprise Investment Scheme (EIS).

  However it would probably take up to a year to raise this equity, it would be difficult to raise enough from community funding alone to fund the development stage, and having a large number of small investors would make managing the company more difficult.

- Yield based investments i.e. investing in high-yield debt issued by the company who owns the project.

There are a number of ‘YieldCo’ funds which invest in operating windfarms and provide a high return (5-10%pa) investment opportunity for individuals.

However raising funds for operational windfarms is not difficult and other sources of funding may be cheaper. The amount that could be raised from individuals on Guernsey will be limited and it probably would not create such a strong connection with the community as an equity investment.

### 2.2.3 Supplier/manufacturer

Suppliers or manufacturers of equipment are unlikely to be major providers of finance to an offshore wind project, although some WTG suppliers have taken minority equity stakes in projects, and manufacturers may be prepared to give more support to a pilot project eg a floating windfarm. It might also be possible to negotiate extended payment terms with the WTG manufacturer as part of the contract negotiations.

### 2.2.4 Developer

There are a number of independent developers of offshore renewable energy projects. They often aim to develop the project until all consents have been received and then sell the project on to a larger investor to fund construction.

Alternatively they may retain ownership and build the project using external debt. However this is a much more challenging approach as it significantly increases the risks for the banks providing the loans, unless the developer has a strong balance sheet.

Independent developers will be looking for a very high return on their investment for the development and consenting phase (more than doubling their initial investment), due to the length of this phase and its potentially very high risk.

### 2.2.5 Bank

There are a number of banks which have regularly invested in the construction of offshore wind projects as part of a banking consortium. They seek interest margins of at least 2% over government debt interest rates, typically lend no more than 70% of the project cost, and generally require the developer to bear the majority of risk of cost overruns during the construction phase. The exact terms will depend on the perceived risk of the project and the state of the banking market at the time that funding is raised.  Generally banks don’t accept much risk, however some lenders specialise in providing pre-construction mezzanine project finance for offshore wind projects at higher interest rates.

As noted previously, once the windfarm is operating this debt might be refinanced by other funders at lower interest rates.

### 2.2.6 Institutional

Institutional investors cover a wide range of disparate bodies such as pension funds, insurance companies and sovereign wealth funds, which are looking for stable long-term investments at a reasonable yield. They may invest in the operational phase of an offshore wind project as part of a refinancing of the original debt, but are unlikely to fund the construction phase due to its higher risks.

## 2.3 Sources of operational income

There are 2 main sources of operational income for offshore wind projects:

- Electricity income
- Public subsidy

### 2.3.1 Electricity income

The income from the sale of electricity will vary depending upon the market in which it is sold. It can be sold at market price, if there is a wholesale electricity market, otherwise it will be sold via contracts with users of electricity. These contracts can accommodate a wide range of terms on price, volume, period, indexing etc.

There are a number of key risks to the windfarm operator for this income stream:

- Wind – actual electricity generation will be unpredictable and may differ substantially from historic long-term averages
- Operational – failures of WTGs or cables will reduce income and increase costs
- Market – the structure of the electricity market and its participants may change over the life of the project
- Counterparty – a contracted purchaser may be unable to meet its commitments under its contracts, or there may be no willing purchasers when contracts need to be renewed

### 2.3.2 Public subsidy

Income from public subsidy will depend on the market in which the electricity is being sold. There are a number of different structures that could be used:

- Capacity related payments linked to the size of the windfarm. These may be made either as grants against capital expenditure, or as payments over the life of the project.
- Output related payments linked to the electricity generated (per MWh). These may be at a single price, or tiered depending on output, and may also be fixed or indexed to inflation.
- Subsidies to increase the payment received by the generator on the sale of electricity to pre-determined level. Again these prices may be fixed or indexed to inflation.

Each country uses a different regulatory and subsidy regime reflecting the local electricity market. For example, the UK is currently in the process of moving from:

- A Regulatory Obligation system where electricity companies were required to purchase a certain proportion of their electricity from renewable sources at market prices, and the government provided a subsidy to the renewable energy generators based on the amount of electricity produced and the technology used, for a period of 20 years;

to

- A Contracts for Difference scheme where the electricity companies buy renewable energy at market prices and the government provides a subsidy to increase this price to an agreed level (linked to the technology used), for a period of 15 years (for offshore wind).

Given the small size of the Guernsey electricity market, setting up a regulated wholesale electricity market would probably not be useful. Therefore further work will need to be done to agree the outline structure of a subsidy regime suitable for Guernsey.

## 2.4 Regulation

A key risk for renewable energy projects is lack of certainty about who will purchase their output and this requires a transparent, robust and stable regulatory and subsidy regime.

For example, an electrical utility may not be keen to purchase electricity produced from an offshore windfarm owned by a third party. This is because electricity from an offshore wind project may be more expensive and less predictable than energy supplied from other sources. However external investors in the offshore wind project will want certainty that the utility will buy the electricity at a pre-determined price.

To balance these different priorities there should be in place, before any external fundraising, either:

- A regulated wholesale electricity market and subsidy regime; or
- Long-term contracts with Guernsey Electricity and a subsidy regime

which cover the life of the project.

As noted above, a regulated wholesale electricity market would probably not be useful for Guernsey, especially given the recent decision to end independent regulation of Guernsey Electricity. Therefore further work will need to be done to agree the structure of power purchase agreements with Guernsey Electricity for the sale of electricity generated by the offshore windfarm.

