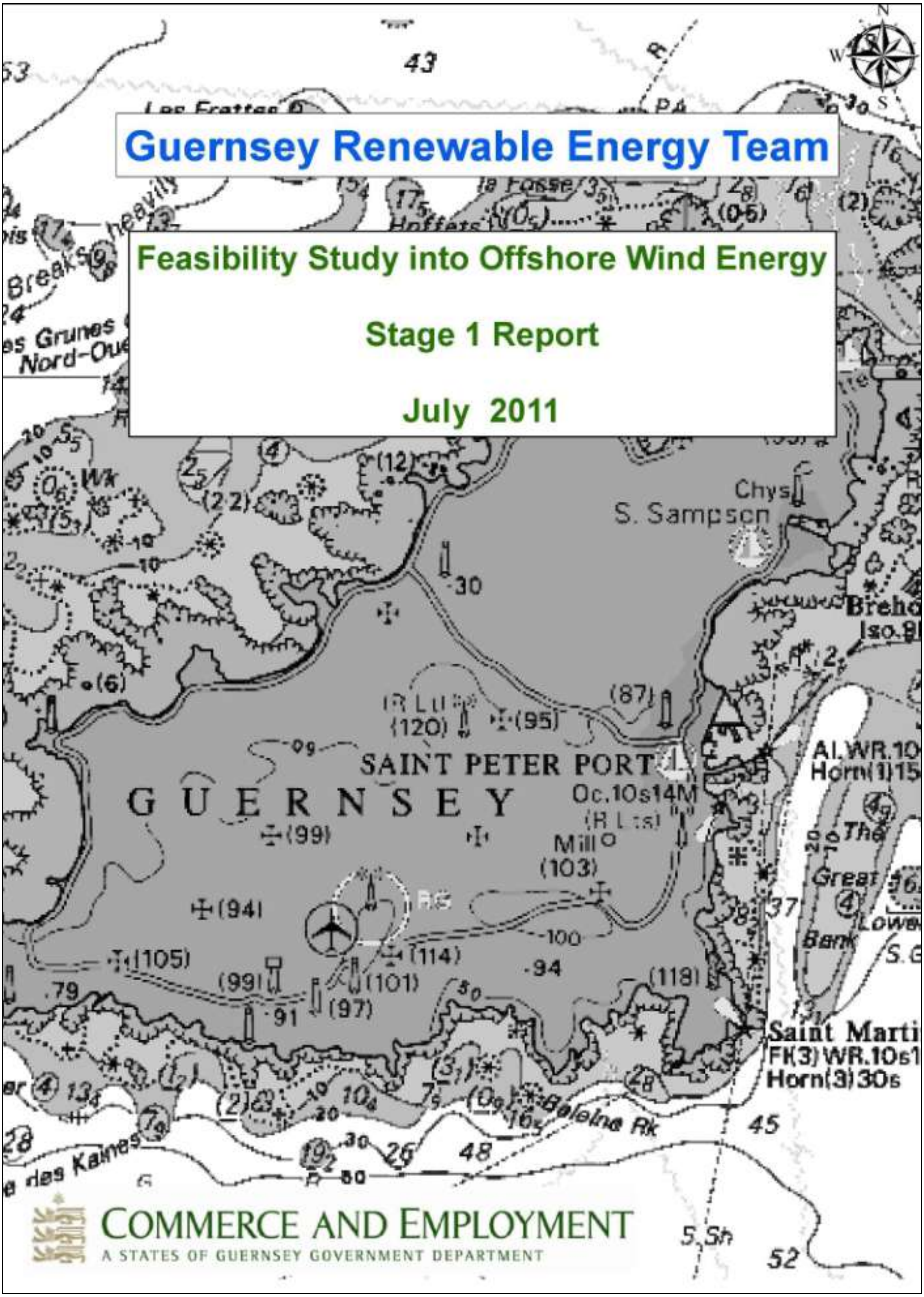
Guernsey Renewable Energy Team

Feasibility Study into Offshore Wind Energy

Stage 1 Report

July 2011



COMMERCE AND EMPLOYMENT

A STATES OF GUERNSEY GOVERNMENT DEPARTMENT

GUERNSEY RENEWABLE ENERGY TEAM

FEASIBILITY STUDY INTO OFFSHORE WIND ENERGY

STAGE 1 REPORT

Contents Amendment Record

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GUERNSEY RENEWABLE ENERGY TEAM
FEASIBILITY STUDY INTO OFFSHORE WIND ENERGY

STAGE 1 REPORT

Contents

Executive Summary

This feasibility report has been prepared on behalf of the Guernsey Renewable Energy Team by a team of specialists comprising members of the States of Guernsey's Commerce and Employment Department and their consultant engineers, Halcrow Group Ltd. It is the intention that this feasibility report will allow the reader to gain a broad understanding of the constraints that apply to offshore wind energy development and how these manifest themselves within Guernsey's unique coastal environment.

Two potential development scenarios have been devised for the purposes of this study. These represent what is considered to be practical minimum and maximum short-term deployment opportunities using currently available technology.

- Minimum Development – 12MW (4 x 3MW turbines)
- Maximum Development – 30MW (10 x 3MW turbines)

The study has considered various environmental and technical constraints to development. There appears to be only one potentially suitable deployment zone, off the north-west coast of Guernsey. However, this would be of adequate size to meet the requirements of both development scenarios.

The study has made use of existing available wind record data to estimate the wind resource at likely offshore deployment sites. This has concluded that there is, in all probability, a viable wind resource that is suitable for exploitation for generation of electricity. The energy yields are likely to be comparable with those generated at other offshore generation sites in the UK.

A simple financial analysis was developed for each development scenario. The analysis used range of assumptions regarding costs of deployment, operation and maintenance. A sensitivity analysis showed that the business case is sensitive to any inaccuracies in the wind resource assessment that may be caused by a lack of local wind data.

The cost of offshore wind energy on Guernsey would be higher than that from conventional sources. However, it is likely to be comparable with that from offshore wind farms in the UK, and likely to be lower than current estimates for wave and tidal energy.

The study has recommended a number of actions to allow the development of offshore wind energy to be taken further forward. Whilst the proposal is likely to be both technically and economically feasible, there remain a number of environmental risks that should be addressed at the earliest opportunity, through a Landscape and Visual Impact Assessment, further studies into public attitudes, and confirming the wind resource through the establishment of a local weather station close to the potential deployment site.

1. Introduction

1.1. Background

Initial investigations have been progressed into the potential for wave and tidal energy production in the waters of Guernsey and Sark. The States of Guernsey have achieved key objectives in preparation for marine renewables, including the establishment of primary legislation and the production of a Regional Environmental Assessment[1]. Now, attention is turning to the potential for offshore wind power production.

This report has been prepared on behalf of the Guernsey Renewable Energy Team by a team of specialists comprising members of the States of Guernsey's Commerce and Employment Department and their consultant engineers, Halcrow Group Ltd.

A primary aim of the feasibility study has been to provide information that could be used to form a business case for offshore wind energy production. This has required estimates to be made of both capital and operating costs of generating energy in Guernsey's unique environment, as shown in section 7. A key component of the preparation of a business case is the accurate assessment of the available wind resource, and it is common for this to be undertaken using long-term wind speed records from a nearby meteorological station, in combination with short-term records from a temporary anemometer mast at a prospective deployment site. However, site data is not available to this initial stage of the study, which is split into two separate phases, as follows:

Current Phase - Phase 1 – Preliminary Study

Phase 1 covered in this report has made use of existing available wind record data from Guernsey Airport and the Channel Lightship station using appropriate adjustment factors to estimate the wind resource at likely offshore deployment sites. The work has included the development of a preliminary estimate of the capital and operational costs associated with a notional offshore wind energy array. It is acknowledged that there is some scope for inaccuracies in the assessment due to the incompleteness of the data upon which it is based. However, this feasibility report allows the reader to gain a broad understanding of the constraints that apply to offshore wind energy development and how these manifest themselves within Guernsey's unique coastal environment.

[1] GREC, Regional Environmental Assessment (REA) of Marine Energy (www.guernseyrenewableenergy.com/downloads/Regional-Environmental-Assessment-of-Marine-

Possible Future Work - Phase 2 – Resource Assessment Update

Depending on decisions based on the results of this report, and if instructed to proceed, it is envisaged that Phase 2 will make use of improved wind record data from the Guernsey Renewable Energy Forum (GREF) met mast at Chouet and combine these with existing data from the Airport. For further details, see section 3.2 and Appendix A.

1.2. *Scope and Boundaries of Study*

The scope of this Phase 1 Study was prepared following discussions between George Sauvage of the States of Guernsey's Commerce and Employment Department and Chris Green of Halcrow Group. The geographical scope of the study has been limited to the current 3 Nautical Miles (nm) limit of territorial waters of Guernsey and Sark, but where appropriate, consideration has been given in the text to the potential for future expansion to the 6nm and 12nm territorial limits.

The main outputs from the study are as follows:

- The wind resource assessment - availability and suitability for exploitation with current wind turbine technology;
- A review of available technology, and its application to the required scale of deployment and the unique coastal environment of Guernsey;
- A review of spatial and technical constraints that may apply to the selection of deployment sites;
- Screening and preliminary site selection;
- Selection of a preferred deployment site and development of a concept for an offshore wind energy generation project, including likely number, size and type of turbines;
- Technical and commercial assessment of energy yield;
- Estimates of capital and ongoing operational costs;
- Indication of level of likely feed-in tariff required and comment on the potential impact on electricity prices;
- Production of GIS maps to support the report.

In order to provide a simple and robust business case, it has been necessary to limit the number of potential deployment options for detailed analysis. In discussions with George Sauvage of the States Commerce and Employment Department, it was agreed that potential deployment options would be based on well established turbine technology with a track record showing reliability and longevity of service, and that 12MW and a 30MW array options would be considered. Further information regarding selection of appropriate technology is shown in section 2.

1.3. Offshore, not Onshore

The scope of this study specifically excludes investigations into onshore wind energy. This is due to perceived environmental constraints relating to visual impact, noise and potential interference with aviation, which, in the opinion of the authors, preclude onshore development in the short-term.

It is acknowledged that these constraints also apply to offshore wind energy, but to a lesser degree which does not exclude development.

However, the production of energy from onshore wind turbines is less costly than that from offshore arrays. Therefore if, at some point in the future, economics becomes critical to decisions relating to the energy mix on Guernsey, the onshore wind energy option could be investigated further.

1.4. Current and Possible Future Territorial Limits

The seabed and waters around Guernsey and Sark belong to the UK Crown, represented by The Queen, as the Duke of Normandy. Throughout the coastal waters of the UK, this is managed through the Crown Estate. However, the Crown Estate does not extend to the Channel Islands, and leasing of the seabed is arranged through Her Majesty's Receiver General (HMRG) in the States of Guernsey.

At present, Guernsey and Sark have legal jurisdiction of waters and the seabed to 3nm, with some special areas of legislation (e.g. fisheries) extending to 6 or 12nm. However, neither Guernsey nor Sark can claim to 'own' this area, and ownership rests with the Crown. This matter has been considered thoroughly in Guernsey and Sark's investigations into the potential development of tidal and wave energy. Both communities have applied to the UK Crown for a long-term lease of the seabed to 3nm, and this is anticipated to be forthcoming within the timescales required to develop offshore wind or marine renewable projects to deployment.

Further consideration was given by the States of Guernsey and Sark's Chief Pleas to the further extension of legal jurisdiction, and subsequently the right to lease the waters and seabed out to 6 or 12nm. This would give access to significant additional energy resources. However, for the purposes of this study, it is generally assumed that no deployment of wind turbines would be allowed outside of the current 3nm territorial limit. Where opportunities for future extension would have an impact on the technical and economic conclusions of this report, then these are considered within the text.

2. Review of Available Technology and its Application to Guernsey

In this section, the report discusses the state of the offshore wind industry and available technology for the various parts of the turbines themselves, through to foundations, and common approaches to deployment.

2.1. The State of the Offshore Wind Energy Industry

There are currently 13 offshore wind farms in the waters around the UK with a total of 436 turbines installed with a rated capacity of 1,341MW. There are further 7 projects under construction with a total of 610 turbines being installed which will have a rated capacity of 2,238MW. Another 5 projects with 410 turbines and 1,808MW of installed capacity are approved and either just starting or awaiting start of construction. Moreover, under the remainder of Round 2, Round 3, Extensions to Round 1 and 2 sites and the Scottish Territorial Waters awarded by Crown Estate, there are expected to be further 25 projects with approximately 40,600MW of installed capacity[2].

Around the rest of Europe, there are 17 more projects, the bulk of which are offshore Denmark within the waters around Netherlands, Sweden and Belgium. Further afield, China has started installing large scale offshore wind farms and there are significant prospects being explored in USA, France, Malta and Spain[3] [4].

The offshore wind sector is relatively new and growing very fast despite the much higher costs of offshore wind compared to onshore wind. To date, the dominant manufacturer of turbines in the offshore market is Vestas with their V80 2MW turbine in the early days, moving to the V90 3MW turbine for the larger, more recent projects. Since their first project in 1990, Vestas have installed over 1,000MW of offshore wind power projects in countries within and outside of Europe[5].

The V90 3MW has 2,170 units installed worldwide both onshore and offshore and thus has a strong track record with known performance, and over 250 of these turbines have been installed offshore. The first project to use this turbine offshore was Kentish Flats in 2004. Vestas have recently introduced a V112 3MW turbine with better energy capture from the larger swept area but in December 2010 only two of these turbines had been installed. It is worth noting that the V112 is expected to account for the bulk of offshore turbines from Vestas in 2012 onwards and once track record has been established in the offshore market, this turbine is worth considering in the future. The company recently announced a new offshore turbine the V164 with a rated power of 7MW, but it is not yet clear when this product is likely to be commercially available[5].

[2] RenewableUK, Offshore Wind Farms (www.bwea.com/ukwed/offshore.asp)

[3] RenewableUK, Offshore Wind Farms, Worldwide (www.bwea.com/offshore/worldwide.html)

[4] reNews Europe (www.renews.biz)

[5] Vestas (www.vestas.com/en/)

The other main supplier of turbines to the offshore market is Bonus Wind Turbines who were taken over by Siemens and is now known as Siemens Wind Turbines. They have 152 of their 107m diameter 3.6MW turbines installed offshore, with further 36 smaller turbines of 2MW and 2.3MW rating. The 3.6MW turbine is a relatively recent introduction produced first in 2004, with the first offshore project using this turbine in 2007. The company has secured the bulk of current orders for the offshore projects being constructed and is introducing a 120m rotor diameter turbine[6].

There are a number of other minor players:

- **REpower** have two of their 5MW turbines installed as a demonstration project on the Beatrice field off the east coast of Scotland, with further 30 turbines scheduled for the Ormonde project off the north-west coast of England[7].
- **Bard** from Germany have 80 of their 5MW turbines scheduled to be installed this year on the Bard 1 project offshore in northern Germany[8].
- **Multibrid/Areva** again from Germany are developing a large 5MW offshore turbine[9].
- **General Electric (GE)** are positioning themselves with a 3.6MW offshore turbine[10].
- **Clipper Wind**, from USA and UK, now owned by United Technologies are developing 5MW and 10MW turbines[11].
- From Asia **Goldwind** and **Sinovel** from China are installing 3MW plus turbines offshore, **Mitsubishi** from Japan and **Doosan** from Korea are also developing 3MW plus offshore turbines[12 13 14 15].
- **ABB/Acciona** and **Gamesa** from Spain are also developing large offshore turbines[16 17].

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[6] Siemens (www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/)

[7] REpower (www.repower.de)

[8] BARD (www.bard-offshore.de)

[9] Areva (www.areva-wind.com)

[10] GE (www.ge.com)

[11] Clipper Wind (www.clipperwind.com)

[12] Goldwind (www.goldwindglobal.com)

[13] Sinovel (www.sinovel.com)

[14] Mitsubishi Power Systems (www.mpshq.com)

[15] Doosan (www.doosan.com)

2.2. *Turbine Selection*

In terms of the turbine selection for Guernsey for a base case analysis, we would suggest that the two manufacturers who should be considered, as they have well proven products with significant track record over many years both within the wind industry but also in the offshore sector, are **Vestas** and **Siemens**. They are the first division players.

Siemens have a reputation of not being interested in small projects such as those being considered for Guernsey and it may prove difficult to enter into a meaningful dialogue with them.

After a thorough revision of the Vestas products, we propose the **Vestas V90 3MW** turbine as perhaps a slightly conservative choice. This turbine type is highly utilised in the offshore wind industry and proves reliable. Compared to other products, the 90m rotor is more capable of withstanding the relatively high wind conditions off the north-west of Guernsey.

2.3. *Foundations*

The vast majority of offshore wind turbines which have been installed so far have been in relatively shallow water depths, up to 20m. They have also tended to be in areas where the seabed comprises sand or clay for a significant depth, allowing single monopile foundations to be driven into the sea floor to support the turbines. In some instances where the seabed conditions are hard rock, such as in case of the offshore turbines at Blyth, sockets have been drilled into the rock and the monopiles grouted into the sockets. In recent projects monopiles have been used for increasingly deeper sea water conditions up to 30m and may in future be used for even deeper water. Until the last few years the restriction on monopiles was largely due to the ability of the installation vessels to handle the weight of the piles. A significant number of new vessels or refits of older vessels with larger crane capacity has enabled them to undertake installation of piles up to 400 tonnes.

