Guernsey Renewable Energy Feasibility Report

in co-operation with the Guernsey Renewable Energy Team

RE | 2012

STATES OF GUERNSEY

UNIVERSITY OF EXETER

GUERNSEY

RENEWABLE ENERGY FEASIBILITY REPORT

June 2012

Version 5

Report Created For:

STATES OF GUERNSEY

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ACKNOWLEDGMENTS

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- Alun Williams (Education Department);
- Andrew Casebow (GREF & La Societe Guernesiase);
- Bob Beebe (Guernsey Electricity Limited);
- Claire Barrett (Planning Division);
- Damon Hackley (Policy Council);
- David Parish (University of Exeter);
- Deidrie Dudley-Owen (CT Plus);
- Elizabeth College;
- Helen Shorey (States of Guernsey);
- Helen Smith (University of Exeter);
- John Sexton (Guernsey Electric Limited);
- Jonathan Gilbert (Environment Department);
- Justin Hinshelwood (University of Exeter);
- Lars Johanning (University of Exeter);
- Mark Parr (Electric Vehicle Company);
- Mark Reeve (Electric Vehicle Company);
- Martin Crozier (Met Office);
- Martyn Haywood (University of Exeter);
- Mat Desforges (Commerce & Employment);
- Neill Wood (University of Exeter);
- Paul Fletcher (E-Si Limited);
- Peter Barnes (Commerce & Employment);
- Peter Gill (Harbour Master);
- Richard Lord (Sustainable Guernsey);
- Sally-Ann David (Guernsey Electricity Limited);
- St. Sampson High;
- Steve Morris (Policy Council);
- Yvonne Burford (Environment Department).

Significant assistance was received from many people on Guernsey and it is not possible to list everyone but a special thanks goes to those listed.

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AD	Anaerobic Digestion
AIS	Automatic Identification system
BSP	Bulk Supply Point
CAES	Compressed Air Energy Storage
CCC	Committee on Climate Change
CES	Cryogenic Energy Storage
CFD	Contract For Difference
CHP	Combined Heat and Power
CSTR	Continuous Stirred Tank Reactor
DNO	District Network Operator
EfW	Energy from Waste
EIA	Environmental Impact Assessment
EVC	The Electric Vehicle Company
FEPA	Food and Environmental Protection Act
GDP	Gross Domestic Product
GEBCO	General Bathymetry Charts of the Oceans
GEL	Guernsey Electric Limited
GIS	Geographical Information System
GREF	Guernsey Renewable Energy Forum
GTA	Guernsey Training Agency
GWh	Gigawatt-hour
HT-TES	High Temperature Thermal Energy Storage
HV	High Voltage
IRP	Infrastructure Resource Plan
kWh	Kilowatt-hour
LFG	Landfill Gas
MCS	Microgeneration Certification Scheme
MCT	Marine Current Turbines
MWh	Megawatt-hour
NPV	Net Present Value
O&M	Operation and Maintenance

OTD	Overtopping Devices
OWC	Oscillating Water Column
PV	Photovoltaic
R&D	Research and Development
REA	Regional Environmental Assessment
RET	Guernsey Renewable Energy Team - part of States of Guernsey Commerce and Employment, which is progressing macro marine renewables
RGU	Robert Gordon University
ROC	Renewable Obligation Certificate
SAP	Standard Assessment Procedure
SCADA	Supervisory Control and Data Acquisition
SVC	Static VAR Compensator
SSP	States Strategic Plan
VAR	Reactive Power
WAB	Wave Activated Bodies
WECs	Wave Energy Converters
WTG	Wind Turbine Generator
WTIVs	Wind Turbine Installation Vessels

DISCLAIMER

The opinions and conclusions of this report are those held by the working team of final year BSc Renewable Energy Students (2011/12) at the University of Exeter and not necessarily those of the Guernsey Renewable Energy Team.

1 EXECUTIVE SUMMARY

The following report, commissioned by the States of Guernsey Renewable Energy Team (RET), assesses the suitability and feasibility of deploying macro-marine renewable energy technologies off the shore of Guernsey. By taking a holistic approach to renewable energy, context could be given to the individual technologies considered – wave, tidal and offshore wind.

The report was carried out to further the work already being done on the island by RET who have identified the need for localised renewable energy and highlighted the potentially affluent offshore resource. Renewable energy can offer Guernsey improved energy security and a diverse economy if employed correctly.

Guernsey currently sources 78% of its electricity from France using an interconnector through Jersey, whilst generating the remaining 22% on-island using diesel generators. This poses risks with respect to energy security and impending fuel price rises, especially as the demand continues to rise, at an estimated 3.5% per annum.

A key aspect of marine renewable energy is licensing. In offshore wind development, this was a key barrier to deployment that slowed the process down significantly. Guernsey can learn lessons from mistakes made by the UK and prepare a licensing system ready for the deployment of offshore renewable energy arrays. By ensuring this system is simple, clear, flexible and communicated effectively, Guernsey can prevent it being a significant barrier to deployment.

Previous studies have been carried out identifying the significant tidal resource in the English Channel. A critique of a particular report produced by the Robert Gordon University (RGU) found that this provides a good basis for further analysis. Using GIS software, constraints mapping discovered two main sites within the 3 nautical mile radius – the Big Russel and south east of Sark. By extrapolating data from the RGU study, the resource around Guernsey could be analysed and matched to tidal stream devices at the two potential sites. It was discovered that the estimated energy yield at the Big Russel site could be 566 GWh/yr whilst the site south east of Sark could produce 749 GWh/yr. These figures are larger than those found in the RGU report, and therefore this highlights the need for empirical data. There are, however, some important constraints to the development of tidal power off the island. It is crucial that installation and maintenance vessels are available when needed, cables can be supplied, the skilled workforce is available and, crucially, more accurate data is obtained before any further plans are formulated. Tidal stream technologies are still in their infancy and therefore the levelised cost per kW is still high and still unknown. It is expected to fall in the future and it is at this point that Guernsey should consider entering the commercial market. There is also the potential for Guernsey to designate some of its waters as testing grounds for tidal devices, building up relationships with potential developers and aiding the industry. This should be investigated further as the sites have great potential.

Currently, the wave energy sector is in its youth and there is no complete wave energy converter solution. Therefore, an initial resource assessment has been carried out using UK Met Office modelled data. Constraints were also applied to the waters around Guernsey to find suitable sites for the potential deployment of an array. A site was located north west of Guernsey with potential for a 28MW array yielding approximately 40 GWh/yr. It is recommended that further study is undertaken with more accurate data from actual wave buoys, and, if possible, a wave buoy deployed by RET to obtain truly representative data.