# 3 SCENARIOS

We set out below descriptions of a number of different project sponsor scenarios. These are:

- Public ownership
- Community ownership
- Guernsey Electricity ownership
- Developer ownership

This takes into account the results of the 2011 survey of Guernsey public opinion which showed that over 75% of respondents supported some form of local ownership, and the 2015 survey which also showed 63% support.

We have made assumptions about the funding scheme for each scenario, but a wide range of other funding schemes are possible.

The estimates for costs of construction and electricity generated in this section are based on the Project Economics model and assumptions (see Technical Note 04). As noted there, at the feasibility stage there is a high level of uncertainty about project costs. However, we believe that the CAPEX costs will lie within a range of approximately +/- 20% around the central cost estimates.

These costs are based on UK offshore wind projects currently in the development and consenting phase. The industry expects costs to fall further as the industry matures by 1-2% pa in real terms.

## 3.1 Public ownership

Public ownership of the offshore wind project can be achieved in a number of ways, but this scenario is based on a public interest not-for-profit basis as used by Welsh Water (http://www.dwrcymru.com/en/company-information.aspx). This is a special purpose company with no shareholders and narrowly defined objectives. The role of shareholders is taken by a large (50+) group of Members selected to represent the interests of the community, who meet twice a year. The company is run by a board of executive and non-executive directors.

As it is run on a not-for-profit basis, non-financial objectives can more easily be included in the company's strategy.

### 3.1.1 Development and consenting phase

Funding for this phase would come from the government in the form of initial capital or grant, due to the relatively high risk of this phase.

### 3.1.2 Construction phase

Funding for the construction of the offshore windfarm would come from long-term government loans, the lowest cost form of funding. However this would require the government to provide at least c£60m of debt, and it would bear the risk of cost overruns during the construction phase (beyond normal contractual risk mitigation).

An alternative funding approach would be to replace some of the government loans by higher cost loans from commercial banks. In addition it might be possible to raise some local debt funding from individuals in Guernsey.

If all the funding for the construction of the project came from low-interest government loans, the cost of electricity generated by the offshore wind project is likely to exceed £90/MWh. Therefore, unless Guernsey Electricity is prepared to purchase all the electricity generated at this cost, some form of subsidy or revenue support will be required for the offshore wind project.

### 3.1.3 Operation phase

Once the project is operational, then its risk profile will be reduced, but the government will still be exposed to the operational risks of the windfarm that could impact loan repayments. The government will however have a long-term income stream from the project.

## 3.2 Community ownership

Community ownership of the offshore wind project can be achieved in a number of ways but this scenario assumes that the developer is a company owned by a large number of individuals based in Guernsey. This is structured so that all investors subscribe for a small amount of equity in the company, and therefore it is not dominated by a small number of individuals.

This differs from the public ownership scenario in that the shareholders are self-selecting, and have greater control over the future strategy and management of the company. To ensure ongoing community ownership there may need to be safeguards put in place to prevent certain changes in ownership of the company, such as being sold to a developer or outside investor.

The investors would be taking the risk that they would lose their money if the project did not go ahead. However as owners of the project they would receive all profits after paying interest and loan repayments, but may set strategy to also promote non-financial objectives.

It would probably take up to a year to establish the company and raise the funds. An outline design of the windfarm, information on the regulatory and subsidy regime, and indications of likely returns would be needed before this fundraising could start.

### 3.2.1 Development and consenting phase

The funds received from the shareholders would provide some of the funding for the development and consenting phase, but it is unlikely that enough equity could be raised to cover all the costs. Therefore further funding from the government would be needed, probably in the form of grants. Other sources of funding would be unsuitable due to the relatively high risk of this phase.

### 3.2.2 Construction phase

Funding for the construction of the offshore windfarm would come from a mixture of government funding and commercial bank loans. The banks would want any government funding structured so that the banks had priority for repayment to reduce their risk. This approach would require up to c£25m of government funding.

In addition some further local debt funding could be raised from individuals in Guernsey on the same terms and conditions as the bank finance to enhance community involvement.

Even if part-funding for construction of the project came from low-cost government funding, the cost of electricity generated by the offshore wind project is still likely to exceed £100/MWh.

An alternative funding approach would be to fund most or all of the construction by long-term government loans.

Finalising the total funding package (including subsidies) will be complex as the priorities of the banks, project owner and government will not be aligned. For example the banks will want a project which is designed to be low risk, while the government will want a project designed to be low cost and also to meet other non-financial targets, and the owners will want a project designed to maximise their return as shareholders. However this is typical of all offshore wind projects.

### 3.2.3 Operation phase

As noted above, once the project is operational, it may be possible to refinance the commercial bank loan funding. Again further local debt funding could be raised from individuals in Guernsey on the same terms and conditions as the bank finance to enhance community involvement. However any benefits from refinancing at lower interest rates will go to the owners of the project.

The regulatory and subsidy regime will be a key issue in the finalising the funding package, as the banks will increase the interest rate on their loans if there are perceived to be any risks to them from the regime, or it could be a potential show-stopper for the banks.

## 3.3 Guernsey Electricity ownership

This scenario assumes that the project is fully owned by Guernsey Electricity in a special purpose subsidiary. This is to ensure that there is transparency to the public on the costs of the project and its impact on electricity prices.

Guernsey Electricity may choose to include non-financial objectives in its strategy for developing the project, subject to agreement with its shareholders.