Occasionally, caisson foundation have been used, notably for the Middelgrunden project off Copenhagen, where gravity caisson foundations have been constructed in a dry dock, floated out to site and sunk onto prepared seabed areas. This is not common and there have been reports from the project on the caissons settling over time.

Other foundation structures used to date are conventional jacket fabrications similar to those used for small offshore oil and gas platforms, but these have been used for the larger 5MW and plus turbines and in deeper water conditions, the reason being that with the larger turbines and also because of the greater water depth the overturning

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[16] Acciona (www.acciona.com)

[17] Gamesa (www.gamesa.es/en/)

moment on the foundation is greater and the load needs to be spread over a greater area. Such jacket structures were used on the 5MW REpower turbines for the Beatrice and Ormonde projects.

There are also proposals for tripod and quadropod foundations, examples of which are being developed by manufacturers such as Bard and Multibrid/AREVA.

In general, the simplest and most common offshore wind turbine foundation is a monopile, applied in a large number of wind farms, among them Blyth, Scroby Sands, Kentish Flats or Horns Rev[18]. Jacket structures are relatively expensive and currently restricted to large turbines and/or deep water applications.

The selection of photos below shows transport and installation of various offshore wind farm foundations.

[18] EWEA, Wind Energy – The Facts, A guide to the technology, economics and future of wind power, 2009

Figure 2.1 – Jacket structure for the Beatrice offshore wind project being towed out to site (photo - Courtesy REpower)

Figure 2.2 – Pre assembled 5MW REpower turbine being installed on jacket structure for Beatrice (photo - Courtesy REpower)

Figure 2.3 – Bard 5MW turbine (photo – Renewable Energy Development[19])

[19] Renewable Energy Development (renewableenergydev.com/red/wp-content/uploads/2010/10/Bard-1-Offshore-Wind-Project.jpg)

Figure 2.4 – Bard 5MW transition piece on barge before installation onto multiple piles (photo – Renewable Energy World[20])

Figure 2.5 – Multibrid tripod foundations being towed out (photo - Renewable Energy World[21])

Figure 2.6 – Multibrid tripod foundations being installed (photo – Recharge[22])

The choice of foundation type to use for a potential deployment on Guernsey will depend on the geology and depth of water at the selected deployment site (see section 3.3). The REA for marine energy resources (wave and tidal) indicates that off the north-

[20] Renewable Energy World (www.renewableenergyworld.com/assets/images/story/2008/11/18/4-1332-5-mw-bard-near-shore-wind-turbine-erected-in-germany.jpg)

[21] Renewable Energy World (www.renewableenergyworld.com/assets/images/story/2009/5/26/1-1332-areva-multibrid-s-series-production-an-ambitious-growth-path.jpg)

[22] Recharge (www.rechargenews.com/multimedia/archive/00030/ALPHA_VENTUS__230509_30157b.jpg)

west coast of Guernsey there is very little sand or clay on the seabed and it is basically quite hard exposed rock. Given the industry's general lack of experience with caisson foundations we would propose that for the base case assessment we should consider monopiles grouted into rock sockets.

Worth mentioning is Carbon Trust's Offshore Wind Accelerator initiative, a design competition for a number of new and promising foundation concepts aimed to see if the costs of these structures can be reduced. The Carbon Trust has recognized that mass-deployment of offshore wind is inevitable to meet the UK's 15% renewable energy target and that among success factors are faster rate of installation and capability to install in more challenging conditions, i.e. deeper water further away from the shore, for which robustness and cost effectiveness of design are crucial. The organization reacted to this need by running the competition, which is currently in the design optimisation stage[23].

2.4. Transition Pieces and Towers

Once the foundation piles are in place the next part of the equipment, namely the transition piece, can be installed. The structures are grouted to the top of the pile and are complete fabrications with J tubes for power cable take-offs, boat access points, communication cables etc.

Once these have been installed, the turbine towers, nacelles and rotors can be installed. Figure 2.7 below shows all components of an offshore turbine.

[23] Carbon Trust, Offshore Wind Accelerator (www.carbontrust.co.uk/emerging-technologies/current-focus-areas/offshore-wind/pages/offshore-wind.aspx)

Figure 2.7 – Components of an offshore wind turbine (image – the Crown Estate[24])

[24] The Crown Estate, A Guide to an Offshore Wind Farm (www.thecrownestate.co.uk/guide_to_offshore_windfarm.pdf)

2.5. Installation Vessels

There are an increasing number of installation vessels being brought into service which can handle all aspects of the offshore wind farm installation process. Which ones are used will depend on their commitments at the time over the wide range of offshore projects being developed.

The following illustrations show various stages of installation process.

Figure 2.8 – MPI Resolution installation vessel about to install monopiles and transition pieces (photo - Courtesy of MPI)

In figure 2.8 above the installation vessel can be seen to be carrying monopiles (rust coloured elements lying along the centre of the deck) and transition pieces (yellow upright fabrications).

Figure 2.9 – MPI Resolution installation vessel completing installation of an offshore turbine (photo - Courtesy of MPI)

In the figure 2.9 above the tower sections can be seen standing upright on the main deck and the root ends of the blades in their cradles are seen at the front end of the main deck. The vessel is completing the erection of a turbine with the installation of the final blade.

2.6. Installation and electrical connection

It is assumed for this project that the various parts of the installation will be assembled at a suitable local port, such as Cherbourg, loaded onto the installation vessel and taken directly to site.

Many of the earlier and smaller projects utilised local marshalling of turbines and foundation parts and then relatively simple and conventional jack up rigs to carry out the installation. Later and larger projects have utilised purpose built installation vessels such as the MPI Resolution and have tended to use larger ports, further from the installation site for marshalling components and pre assembly and pre commissioning of turbines. Some utilities have commissioned and are building their own installation vessels and some of these will be able to transport ten complete turbines in one trip.

For a small project of four or ten turbines it is likely that use of a jack up rig and a local port will be the optimum solution. However, if a project on Guernsey was to 'piggy-back' a larger deployment in Jersey or French waters, then the use of a purpose built installation vessel and a larger more distant port with more pre assembly may be preferred. It will depend on turbine supplier and what other projects are ongoing at the time as to which method, equipment and port is selected. For example the Thanet offshore project off the Kent coast used Dunkirk in Belgium for marshalling and pre-assembling turbines before shipment to site (see the image 2.10 below). On this project 8 complete turbines were shipped on a single vessel and installed at a rate of one per day on prepared foundations.

Figure 2.10 – Port of Mostyn turbine pre-assembly area (photo – courtesy of Port of Mostyn)

The turbines will be erected and then the subsea 33kV power cables will be layed along the seabed. The seabed conditions are likely to preclude burial or trenching, and the cable will require protection with dumped rock armour together with localised placement of larger rock pieces as necessary. The cable will be brought ashore as close as possible to an existing or new substation. As described in section 3, on Guernsey, the most suitable wind energy resource is likely to be found along the north-west coast. A suitable cable landfall point may be at Cobo Bay and this would require connection by laying cables within roads to the Le Murier substation or a similar new facility nearby.

Control and instrumentation cables will be layed as a fibre optic link with the power cables and then taken back to a control centre, either close to the sub-station, or at Guernsey's main power station at St Sampson.

The turbines will have internal step-up transformers such that the outgoing voltage from the switchgear will be 33kV, thus avoiding the need for any other transformer stations or platforms as found on larger offshore projects.

2.7. Opportunities for Integrated Wind and Wave Energy Generation

A number of wave energy technologies in development allow for integration with wind turbines (eg. Green Ocean Energy's Wave Treader). The advantages include:

- Wind and wave energy resources are normally available in the same deployment areas
- The foundation, support structure, cable connections and other infrastructure may be shared
- At a particular site, the wave energy resource may be expected to be less intermittent and more predictable than the wind resource
- The combination of devices could provide a more continuous supply

The REA of wave and tidal energy found that there was, in all probability, a viable wave energy resource off the north-west coast of Guernsey. However, suitable wave technologies are at the early stages of development and there are no full-scale prototypes yet deployed. Therefore, for the purposes of the business case developed within this report, these opportunities have not been considered further.

Figure 2.11 – Green Ocean Energy's Concept for an Integrated Wave Energy Device (photo – www.greenoceanenergy.com)

3. Constraints to development

3.1. Introduction

Through its partnerships with the former Shadow Guernsey Renewable Energy Commission (GREC), Sark's Government (the Chief Pleas), and the Guernsey Renewable Energy Forum (GREF), the States have already undertaken a strategic environmental investigation into the potential impacts of wave and tidal energy production. This is recorded in the Regional Environmental Assessment (REA). There is a significant overlap in the infrastructure requirements and potential environmental impacts of offshore wind and other marine renewable (wave and tidal) energy developments.

The proposal does not allow for repetition or detailed reference to the REA, as this would be wasteful. However, where obvious environmental constraints apply to the selection of potential deployment sites, the study will draw upon key information and recommendations contained in the REA.

This feasibility study will not include a formal environmental impact assessment of offshore wind energy production, and environmental matters are only given consideration insofar as they may impact on outline site selection. If firm proposals are to be developed to implement wind energy production within the waters of Guernsey or Sark, then it would be recommended to carry out a separate study to update the existing REA.

The most significant potential constraints that apply to the selection of potential deployment sites for an offshore wind farm are considered in this section and used as the basis of screening and site selection as shown in section 4.

3.2. Wind resource

Introduction

This section of the report describes the wind resource that is understood to exist within the territorial waters of Guernsey and Sark. It is clear that, for wind energy generation to be feasible, there must be a wind resource of sufficient magnitude. Furthermore, the wind resource should be of a suitable quality insofar as it is free from excessively high or low wind speeds, or turbulences, causing turbines to shut down. The scope of this study requires that potential deployments sites are considered within the 3nm territorial limits. As such, some potential sites may be subject to sheltering effects from the islands. The analysis has found that, consistently with the expectations for this part of Europe, there is a predominant wind direction from the west. This significantly limits the number of available sites around the coast, and the study has focussed on the west and north-west coasts of Guernsey. Other areas, including those around Sark, have been discounted due to these sheltering effects.

Through his connection with the Guernsey Renewable Energy Forum, Martin Crozier has prepared a meteorological analysis of the wind climate at Guernsey Airport. This is included in Appendix A, and gives detailed advice on the ongoing measurement of wind data here and at the temporary met mast commissioned by GREF for deployment at Chouet.

The wind energy resource assessment in this report makes use of both the existing records from the airport and a number of other data sources, to provide an estimate of the energy yield from two alternative conceptual arrays as shown in section 7.

Historical Wind Records

Wind speed data has been obtained for Guernsey Airport meteorological station (Lat 49.43, Long -2.6) from two sources, namely from the archive of weather records[25] and from the supervisor of the station, Martin Crozier.

The historical weather records provide daily and monthly wind speed averages. Analysis of the time period 2000-2011 has indicated an annual average wind speed of 5.7m/s at a height of approx 110m above sea level. Data sourced from the station supervisor have provided information on wind speed and direction for the time period 2006-2010, and confirmed the mean annual wind speed of 5.7m/s. On the basis of annual reports provided alongside the data, it has been identified that the predominant wind speed range observed at the airport within the last 30 years has been approximately 2 to 11m/s (4-21 knots), and the predominant direction of wind has been 230-280 degrees, which means south-westerly and westerly wind.

Wind speed data has also been sourced from a reference station in the middle of the English Channel, namely Channel Lightship station 62103 (Lat 49.9, Long -2.9) at a height of 14m above sea level. Daily and monthly wind speed averages have been analysed for the time period 2000-2011, and the resulting mean annual wind speed is in the range 8.61-8.76m/s.

[25] Historical Weather Records - United Kingdom (www.tutiempo.net/en/Climate/United_Kingdom/GB.html)

Estimated Annual Average Wind Speed

As an initial feasibility assessment, Phase 1 of this study has not provided for the creation a digital terrain model to assess how the wind speed will vary across the Island and the inshore waters. No absolute or accurate method of determining the annual average wind speed in the selected area off the north-west coast of Guernsey can be developed solely on the basis of extrapolation of the known data described above. Hence, likely wind speeds need to be assessed and estimated using an additional range of published data based on large scale atmospheric models such as the UK Marine Energy Atlas[26], the European Wind Energy Atlas[27], satellite data and specific existing and proposed offshore wind farm site data, with interpolation based on experience.

Based on the open sea data for the Channel Lightship station, the annual mean wind speed can be estimated at a likely hub height for offshore wind turbines, 80m, by using a number of methods.

One method using a programme developed by the Danish Wind Industry Association[28] gives an annual average wind speed of 10m/s at 80m height.

If one goes back to the basic seventh power law, one can also calculate the wind speed at 80m and using an exponent of 0.11 for open water rather than the usual 0.143 or 1/7 (used in early days of wind industry when all wind energy projects were onshore). The result is 10.43 m/s.

Other variations and methods give similar answers.

One of the methods utilised is described in more detail in the following steps:

1. Collect (estimate) wind speed data and derive mean annual figure v_1 [m/s] at a height H_1 [m]
2. Identify desired turbine hub height H_2 [m]
3. Divide the hub height H_2 by the height of wind speed measurement H_1
4. Raise the resultant ratio to the power of the shear exponent n. Shear exponent varies with different terrain, and is 0.1 for the open water surface.
5. Apply (by multiplication) the resultant factor to the speed v_1 at height H_1 to calculate speed v_2 at height H_2.
6. The resultant wind speed for this exercise is 10.25m/s.

The equation that summarizes this method is:

$$v_2 = v_1 * (H_2/H_1)^n$$

[26] Atlas of UK Marine Renewable Energy Resources, Wind Map (www.renewables-atlas.info/wind_map.aspx)

[27] The World of Wind Atlases – Wind Atlases of the World (www.windatlas.dk)

[28] Danish Wind Industry Association (www.windpower.org/en/)

It should be stressed that these figures are for open water in the middle of the English Channel. They would be appropriate to use if the proposed wind farm was to be situated well out to sea, for example if a 30nm limit was to be considered.

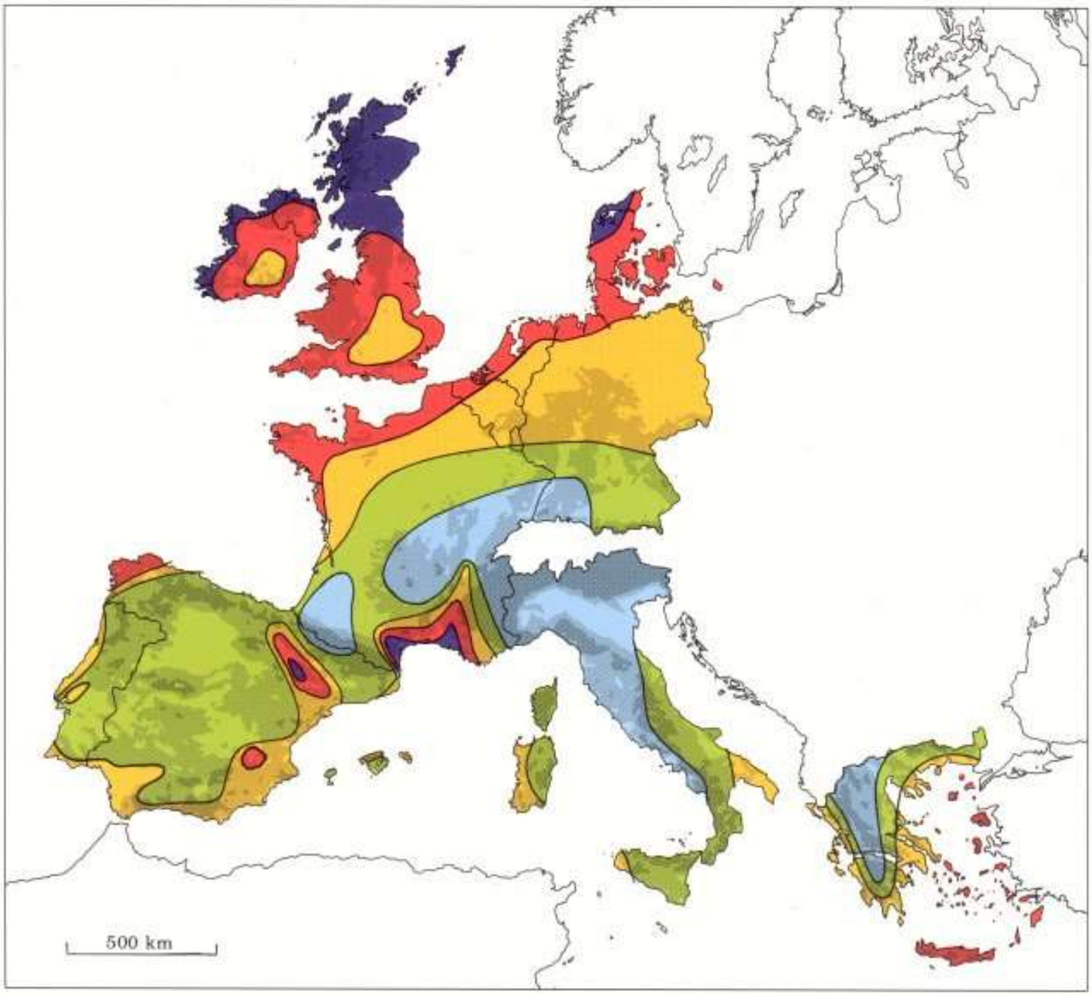
It is of interest to compare these results with the predicted wind speeds for the proposed Argyll Array and Islay wind farm projects in the west of Scotland, which from satellite data are expected to be 11.19m/s and 10.9m/s respectively at 100m height[29].