The potential for offshore wind farms has also been considered, with an initial look at the previous feasibility study produced. It has been concluded that a 12MW site is unfeasible due to economies of scale, but a 30MW site could be made possible by incorporating it with a larger order for an offshore wind farm off France. Constraints mapping has been carried out using GIS software. This has led to three sites being found – North Herm (30MW), North Guernsey (30MW) and North East Guernsey (300MW). By correlating data collected at the Chouet met mast with wind turbine power curves, energy yields could be estimated. For the two 30MW sites, it has been estimated that they will yield 94GWh/yr with the 300MW site producing 1270GWh/yr. Whilst financing and port facilities provide significant barriers to the deployment of these arrays, there is significant potential at these sites for further research to be carried out.

Environmental issues attaining to each technology have been considered and the key potential impacts identified. The visual impact of offshore wind is a key concern for the public, but by using realistic images it can be seen that this should be kept to a minimum. Other issues surrounding ecology, shipping and fishing have also been identified but, if mitigated against, should not be significant barriers to deployment. There will also be potential impacts in the construction phase, but these should not be significant due to the limited time that they are present. Also, onshore works may have some environmental impacts that will need to be assessed in more detail nearer to deployment. Finally, there will be some positive environmental effects induced by the technologies. Foundations can form new marine habitats leading to new breeding grounds for birds whilst wave devices such as the Pelamis have proven to encourage fish populations by providing a new habitat.

Energy efficiency measures can help limit the increase in energy demand of the island. By aiding the implementation of these measures, Guernsey could see a reduction in CO_2 emissions and aid the deployment of marine renewables through reducing required capacity. Analysis has been carried out on a variety of micro generation technologies. This found that domestic solar PV won't payback within its lifetime and has an NPV of -£284. Commercial solar PV, however, pays back in 12 years with an NPV of £5490. Solar thermal technology is estimated to payback in 18 years when displacing gas heating, and 14 years when displacing electric heating. However, for these to be practical, barriers such as planning issues, limited number of installers and no set installation standards must first be overcome. Medium scale anaerobic digestion has also been considered but with a system payback of 20 years this has not proved to be feasible. Waste management has also been highlighted as a potential issue on the island. An energy from waste generation plant or exporting waste to Scandinavia for this purpose have been highlighted as possible solutions for the island.

It is assumed that the grid can accept up to 30MW of renewable energy installations before requiring a major upgrade – this would need further work to test this. For installations larger than this figure, export would be the best solution and as such a new cable could be required in order to allow for export to the European Grid. A key issue with renewable energy is its inherent intermittency and unpredictability. This makes it a prime candidate for energy storage. The options for energy storage technologies have been evaluated and cryogenic energy storage has proven to be potentially suitable for Guernsey. The technology is still fairly new and as such will need to develop further before any firmer plans are made. Energy could also be stored in cars if an electric transport system was setup. This would allow cars to be charged at night utilising potentially unwanted renewable energy. The current ports have been deemed to be unsuitable for large-scale renewable energy installations and as such French ports would have to be used. However, there is currently a plan in place to improve the harbour and it has been suggested that this could be adapted to incorporate larger marine renewable energy vessels at little extra cost.

Public consultation is crucial to quick and efficient deployment of marine renewable energy. Therefore, it is essential that the Guernsey public are aware of and educated about any future plans for renewable energy installations. This includes furthering education in schools, the workplace and among communities. It is also crucial to consult stakeholders and keep open lines of communication at all times. A seven-phase plan has been devised, including public exhibitions, meetings and press releases.

Finally, three scenarios have been devised and analysed. They offer guidance on what options there are when deploying offshore devices and some rough timescales. The first is a base case to show the need for renewable energy whilst the other two are possible pathways for Guernsey to take that would be cost-effective and practically prudent. Scenario 1 sees no installation of renewable energy and highlights the risk of being exposed to energy security issues and rising energy bills. Scenario 2 sees renewable energy act as a base load for the island, and suggests the possible deployment of 30 MW of offshore wind in 2020 or 30 MW of tidal stream devices in 2030. Scenario 3 shows a potential export option by deploying wave, tidal and offshore wind. This scenario would only be economically feasible if subsidies from the UK could be accessed. It is clear, due to the large potential capacity installed, that this is the most financially rewarding scenario for Guernsey; however it has some of the most significant barriers to its viability. This scenario is likely to be a longer-term plan for the future.

Several recommendations have also been laid out. For tidal it is advised that more data is obtained and that the commercial R&D opportunity is investigated further.

To develop the knowledge of the wave resource, a further wave resource assessment would require more data and the potential deployment of Guernsey's own wave buoy.

Offshore wind, a promising prospect, requires further wind speed data as well as environmental, hydrodynamic, geological and wind loading surveys.

To gain a better idea of the environmental impacts caused by macro-marine renewables, surveys of marine mammals and all species in the waters around Guernsey are required, as well as assessing the visual impacts of an offshore wind farm.

To ensure the complete integration of these developments, the policy mechanisms to ensure that renewable energy receives the right level of support also need to be finalised. The potential electrification of the transport network should be explored; and the effect this will have on renewable energy capacity.

Public consultation also needs to be assessed, with education at an early stage essential, along with training workforces and increasing awareness amongst different communities. A phased, planned public consultation strategy should also be finalised, accommodating all stages of the procedure.

To ensure the correct strategy for deployment, the relative benefits of tidal and offshore wind need to be assessed, to see which may be the most suitable technology to progress in order to meet the baseload requirements of the island. Finally, talks regarding the access to French or UK subsidies need to be maintained, as this could provide Guernsey with the most financial gain.

Overall, it is clear that Guernsey has a significant marine renewable energy resource that, if handled appropriately, has the potential to provide the island with many benefits.

2 INTRODUCTION

2.1 The Need for Renewable Energy

Before outlining the scope of this report, it is first important to understand the broad need for renewable energy and the benefits it can bring to the island.

There are four key reasons for the deployment of renewable energy on Guernsey.

The first, and perhaps most widely reported, is to reduce greenhouse gas emissions. There is scientific evidence to show that the combustion of fossil fuels worldwide is having a devastating effect on the earth's atmosphere, causing anthropogenic global warming. Renewable energy generation methods do not emit these gases, and as such can help guard against these effects.