### 3.3.1 Development and consenting phase

Funding for this phase would come from Guernsey Electricity in the form of equity or inter-company loans.

An alternative funding approach would be to use government grants to fund some of the costs due to the relatively high risk nature of this phase, similar to the approach used for new electricity import cables etc.

### 3.3.2 Construction phase

Funding for the construction of the offshore windfarm would come mostly from commercial banks. However banks are unlikely to provide all the funding and so further investment from Guernsey Electricity would be required, of up to £25m. The exact form of investment would need to be negotiated with the banks as they would want it structured to reduce their risk, with Guernsey Electricity exposed to any cost over-runs during construction.

Depending on the cost of funding from Guernsey Electricity, the cost of electricity generated by the offshore wind project is likely to exceed £110/MWh.

An alternative funding approach would be to replace some or all of the bank loans by long-term government loans. Clearly this would reduce the costs in line with the previous government funded scenarios, to below £100/MWh.

Finalising the total funding package (including subsidies) will be complex as the priorities of the banks, Guernsey Electricity and government will not be aligned. For example the banks will want a project which is designed to be low risk, while the government will want a project designed to be low cost and also to meet other non-financial targets. Guernsey Electricity will want to balance the impact on electricity prices, risk to the project and Guernsey Electricity as a whole, and returns to itself as project owner.

### 3.3.3 Operation phase

As noted previously, once the project is operational, it may be possible to refinance the commercial bank loan funding.

The regulatory and subsidy regime will be a key issue in finalising the funding package, as the banks will increase the interest rate on their loans if there are perceived to be any risks to them from the regime (and this could also be a show-stopper for the lenders pre-construction).

## 3.4 Developer ownership

This scenario assumes that an independent developer from outside Guernsey with experience in offshore wind will own the project.

This should require a tender process to select the most appropriate developer for the project. However this might be hard to achieve without a regulatory and subsidy regime in place as potential bidders will find it difficult to estimate their potential returns from the project. There may also be a limited number of developers interested due to the small size (30MW) of the project. Although a floating project may attract higher interest as either a pilot project and/or a first step towards a larger project in French waters.

There is also a possibility that the original developer will seek to sell on the project to maximise its return, either during the development phase, or more likely, once all consents are in place. Although this should not affect the outcome of the project, it should be taken into account in designing the regulatory and subsidy regime.

### 3.4.1 Development and consenting phase

Funding for this phase would come from the project developer.

An alternative funding approach would be to provide some government grants towards the costs of site surveys and information gathering. This would make the project more attractive to developers, as it would reduce the amount of investment at risk if the project did not go ahead.

### 3.4.2 Construction phase

Funding for the construction phase would come from the developer and commercial banks on a non-recourse project finance basis. In this case the developer does not bear the risk of construction cost overruns beyond agreed contingency levels, which would be funded instead by further loans from the banks.

A project finance funded project requires that it is designed to minimise risk and uncertainty, even if this increases total CAPEX for the project. Under this fully commercial scenario, the cost of electricity generated by the offshore wind project is likely to exceed £120/MWh.

An alternative funding approach would be to replace some or all of the bank loans by long-term government loans.

Finalising any subsidy scheme will be complex as the banks will want a low risk project, while the developer will want to maximise the return on their investment. These will not align with government objectives to minimise the cost of the project to Guernsey and promote non-financial objectives e.g. environmental and socio-economic.

### 3.4.3 Operation phase

As noted previously, once the project is operational, it may be possible to refinance the commercial bank loans at a lower interest rate, but this benefit will go to the developer.

# 4 ASSESSMENT OF SCENARIOS

We have identified 4 main differentiator categories to use when assessing the advantages and disadvantages of each of the project sponsor scenarios. These are:

- Localism
  - Degree of local control of the project
  - Community involvement
  - Transparency – are the costs and benefits of the project clear to population of Guernsey?
- Cost
  - Total project capital and operating costs
  - Returns to project funders
  - Impact on electricity prices
  - Amount of government support required
- Non-financial
  - Opportunities for local businesses
  - Environmental impact and benefits
  - Energy independence
- Project delivery
  - Certainty of project being built
  - Timeliness – risk that project is unnecessarily delayed
  - Flexibility

It is possible that a scenario will have both advantages and disadvantages under each of the main categories.

We assess each of the project sponsor scenarios below. It should be noted that these scenarios are just examples and many others could be created, especially by changes to the funding mix.

## 4.1 Public ownership

The advantages and disadvantages of this scenario are:

| | **Advantages** | **Disadvantages** |
|---|---|---|
| **Localism** | > All decision making in Guernsey<br>> Corporate structure allows involvement of wide range of interest groups<br>> Project owner is independent of government and Guernsey Electricity | |
| **Cost** | > Funding is from government sources and so lowest cost possible<br>> Lowest electricity prices | > New and inexperienced body may increase development stage costs<br>> Strategy choices to maximise non-financial objectives may increase costs<br>> All funding (c£70m) from government sources |

| | | |
|---|---|---|
| **Non-financial** | > Strategy to maximise opportunities for local businesses<br>> Strategy to minimise negative environmental impact<br>> Local control ensures energy independence | |
| **Project delivery** | > Local control makes it more certain that project will be built<br>> Local control will ensure flexibility in project design and schedule | > Corporate structure may slow down decision making<br>> Need to balance local interests may slow project delivery |