Whilst the current inshore site is well exposed to the north and west, there will inevitably be some sheltering from the south and east which, although the prevailing wind direction is south westerly and westerly, will lead to a reduction in annual average wind speed. In general the winds coming from the sectors from the north east through the north and round to the south west are travelling long distances over open water and will be strong and consistent with very little turbulence. Those winds which approach the wind farm site after passing over the island of Guernsey will be disrupted and turbulent, and thus weaker with a lower average speed.

If one looks at the European Wind Energy Atlas, they have derived wind energy contours for both onshore and offshore wind resources, as presented in the images 3.1 and 3.2 below.

[29] 4COffshore, Offshore Wind Farms Database (www.4cOffshore.com/windfarms)

Figure 3.1 – Wind resource at 50m above ground level (photo – European Wind Atlas, Copyright © 1989 by Risø National Laboratory, Roskilde, Denmark)[30].

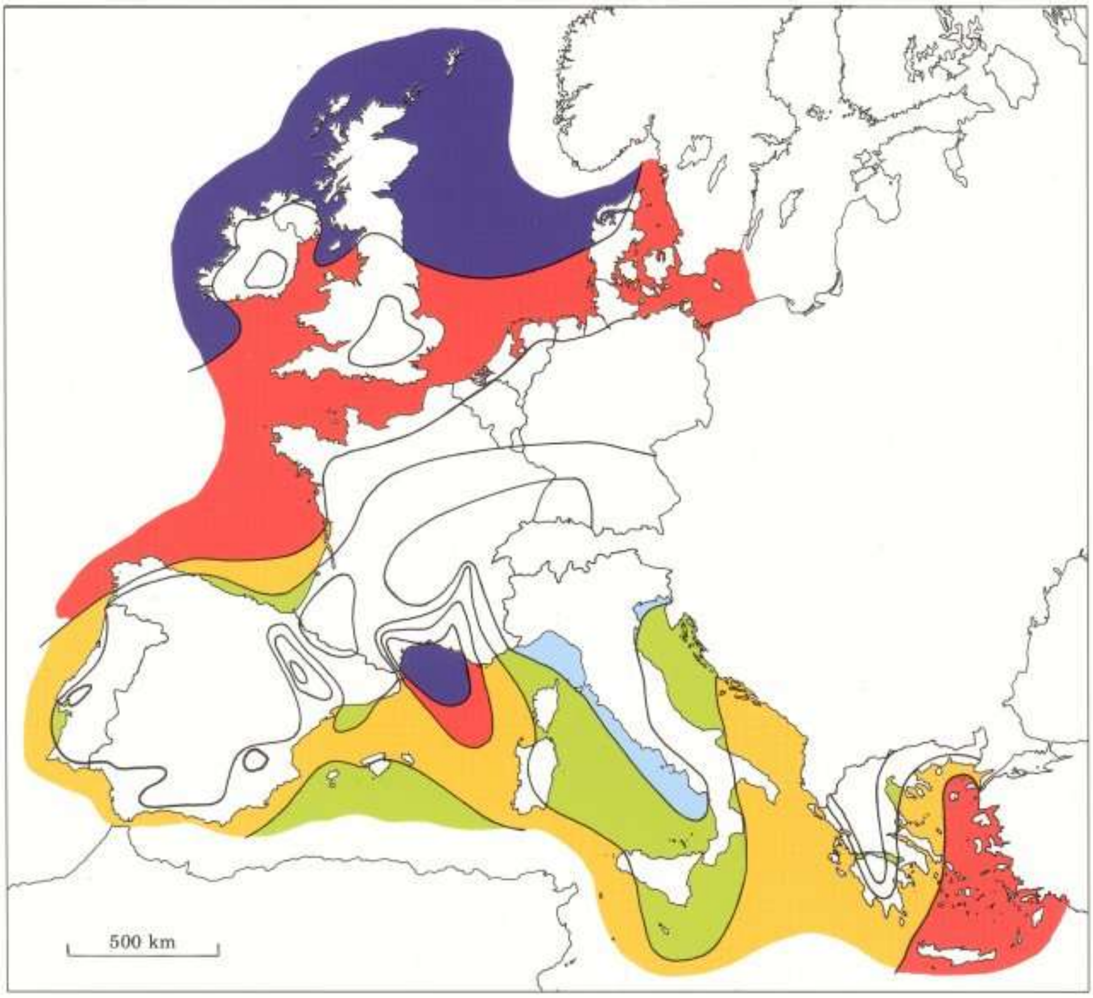


Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

The map shows the so-called generalised wind climate over Europe, also sometimes referred to as the regional wind climate or simply the wind atlas. In such a map, the influences of local topography have been removed and only the variations on the large scale are shown.

[30] The World of Wind Atlases – Wind Atlases of the World, European wind resources at 50 metres a.g.l. (www.windatlas.dk/Europe/landmap.html)

Figure 3.2 – Wind resource over open sea (photo – European Wind Atlas, Copyright © 1989 by Risø National Laboratory, Roskilde, Denmark) [31]



Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

The map shows the so-called generalised wind climate over Europe, also sometimes referred to as the regional wind climate or simply the wind atlas. In such a map, the influences of local topography have been removed and only the variations on the large scale are shown.

[31] The World of Wind Atlases – Wind Atlases of the World, European wind resources over open sea (www.windatlas.dk/Europe/oceanmap.html)

One can see from the first map shown in figure 3.1 that Guernsey lies in the band 8-9m/s over open sea at 50m altitude and 7-8.5m/s at the sea coast. From the second map presented in figure 3.2 the offshore wind speeds in this area are again 8 to 9m/s at 50 m altitude. Increasing to 80m hub height would add 0.25 to 0.3m/s to these wind speeds.

The UK Marine Energy Atlas which uses a very coarse grid gives average wind speed at 100m of 9.8-9.9m/s in open water in the area of the Channel Light Vessel and 7.68m/s in the inshore area off the Guernsey coast[32].

It is of interest to note that North Hoyle wind farm off the North Wales coast and Kentish Flats wind farm off the North Kent coast, both relatively inshore and both less exposed than Guernsey, both have an annual average wind speed of 8.7m/s.

From the above it is our opinion that a reasonable estimate of the annual average wind speed for the inshore Guernsey site is 8.5m/s with a lower estimate of 8m/s and an upper estimate of 9m/s.

For an offshore site in open water out towards a 30nm limit the central estimate would be 10m/s with a lower estimate of 9.5m/s and an upper limit of 10.5 m/s. These values have been taken forward into the energy yield calculations discussed in section 7.

3.3. Bathymetry and seabed conditions

The wind resource assessment described above found the predominant wind direction to be from the west. This has limited potential deployment areas to the west and north-west coasts of Guernsey, and it is considered that there are no potential sites around Sark.

Current foundation technologies are described in section 2.3, which concludes that the exposed bedrock is likely to be hard, and the Wave and Tidal REA desk study identified that the north-west coast is formed predominantly from granodiorite. However, this would not present insurmountable problems for the formation of foundations, as it can be drilled using appropriate modern equipment.

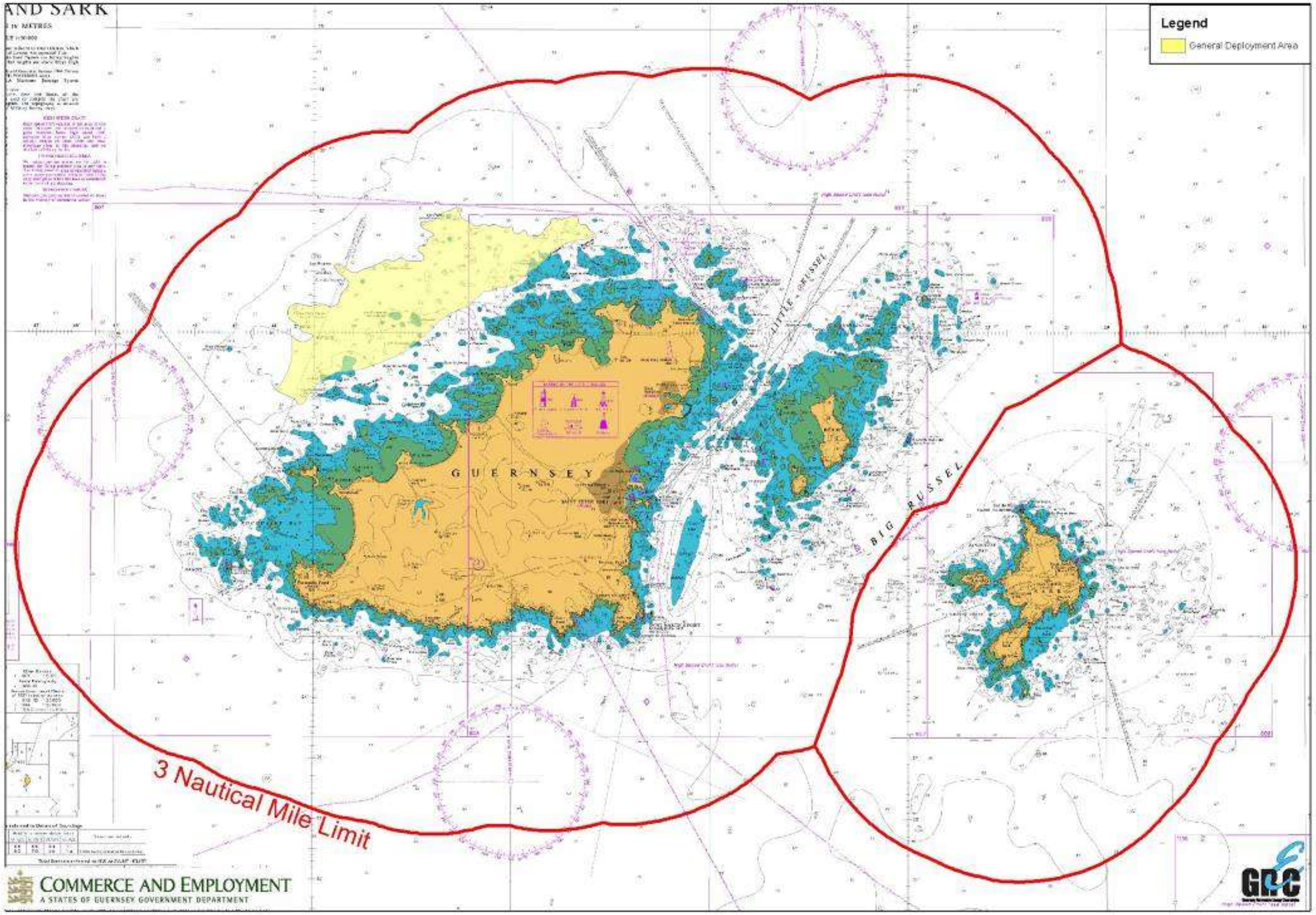
If tried and tested turbine and foundation options are to be used, then it should be aspired to find a potential deployment site with a suitable wind resource and a flat seabed in depths of water between 10 and 30m. A review of the UK Admiralty Chart for Guernsey, Herm and Sark (ref. 3654) indicates that much of the Coastline of Guernsey and Sark is dominated by steeply sloping seabeds that present very deep water within a few nm of the shore. However, there is a large area of relatively flat seabed off Vazon and Cobo on Guernsey at between 20 and 30m depth. This represents the most likely suitable deployment area and is shown on figure 3.3. It is important to note that the area shown is large in relation to the area required to accommodate either of the two

[32] Atlas of UK Marine Renewable Energy Resources, Wind Map (www.renewables-atlas.info/wind_map.aspx)

deployment options considered in the outline business case. Furthermore, as water depths are significantly deeper beyond the current 3nm territorial limit, there would appear to be no opportunities for development of wind energy further offshore using currently available technology.

As far as Sark is concerned, the study concludes that due to likely shadowing effects of Guernsey and Herm, and the lack of level seabed at an appropriate depth within its waters, Sark would not present good opportunities for offshore wind generation. Hence, it is excluded from a further analysis of constraints.

Figure 3.3 – Likely General Deployment Area (image - Guernsey Renewable Energy Team)



3.4. *Sea-state and tidal conditions*

The north-west coast of Guernsey is exposed to the Atlantic Ocean, and was identified in the REA for Wave and Tidal Energy as suitable for wave energy generation. The average significant wave height shown on the BERR Atlas suggests is of the order of 1.51-1.75m[33].

Turbine structures and foundations would be designed to withstand a 1:100 year design wave condition. If wave climate data were to be obtained from a wave buoy survey undertaken at the deployment site, this condition could be calculated. However, for the purposes of this study, the conditions are not considered to present any constraint to development.

The REA also investigated the tidal regime around the coasts of Guernsey. This was done through the construction and interrogation of a hydrodynamic tidal model and through consideration of the Admiralty Chart. These indicate an average peak spring tide velocity of approximately 1.5m/s. Whilst further surveys and analysis would be required in the development of an actual scheme, these conditions are not considered to present any constraint to development at this time.

3.5. *Navigation*

The Wave and Tidal REA considered the impact that renewable energy arrays could have on marine navigation and safety. Through the assessment of charts, search and rescue arrangements and AIS (Automatic Identification Systems) data, it identified key vessel routes throughout the study area. The rocky nature of the north-west coast means that it is avoided by large vessels and it is unlikely that an array of wind turbines would affect commercial or passenger traffic.

The nature of the coast in the likely deployment area raises questions regarding the safety of any deployment operations. It is important to note that construction vessels are able to be positioned and held in position with very high degrees of accuracy through the use of Dynamic Positioning (DP) systems. Therefore, whilst the rocky nature of the coast would be carefully considered during the siting, planning and implementation of deployment operations, it is not considered to be a significant constraint to development.

The REA found that there are a number of surface floating or surface piercing wave and tidal devices in various stages of technical development. There are concerns that an array of such devices could attract sight-seers and this in itself could create safety risk for small leisure crafts. This could equally apply to an array of wind turbines. However, wind turbines do not incorporate dangerous features such as low or sub-surface

[33] Atlas of UK Marine Renewable Energy Resources, Wave Map (www.renewables-atlas.info/wave_map.aspx)

obstructions that could be difficult to see, or mooring lines. Mitigation for such risks to small vessels can take the form of a marked Safety Zone around the turbines.

There is a further navigation risk presented to fishing vessels and fishing activity. This is covered in section 3.12.

3.6. Grid capacity

The Wave and Tidal REA made investigations into the potential for receiving renewable energy from a grid-connected offshore array of generation devices. The existing network is arranged to support the generation and import of electricity to the eastern side of the Island, and this is also the location of greatest usage. There is a general flow of electricity from the urbanised eastern side of Guernsey out towards the more rural areas of the west. Therefore, the connection of a wind turbine array off the north-west coast could be more problematic.

This study has benefited from early dialogue with Guernsey Electricity Ltd (GEL), the island's publicly owned generator and distributor. Discussions with Sally-Ann David of GEL indicate that a connection under the smaller development scenario considered (12MW) would not require any additional work to upgrade the surrounding network. There is already a substation at Le Murier , and GEL are investigating opportunities for further substations along the north-west coast.

However, GEL indicate that the larger development scenario considered by the study (30MW) would require additional works to upgrade or provide additional substations, together with cable upgrades.

Due to fluctuations in the available wind energy resource, the introduction of renewable energy generation would introduce variability into the existing supply mix. By contrast, under the existing arrangements, generation from fossil fuel sources or imported electricity from Jersey and France is normally stable. If wind turbines are installed, GEL would be required to take more corrective action in the management of other generators in order to balance inputs.

To properly understand the impact of specific generation proposals on the existing grid infrastructure, detailed power system studies would be required. Without the benefit of such studies, any predictions made regarding the impact of additional generation capacity are speculative. Nevertheless, the existing grid capacity does not appear to present any insurmountable problems.

3.7. Connection

Wind turbines would be connected to land via a subsea power cable. The seabed conditions are likely to be too hard to allow burial or trenching, and the cable would be laid directly on the seabed. This would be protected with rock armour, and brought ashore and routed along to an existing or new substation. Control and instrumentation cables will be layed as a fibre optic link with the power cables and then taken back to a control centre, either close to the sub-station, or at Guernsey's main power station at St Sampson.

The routing of the cable to landfall would be complicated due to the presence of wrecks, rocky outcrops and other environmental constraints. The Wave and Tidal REA identified important archaeological sites at the beach at Vazon, and a more suitable route may be available for landfall at Cobo.

3.8. Planning and Legislation

The States of Guernsey are a UK Crown Dependency. As such, it has its own laws that are, for the most part, independent from the UK. The States of Guernsey are in the process of enacting the Renewable Energy (Guernsey) Law, 2010. This will cover the planning, deployment, operation and decommissioning of renewable energy devices within the territorial seas to 3nm. Although the law is not specific on the type of devices that may be used, it does not preclude wind turbines. Secondary legislation and regulations are in preparation and due for enactment over the next few years and they may be easily adapted for use with wind energy.

Guernsey also has its own Pollution Laws and an equivalent of the UK's FEPA legislation to control deposits at sea[34].