A particularly prominent reason for Guernsey to deploy renewable energy is for reasons surrounding energy security. Currently, the island relies heavily on imports both through a cable in the form of direct electricity and through oil imports to power on-island diesel generators. As seen recently, the cable has been damaged meaning the island has to rely solely on its own generation methods. Should oil, subject to volatile price fluctuations and a highly contentious political subject, be unavailable the island would be at risk of not being able to supply electricity. Renewable energy, being localised, negates this risk and increases the overall energy security of the island.

Another key reason that the States of Guernsey wish to invest in renewable energy is to diversify their economy and provide jobs. Renewable energy projects provide sustainable, constant sources of employment through monitoring, control and maintenance and as such would help diversify an economy dominated by financial services.

Finally, renewable energy can provide a return on investment bringing money into the economy through the sale or export of energy. In addition, it can protect against rapidly rising energy costs, largely caused by ever increasing fuel prices.

Having identified this need, RET has commissioned this report to assess the feasibility of marine renewable energy off the coast of Guernsey.

2.2 Project Scope

The states of Guernsey have a real ambition to exploit the renewable energy resources of the Bailiwick and RET have already undertaken a significant amount of work in relation to the deployment of marine renewables, and continues to add to this body of knowledge.

RET have instructed RE 2012 to carry out a high level report on the feasibility of supplying a large proportion of the Bailiwick's energy from marine renewable energy technologies. Specific objectives of the project are:

- Focus on the strategic implementation of offshore wind, wave and tidal energy; to develop an energy management strategy for Guernsey;
- Work using both existing and new data. Focussing on the potential for development of marine renewable energy in Guernsey's waters;
- Consider, assess and explain:
  - Visual impact of wind, tidal and wave devices;
  - Resource assessments for offshore renewable energy deployments;
  - Grid connection, balancing and power distribution;
  - Infrastructure for offshore deployments and maintenance;
  - Acceptability of renewable energy technologies for the Guernsey public and assessment of the development of public consultation procedures.

2.3 RET Ambitions

Having outlined why RET have commissioned this study and what the scope is, it is also crucial to outline the ambitions of this team and any goals that the States of Guernsey have set.

Firstly, there is an overarching target to generate 20% of the island's energy demand using renewable energy sources by 2020 (Channel Television, 2011). Whilst this could be met from imported electricity, the most sustainable and secure way of meeting this target would be to use indigenous renewable sources.

As well as this, RET have some specific objectives as a group. These, taken from RET's website (RET, 2012; States of Guernsey, 2011) are as follows:

- Prepare an initial Environmental Assessment - this strategic study will establish the likely environmental impacts associated with the deployment of Marine Renewable Energy devices in the seas around Guernsey.
- Develop a Consenting regime - to control and permit the deployment and operation of devices and associated works such as cabling and shore connections.
- Develop Policy - We are aware that the introduction of renewable energy has the potential to impact, on numerous other aspects of life on Guernsey. We are working closely with the other Channel Islands, the Guernsey Renewable Energy Forum and the relevant departments within the States to ensure that Renewable Energy is smoothly integrated into our way of life.
- Attract Developers - With the potential to establish a very powerful energy resource, located so close to our shores, we hope to attract responsible energy developers to Guernsey who will want to generate energy for domestic sales or export to Europe. We will work to ensure that we get the best deal for Guernsey in benefiting our environment, reducing our carbon emissions, and in terms of the commercial arrangements.

2.4 Report Methodology

To make this report as effective and current as possible, it was important for RE 2012 to understand what had already been done. From this, particular areas of study could be identified before carrying out the research and analysis. The following areas were identified as being key to the report and provide the basis for this report:

- **Overview** – to provide an energy context for other technologies and identify current issues and needs;
- **Licensing** – identifying any issues surrounding licensing, especially those lessons that can be learned from the UK's offshore licensing experience;
- **Energy Efficiency** – measures to try and limit the increase in energy demand that the island will experience, thus reducing the amount of renewable energy that would be required to power the island;
- **Onshore Renewables** – giving context to the marine renewable energy technologies and allowing for an assessment of more mature technologies to compare against;
- **Tidal** – a review of the work that has already been done, as well as identifying potential sites through resource assessment and constraints mapping.
- **Wave** – a resource assessment using modelling techniques to indicate whether this is an area where further study is required, and what data gaps there are;
- **Offshore Wind** – assessing the feasibility of offshore wind sites other than those already identified by previous studies and discussing the issues and impacts involved;
- **Environmental Scoping** – identifying the potential environmental impacts, both positive and negative, caused by the deployment of offshore renewable energy devices;
- **Infrastructure and Integration** – assessing the suitability of the electrical and supporting infrastructure for the installation of different levels of renewable energy;
- **Public Consultation** – developing a public consultation procedure for the potential deployment of marine renewable energy technologies. Also, suggesting measures to increase the acceptability of renewable energy and raise awareness on the island;
- **Scenarios** – analysing three potential scenarios for the deployment of renewable energy, how they might be achieved and the effects on the island.

By breaking this report down into these sections, a holistic approach has been taken that encompasses all aspects of renewable energy and gives an insightful outlook into the possibilities for renewable energy on the island.

3 OVERVIEW

3.1 Introduction

The following section describes in detail Guernsey's current energy market and mix while using the trends of the past few years to predict future demands. The cost of imported electricity and the price of oil was looked into and assessed for its future viability as a dependable fuel source.

3.2 Energy Mix

Guernsey currently imports its electricity from France as well as generating part of its demand on the island. The electricity mix for 2010/11 is broken down and shown below (States of Guernsey, 2011a):

- Nuclear - 64%
- Oil - 23%
- Renewable energy - 8%
- Coal - 3%
- Gas – 2%.
- Other - <1%

3.3 Energy Consumption

The total energy consumption over the three years leading up to 2011 increased and the type of fuel source varied considerably with the following fluctuations (States of Guernsey, 2011a):

- Electricity - 6.5% increase
- Gas Oil/Heavy Fuels Oils - 12.2% increase
- Kerosene - 7.6% increase
- Aviation fuel - 45.3% decrease (due to increased quantities of aviation fuel provided to consumers from outside the Bailiwick, mainly from the UK mainland. Without this switching of suppliers, total energy consumption would have increased.)