## 4.2 Community ownership

| | **Advantages** | **Disadvantages** |
|---|---|---|
| **Localism** | > All decision making in Guernsey<br>> High level of community involvement<br>> Project owner is independent of government and Guernsey Electricity | > Local investors will be self-selecting and may cause unbalanced representation |
| **Cost** | > Some funding is from government sources and so lowest cost possible | > New and inexperienced body may increase development stage costs<br>> Strategy choices on non-financial objectives may increase costs<br>> Some funding (c£30m) from government sources |
| **Non-financial** | > Strategy provides opportunities for local businesses<br>> Strategy reduces negative environmental impact<br>> Local control ensures energy independence | |
| **Project delivery** | > Local control makes it more certain that project will be built<br>> Local control will ensure flexibility in project design and schedule | > Need to balance local interests may slow project delivery<br>> Set-up and fundraising stage may slow project delivery |

## 4.3 Guernsey Electricity ownership

| | **Advantages** | **Disadvantages** |
|---|---|---|
| **Localism** | > All decision making in Guernsey | > Limited community involvement<br>> Limited transparency on decision making |
| **Cost** | > Simple structure should minimise overall electrical system costs | > Owner inexperienced in offshore wind may increase development stage costs<br>> Funding of project will be at commercial rates<br>> CAPEX funding (c£30m) from Guernsey Electricity<br>> Limited transparency on setting electricity price |

| | | |
|---|---|---|
| | | > Strategy choices on non-financial objectives may increase costs |
| **Non-financial** | > Strategy may provide opportunities for local businesses<br>> Strategy may reduce negative environmental impact<br>> Local control ensures energy independence | |
| **Project delivery** | > Local control makes it more certain that project will be built<br>> Local control will ensure flexibility in project design and schedule<br>> Simple structure should avoid project delays | |

## 4.4 Developer ownership

| | **Advantages** | **Disadvantages** |
|---|---|---|
| **Localism** | > Decision making on regulatory framework on Guernsey<br>> Project owner is independent of government and Guernsey Electricity | > Key commercial decisions made by developer outside Guernsey<br>> Limited community involvement |
| **Cost** | > Experienced developer will minimise total project CAPEX and OPEX | > Funding of project will be at fully commercial rates<br>> Extra government subsidy needed to minimise impact on electricity prices |
| **Non-financial** | > Project increases energy independence | > Difficult to ensure opportunities for local businesses<br>> Developer will aim for minimum compliance on environmental issues<br>> Off island control reduces energy independence |
| **Project delivery** | > Developer will aim to complete project quickly to maximise financial return | > Risk that developer could withdraw from project if not financially attractive<br>> Need to put regulatory regime in place prior to selection of developer will slow down project<br>> Developer likely to charge for any changes to project scope |

# 5 CONCLUSIONS

Our analysis has noted the advantages and disadvantages of each of the 4 project sponsor scenarios, and the wide range of alternative funding schemes.

Our key conclusions are as follows:

> Following discussions with RET and GEL it is clear that the estimated LCOE is a potential show stopper and as such the highest priority should be given to minimising the cost. The lowest cost funding will be from funds raised by the States of Guernsey. As noted in the Project Economics study, the cost of funding has a significant impact on the LCOE for the electricity generated by the project.

  Therefore we recommend that the project is funded by the States of Guernsey as far as possible, to reduce the cost of electricity generated by the project.

> The highest cost of funding will be private sector investment in the development and consenting phase due to the high risk nature of this investment. In addition prior to any private sector investment in this phase, a complete regulatory and subsidy scheme will need to be in place to allow potential investors to assess the investment opportunity.

  Therefore we recommend that the development and consenting phase is funded by the States of Guernsey, to reduce the cost of electricity and reduce potential delays.

  We also recommend that the Community ownership and Developer ownership scenarios are not considered further for the same reasons.

> We recommend that the Public ownership (ie not-for-profit) and Guernsey Electricity ownership scenarios are considered further, as they do not require private sector investment in the development and consenting phase.

  Both these options allow for considerable flexibility for raising funds for the construction phase from local investors and banks if necessary, and for flexibility in the design of regulatory and subsidy schemes.

  They also ensure that decision making is in Guernsey, and that project strategy could be set to take into account non-financial benefits such as energy independence and local business opportunities.

# APPENDIX F SOCIO ECONOMIC ANALYSIS

Refer to Xodus Group Report “Offshore Wind - Socio Economic Analysis (L-500042-S00-TECH-006-R02)”

# Offshore Wind - Preliminary Feasibility

## Socio-economic Analysis

**States Of Guernsey**

**Assignment Number:** L500042-S00
**Document Number:** L-500042-S00-TECH-006


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# Recommendations for next iteration of permitting pathway document

**L500042-S00**

**Client:** States Of Guernsey
**Document Type:** Technical Note
**Document Number:** L-500042-S00-TECH-006

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| R02 | 17/5/16 | Incorporating client comments | JI | JJ | JI | |
| R01 | 04/05/2016 | Issued for Review | JI | JJ | JI | - |
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# CONTENTS

# 1 INTRODUCTION

This technical note forms part of a wider study being performed by Xodus Group for Guernsey Renewable Energy Team (RET), acting in collaboration with Guernsey Electricity Limited (GEL), for the feasibility study of the proposed 30MW offshore wind project. It should be read in conjunction with the wider study reports.

In particular, it is important to understand that the design, ownership and other features of a wind farm have not yet been finalised. Therefore, the views in this report are preliminary and subject to change.

The socio-economic risks and opportunities are presented in the project risk and opportunities register. This brief technical note summarises and expands on those findings.