Onshore components will be covered by Guernsey's existing planning laws and, as per the Renewable Energy Law, developers are required to make a formal application that considers the environmental impact (including visual and human aspects) of their proposals.

For the purposes of this study and subject to the consideration of individual project applications, it may be assumed that there will be no fundamental obstruction due to any existing or proposed planning legislation.

3.9. Aviation

Guernsey operates a busy airport that provides for daily commercial services to the UK, the other Channel Islands and a small number of other European destinations. Guernsey's airspace is used by air traffic to and from Jersey and some French regional airports. If installed in the identified most likely deployment site, offshore wind turbines would be unlikely to directly interfere with normal flight paths. However, wind turbines are known to present difficulties for Radar systems.

[34] States of Guernsey, Office of Environmental Health and Pollution Regulation (www.gov.gg/ccm/navigation/government/office-of-environmental-health-and-pollution-regulation)

Discussions with the Guernsey Renewable Energy Forum (GREF) and Chris Arnold of Guernsey Airport have identified that wind turbines can present false contacts and other interference signals to Radars used for Air Traffic Control. This is particularly the case with older systems that have limited computing power to process the signals. Modern systems are designed to allow identification and filtering of signals from static objects such as wind turbines, such that the presence of a small number of turbines could be accommodated.

Guernsey Airport in planning to upgrade its Radar systems in the next few years, and it is anticipated that a replacement system will be installed within the time required to develop offshore wind energy projects to deployment, and would be able to accommodate an array of turbines.

However, Fergus Woods, Director of Civil Aviation for Guernsey and Jersey, has recommended a cautious approach, as quoted below:

" Wind farms have huge potential to interfere significantly with airport operations; both in terms of routing traffic to avoid their over flight and, more importantly the potential for interference with radars, the creation of spurious returns and even total masking of radar returns. The problems are not simply solved by the use of modern radars, which can have filters incorporated which help reduce the interference.

I would suggest that any proposed development should take account of the UK CAA publication CAP 764, which gives good advice and background on wind farms and aviation. The UK CAA has had to deal with a number of these developments near airports, and they are recognised as leaders in the field of advising on the safeguarding of airports and their associated air traffic facilities with respect to wind farm development in the vicinity of airports. The ones in the SW of Scotland near to the approaches to Glasgow Airport are a case in point."

It is clear that significant further work is required in updating the REA to reflect the potential impact on aviation from wind turbines, and a full impact assessment would be required prior to development of any specific project.

3.10. Noise and Visual impact

Guernsey is well known for its distinctive and attractive landscape, which is highly valued by residents and tourists alike. A Rural Area Plan has been prepared by the States of Guernsey's Environment Department and this aims to protect and preserve the landscape and to control development[35].

The whole of the coastline of Guernsey is defined in the Rural Area Plan as an 'area of high landscape character', and there is an almost continuous coastal footpath around

[35] States of Guernsey, Detailed Development Plans (www.gov.gg/ccm/navigation/environment/planning/planning-policy/detailed-development-plans)

the island. It is likely that an offshore wind farm development will be clearly visible from the coastal footpath, beaches and properties that enjoy views of the north-west coast.

Studies have been undertaken in the UK into the value that people place in their local coastal landscape character. Often, the expansive and unbroken horizons of sea views are cited as being of particular importance. However, these opinions are frequently countered by those who consider renewable energy installations to be points of interest in coastal views. The Guernsey Renewable Energy Forum (GREF) has undertaken an initial survey of public attitudes towards offshore wind energy. The results of this have been published[36]. Although the sample population was small and (to some degree) self-selected, the results were generally positive. This study recommends further public attitude surveys in association with a Landscape and Visual Impact Assessment.

It is clear that wind turbines in the likely deployment area would have an impact on landscape character. The impact would be dependent on the proximity of a development to the shore, the surface area, colour and height of the equipment above water, and the numbers of people who will be affected. Secondary impacts may also be caused through actions taken to mitigate navigational safety risks, which may require the provision of lighting and marking to increase the visibility of the turbines.

It must be acknowledged that the siting of turbines within 3nm of a busy shoreline is not common practice, and viewing distances of between 6 and 12nm are more common. It is clear that, if offshore wind energy is to be considered seriously in the short-term, then further studies (eg. a Landscape and Visual Impact Assessment) will be required into the landscape and noise impact of potential arrays, and the results of these considered carefully alongside the economic and environmental benefits that could be provided by offshore wind energy.

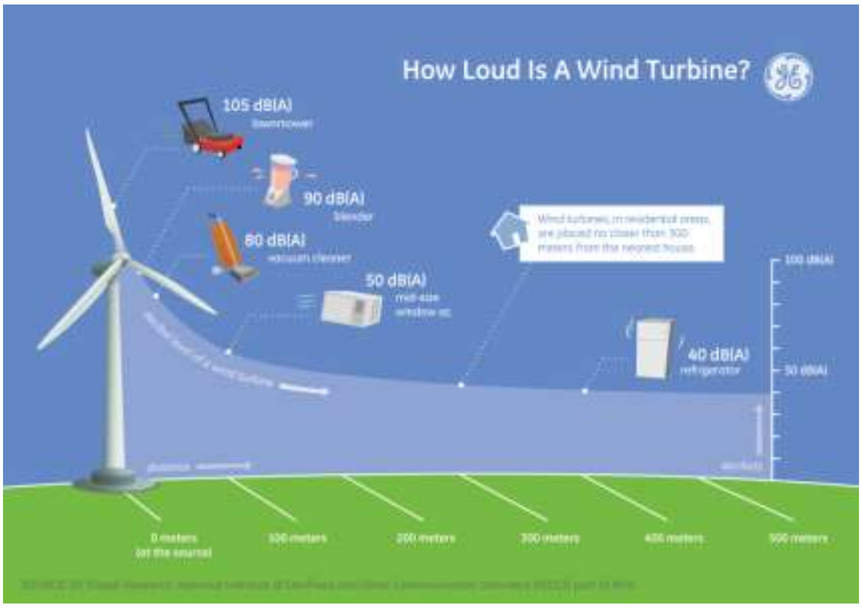
Whilst it is acknowledged that visual impact will probably be the most significant constraint to development, the remainder of this report will be based on the assumption that this can be overcome in some way, and the business case in section 7 has been developed accordingly.

In addition to visual impact, wind turbines create noise, although at the distance from shore under consideration (1-2nm), this is not likely to be a constraint to development.

Figure 3.4 below shows a summary of noise levels from a wind turbine in relation to other common noise sources, with indication of distance from the turbine.

[36] GREF, Yvonne Burford, Public attitudes to the possibility of near-offshore wind power in Guernsey, 2011

Figure 3.4 – Wind turbine noise in relation with other noise sources (image – GE reports[37])



3.11. Environment and Ecology

The Wave and Tidal REA covered a broad range of ecological and other environmental impacts that could emerge from development of those technologies in Guernsey's waters. Offshore wind energy has similar infrastructure requirements (foundations, cabling, landfall arrangements, shore station) and environmental impacts to wave and tidal energy development. As such, the Wave and Tidal REA presents good information that can be used to understand the constraints that apply.

However, there is a further significant potential impact that is specific to wind energy generation. The turbines could obstruct the migration routes of sea birds. Furthermore, if sited within important feeding grounds, turbines could affect feeding behaviour. The REA identified a lack of knowledge of the flight routes and feeding behaviour of sea birds, and further studies would be required to identify potential impacts.

3.12. Fisheries

Commercial fishing is an important industry to Guernsey, generating approximately £3.5M worth of first-sale landings within Guernsey ports each year. Furthermore, all of Guernsey's coasts are fished recreationally for a variety of species and Guernsey is a well known tourist destination for fishermen. The Wave and Tidal REA identified a number of potential impacts on both commercial and leisure fisheries, including exclusion from valuable areas, risk of snagging equipment and the possibility of displacement of fishing activity from a development site into adjacent areas. All of these

[37] GE reports (www.gereports.com/how-loud-is-a-wind-turbine/)

potential impacts apply equally to offshore wind energy developments. The most likely deployment area is known to be fished for crab and lobster using potting techniques.

The maximum area of exclusion that could be caused by the larger (30MW) deployment scenario would be in the order of $4km^2$. This represents less than 1% of the available sea area within the 3nm limit. Studies in the UK regarding a fishing exclusion zone around the island of Lundy in the Bristol Channel[38] have indicated that fish stocks can increase in the vicinity of an exclusion zone within a few years of establishment. Therefore, any exclusion zone associated with a wind turbine array could have the potential to act as a protected area and nursery to encourage recovery of stocks.

[38] BBC news (www.bbc.co.uk/news/uk-england-devon-13668077)

4. Site selection

4.1. Initial screening

As described in sections 3.2 and 3.3 above, initial screening for potential deployment sites presents the following simple requirements.

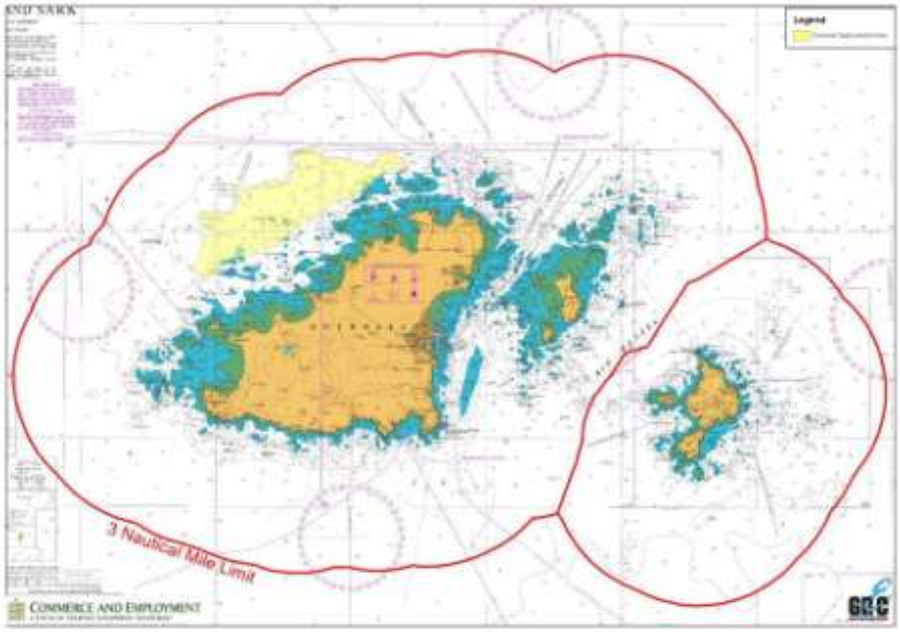
- There must be a suitable wind resource.
- There must be a suitable flat surface of seabed in a suitable depth of water (10 to 30m).
- The site should be placed outside areas with major environmental constraints or designated protected areas.

In addition, the following criteria may be used to further refine or check the feasibility of a potential site.

- In order to minimise visual impact as much as practically possible, the deployment site should be beyond 1nm offshore. This constraint was used in the screening for Wave and Tidal sites in the REA.
- The site should be free from existing subsea cables.
- The site and export cable route should avoid wrecks and other sites or objects of cultural heritage.
- There should be suitable space, topography and coastal geology to allow cable landfall and shore facilities.
- There should be easy access to a suitable grid connection, and the existing grid network should be able to accommodate the additional generation capacity.

These criteria resulted in the identification of a large area off the north-west coast as shown in figure 3.3 in section 3, copied again at a smaller scale below.

Figure 4.1 – Likely General Deployment Area (image - Guernsey Renewable Energy Team)



4.2. Selection of preferred site

Using the States of Guernsey's GIS system, the large area shown in the figure 4.1 has been overlain with various environmental constraints identified in the Wave and Tidal REA, as shown in figure 4.2 below. It should be noted that to improve the clarity of the plan most of the fishing areas have not been shown. As discussed in section 3.12 above, the whole of the coastal waters of Guernsey are fished either commercially or recreationally, and it is acknowledged that some degree of impact to fisheries would be unavoidable if offshore wind energy was to be pursued.

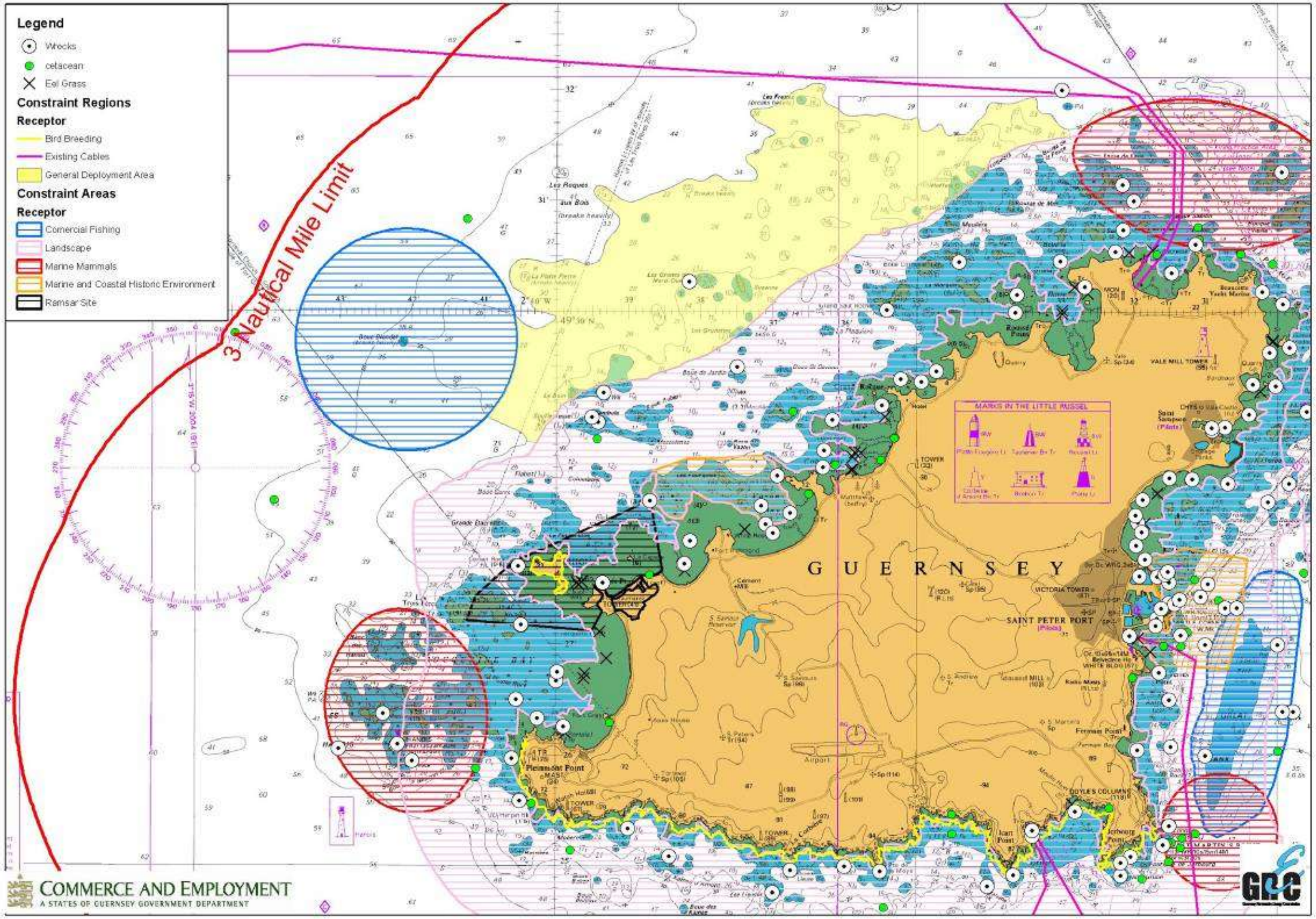
It can be seen that there are a number of constraints within or close to general deployment area:

- Fishing (potting throughout the area and a concentration of fishing using a variety of techniques around the rocky outcrop known as the Boue Blondel);
- Marine Mammal sightings;
- Ramsar site (birds, benthic ecology, landscape);
- Wrecks;
- Cultural Heritage Sites (known artifacts in peat horizons at Vazon beach, Fort Hommet);
- One Nautical Mile Landscape buffer zone (from the REA);
- Eel Grass.

In consideration of the constraints listed above, this study concludes that it is extremely likely that the various constraints can be avoided, or that potential impacts can be adequately mitigated. However, this is with the exception of impacts on fishing and landscape value, and possibly on sea birds, which should be investigated in further detail before further development of the outline proposals provided in this study.

It is considered that within the large area shown in the figure 4.1, there is adequate space to accommodate either of the two deployment options considered by the study.

Figure 4.2 – Environmental constraints (image - Guernsey Renewable Energy Team, based on the Wave and Tidal REA)



5. Proposals for further work

Outline scheme arrangements are described in section 6 below. The overall feasibility of specific scheme proposals could only be defined after carrying out a number of project specific surveys and investigations as follows. Many of these are similar to the recommendations made by the Wave and Tidal REA.