3.4 Electricity Demand

The maximum electrical demand has shown a constant growth over the past 20 years with considerable growth after 2006 (States of Guernsey, 2011a). Maximum annual demand went from 63MW in 2000 to 85MW in 2010, an increase of 35% in ten years. The amount of electricity consumed increased from 310GWh per annum to 400GWh per annum over the past ten years (States of Guernsey, 2011a).

The minimum demand, or base load, has increased by 2MW in the past five years, and stood at 22.9MW in 2011.

For the year ending March 2011, the following units were recorded:

	2011	2010
Units imported (MWh)	308,600	239,332
Units generated (MWh)	84,633	152,243
Total units imported/generated(MWh)	393,233	391,575
Average price to consumer per kWh (pence)	12.33	12.33

Table 3:1 - Guernsey's Imported/Generated Electricity (Guernsey Electricity Limited, 2011)

Guernsey Electricity introduced smart metering over the previous few years; currently 95% of the population has smart meters installed, allowing for information to be constantly collected on the various electricity uses throughout the island.

Figure 3:1 shows a small increase per year on the electric consumption per capita.

Although the population increased slightly over the years the main reason for this increase is the rise in demand for electric heating and electricity becoming a greater part of lifestyle activities (States of Guernsey, 2011a). Figure 3:3 shows how the increase in demand was met using the 'least cost – economic dispatch principal from imported or generated electricity.

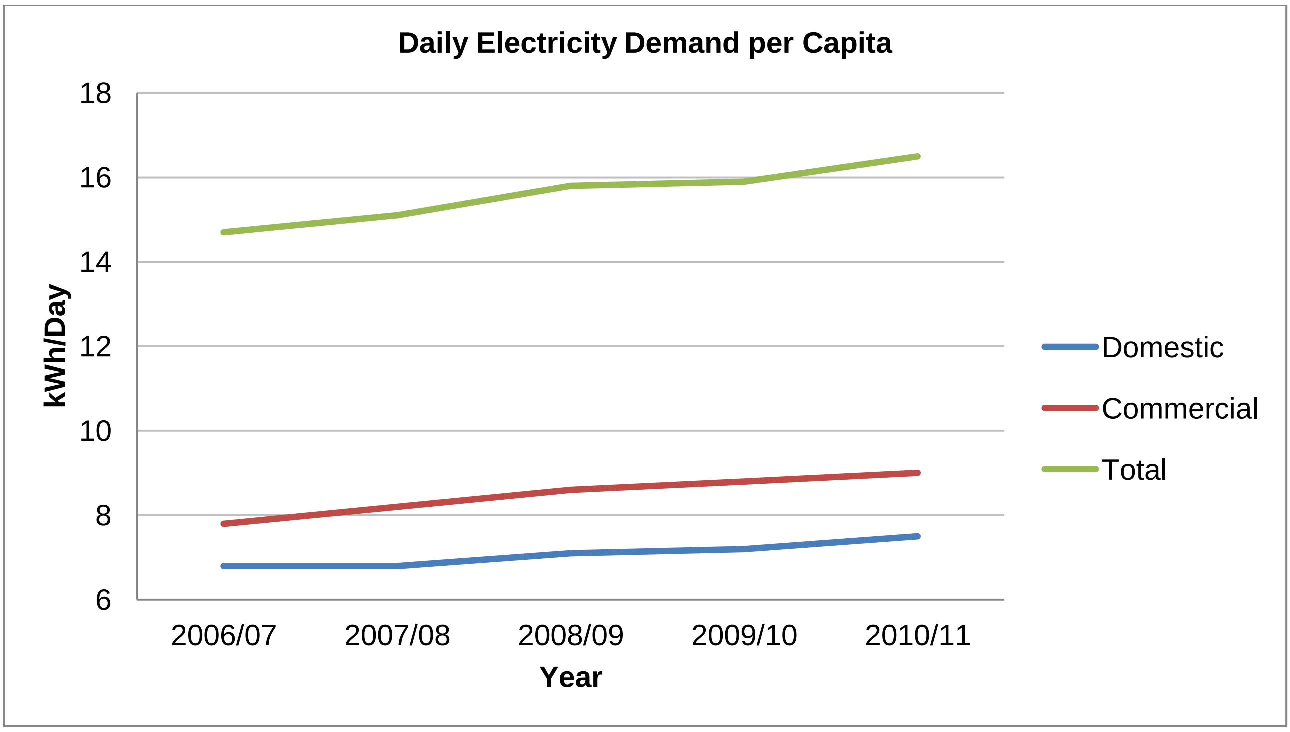

Figure 3:1 - Daily Electricity Demand per Capita (States of Guernsey, 2011a)

The annual generation and unit production for 2010 – 2011, is shown in Figure 3:2. The cost of crude oil is shown relative to the generation capacity. The cost per barrel will directly affect the on-island generation costs. As oil prices are expected to rise consistently there will be a push towards a form of generation that does not rely simply on conventional fossil fuels.