# 2 SCOPE, ASSUMPTIONS & SITES

## 2.1 Scope

For this stage of the project we have performed a preliminary review of the socio-economic risks and opportunities. RET has already acknowledged that Guernsey is highly unlikely to see significant involvement in the manufacturing or installation associated with an offshore wind farm development – the equipment will most likely be delivered directly from large dedicated factories using specialist vessels with only smaller crew transfer and/or guard vessels coming from Guernsey (the latter possibly using local fishing vessels).

However, there will clearly be both positive and negative and direct and indirect socio-economic impacts on Guernsey as a result of this proposed project. Socio-economic impacts include local employment and job creation, impacts on the local economy based on spend, impacts on local supply chains and recreation and tourism. It also includes fisheries, shipping and navigation (air and sea) and the seascape, landscape and visual impact.

This brief report presents the main socio-economic risks and opportunities that have been identified by Xodus Group and the project teams at RET and GEL to date. The full project risk and opportunity register has been issued as an excel file as part of this overall study (Offshore Wind Feasibility Risk & Opportunity Register Rev 03 April 2016).

It will be necessary to perform a detailed analysis to establish the full extent of the impact of the offshore wind project throughout the life cycle from initial planning through to final decommissioning. This analysis will form an integral part of the detailed planning for the project and allow the various stakeholders to engage with the project team and the authorities, and to work towards minimising negative impacts and preparing early to capitalise on the opportunities.

## 2.2 Assumptions

For the purposes of this assessment the following key assumptions have been made:

1. The project will be relatively small, of the order 30MW or 5 or 6 turbines.
2. The project will not be located close to shore producing a large visual impact, and potentially also having a negative impact on tourism. (This will need to be reviewed if the North Coast site stays on the shortlist after the next stage of engineering and assessment.)
3. Other users of the sea and air space will be consulted and the project will be sited where impacts will be negligible or managed.
4. The turbines and foundations will not be fabricated on Guernsey.

## 2.3 Shortlisted sites

During Site Selection we have identified 3 sites for offshore windfarms for further assessment. These are:

1. North Coast (Option 2) – selected after Schole Bank was screened out
2. West of Schole Bank (Option 4)
3. Offshore floating (12 nautical miles) (Option 8)

These are shown on the map below:

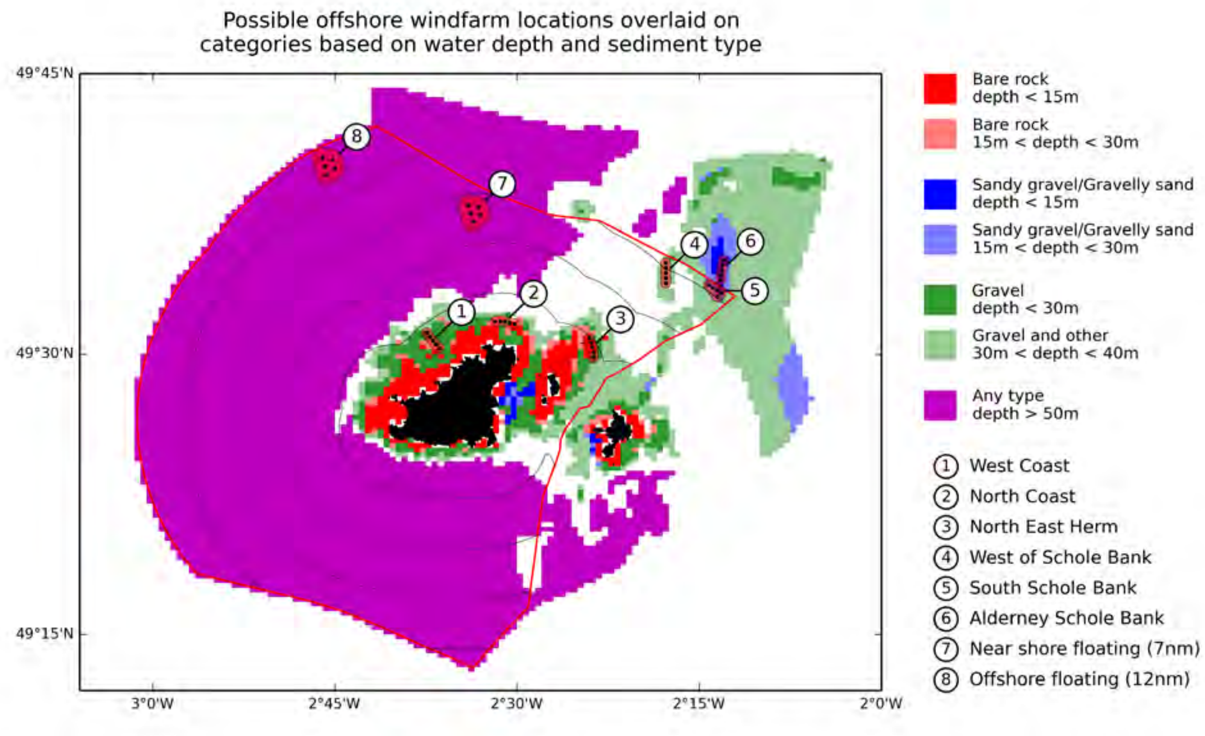


Figure 2.1 Offshore wind farm sites (shortlisted sites are 2, 4 and 8)