- Detailed wind resource assessment based on data recorded from a met mast installed at the deployment site and integration with other wind data sources and digital terrain modelling;
- Project specific hydraulic and sediment modelling of the effects of turbines on tidal flows and wave propagation, leading to careful design minimising the risk of scour or large scale changes in sediment movements;
- Project specific and strategic benthic habitat surveys and mapping, which will allow to mitigate the risk of disturbance of unknown vulnerable habitats and species;
- Baseline Noise Measurement and Assessment. This will be used alongside established noise mitigation methods to control noise pollution during construction and operation;
- A detailed assessment of the likely impacts of offshore wind energy on seabirds;
- Early liaison with fishermen regarding site selection;
- Project specific navigation risk assessment, considering establishing Safety Zones around turbines or whole array;
- Landscape and Visual Amenity Assessment.

In addition, the existing REA for Wave and Tidal Energy should be updated to cover wind energy.

6. Concept deployment for costing purposes

6.1. Number, type, size and arrangement of turbines

In discussions with George Sauvage of the States Commerce and Employment Department, it was agreed that potential deployment options would be based on well established turbine technology with a track record showing reliability and longevity of service and that 12MW and a 30MW array options would be considered. Further information regarding selection of appropriate technology is shown in section 2.

Therefore, the following deployment options are proposed.

- A single line of four 3MW turbines = 12 MW
- A modified square grid of 10 x 3MW turbines = 30 MW

Wind turbine

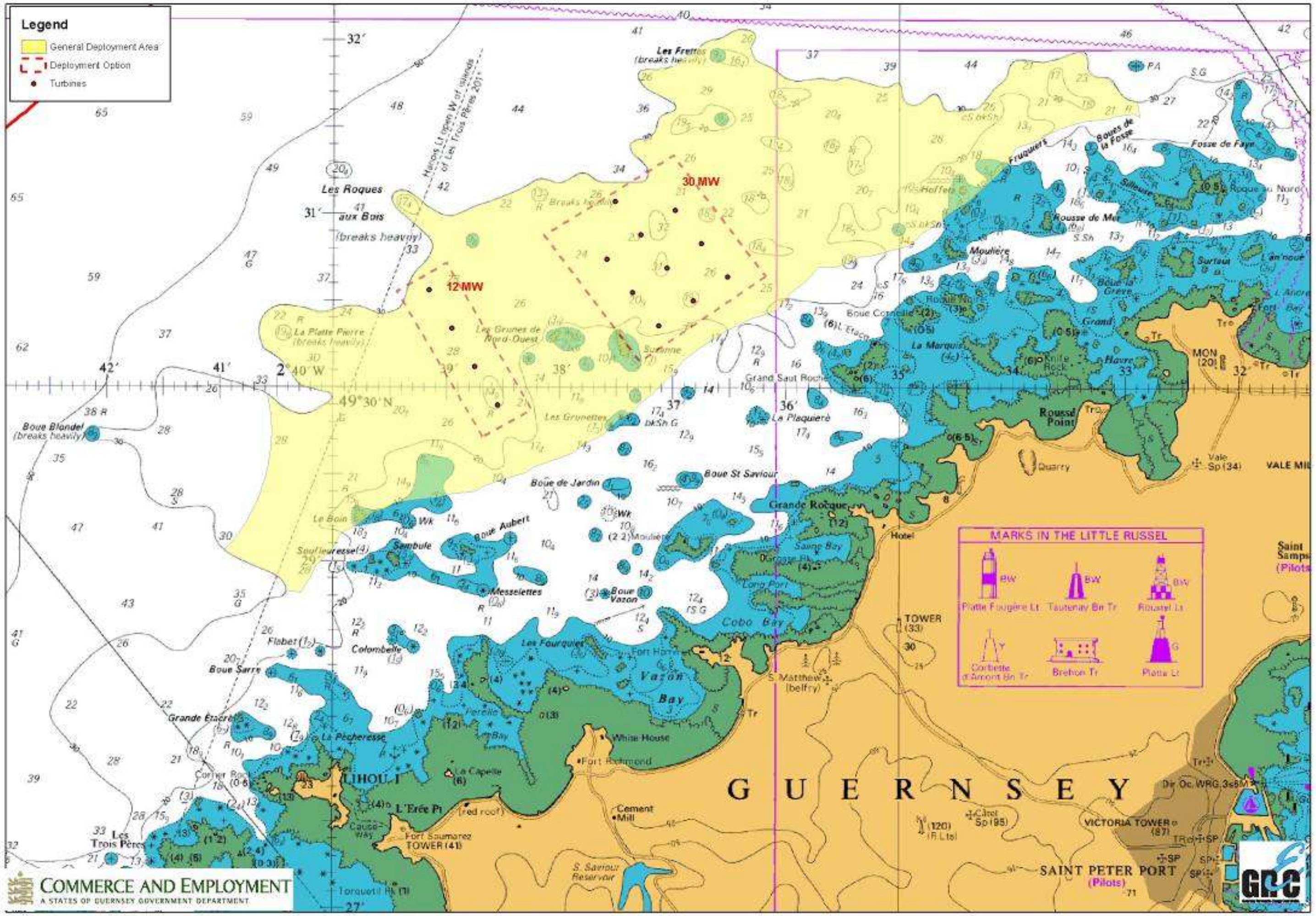
For both options, the Vestas V90 3.0MW 80m hub wind turbine is recommended for outline design and costing purposes. As discussed in section 2, there are several alternative suppliers and models that could meet the requirements of a specific project, and savings could be made if a small project on Guernsey was to be linked with a shared technology to a larger project in Jersey or French territorial waters.

Arrangement

For the purposes of identifying a suitable deployment layout, it has been assumed that turbines will be arranged in a grid spaced at 5 times the rotor diameter (90m) in each direction. The alignment of the grid should be arranged such that columns are positioned to minimise impact from important view points.

Both options are shown in the figure 6.1 below.

Figure 6.1 – Deployment layout options (image - Guernsey Renewable Energy Team)



7. Preliminary technical and economic appraisal

7.1. Introduction

A primary aim of the feasibility study is to provide information that could be used to form a business case for offshore wind energy production. This has required estimates to be made of both capital and operating costs of generating energy in Guernsey's unique environment, as shown in this section. Whilst Guernsey should refer to other European states for benchmarks for both costs and levels of subsidy applicable to attracting developers, the quality of the resource, its proximity to existing demand centres and good landfall potential could present opportunities for a more economic solution. Conversely, the relatively small scale of development and the challenging sea conditions may present difficulties.

However, as will be shown in this section of the report, the capital costs of an offshore wind farm project are as much dependent on market forces at the time of procurement as they are on the specific nature of the scheme in question. Whilst turbine, component and deployment costs may be drawn from UK examples, the remoteness of Guernsey from any existing offshore wind farms means that time taken to mobilise specialist maintenance staff during inspections and repairs could lead to proportionally increased downtimes and a marginally reduced productivity in comparison with other wind farms.

Another key question raised in the development of the REA for Wave and Tidal Energy was regarding the impact that renewable energy would have on the overall energy mix on Guernsey. This section of the report considers this and the consequential impact on cost of energy.

7.2. Indicative Energy Yield

Energy yield calculations have been prepared for a number of scenarios. The common inputs into all the models and scenarios were as follows:

Wind resource

- Wind speeds measured at 80m
- Wind shear exponent = 0.1 (open water surface)
- Annual air temperature = 11.3°C
- Annual atmospheric pressure = 101.3kPa

Wind turbine

- Power capacity per turbine = 3,000kW
- Manufacturer = Vestas
- Model = Vestas V90-3.0MW-80m
- Hub height = 80m
- Rotor diameter per turbine = 90m
- Swept area per turbine = 6,361.73 m^2
- Standard energy curve data
- Shape factor = 2
- Power curve data – for the Vestas V90-3.0MW-80m

At first, RETScreen software was used to calculate energy yields for 4 models and 12 scenarios. Model specific inputs and results of the simulation exercise are summarized in table 4.1 below. The Danish Wind Industry Association model was also used to calculate energy capture for numerous scenarios, as presented in table 4.2, and compared with the estimated energy capture for particular wind speeds as calculated by Vestas, and presented in the technical specification for the V90 3MW turbine. This second model was used in the development of the business case.

It should be noted that the results were subject to sensitivity testing through the use of a far offshore scenario, specifically a deployment in open sea conditions 30nm offshore. Whilst such a scenario would be impractical for further investigation due to excessive water depths and territorial limits at only 3nm, this indicates that far offshore conditions would provide up to 30% more energy. However, even if development of deepwater foundation technology was to allow this, the additional energy would be at significant cost.

Table 7.1 – Results of calculations based on RETScreen model – Annual Energy Production (in MWh)

Parameter	Model A			Model B			Model C			Model D		
	Lower estimate	Central estimate	Upper estimate	Lower estimate	Central estimate	Upper estimate	Lower estimate	Central estimate	Upper estimate	Lower estimate	Central estimate	Upper estimate
Wind speed [m/s]	8	8.5	9	8	8.5	9	9.5	10	10.5	9.5	10	10.5
Number of turbines	4			10			4			10		
Nautical mile limit [nm]	3						30					
Array losses [%]	4			8			4			8		
Airfoil losses [%]	1											
Miscellaneous losses [%]	2											
Availability [%]	90			95			90			95		
Capacity factor [%]	0.32	0.35	0.38	0.32	0.35	0.38	0.41	0.43	0.46	0.41	0.44	0.46
Electricity exported to grid [MWh]	33,170	36,449	39,727	83,886	92,176	100,467	42,629	45,531	48,012	107,805	115,144	121,418

Table 7.2 – Results of calculations based on the Danish Wind Energy Association model– Annual Energy Production (in MWh)

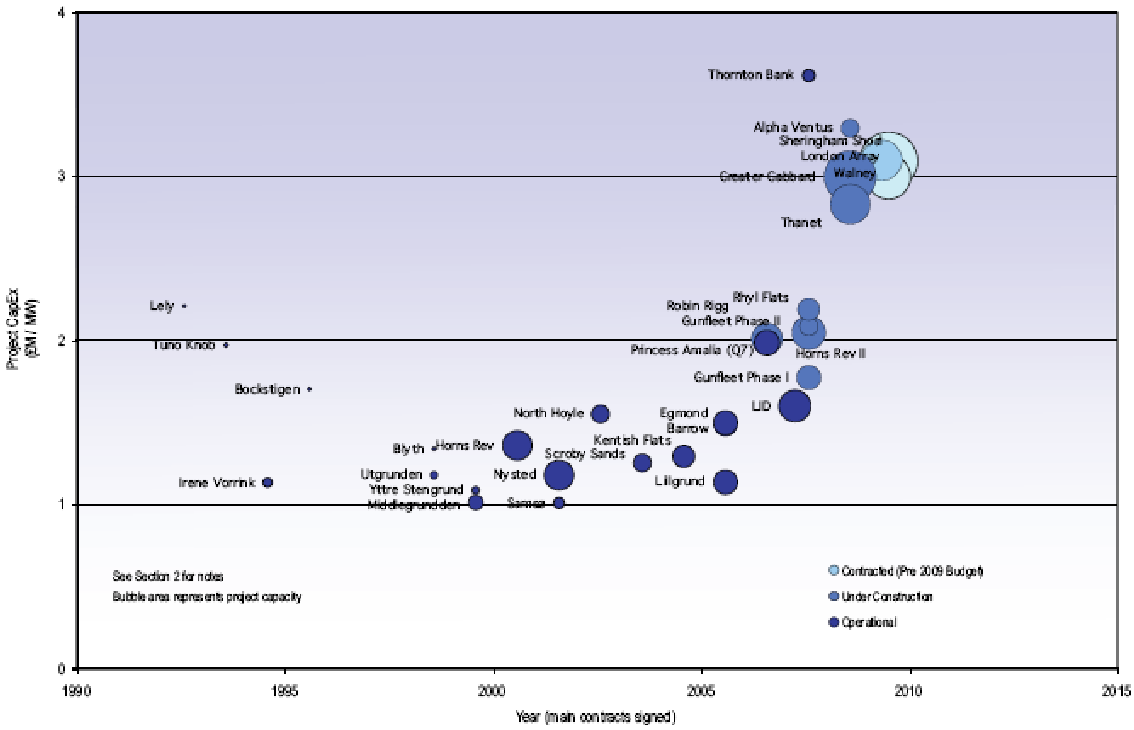
Parameter		Lower estimate	Central estimate	Upper estimate	Lower estimate	Central estimate	Upper estimate
Wind speed [m/s]		8	8.5	9	9.5	10	10.5
Energy yield for 1 turbine [MWh]	DWEA	9,703	10,707	11,655	12,492	13,273	13,942
	Vestas	9,706		11,650		13,298	
Energy yield for 4 turbines [MWh]		38,812	42,828	46,620	49,968	53,092	55,768
	5% Array loss	36,871	40,687	44,289	47,470	50,437	52,980
	2% Electrical losses	36,134	39,873	43,403	46,520	49,429	51,920
	90% Availability	32,521	35,886	39,063	41,868	44,486	46,728
Energy yield for 10 turbines [MWh]		97,030	107,070	116,550	124,920	132,730	139,420
	9% Array loss	88,297	97,434	106,060	113,677	120,784	126,872
	2% Electrical losses	86,531	95,485	103,939	111,404	118,369	124,335
	95% Availability	82,205	90,711	98,742	105,833	112,450	118,118

7.3. *Installed Cost Estimate*

Historic Data

Much has been written and researched regarding the costs of offshore wind energy over the past twenty years since the very first offshore wind turbines were installed. The costs of early and recent projects are summarised by Garrad Hassan in their UK Offshore Wind, Charting the Right Course report prepared for BWEA[39].

Figure 7.1 – Historic Trend – Offshore Wind CapEx (image - Garrad Hassan for BWEA)



It can be seen that the very early projects which were small, close to shore and in shallow water depths were relatively cheap. The first prototype projects were around £2M/MW and this cost dropped fairly quickly towards £1M/MW around the year 2000, then slowly increased up towards £1.5M/MW in 2005, and then again increased towards the £2M/MW mark around 2007. As we reached 2010 and the generally much larger, further offshore and deeper water projects, the costs appear to settle around the £3M/ MW installed.

It is of particular interest in the case of Guernsey to look at the costs of Blyth wind farm which comprises two turbines with rock socket foundations and is close to shore,

[39] BWEA, Garrad Hassan, UK Offshore Wind: Charting the Right Course, Scenarios for offshore capital costs for the next five years (www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf)

Scroby Sands which is close to shore and more recently Kentish flats which is just off the Kent coast, all of which were delivered at costs below £1.5M/MW installed.

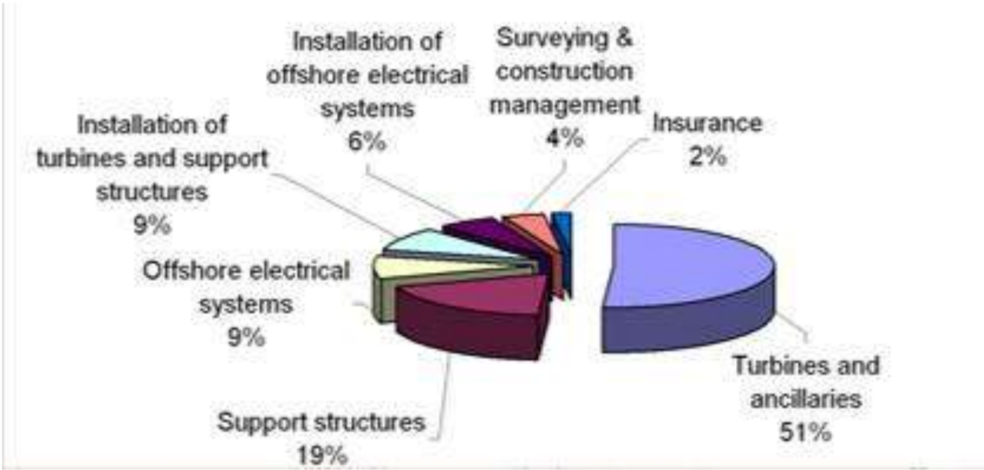
Other projects where developers have stated an expected CapEx are:

- Rodsand 2: £2M/MW
- Ormonde: £3M/MW
- Lincs: £2.7M/MW
- Borkum West: £2.9M/MW
- Global Tech 1: 2.9M/MW
- Dudgeon: £2.3M/MW

It is common practice at present, based on the above, to estimate the future costs of offshore wind projects to be in the area of £2.5M/MW to £3M/MW installed.

From the same report the split of project costs has been determined as shown in figure 7.2 below.

Figure 7.2 – Split of project costs (image - Garrad Hassan for BWEA)



Different projects will inevitably have a slightly different makeup but in general this type of split is useful for the preliminary appraisal of a potential project.

Price Fluctuations

It is worth noting that typically turbines account for 51%, support structures 19% and offshore electrical systems for 9% of capital cost, i.e. a total of 79% (the other elements including insurance, surveying and installation).

Nearly all this wind energy equipment was procured in Europe either in Danish Kroner for turbines or elsewhere in various European currencies until the Euro came in 1999. For much of this period the Danish Kroner stayed around 11-12 Kroner to the Pound until Sterling collapsed in 2008 and the exchange rate fell to 7-8 Kroner to the Pound. It is now around the 8.4 level. During the last 3-4 years the Pound has also lost almost a third of its value against the Euro declining from 1.5 to 1.1 Euros to the Pound. Allied to the exchange rate issues steel prices rose dramatically by nearly 50% around 2008 but have since returned to nearer historic levels. Prices of other commodities, such as copper, also rose and remain relatively high. It is therefore reasonably apparent why the costs of offshore wind energy has risen from around £2M/MW installed to nearer £3M/MW installed over the last five years.