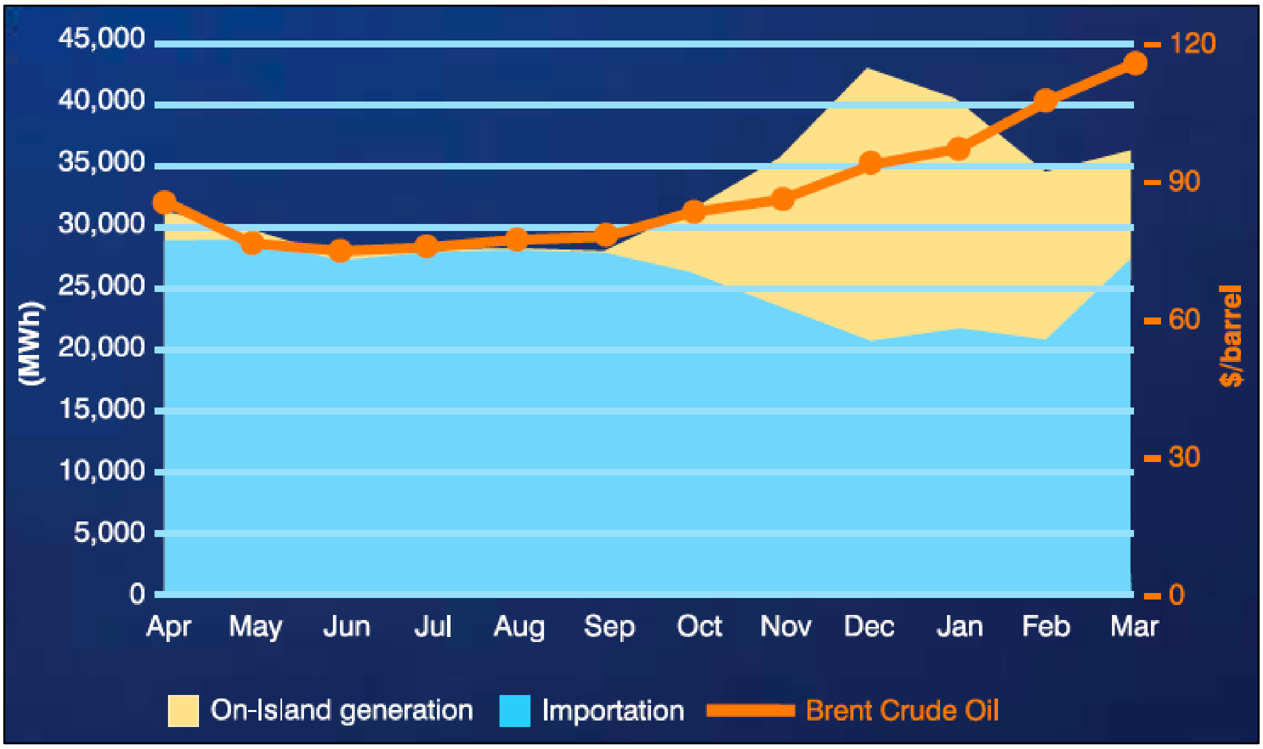

Figure 3:2 - Importation and On-island Unit Production April 2010 – March 2011 (Guernsey Electricity Limited, 2011)

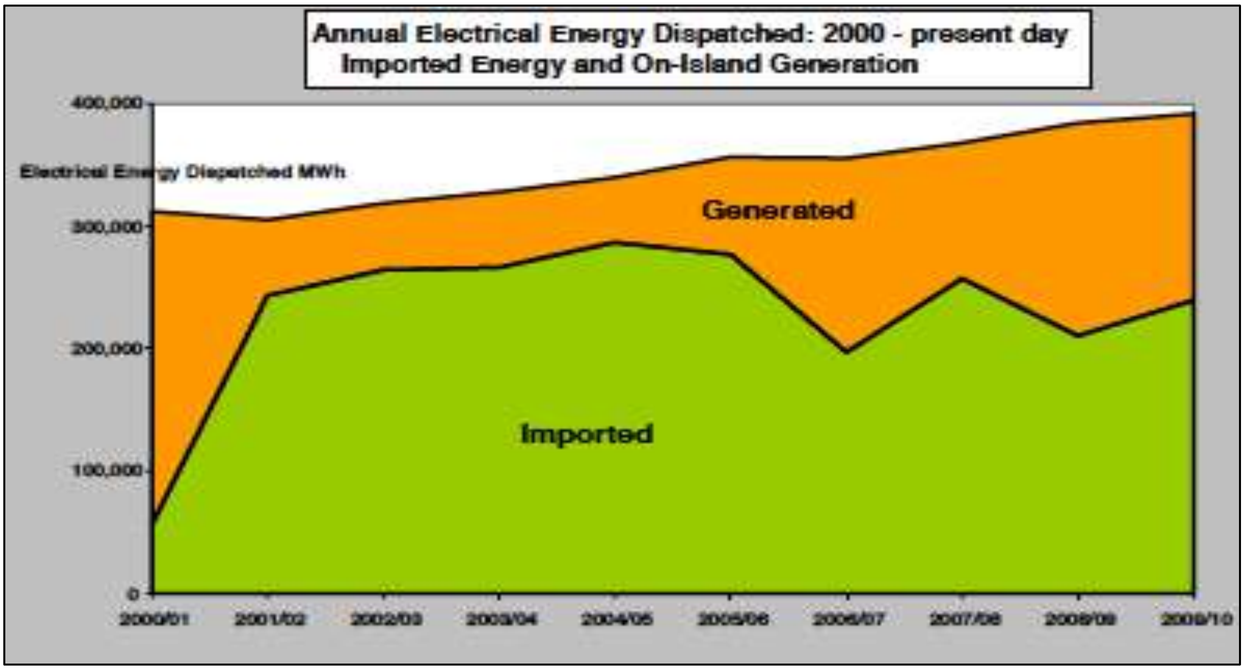

Figure 3:3 - Imported Energy and On-island Generation (States of Guernsey, 2011a)

3.5 Interconnector

Jersey secures the majority of its electrical supply from France through a 145MW interconnector; however this still does not meet the islands peak demand of 185MW. Guernsey partly financed a second cable between Jersey - France in 2000; this gave them the contractual right to draw a guaranteed 16MW from France through Jersey passing through the 55MW Jersey-Guernsey interconnector (States of Guernsey, 2011a). Up until at least 2023, there is a 'take-or-pay' clause on the cable, meaning that even if Guernsey does not draw 16MW they must still pay for it. Guernsey Electricity is given access to capacities greater than 16MW if Jersey has a shortfall in demand, which is often the case (States of Guernsey, 2011a). From discussions, it seems likely that a third cable between Jersey-France will be installed, with a capacity of 100MW, increasing Guernsey's guaranteed capacity by 24MW bringing it to 40MW in total (States of Guernsey, 2011a). However a key drawback lies in the cable's inaccessibility; if damaged it could take up to six months to repair (States of Guernsey, 2011a). If the proposed project is approved, Guernsey could effectively import 95% of all its electrical demand with the shortfall being made up mainly in winter by conventional fossil fuels. The electricity imported from the interconnector supplied 78% of the country's electricity in the year ending March 2011 (Guernsey Electricity Limited, 2011).

3.6 Future Demand

The yearly increases and fluctuations in demand, if averaged out, give an estimate of future energy demands, shown in Figure 3:4. This prediction is already out-dated, as the maximum demand for 2010 was 83MW, exceeding the 77MW maximum demand estimated for the year. The trend in the past ten years has shown an increase of 3.5% in base load demand per year. This figure will more accurately represent the future demand predictions.