# 3 RISKS AND OPPORTUNITIES

## 3.1 Overview

The typical socio-economic impacts associated with a project of this nature can be categorised as shown in the following table (Table 3.1).

| **Magnitude of effect (positive or negative)** | **Impact Definition with comment on Offshore Wind Feasibility Project** | | | |
|---|---|---|---|---|
| | **Recreation** | **Tourism** | **Supply chain** | **Economic** |
| **Major** | *Major visual impact and/or physical interruption.* | *>15% turnover change.* | *>15% turnover change or substantial new job numbers.* | *Greater than local scale or which exceeds accepted performance.* |
| **Moderate** | *Moderate visual impact and/or physical interruption.* | *10-15% turnover change.* | *10-15% turnover change or numerous new job numbers.* | *Noticeable and viewed as important at a local scale.*<br>The likely cost of energy from an offshore wind project will almost certainly be more than energy from France. The scale of the impact will clearly depend on the size of the project. |
| **Minor** | *Minor visual impact and/or physical interruption.*<br>Visual impact is the top driver for site selection. Impact is likely to be minor due to distance offshore. Any physical interruption will be short term during offshore operations or new onshore electrical works. | *5-10% turnover change.* | *5-10% turnover change or some new job numbers.* | *Limited or very local impact.* |
| **Negligible** | *Negligible visual impact and/or physical interruption.* | *<5% turnover change.*<br>There may be a slight enhancement to tourism, especially if a marine park is developed and/or a special angling site develops at the site. Industrial activity (of any kind) may also have a slight negative impact. | *<5% turnover change or very few new job numbers.*<br>Offshore wind projects are very specialist. Supply chain positive impacts will be associated with port and vessel use and a few professional jobs associated with developing and running the project and possible spin-off research. | *Practically no local scale or wider impact.* |

Table 3.1 Socio-economic impacts overview (colours highlight the scores)

Xodus Group has recently performed an analysis for an island community with similar characteristics to Guernsey with regard to offshore renewable energy project development. Most importantly, the island population and project size are of a similar order. The overwhelming conclusion was that any potential impacts would be very minor or negligible simply because of the small scale of the project, even though for a small island community it is a relatively large project.

Clearly a detailed analysis is required for the specific circumstances on and around Guernsey, but there should be sufficient flexibility and control by the States of Guernsey Government to ensure most impacts are either favorable or minor (as shown in Table 3.1). The noticeable exception is the moderate (potentially major) economic impact due to the cost of energy which is relatively high for offshore wind compared to most alternatives available to Guernsey. The following sections elaborate on the key issues for Guernsey.

## 3.2 Recreation and Tourism

### 3.2.1 Location

The relatively small amount of port and shore based activity associated with building and operating this proposed offshore wind project will not significantly impact normal recreation and tourism activities. The most important consideration with regards to potential impacts is the location of the site. The selection of the short listed potential sites was based on a scoring analysis of the key project drivers. The relative importance (weighting) of the site selection drivers (calculated using quantitative methods) is presented in Figure 3.1. The figure clearly shows that socio-economic factors in general and especially visual and other human impacts have been chosen by the Xodus and Guernsey project team as the most influential drivers. For this reason two of the three shortlisted sites are far offshore (see Figure 2.1) and the near shore site has been shortlisted only after other far offshore sites had been ruled out.

The final site selection is subject to more detailed project development work but the socio-economic impacts will continue to influence the final location decision.