Having said this, the cost of onshore wind has remained relatively static at £1M/MW installed and there is perhaps a considerable element in offshore wind pricing that manufacturers are building into their project costs, since many of the early projects suffered from very major problems, such as severe gearbox problems which required major refits (e.g. Horns Rev in Denmark where all the nacelles had to be taken down and brought back to shore).

Offshore wind has not been an easy transition for any of the turbine manufacturers. However the mainstream producers such as Vestas and Siemens do now have a great deal of track record and experience and knowledge, and should be in a position to cope with the challenges of offshore wind projects. Offshore wind used to be a very high risk business for them but now is getting to the point of being routine.

Aspects that may affect the cost of Offshore Wind

Amongst the many key questions which will affect the future costs of offshore wind are:

- Will Sterling recover its value against the Euro and Danish Kroner?
- Will the advent of a number of major manufacturers such as Siemens, Vestas and Gamesa setting up production in the UK help to offset the exchange rate issues?
- Will the recession return steel and other commodity prices to or near historic trend levels?
- Will the technology improvements, increased competition and particularly cheaper foundation concepts stabilise prices?
- Will the potentially rapidly increasing market size bring economies of larger scale production?
- Will there be finance available to support the increased number of projects and maintain market expansion?
- Will governments and electricity consumers be prepared to maintain the levels of subsidy necessary (in the UK ROCs now cost electricity consumers over £1Billion per annum) to grow the market during the current period of public spending constraints?
- Will turbine manufacturers have the confidence to price offshore projects on the basis of “get it right first time”?

Conclusion

Answering the above questions, amongst many other factors, and forecasting future prices for offshore wind projects is extremely difficult and prone to errors. However, we need to attempt to address the likely costs of the two alternative proposals for a 12MW and 30MW offshore wind farm on the northwest coast of Guernsey.

As a base case we are suggesting that these should consist of either 4 or 10, 3MW Vestas V90 turbines situated relatively close to shore in water depths of around 20m in the area shown in figure 4.1. It is assumed that the turbines would have foundations consisting of steel monopiles routed into rock sockets drilled into the hard rock seabed.

These proposed scheme options for Guernsey have the following potential advantages over the larger more recently proposed offshore projects elsewhere in Europe.

- They are near to shore with shorter, cheaper cable routes;
- Once foundation conditions are established with trial boreholes on the turbine locations the rock sockets can be drilled with a low level of risk;
- The piles will be shorter and cheaper than those used on sandbank/clay areas, with no risk of erosion or scour;
- The turbines and transition pieces are standard pieces of equipment which have been used many times before and therefore have a low level of risk;
- The projects are small and the installation times short (for four turbines 2 periods of two weeks and for ten turbines 2 periods of four weeks, thus weather windows for the installation process can be established and a wide range of installation vessels can be used. This should reduce prices and also reduce risk;
- Guernsey is quite close to good port facilities at Cherbourg or St Malo where equipment can be marshalled and brought to site with a short transit time;
- The relatively small size of the projects means that no very large marshalling area or facilities are required. Similarly no large organisational infrastructure will be required to manage the projects during construction;
- The onshore grid connection should be low cost and straightforward. Connection would be into the Kingsmill substation at 33kV, although some grid reinforcement may be required for the 30MW project;
- It is possible that the smaller project may be connectable without the use of a STATCOM or other grid stabilisation equipment. Such equipment providing static reactive power compensation may be required to provide support to the existing grid during fault conditions in the offshore wind energy equipment and to allow the wind turbines to ride through fault

conditions occurring elsewhere on the system if this is required. GEL will be able to advise on their requirements in this respect.

Given all of the uncertainties from the introduction to this section and given all the potential advantageous points mentioned above we are of the opinion that one of these two alternative projects could be installed off the north-west coast of Guernsey for between £2M/MW and 2.5£M/MW installed, giving a total price for the four turbine project of between £24M and £30M and for the ten turbine project of between £60M and £70M.

The business case presented in this report assumes 2.5£M/MW installed, and includes for a 10% contingency. This covers all capital costs, including cabling and shore-side works.

7.4. Operating and Maintenance Costs

In 2009 Ernst and Young produced a report for the UK Dept of Energy and Climate Change (DECC) Cost of and Financial Support for Offshore Wind[40].

In terms of operating costs they concluded that average total operating costs had increased from £48K/MW/annum to £79K/MW/annum in the 5 years to January 2009 and were expected to reach nearly £100K/MW per annum for projects reaching commercial operation in 2012. These include leases, system charges, grid maintenance, insurance premiums and decommissioning provisions.

Operation & Maintenance (O&M) costs were found to have increased from £38K/MW/annum to £60K/MW/annum during the five years to Jan 2009. In the Garrad Hassan report Charting the Right Course they estimated O&M costs at Euro 150K/turbine/annum equating to approximately £45.5K/MW/annum. One of the early UK offshore wind farms at Scroby Sands is quoted as having O&M costs of £25K/MW/annum and North Hoyle offshore wind farm had an O&M cost of £49K/MW/annum in its first year of operation but this was expected to drop considerably since it included environmental monitoring and other non recurring factors such as gearbox issues[41].

In June 2011, Arup prepared a report for the UK Department for Energy and Climate Change (DECC), 'Review of the generation costs and deployment potential of renewable electricity technologies in the UK'[42]. This work was based on a literature review across all renewable markets but with little opportunity for direct consultation with developers. It considered a range of development scenarios for expansion of the

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[40] DECC, Ernst & Young, Cost of and financial support for offshore wind, A report for the Department of Energy and Climate Change, 2009

[41] DECC, Scroby Sands offshore wind farm: annual report 2005

[42] DECC, Arup, Review of the generation costs and deployment potential of renewable electricity technologies in the UK, June 2011

offshore wind industry depending on developments in energy policy and planning. The report indicated O&M costs for offshore wind projects of <100MW of £100k to £167k/MW/yr. However, this is based on a variety of turbine types and sizes and in a variety of operating environments.

For the case of Guernsey it is anticipated that routine servicing would be accessed through St Peter Port via workboats and for larger or non routine work would be accessed through either St Malo or Cherbourg if specialist vessels are required.

It is unlikely that for projects of the proposed scale the dedicated service crews would be based on Guernsey, but crews from other Vestas facilities or projects either in France or the UK are more likely to be utilised. Longer response times will inevitably reduce the availability of the turbines but this has already been factored into the annual energy capture calculations.

It will obviously be an advantage for these projects to use turbines which are tried and tested, with a good availability of spare parts within easy reach from European service bases.

It is understood that there are proposals for building a large offshore wind farm between Jersey and the French coast and it may well be that consideration should be given to use the same turbines on the Guernsey project so that there is a commonality of spares and service facilities for the two projects.

Vestas have over 500 turbines installed in France and over 1,000 turbines installed in the UK so there should be no difficulty in obtaining spares and service for Guernsey.

On the evidence to date we feel that an operating cost of £100K/MW/annum or £300K/turbine/annum should be prudent for the situation in Guernsey.

7.5. *Assumed Current Cost of Electricity*

The following subsection describes the analysis of the cost of energy from offshore wind generation. However, in order to make a comparison with current generation arrangements, the assumptions have been agreed with Guernsey Electricity Ltd (GEL) regarding the average cost of electricity in 2011, as shown in table below. The right hand column shows figures estimated for a deployment year of 2014, as described in section 7.6 below.

Table 7.3. Assumed Current Cost of Electricity

	2011	2014
Cost of Generation from conventional fossil fuel or import from Jersey/France	6.5p/kwh	6.9p/kwh
Fixed Running costs (eg. Cost of depreciation of existing capital assets, Operation & Maintenance)	2.0p/kwh	2.2p/kwh
Cost of Distribution (cost of operating and maintaining the island's local distribution grid)	3.0p/kwh	3.0p/kwh

7.6. *Estimated cost of Electricity from Offshore Wind*

It is an objective of this study to gain an understanding of the proportion of the overall electricity supply that may be provided by wind energy and its associated impact on electricity prices. The capital and revenue cost estimates discussed above have been used to develop a simple business model. The modelling is presented on a Microsoft Excel spreadsheet based on similar work undertaken for the Wave and Tidal REA. The spreadsheet takes the following input data and can be used to calculate an Investment Rate of Return (IRR).

- Units of electricity produced
- Level of subsidy (p/kWh)
- Capital Cost
- Annual operation and maintenance cost
- Debt ratio (proportion of debt to owner investment)
- Interest on debt

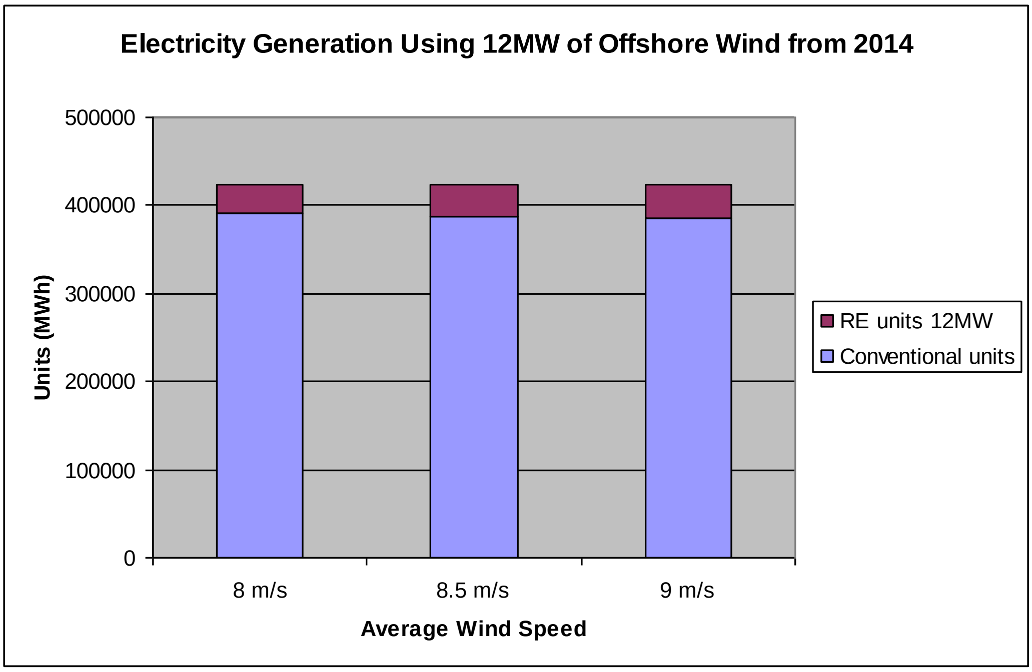
The spreadsheet assumes that income arises from both a user-defined subsidy and direct revenue from sales of electricity at the market rate for fossil fuel based generation. The price of electricity is predicted to rise in line with oil prices as presented by the International Energy Association's Energy Outlook for 2009[43]. It is important to note that this estimates the long-term oil price based on predicted levels of supply and demand, and does not account for short-term fluctuations due to world events or speculation. The IEA's updated 2010 outlook has been published, but this focuses on a 'current policies' scenario that assumes that all current national and international sustainable energy policy objectives will be pursued and achieved. The business case uses the 'reference scenario' from the 2009 report because this shows slightly higher oil prices in 2035 and this, in the opinion of the authors, is more realistic. Predicting future energy prices is extremely difficult and depends on a very wide range of international factors but the IEA estimates are generally considered to be amongst the best available.

The spreadsheet has been used to model the cost of energy and the projected affects on energy tariffs from the two alternative deployment options under a number of scenarios. This has allowed some degree of sensitivity testing. Comprehensive results are shown in Appendix B and a selection of key findings are presented below. The proportions of electricity provided from wind and conventional sources are shown on charts for each scenario on the following pages.

[43] IEA, World Energy Outlook 2009 - http://www.iea.org/weo/index.asp

12MW Deployment from 2014

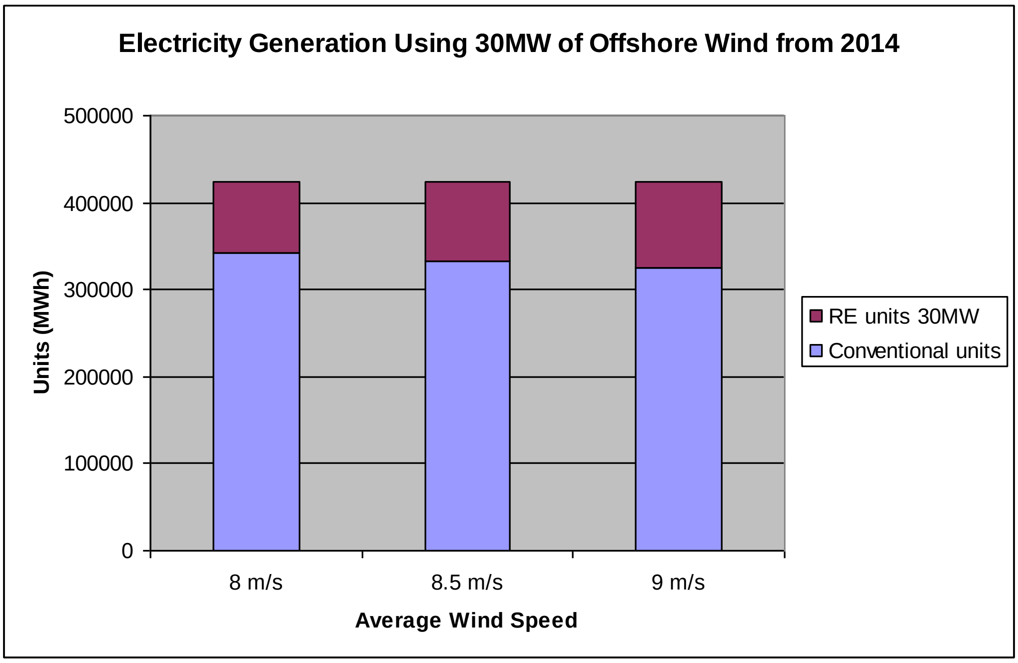
Figure 7.3 – Predicted Electricity Production with a 12MW Deployment (image RET)



- Subsidy: 6.0 to 9.2 p/kwh
- Cost of wind energy (excluding distribution): 15.1 to 18.3 p/kwh
- Impact on energy tariffs: 4.5 to 5.8 %

30MW Deployment

Figure 7.4 – Predicted Electricity Production with a 30MW Deployment (image - RET)



- Subsidy: 5.2 to 8.3 p/kwh
- Cost of energy (excluding distribution): 14.3 to 17.4 p/kwh
- Impact on energy tariffs: 10.0 to 13.2 %

Notes – The results are based on the assumption that all of the cost of energy is covered by the commercial or domestic electricity users, including the subsidy, and that no additional subsidy will be forthcoming from the States of Guernsey (e.g. from a carbon tax).

Required Investment Rate of Return on Equity = 15%

Previous unpublished studies by the Guernsey Renewable Energy Team (RET) have indicated that the cost of wave or tidal energy deployed at a commercial scale (circa. 50MW) could be in the range of 25 to 35p/kWh. The cost of conventional fossil fuel based electricity is in the region of 7p/kWh. The above figures exclude distribution costs.

This indicates that the cost of wind energy, if generators are deployed at the scales considered in the development scenarios within this report (12MW or 30MW), is likely to be cheaper than early wave or tidal energy, but more expensive than conventional energy.

7.7. Subsidy

The above assessment indicates that some form of subsidy or incentive is required to make wind energy commercially viable in the short-term. One option is for the subsidy to be provided by the States and then subsequently recouped via an increase in domestic and commercial energy tariffs. However, this may be seen as counter-productive as there is a risk that it could differentiate electricity from fossil based fuels, and suppress the uptake of renewable electricity as a sustainable source of energy. Alternatively, and as used in the UK, a carbon tax could be developed. However, this would need to be established through further debate and through the development of States Energy Policy. At present, Guernsey Electricity Ltd (GEL) must take the lowest cost form of energy from the various sources available to it.

7.8. Business model options

There are two main sources of finance for large infrastructure, namely government and private. Governments have advantage in terms of their ability to borrow money at lower interest rates. However, the construction of a large publicly funded project would place an obligation on a government to operate and maintain the asset for a long time. The states of Guernsey would not be well placed to operate a small wind farm, due to the need for specialist skills that are not currently available in Guernsey's workforce. With international concerns about levels of government borrowing and Guernsey's tax-efficient approach, there is a presupposition that funding, construction, operation and maintenance of an offshore wind energy project would be at no cost to public finances and would best lie with the private sector. This report, and the business case within, has been prepared based on the assumption that a project would need to cover interest and repayments at a high rate of investment returns typical for the offshore wind industry, namely at 15%.

8. Next steps

8.1. Phase 2 – Resource Assessment Update

If the States of Guernsey choose to further develop proposals for offshore wind energy generation, it is recommended that Phase 2 of this study is implemented. It is proposed that Phase 2 should make use of improved wind record data from the GREF met mast at Chouet and combine this with existing data from the Airport. In combination with high quality records from the Channel Light Vessel, the improved wind speed data will allow a comprehensive wind resource assessment to be undertaken and the business case for wind energy to be re-stated. An update will be made to this feasibility study report.