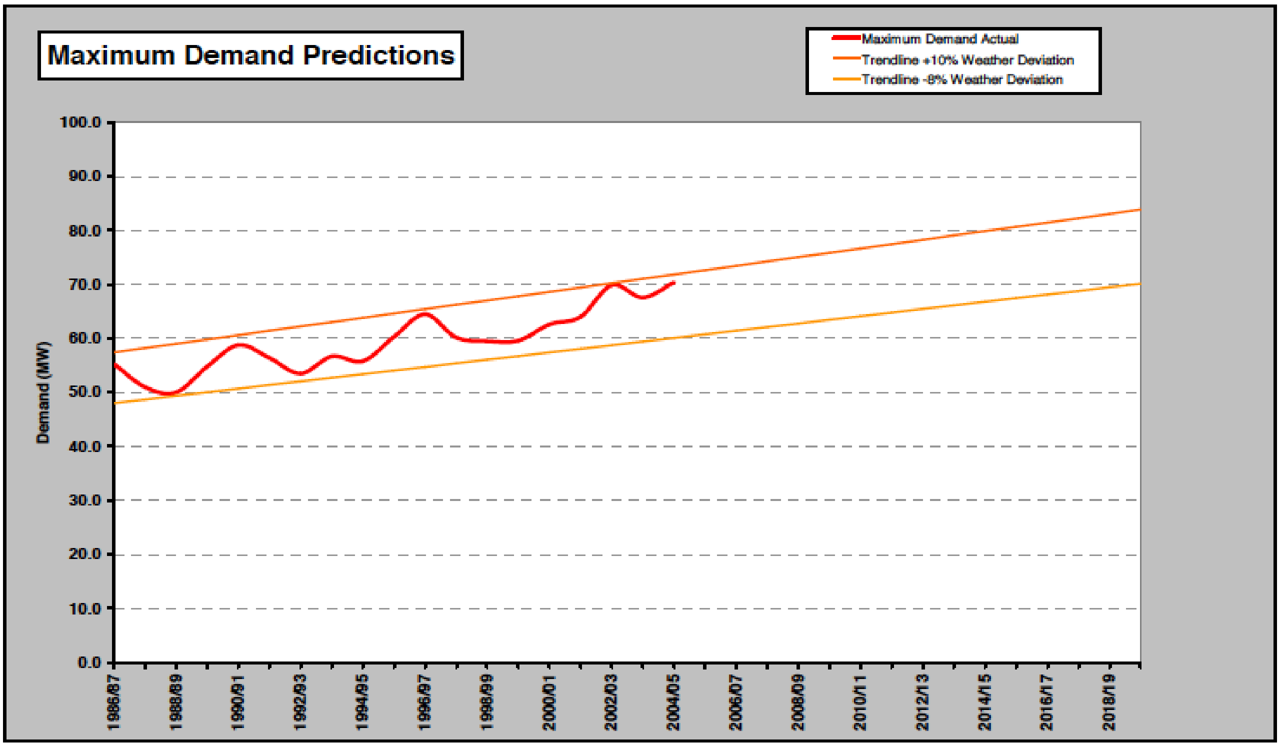

Figure 3:4 - Electricity Demand Predictions (Guernsey Electricity Limited, 2005)

3.7 Current Energy Costs

To allow the potential benefit of marine renewable energy on Guernsey to be fully understood it is important to know the current cost profile of Energy for Guernsey. As marine renewable energy will only be used to generate electricity, this section will only consider the cost of electricity, discounting energy required for transport and non-electrical heat.

In the year ending 31st March 2011; 308,600MWh (78.4% of demand) were imported and 84,600MWh (21.6% of demand) were generated giving a total electricity consumption of 393,200MWh, at an average cost to consumers of £123.30/MWh, or 12.33p/unit (kWh). This meant that in the year ending 31st March 2011 the total cost of electricity to Guernsey was £48.48m (Guernsey Electricity Limited, 2011).

Ideally the wholesale cost of electricity and the individual costs of generated and imported electricity would have been used rather than the average value used. However, due to time and confidentiality constraints this was not possible, but should be considered in future studies.

4 LICENSING

The licensing regime in Guernsey is currently similar to that currently in use within the UK using a Renewable Energy License for all offshore works. Currently the deployment of offshore renewable systems will also require onshore planning permission and potentially licenses under the Food and Environmental Protection Act (FEPA).

There are a series of measures that can be taken to ensure that this system operates efficiently and without some of the difficulties that occurred in the early leases in the UK:

- *Simplification*: It is recommended that the FEPA licenses are either rendered unnecessary or included in the issue of the Renewable Energy license.
- *Timeframes*: These should be introduced for the duration of consideration allowed by the Guernsey Renewable Energy Commission (RET).
- *Guidance*: Outline how and when consultation should take place. The UK's model for developers conducting all consultation prior to submission may prove the best option, as it can lead to effective solutions and reduce consenting risk to the developer.
- *Flexibility*: This should be sought in license and planning conditions as seen fit by RET. Appropriate flexibility reduces the need to apply for minor amendments, especially on larger schemes.
- *Pragmatism*: It is essential for RET to take a pragmatic approach to the risk posed by marine renewables where the potential environmental, social and industrial benefits of offshore renewables generation are looked at against any adverse impact.

In the case for Guernsey it is likely that a deploy and monitor approach will be the most effective way forward for early projects with a more impact led approach being utilised if larger export projects are undertaken, especially offshore wind.

5 TIDAL

5.1 Introduction

Tidal energy has a unique place amongst other renewable energy resources due to its dependency on gravity rather than intermittent weather patterns. The gravitational interaction between the sun, the earth and the moon is well understood and the tidal cycles are highly predictable to the precision of the nearest minute, up to several years ahead. A flowing medium, in this case seawater, carries energy that can be extracted by tidal stream devices in a similar way in which the contemporary wind turbines utilise wind resource. The difference lies in the density, with seawater being approximately 1000 times denser then air, which greatly increases the energy potential for extraction. Both tidal stream and tidal range technologies, with some of the devices soon to reach commercial maturity, could represent an important contribution to the wider renewable energy mix.

It has been recognised in several previous studies that the tidal resource available in the English Channel is significant and worth further investigation into its potential exploitation. The tidal resource assessment carried out by Alan Owen of the Robert Gordon University, Aberdeen (Owen, 2010) confirms the considerable tidal stream potential in the Big Russel and several other sites around Guernsey. The University of Southampton and Marine Current Turbines (MCT) initial assessments of tidal resource also arrived at the same conclusions. Up to 760 MW of installed capacity could be deployed in the Big Russel (MCT, 2004).