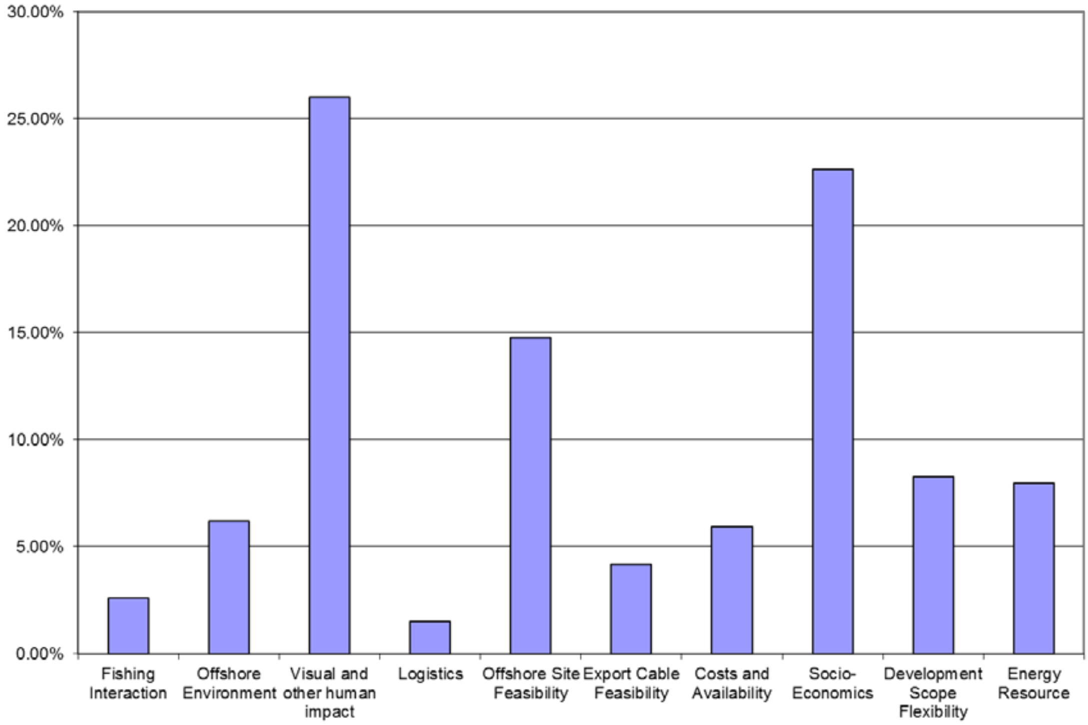


Figure 3.1 Site Selection Criteria

### 3.2.2 Creation of a Marine Reserve

There is some undocumented evidence that offshore wind farms create safe habitats for fish and their food chain due to the exclusion of some commercial fishing vessels. This has led to commercial anglers reporting improved fishing grounds, with larger fish within wind farms. If this is demonstrated to be the case, and there is clearly logic to it, then it may be possible to promote advantages of improved angling and overall benefits to the marine environment. If a floating wind farm is selected then some vessels may need to be excluded from the site in any event due to the navigational risk associated with the mooring system.

The socio-economic impact of creating a marine reserve of some sort will not be a key project driver because it will be relatively small, especially given the size of the project, but it should be considered during the planning stages.

## 3.3 Supply Chain (local employment)

Offshore engineering is a specialist sector and offshore renewable energy is a particularly challenging subsector. In addition to the health and safety issues and designing and working in a hostile environment, there is a huge challenge to reduce costs in all parts of the supply chain. This has led to the formation of a highly skilled and competitive supplier base, using special purpose technology for offshore construction and maintenance tasks. For this reason local employment opportunities will be limited to areas where the local supply chain has specific skills or assets that are essential to the project such as:

- Project management and financial planning
- Asset operations and management
- Mechanical and electrical engineering for maintenance work;
- Marine operations (crew transfers).

That said, it is of course possible to enhance the local supply chain’s skills and capability through a coordinated economic development programme. There are examples of this on island communities around the UK in places like Anglesey and Orkney - two small islands using offshore renewables development as a driver for economic development.

The Anglesey Energy Island Programme was established by the local Council several years ago in response to the planned energy projects coming to the island (nuclear, wind, tidal, solar, biomass). At the same time Bangor University boosted support for the planned tidal energy projects by developing their School of Ocean Sciences located on Anglesey, and the University is building a new Science Park on Anglesey with a priority focus area of low carbon marine energy, amongst other things. A local not for profit Enterprise Company has taken on a lease from The Crown Estate to develop a tidal energy demonstration zone off Anglesey and grant funding is potentially available to help establish the necessary new electrical infrastructure that will encourage companies to come to the island. This combined effort is to support one of the Energy Island’s aims of establishing a Centre of Excellence in marine energy on the island and create associated employment.

Similar, more advanced, coordinated effort is seen on Orkney off northern Scotland. Orkney receives a great deal of national and local political backing and grant funding to develop its supply chain by promoting renewable energy initiatives. A clear example is the development of the European Marine Energy Centre (EMEC) that has become an internationally leading wave and tide test facility. This was a spin-off from the Marine Renewable Energy focus at Heriot-Watt University’s Orkney Campus. Research from 2012 presented on the University’s website claims that the Orkney Campus had contributed £8.8m to the local Orkney economy, with the creation of 119 jobs at companies like EMEC and Scotrenewables Tidal Power Ltd. Although the high profile activity in Orkney is in marine energy, they focus on several forms of low carbon energy and spin-offs include a fleet of over 70 electric cars and a claim to be leading Scotland in this capacity.

The economic success on Orkney has been cited by the tidal energy developers on the Isle of Wight who have set up Perpetuus Tidal Energy Centre Ltd (PTEC), a consortium including the Isle of Wight Council. Interestingly the Isle of Wight is also trialing low carbon hydrogen cars. Although this is not a spin-off from PTEC it perhaps shows how low carbon initiatives tend to diversify and spread on small island communities interested in sustainability. The cumulative socio-economic impacts associated with the "Energy/Eco Island" approach are not the focus of this study but they are worth considering if this project becomes a catalyst for other low carbon initiatives.

That all said, creating significant local employment opportunities from a specialist project like an offshore wind development is challenging and requires stakeholder alignment and commitment from authorities and the main project Sponsors and Developer. This is well understood by the Guernsey project teams in RET and GEL and it is already shaping early project planning and ownership strategy as noted previously. It is also recognised that relative to Guernsey, the UK is financially able to invest significant funds to support local communities to capitalise on new infrastructure projects that are outside existing local supply chain capability.

The following sections focus on local capability and assets, but also mention longer term spin-off opportunities linked to the development of a Centre of Excellence. While local employment opportunities will not be a key driver to progress with an offshore wind development, a coordinated approach by Government, industry and perhaps academia will maximise the socio-economic opportunities.

### 3.3.1 Project Development Engineering, Finance and Administration Activities

Offshore wind project development requires a multi-disciplined team. It is reasonable to assume that several million pounds will be spent by the project team during the feasibility, consenting and detailed engineering stages. The finance planning and general administration activities are likely to be skills readily available on Guernsey. Also, elements of the environmental planning, some surveying (at least vessel charter) and associated consent application works could be performed by locally based staff.

It is usual for such projects to have one or two framework contracts with specialist major engineering consultancies. Support could be in the form of both Guernsey based secondment into the project office and off island studies. Overall perhaps 30% to 40% of the project development spend could be Guernsey based with a total spend of the order £1-2 million over 3-5 years.