It is clear that successful stakeholder engagement is central to the Guernsey Renewable Energy Team's (RET's) approach in preparing for renewable energy generation. The output from Phase 2 could be used to provide greater clarity to stakeholders and encourage support for a programme of offshore wind generation, should this be determined by the States as an appropriate way forward.

8.2. Update to Regional Environmental Assessment (REA)

The current REA covers Wave and Tidal energy generation, and it is proposed that this should be updated to account for the possibility of offshore wind energy. Discussions with GREF have identified that changes will be required throughout the REA, but will be particularly focused on the following:

- The Wind Energy Resource;
- Birds – the impacts on migration routes and feeding patters, and the risk of collision;
- Marine and Coastal Historic Environment – the proximity of turbines and impacts on the setting of historic structures (eg. Fort Hommet);
- Tourism and Recreation;
- Noise;
- Radar and Air Traffic Control;
- Landscape and Seascape Character.

8.3. Stakeholder Consultation

The deployment of offshore wind turbines within 3nm of the coast of Guernsey would cause unavoidable visual impacts. Whilst some may strongly object, they may be acceptable to many others. Prior to the presentation of serious proposals, the States should undertake further research into public attitudes over statistically significant part of the population. The results of this should be a matter of public and governmental debate prior to further investment in significant technical studies.

8.4. Electrical Distribution Network Studies

Electrical distribution network studies should be undertaken to examine opportunities for and constraints to connection, and any compensation equipment required.

9. Conclusion

This study has found that:

1. The establishment of offshore wind energy technology in Guernsey's waters would appear to be technically feasible due to adequacy of the wind resource, a suitable deployment zone, and proximity to a demand centre;

2. There would appear to be no suitable sites in Sark's territorial waters, due to the sheltering effect of Guernsey and Herm and a lack of suitable seabed;

3. The wind energy resource is comparable with that of other well established parts of the UK and Europe;

4. Pending further investigations and analysis, an average wind speed of 8-9m/s should be assumed. However, this assessment is based on limited data and the implementation of Phase 2 of this study would seek to improve this aspect of the report;

5. The cost of energy would be comparable with offshore wind farms in the UK, and likely to be lower than current estimates for wave and tidal energy;

6. The cost of offshore wind energy would be higher than from conventional sources;

7. There is a large potential deployment area off the north-west coast of Guernsey. However, elsewhere within the study area, seabed depths and conditions are not suitable for use with currently available turbine foundation technology;

8. Many of the potential environmental constraints identified by the Wave and Tidal REA can be avoided, or environmental risks mitigated. However, significant residual risks are presented to the landscape character of the north-west coast, air traffic control systems, and there would be some unavoidable impact on fisheries.

9. Electrical distribution network studies should be undertaken to examine opportunities for and constraints to connection, and any compensation equipment required.

Appendix A – Meteorological Analysis of Wind Climate at Guernsey Airport

COMMERCIAL SCALE ELECTRICITY GENERATION FROM WIND POWER IN GUERNSEY – A METEOROLOGICAL PERSPECTIVE

Introduction

This chapter will examine meteorological processes that relate to commercial scale renewable energy production in the form of generation of electricity from wind power. Solar energy is also discussed briefly.

The characteristics of wind flow in the Bailiwick of Guernsey

Wind Direction

Guernsey is said to have a prevailing south-westerly wind but this does not begin to describe the local peculiarities of wind flow across the island. The following wind rose diagram (Fig 1) shows wind direction averaged over 30 years at Guernsey Airport. The figures on the y-axis show the average percentage of time with light and stronger winds in each 30° sector.

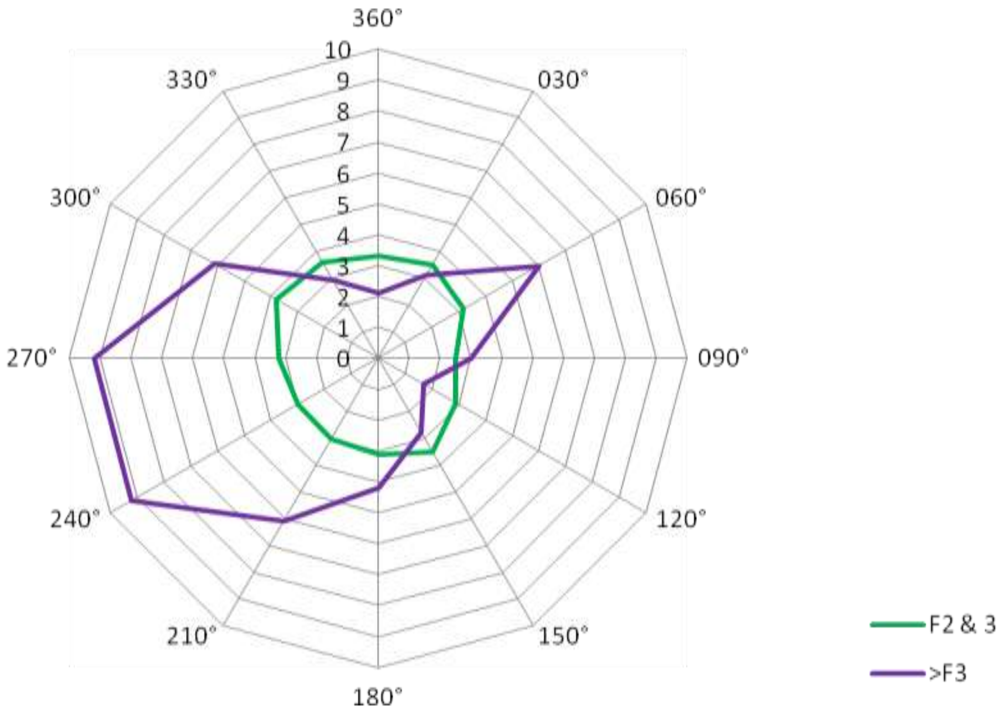


Fig. 1

The diagram shows that light winds of force 2 or 3 have no real prevailing direction whilst stronger winds of force 4 and above come mainly from a quadrant centred on a west-south-westerly direction. East-north-easterlies also provide many days with stronger wind speeds but strong winds from due north and from the east-south-east are relatively rare. The wind rose shows the 2 main influences on wind flows across the island, namely:

1. The established global circulation patterns which – in the North Atlantic Ocean – favour the development of semi-permanent "Icelandic Low" and "Azores High" pressure systems. The resulting atmospheric pressure differential forces a west or south-westerly airflow over the island which is generally stronger in winter than in summer.
2. The proximity of a large continental landmass which occasionally affects atmospheric pressure patterns and wind flow across the island. Strong solar heating of France combined with relatively cool sea temperatures over the English Channel can cause surface air pressure to fall over France with the formation of a "heat low". The effect is negligible in winter but reaches a maximum during spring and early summer (when land / sea temperature differences are at their highest) with east-north-easterlies being the most common local wind direction in the months of April and May.

The anemometers at Guernsey Airport are located so that they are not subject to any notable sheltering or funnelling effects and this means that the wind direction data from the airport can be used as a good guide for the open waters surrounding the island with the minor caveat that winds over the sea tend to slightly more "veered" than over land – hence a wind direction of 270° over open waters may be recorded as 250° or 260° at the airport. Only waters within a few hundred metres of the shore (especially where the shoreline consists of cliff) are likely to differ notably with respect to wind direction characteristics. On the island itself, various locations will however be subject to localised funnelling and sheltering and – in certain inland locations - this may alter the directional characteristics of the wind flow to a great extent.

Wind Speed

The mean wind speeds (in knots) at Guernsey Airport in 2010 and averaged over the past 30 years are shown in the table below together with some additional data on extremes:

	WIND SPEED									
	MEAN SPEED (KNOTS)		NUMBER OF DAYS OF GALES				HIGHEST GUST (KNOTS)			
MONTH	2010	AVERAGE 1971-2000	2010	AVERAGE 1971-2000	RECORD HIGHEST	YEAR	2010	DATE	RECORD HIGHEST	DATE
JAN	10.8	14.7	0	2.6	11	1984	41	16th	77	25/1990
FEB	12.1	13.3	0	1.5	10	1990	41	28th	69	9/1988,11/1990
MAR	12.1	12.6	1	1.0	6	1980	53	31st	70	10/1982
APR	10.6	11.9	0	0.3	2	1964,72,83,94	37	2nd	60	9/1994
MAY	9.0	11.1	0	0.1	2	2007	30	10th	58	19/1996
JUN	8.1	10.6	0	0.0	0	–	34	10th	51	16/1965
JUL	8.7	10.3	0	0.0	1	1956,69	37	14th,15th	63	31/1983
AUG	10.6	9.7	0	0.0	1	1956,61,86	36	23rd	52	26/1986
SEP	9.8	11.1	0	0.2	2	1953,65,74,83	36	14th	60	29/1962
OCT	11.7	12.5	0	0.9	4	1967,76	41	23rd	81	16/1987
NOV	12.2	13.5	2	1.3	8	1977	52	11th	73	23/1984
DEC	11.1	14.5	0	2.2	9	1979	42	20th	83	15/1979
YEAR	10.5	12.1	3	10.1	20	1972	53	31-Mar	83	########

Fig. 2

The 30-year averaged wind speed at Guernsey Airport is therefore 12.1 knots (6.2ms^{-1}). The anemometers are located approximately 12 metres above the airfield. Whilst this figure would be very useful to a householder wishing to install a domestic wind turbine on the roof of a property that had good exposure to the wind, the figure does not give a good representation of the wind speed that would be experienced at the turbine height of a commercial wind farm for reasons that follow.

Whilst Guernsey Airport's wind direction data can be considered representative of unobstructed low level wind flow across the Bailiwick, its wind speed data needs careful interpretation. Several factors ensure that wind speeds across Guernsey and its surrounding waters can vary notably.

1. Altitude of different locations – wind speeds usually increase with altitude.
2. Sheltering – this may be induced by upwind obstructions such as trees and buildings
3. Funnelling – this effect produces localised increases in wind speed caused by airflow being channelled between obstructions or between larger topographical features such as hills.
4. Turbulence – although turbulence may not greatly affect the mean speed of the overall airflow, turbulent flow can cause problems for wind turbines and is therefore mentioned. It can also interfere with ability of instrumentation to accurately gauge wind strength.
5. Frictional effects – friction between the airflow and the surface of the earth has the effect of decreasing wind speeds in the lowest layer of the atmosphere.

The first four of these factors are easily comprehended and need not be discussed further although it should be noted that funnelling and sheltering effects often occur at the same location – all that is needed is a change in wind direction. Frictional effects, however, need further explanation as they vary widely across Guernsey and its surrounding waters and should therefore be fully understood before any decisions are made on the siting of commercial scale wind energy production.

Frictional Effects on wind speed

Frictional effects vary depending on the type of surface over which the wind is flowing. The open, largely unobstructed grassland and concrete surfaces which cover the airfield at Guernsey provide a relatively low friction surface in comparison to a built up area such as the Town Centre or a wooded area such as that which partly surrounds St Saviours Reservoir. Winds speeds at the airport therefore are almost always higher than in these other two locations.

Land surfaces of any nature apart from smooth ice and snow, however, tend to exert a greater frictional drag on airflow than water surfaces. As a result, wind speeds at sea tend to be higher than those experienced under the same weather conditions on land unless the land observer is standing in a location where relatively high altitude and funnelling of the wind overcomes the increased friction of the land surface. An example of such a location is La Coupée in Sark where funnelling can occur if winds are strong and from the WSW or ENE, but such locations are relatively rare.

As has been mentioned, the Guernsey Airport anemometers are generally free from the effects of sheltering, funnelling and turbulence, but they are not at the same height as the hub of a commercial wind turbine, which may be anything from 20m to 70m higher. As the altitude increases, the frictional effects that characterise the surface layer become less pronounced and the wind becomes stronger. The resulting wind profile is known as the **wind gradient**. Over open water, the frictional effects of the water surface are relatively small anyway, and it is for this reason that offshore wind speeds in the lowest layer of the atmosphere tend to be higher than those experienced over land.

Wind Farms

Before considering the viability of commercial scale electricity generation from wind power, it is necessary to understand how it is utilised in the United Kingdom and continental Europe. Groups of wind turbines – collectively known as wind farms – have been installed in increasing numbers in recent years. Wind farms can be divided broadly into onshore and offshore sites with onshore sites being less expensive to develop, but offshore sites being less visually intrusive and more productive in terms of electricity generation.

Fig. 3 (copyright free)

The amount of electricity generated by a wind farm depends on a number of factors including:

1. Installed Capacity
2. Load Factor

The installed capacity refers to the total number of megawatts (MW) which can be generated if each turbine is working at its highest efficiency.

The load factor is the ratio of the net amount of electricity generated by the wind farm divided by the net amount of electricity that the wind farm would have generated had it been operating at its net output capacity. The load factor for wind energy in the British Isles falls within the range of 25% to 40% in a year when wind speeds are average. The prevailing west to south-westerly wind that blows across the British Isles is, on average, strongest in the north and weakest in the south. A wind farm located in Guernsey or its surrounding waters, therefore, would experience a load factor at the lower end of this range.

Thus, to give an example, if a small wind farm was established in the Bailiwick with an installed capacity of 2MW and a load factor of 28% is assumed, the wind farm would produce a theoretical 4,906 MWhours per year[1]. In practice, this would be reduced somewhat by turbines failing or being taken offline for maintenance and also by power transmission losses which will depend on the distance of the wind farm from the customer. To state the obvious, generation of power is limited to periods when the wind is blowing with sufficient strength. Commercial wind turbines are generally allowed to turn slowly in low wind speeds but do not generate viable amounts of electricity until a certain threshold wind speed is attained. Similarly, in very high wind speeds, electricity generation may be suspended to avoid damage to the turbine and surrounding infrastructure.

Siting of Wind Farms

As may be appreciated, the correct siting of a wind farm is critical with regard to its efficiency. A wind farm with a high load factor is considerably more efficient than one with a low load factor. For this reason, we must now consider which areas of Guernsey and its surrounding waters would be most suited to the installation of wind turbines. To sum up, these areas should:

- Be as free as possible from the effects of wind sheltering, funnelling and turbulence.
- Be where frictional effects (as discussed above) are as low as possible.

It is not within the scope of this chapter to comment further, but other considerations affecting the siting of onshore wind farms would obviously include the planning process, proximity to housing and how any installations of commercial wind turbines could impact negatively on existing systems such as the Guernsey Airport radar. Other considerations – such as the latter – could also affect siting of offshore wind farms.

It is therefore important that studies are undertaken to measure or accurately estimate wind speeds at turbine hub height in the areas that are seen to be most favourable for the generation of wind power. The areas which may be practicably used for an onshore wind farm are small. Residential development covers much of the island leaving only cliff lands, some coastal promontories and offshore islets as possible sites.

Areas adjacent to the cliffs in the southern half of the island are generally unsuitable as the cliffs can force an airflow to rise almost vertically in places which, in turn, produces wind shear and turbulence over the cliff lands and renders them largely unsuitable for the placement of wind turbines. Other lower-level coastal promontories may be partly sheltered by nearby high ground.

Two areas that appear to have potential for onshore wind generation are Lihou Island and certain exposed sites in the far north of the island such as Chouet. Lihou has a small amount of shelter from high ground to the east and south-east, but as can be seen from figure 1, strong winds from these directions are relatively infrequent. Chouet, apart from one or two small stands of trees, has little natural shelter from any direction.

Although Guernsey Airport has a long record of wind data, it is unfortunate that the island has no corresponding data set for offshore winds. Data sets such as that for the Channel Light Vessel exist, but that site is too distant from the island to be wholly reliable as an indicator of local marine winds. Enquiries to Trinity House elicited the response that wind data for Les Hanois and the Casquets lighthouses were not kept. Other calibrated anemometers – such as the one at St Peter Port harbour – can give an indication of marine wind speeds but only when the wind is blowing from a direction that is not subject to sheltering or funnelling effects from the adjacent land.

Measurement of coastal wind speeds

Before the suitability of any site for any onshore or offshore site can be assessed, there is a need for at least one full calendar year of wind data from a site that is well exposed to marine winds.

This can be done by several methods:

- Direct measurement at hub height (best if wind farm site is known and approved)
- Remote sensing – e.g. SODAR

- Measurement and extrapolation

Fig. 4 - Source: Garrad Hassan and Partners Ltd

Direct measurement

Direct measurement involves erecting a tower and installing an anemometer at turbine hub height together with a data logger. Onshore, the tower may have a height of 50m to 80m and will need a substantial concrete base. Offshore, the installation of a tower fixed to the seabed as in Fig. 4 is occasionally undertaken in the investigatory / planning stage for wind farm developments.

Direct measurement provides an accurate measurement of turbine height wind velocities. The cost of the mast installations is however high. An offshore installation that is anchored to the sea floor as in Fig.4 can be as expensive as £1m[2]. The development of an adequate database of wind conditions using this method usually takes about 2 years.

Remote Sensing – e.g. SODAR

SODAR stands for Sonic Detection and Ranging and is similar in many ways to RADAR with the exception that sound waves rather than radio waves are used for detection purposes. The system operates by issuing an acoustic pulse and then analysing the intensity and Doppler shift of the return signals. With recent technological advances, even a low range SODAR can now be used to accurately profile wind direction and velocity up to heights of several hundred metres which is considerably higher than is needed for a local study relating to wind energy. Unlike many other measurement systems, SODAR is also able to detect and measure levels of turbulence in the atmosphere.