This tidal report intends to re-investigate the potential sites (both within the 3 and 12 nautical mile territorial limit), review the state of the industry and on-going development progress, critically analyse findings concluded in the published reports, outline the costs of deployment and highlight the benefits for Guernsey if the R&D and testing route were to be chosen.

Tidal stream will represent the main focus of the report. However, the tidal range resource is similarly significant (up to 8.8 m – south east of Guernsey) which led to the decision to include a brief assessment of its potential (approximately 8.6 MW of installed capacity in Southern bays). The tidal range is discussed in Appendix A, together with basic principles, basic energy calculations, findings and recommendations.

5.2 Tidal Resource Mapping – Review and Findings

The report entitled 'Tidal Resource Mapping for the Territorial Waters of Guernsey', written by Alan Owen (2010), was conducted to outline the modelling methodology and provide an initial assessment of the available tidal resource around Guernsey.

Generally, the methodology was found appropriate and sufficient for the initial resource assessment. Bathymetry data in the report was inconsistent with GIS data obtained for use in this report. It is recommended that this be investigated before any further assessment is carried out.

It is understood that total potential resource was considered, ignoring local constraints such as shipping, fishing, archaeology and environmental considerations. This is acceptable as long as the fundamental constraints are understood and applied in the future. Also, the wave and wind resource elements should be taken into account especially in the highly energetic sea off the South-West coast of Guernsey. The combination of strong wave resource and extreme weather conditions in certain areas could represent an unfeasible challenge to the deployment and operation of tidal stream devices.

Major comment could be made on the insufficient explanation of methodology used to generate the results, in particular the energy yield value in GWh/year (Figure 13 of the report, “Raw tidal current resource in Guernsey`s waters”). It is assumed that each value represents the total energy contained within 1 km^2 water column. If this is the case however, it could give a misleading indication of the potential extractable energy. It should be highlighted that only a small proportion of the tidal flow can be utilised due to various limitations such as the device rotor diameter, the Betz limit, the efficiency of the device and the spacing within the array. Additional expression of the energy potential could be, for example, in m^2 of tidal stream cross section or simply in velocities at certain depths which could then be applied to a power curve of a specific device.

The report was found to be a helpful and significant contribution to understanding the resource potential in Guernsey territorial waters. The recent real data measurements recorded at two sites around Guernsey between 2009 and 2010 included in the updated report represent an important crosscheck with the developed model.

5.3 Market Review

Tidal stream devices have been rigorously tested in the past decade at different locations across the world but it is only since 2011 that the UK, one of the most advanced countries in the deployment of marine renewable energies, reached a new milestone and began to realise the imminent potential of the commercial viability of such projects (Adams, Krohn, Matthews, & Valpy, 2012). Tidal stream devices have moved from the early research and development stages to a pre-commercial phase with some devices being connected to the grid across the UK totalling an installed capacity of more than 2MW (see Figure 5:1). More details on specific technologies can be found in the Device section of the present document and in the report written by Adams et al. (2012).

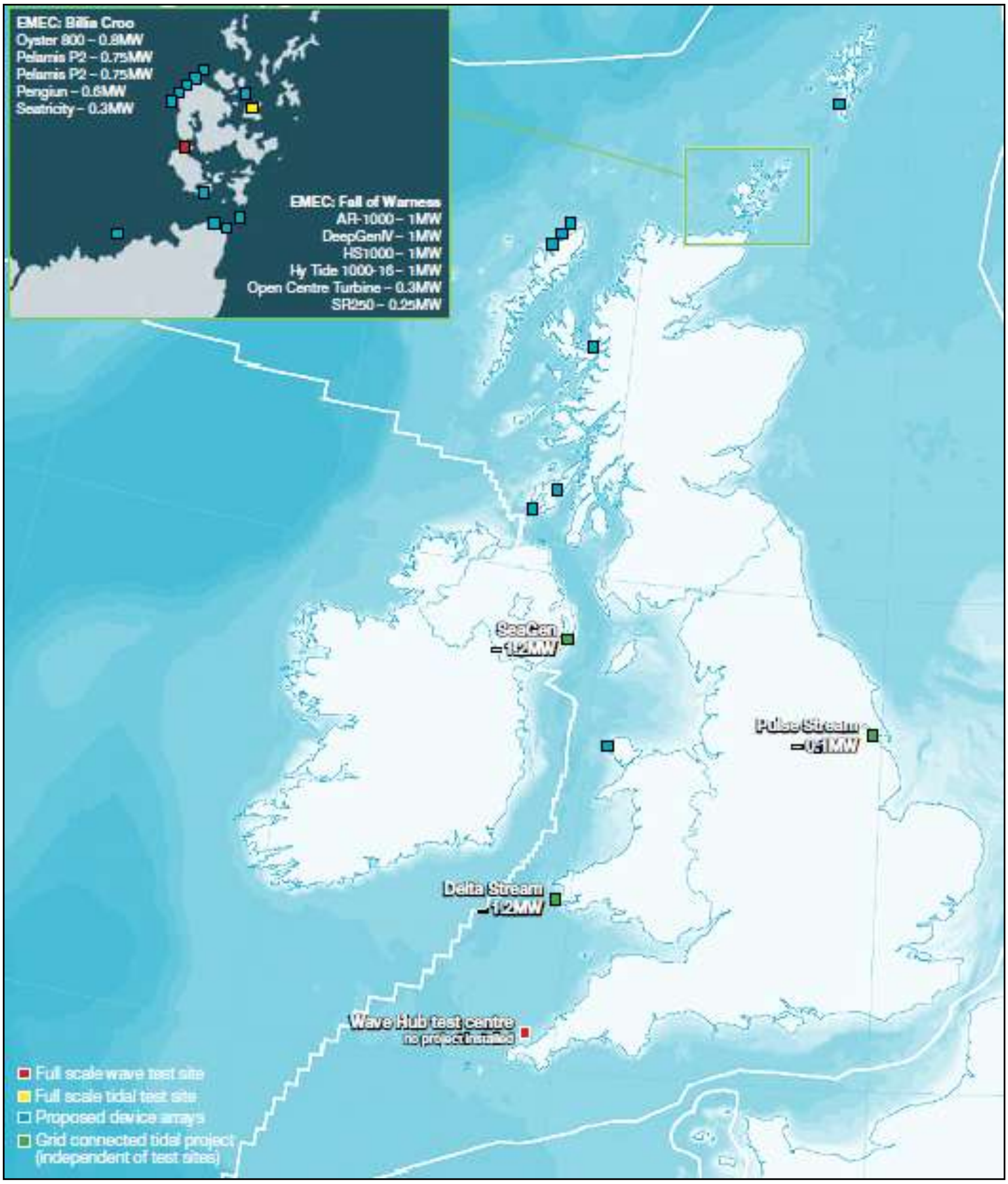

Figure 5:1 - The Crown Estate Current Wave and Tidal Activity (Adams, Krohn, Matthews, & Valpy, 2012)

The UK and Channel Islands represent 50% of the tidal stream resource available in Europe and a significant part of the total resource available in the world (REUK, 2012), which makes Guernsey ideally located for tidal stream projects. The only issue is to identify the point in time at which it will become commercially viable to invest i.e. when the market becomes ready and stable for further developments.