Skills developed as a result of this project could then be used by individuals to work on other projects internationally.

### 3.3.2 Harbour and Local Vessel use During Construction and O&M

#### *3.3.2.1 Direct*

Guernsey will have to operate as a local logistics base for the project both during construction and ongoing operations (O&M). The major construction vessels will have no requirement to make port, and indeed they are too big in any event. But there will be a requirement to transfer work crews and minor maintenance equipment offshore. This will not impact overly on the busy ports but should create of the order of five full time equivalent local jobs. An important factor will be the availability and suitability of local vessels. If necessary a long term charter or new vessel build may be required.

Note that the offshore wind sector has developed a range of special purpose vessels and access systems in an attempt to optimise vessel access. This is very important for large projects that are a long way offshore, however not necessarily the case for Guernsey's proposed small scale project that is relatively close to shore even at 12nm. The use of existing local vessels (with modifications if necessary) or new multi-purpose vessels, that could have a wider application, should be considered in consultation with the selected turbine OEM. Note that if the vessel is not contracted and/or approved by the turbine OEM then the availability and performance of the vessel may limit the strength of the turbine availability warranty.

With reference to the "O&M and Turbine Availability Assessment" Technical Note No. 3 (Xodus ref. L-500042-S00-TECH-003) an appropriate vessel should be able to perform more than 10 visits for minor repairs in a month, even in most winters. In the summer it is possible to double up repairs with long daylight hours – although this may not be needed. Given we may expect 40 failures over an entire year, the use of a single workboat is sufficient, with significant excess capacity to carry out planned maintenance, and indeed other business.

The value of the opportunity could increase if Guernsey partner with other "local" projects that may be developed by neighbouring islands or the French. In this case Guernsey could become a regional logistics base, although this would likely require a state of the art crew transfer vessel(s). Example vessels and operators are presented on these, and many other, websites: http://www.windcatworkboats.com/ and http://www.turbinetransfers.co.uk/.

#### *3.3.2.2 Spin-off*

The increased use of the harbours, particularly during the intensive construction phase of the project, will no doubt benefit supporting local service companies operating hotels, taxis and food outlets. The exact extent of this is not possible to quantify at this stage of planning because it will depend on the design of the project. For example, large diameter drilling through rock required at the North Coast site would require many weeks or months of work before construction can start. The drilling vessel may not have on-board accommodation. By contrast a floating turbine solution may require very little port use even taking account of the mooring system and electrical hook-up.

Other ports that have won construction contracts in the wind sector, such as the Port of Mostyn in North Wales, have claimed a very significant positive impact in the local supply chain. However, the Port of Mostyn is supporting larger projects and it is a fabrication base. Since Guernsey will not be operating as a fabrication base and a circa 30MW development is relatively small, the overall impact will be modest and it will not significantly impact the tourist trade.

### 3.3.3 Professional Scientific and Engineering Job Creation

With reference to the earlier examples of EMEC on Orkney and new developments on Anglesey and the Isle of Wight, there are certainly professional employment opportunities that could result from creating an offshore test facility and working towards creating a Centre of Excellence, perhaps in partnership with a suitable university.

Initially a floating wind test facility could attract great interest from industry. This is new technology and there are many new concepts coming forward but very few full scale test facilities. A review of the current technology status prepared by The Carbon Trust in 2015 is available at this website: https://www.carbontrust.com/resources/reports/technology/floating-offshore-wind-market-technology-review/.

Furthermore, it is likely that France will develop floating wind projects and waters west of Guernsey have been identified as suitable. So technology developers may view a small wind development as an opportunity to demonstrate and develop their technology in water close to a major market opportunity.

## 3.4 Economic (and Political)

The major economic and political socio-economic impact to be considered is the impact on the cost of energy for the Guernsey islanders, and also security of electrical supply. The cost of energy is a priority project driver for RET and GEL. The risk of a major cost overrun and the potential for a phased development were considered when evaluating potential locations (ref. the importance weighting of socio-economics in Figure 3.12).

The other major consideration associated with the cost of energy is the strategic choice of project Sponsor and funding. The conclusion presented in Xodus Group's Technical Note No. 5, "Offshore Wind Feasibility Project Sponsor Strategic Overview" (L-500042-S00-TECH-005), is that the project should be primarily funded by the States of Guernsey. Not only does this minimise the project costs, but it retains control within Guernsey and enables socio-economic drivers to remain a priority.

There is no question that the direct cost of energy from offshore wind is currently higher than importing from France or on-island generation, but certainly cheaper than wave or tidal energy.  The political challenge is to ensure that the costs of an offshore wind development are offset by the opportunities the project can deliver.

# 4 CONCLUSIONS

The main drivers for this project are diversity and security of electricity supply to Guernsey and reducing carbon emissions. There are unlikely to any major negative socio-economic impacts other than the cost of energy may increase depending on the cost of imported energy.

This risk is fully understood by the RET and GEL project teams and the project planning is geared to minimising this impact. Other island communities are taking maximum advantage of the wider potential for economic development associated with the natural resources around them. However, the opportunities are challenging to realise and require detailed case by case planning and potentially significant investment. The focus for opportunities should start with existing local supply chain capabilities and only expand beyond this if a strong business case can be established.

# APPENDIX G RISK & OPPORTUNITY REGISTER

Refer to Xodus Group spreadsheet “Offshore Wind - Risk & Opportunity Register Rev 03 April 2016”