Fig. 5 (copyright free)

SODAR units are, however, generally large, expensive and vulnerable to vandalism. Their use offshore tends to be limited to fixed platforms such as those already installed and utilised by the oil industry. The best suitable local sites for such a unit would be areas from which the public are barred and where there is a 24 hour security presence, but such suitable locations – such as Guernsey Airport – do not coincide with plausible wind energy generation sites. SODAR at Guernsey Airport could prove useful for detecting any potential turbulence and wind shear dangers for aircraft on approach, however SODAR is not generally considered to be essential at the world's airports. Proposing a SODAR installation at Guernsey Airport for the dual use of wind profile data gathering and aviation safety would therefore raise questions of cost effectiveness that would not be easily answered.

Doppler LIDAR (Light Detection and Ranging) can also be used to accurately profile wind direction and velocity in an atmospheric "cone" several hundred metres high.

Measurement and Extrapolation

Although direct measurement of wind speed at turbine height by means of a high mast or using SODAR ensures data that accurately represent winds at this level, as has been mentioned, the costs of purchasing and installing either high masts or SODAR would be considerable. As a less expensive option, monitoring could take place from a relatively low mast (e.g. 10 metres) similar to the one shown in Fig. 6 provided that it is sited in an exposed coastal area – preferably in a location that is seen as promising such as the Chouet peninsula. Ten metre wind data could then be extrapolated to provide an estimate of wind strength at the turbine height of an onshore installation.

A minimum of 12 months of data gathering would be needed, after which the data from the 10 metre mast would then need to be analysed and converted to an estimate of the turbine height wind. One equation that is sometimes used to estimate wind gradient by wind energy engineers is expressed as follows:

$$v_w(h) = v_{10} \cdot \left(\frac{h}{h_{10}}\right)^{\alpha}$$

where:

v_w is the wind velocity in ms^{-1} at turbine hub height
v_{10} is the wind velocity in ms^{-1} as recorded by the anemometer on the 10m mast
h is the height of the wind turbine hub in metres
h_{10} is the height of the mast (=10 metres in our case scenario)
α is the Hellman exponent

However, a more widely recognised equation based on meteorological processes is the following logarithmic relation:

$$u(z) = \frac{u^*}{\kappa} ln \frac{z}{z_0}$$

where:

u(z) = wind velocity at height (z) in metres
u* is the shear velocity
κ is Karman's constant
z_0 is the roughness height

Before an average turbine height wind could be calculated however, Guernsey Airport wind data would then need to be analysed for the period in question to ascertain the windiness of the 12 month period against Guernsey Airport's 30 year average winds. The raw data would then need to be adjusted accordingly to give a statistical interpretation of the 10 metre wind for a year with average windiness. This averaged figure could latterly be extrapolated to show average wind speeds at turbine hub height and then used to calculate potential electricity generation figures for the site and as a minimum indication for an averaged wind velocity figure for an offshore wind farm.

Fig.6 – Measuring wind direction & speed at 10 metres. Source: Campbell Scientific

Before leaving these equations behind, it is worth noting that they also illustrates the fact that wind turbines with the highest hub heights are able to take advantage of stronger wind velocities not to mention the fact that these larger structures allow for the installation of larger turbines with greater generating capacities. In this vein, therefore, bigger installations are more efficient installations and in the event that an onshore wind farm is contemplated it must be said that the efficiency of the installation will be in proportion to its visual intrusiveness.

Other ways of measuring and estimating average wind speeds offshore Guernsey

Accurate measurement and/or estimation of offshore winds is more difficult and expensive than measurement and estimation of onshore winds, but remains possible through a variety of methods. In general though, these methods may be worthy of investigation and financial investment only after a definite decision has been made to undertake detailed professional investigations of offshore wind power generation at a specific offshore site.

The measurement and extrapolation technique described in previous paragraphs can be used in a more complex form known as **MCP (Measure Correlate Predict) Analysis**. MCP could be used in conjunction with data from a 10 metre mast and datasets from nearby locations such as Guernsey Airport and the Channel Light Vessel. Further data is also available from the NCEP/NCAR[3] Wind Reanalysis database which contains data that runs from 1948 to the present.

Computer models may also be used to obtain predicted average turbine height winds. Such models may utilise data from the NCEP/NCAR Reanalysis database, but are designed to be more user friendly to the wind energy industry and offer better resolution of wind speeds than the NCEP/NCAR's rather coarse 2.5° grid.

Existing records from nearby French wind farms may also be of use although none are sufficiently close to Guernsey to be relied upon completely. As an example, Les Grunes Wind farm, which is located between Jersey and the coast of Normandy, quotes a 10 year mean wind speed of 9.28ms^{-1} at a height of 100m a.m.s.l.[4] Whilst it would be tempting to use this figure for planning purposes, it should be noted that the wind farm may benefit from a continental sea breeze effect during the summer months. Conversely, winds from winter depressions passing over or to the north of the UK should be slightly stronger on average over the waters to the NW of Guernsey than over Les Grunes.

It should also be noted that if offshore wind turbines with a relatively low hub height are constructed in Bailiwick waters, a large tidal range means that the effective hub height above water level may be variable enough to affect hub height wind speed in rough weather when high seas exert a greater frictional effect on the lowest layers of the airflow.

Annual and short period variations in local wind speeds

In considering commercial scale generation of electricity from wind power, some comment must be made about the inter-annual and short-period variability of local wind speeds. Figure 2 shows the averaged wind speed in 2010 to be 1.6 ms^{-1} lower than the 30 year average speed. Such a deviation from average is not uncommon. There are also windier years when Guernsey's weather patterns are dominated by a mobile westerly regime with long series of depressions moving over or to the north of Scotland. These variations are not, however, necessarily random and one of the lessons of the local weather record is that calmer years and windier years often group together and these periods of calmer or windier conditions can persist for as long as a decade or two.

The reason for the annual variation has much to do with a climatic phenomenon known as the NAO (North Atlantic Oscillation) which is strongly linked to the strength and direction of travel of depressions in the North Atlantic. As a broad generalisation, high NAO values are associated with windy years, mild winters and an above average number of gales, whilst low NAO values bring calmer conditions, an increased risk of severe cold in winter and few gales. A graph of NAO values shows occasionally quite marked decadal variations. The most recent variation has been towards lower annually averaged NAO values.

The NAO also varies markedly on a shorter timescale that can be measured in terms of days and weeks and this shorter term variation also affects local wind speeds especially in winter.

Unfortunately, the dynamics of the NAO are not completely understood and prediction of NAO values becomes unreliable after 7 to 10 days. This therefore raises the prospect that monthly and annual averaged wind speeds across the island are – for the foreseeable future – unpredictable and notably variable.

Trends in local wind speeds

The variability of annually averaged wind speeds and the tendency of calmer and stormier years to group together can easily lead to a misinterpreted trend via the selection of inopportune start and end dates so there is a need for care to be taken in the interpretation of local wind data.

Some older members of the public have commented to Guernsey Met Office on a perceived fall in average wind speeds in recent decades. If this could be proven, it can probably be attributed to new building developments and a gradual restoration of tree cover following the tree-felling and fuel shortages that occurred during the latter part of the German occupation. These local observations do not, however, indicate that turbine level wind speeds have fallen across the island but rather that the frictional effects of new buildings and trees have reduced wind speeds in areas where people notice.

Climate models have generally forecast increased storminess and higher averaged wind speeds over the north Atlantic and north-west Europe in response to human induced climate change[5]. As a result of this, Professor Edward Hanna from the University of Sheffield undertook a wide ranging and comprehensive study of surface pressure variability (a proxy for changes in wind velocity) across Northern Europe and the North Atlantic[6] which included the use of data from Guernsey. The study concluded that wind strengths and storminess had not increased in recent decades. This accords with Guernsey Met Office statistics from Guernsey Airport which show no statistically significant change in wind speed over long periods of time.

Solar Energy

Guernsey has one of the best sunshine records of any location in the British Isles with the Vale and St Sampsons being the sunniest locations within the island. The island’s southerly location and clean air also ensures that incoming solar radiation levels are also high in comparison with the UK.

The island receives an average total of 1864 hours of direct sunshine per year, although it must be remembered that solar panels also generate some electricity when the sun is hidden behind a relatively thin layer of cloud and light levels remain high.

Sunshine Trends

Sunshine amounts in Guernsey can be quite variable on an annual basis but when decadal averages are examined, there are signs that total sunshine amounts have been gradually increasing since the introduction of clean air legislation and the demise of the polluting heavy industry of the Warsaw Pact countries.

Solar Panels

Solar panels use a semi-conducting material such as silicon which intercepts the photons in sunlight and converts some of the incoming energy of the photons into a flow of electrons that can then be harvested as a DC voltage. Small solar panels can have a variety of uses in an average household – such as trickle charging a mobile phone – the amount of electricity generated however is very low in comparison to the needs of the average home.

There are increasing numbers of commercial scale solar powered electricity generators in the world today, however this method of electricity generation is extremely costly on a commercial scale and such plants depend heavily upon generous subsidies levied through taxes or electricity bills.

It is worth noting, however, that the efficiency of solar panels in turning sunlight into electricity is generally poor and a quantum leap in this technology could lead to a reassessment of the current conclusion that solar powered generation on a commercial scale is unfeasible for the island.

Notes and References

[1] Calculated as 2 x 0.28 x 24 x 365

[2] Intelligent Energy Europe - http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-resource-assessment-offshore/measurement-offshore.html

[3] National Center for Environmental Prediction / National Center for Atmospheric Research

[4] Data from Global Offshore Wind Speed Database - http://www.4coffshore.com/windfarms/request.aspx?id=owsdb&version=2&windfarmid=FR10

[5] Singarayer, J.S., J.L. Bamber, JL & P.J. Valdes (2006) Twenty-first-century climate impacts from a declining Arctic sea ice cover, *Journal of Climate* 19, 1109-1125.

[6] Hanna et al (2007) New insights into North European and North Atlantic surface pressure variability, storminess and related climatic change since 1830 (Journal of Climate).

Hanna commented in his conclusion as follows: "….in general, global climate model (GCM) projections of changes in North Atlantic storminess (as a main example) vary widely and remain unreliable. The models are in urgent need of further refinement and need to be checked against an improved observational record (IPCC 2007**)**."

FEASIBILITY STUDY INTO OFFSHORE WIND ENERGY

APPENDIX B - COST OF ENERGY AND IMPACT ON ENERGY PRICES

Impact of RE on Tariffs from 12MW Deployment in 2014

Existing prices

Cost of conventional	9.1 p/kWh	(Includes depreciation of capital assets, staff, running costs, etc.)
Cost of distribution	3.0 p/kWh	
total	12.1 p/kWh	

Energy Useage

Annual Average Wind Speed (m/s)		Energy (MWh)	Energy (%)
8.0	Total Units	423889	
	Renewables	32521	8%
	Conventional	391368	92%
8.5	Total Units	423889	
	Renewables	35886	8%
	Conventional	388003	92%
9.0	Total Units	423889	
	Renewables	39063	9%
	Conventional	384826	91%

Summary Of Analysis

Rate of Return on Equity	Annual Average Wind Speed (m/s)	Cost of Conventional (£k / year)	Subsidy (p/kWh)	Cost of Wind (£k / year)	Total Cost of Energy (£k / year)	Average Cost of Energy (p/kWh)	Increase in Tariff (%)
10%	8.0	47,434	7.15	6,267	53,701	12.67	4.5
	8.5	47,026	5.50	6,323	53,349	12.59	3.8
	9.0	46,641	4.20	6,375	53,016	12.51	3.2
15%	8.0	47,434	9.24	6,946	54,380	12.83	5.8
	8.5	47,026	7.42	7,012	54,038	12.75	5.2
	9.0	46,641	5.98	7,070	53,711	12.67	4.5

FEASIBILITY STUDY INTO OFFSHORE WIND ENERGY

APPENDIX B - COST OF ENERGY AND IMPACT ON ENERGY PRICES

Impact of RE on Tariffs from 30MW Deployment in 2014

Existing prices

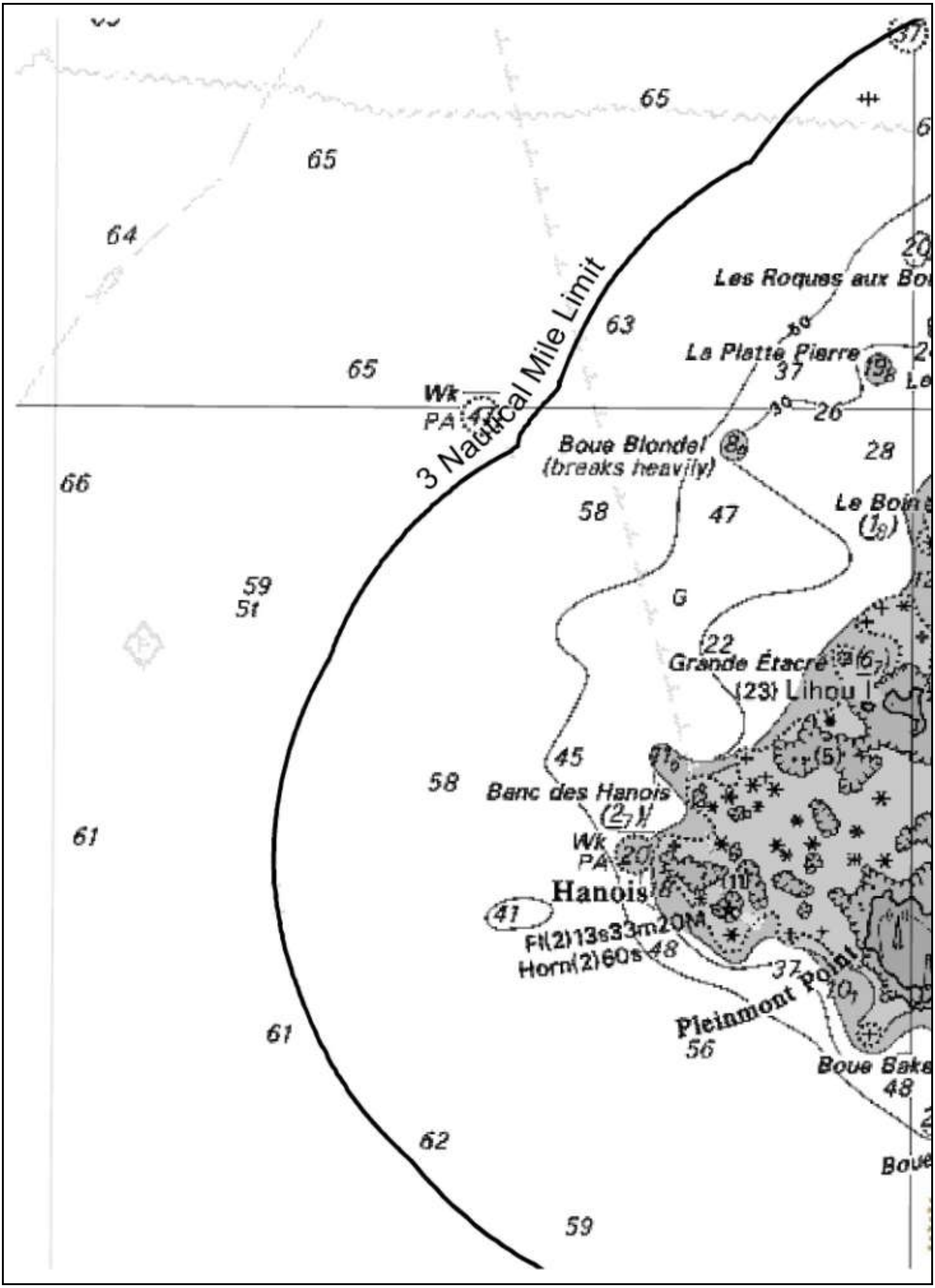
Cost of conventional	9.1	p/kWh
Cost of distribution	3.0	p/kWh
total	12.1	p/kWh

Energy Useage

Annual Average Wind Speed (m/s)		Energy (MWh)	Energy (%)
8.0	Total Units	423889	
	Renewables	82205	19%
	Conventional	341684	81%
8.5	Total Units	423889	
	Renewables	90711	21%
	Conventional	333178	79%
9.0	Total Units	423889	
	Renewables	98742	23%
	Conventional	325147	77%

Summary Of Analysis

Rate of Return on Equity	Annual Average Wind Speed (m/s)	Cost of Conventional (£k / year)	Subsidy (p/kWh)	Cost of Wind (£k / year)	Total Cost of Energy (£k / year)	Average Cost of Energy (p/kWh)	Increase in Tariff (%)
10%	8.0	41,412	6.29	15,134	56,546	13.34	10.1
	8.5	40,381	4.72	15,276	55,657	13.13	8.3
	9.0	39,408	3.48	15,404	54,812	12.93	6.7
15%	8.0	41,412	8.27	16,762	58,174	13.72	13.2
	8.5	40,381	6.54	16,927	57,308	13.52	11.5
	9.0	39,408	5.18	17,082	56,490	13.33	10.0


3 Nautical Mile Limit
Les Roques aux Bo
La Platte Pierre
Wk
PA
Boue Blondel
(breaks heavily)
Le Boin
Grande Étacré
Lihou I
Banc des Hanois
Wk
PA
Hanois
Fl(2)13s33m20M
Horn(2)60s
Pleinmont Point
Boue Bake