Guernsey has understood how beneficial tidal stream projects could be to the island; proof of this was the investment in MCT Ltd by Guernsey Electricity Ltd (BBC, 2012a) who recently sold its shares to Siemens (now the outright owners of the company). By communicating with the main stakeholders involved in the industry, the Committee on Climate Change (CCC) (2011) determined that the technologies are likely to be commercially available between 2013 and 2015. Martin McAdam, CEO of Aquamarine Power, estimates this would be as soon as 2014 and Martin Wright from MCT Ltd stated their technology would be ready by 2016/2017 (NATTA, 2009). With these figures in mind, Guernsey could easily invest in a tidal stream device by 2014. However, slow production processes and general lack of capacity in supply chain industries (e.g. offshore cable manufacturing, availability of installation vessels, etc.) can prolong the period of deployment by up to six years (Johanning, 2012). Leaving another two years for the installation of the devices and other elements, the plant could realistically start producing electricity by 2020, which is in line with the harbour master's port infrastructure reinforcement plans. Projects have an assumed lifetime of 18 years at present (Committee on Climate Change, 2011), but it has been estimated that this could be pushed to 20 years as the devices become more reliable and the industry is further developed, as has been the case for the onshore wind industry and others.

Guernsey is advised to progress its tidal deployment model from that of the UK, which is actively working on removing any market barriers to the deployment of tidal stream projects. Alderney is also making significant efforts towards the deployment of tidal energy devices (BBC, 2011a). Guernsey must find its own way of creating attractive financial mechanisms and political frameworks in order to have its sector ready for tidal stream technology deployment by 2020 while reinforcing its links with the surrounding islands.

5.4 Devices

The majority of tidal devices are based on the horizontal axis turbine; there have also been a number of concepts for vertical axis turbines as well as hydrofoil devices however these concepts are less developed as they have not benefitted from the acceleration of development provided by the progress seen in the wind industry.

5.4.1 Seagen (MCT)

Marine Current Turbines (MCT) are widely considered as the global leaders in tidal stream technology after installing the UK's first tidal stream turbine in 2003. The company, owned by Siemens and based in Bristol, first deployed a 300kW single rotor turbine named Seaflow off the coast of Devon.

After the testing of their basic concept, the company then went on to develop and deploy a 1.2MW prototype Seagen device in Strangford Lough in April 2008. The Seagen device consists of two horizontal axis turbines mounted on a cross bar extending out on either side of a single fixed tower (Figure 5:2). The device is fixed to the seabed by a surface piercing monopile, with the transformer contained in the visible housing above the water surface. The rotors can be fully raised out of the water, by the use of hydraulic rams, in the need of maintenance and the blades will pitch 180° allowing it to produce electricity both in the ebb and flow tides.

Figure 5:2 - Seagen Device (with Rotors Raised for Maintenance) (Aviation Enterprises, 2012)

The device is still in development, currently the construction of a larger 2MW device is underway and there is talk of another 3.2MW design, incorporating a third rotor.

5.4.2 Open Hydro

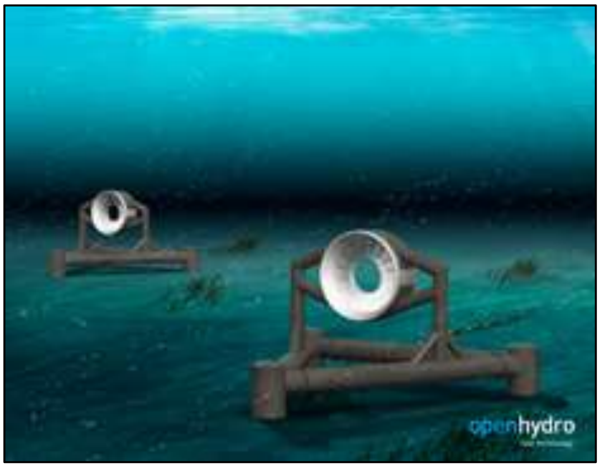

Figure 5:3 - Open Hydro Devices (RenewableUK, 2010)

Open Hydro is also developing a bi-directional device which incorporates a horizontal axis turbine design, except it has fixed blades surrounding a unique open centre; developed with the consideration of marine wildlife which can pass through without harm. The open centre also solves some of the inefficiencies related to the conventional design, allowing the tidal stream to pass through more naturally rather than being obstructed by the central hub. The rotating blades drive a permanent magnet generator incorporated into the enclosing shroud. The device is fixed in place by the use of a gravity base. The first design was installed in the Bay of Fundy, Canada in 2009 with a second 2.2MW device being installed in France in 2011. A further three devices are planned for installation during 2012.

5.5 Moorings

There are a variety of options for offshore foundation/mooring systems:

- *Gravity Base:* This method works by using a substantial mass to fix the device to the seabed by the use of gravity; additional fixing may or may not be required. This method requires the usage of large vessels to transport the necessary mass required to hold the device in place.
- *Pile Mounted:* This method uses a long cylindrical pole, which is driven into the seabed in order to create a stable foundation on which to mount the device. This is a proven method, used to fix most offshore wind turbines to the seabed but it is an expensive process.
- *Floating:* Floating moorings, either flexible or rigid, involve tethering the device, to the seabed using cable or a rigid mooring device. This method is less developed and not yet commercially suitable.
- *Hydrofoil Induced Downforce:* This innovative method uses a number of hydrofoils mounted on a frame to induce a down force from the current flow in order to keep the device in place. A design of this type called Sea Snail (Robert Gordon University, 2012) is currently being developed by the Robert Gordon University (European Marine Energy Centre, 2007).

The two most reliable methods are piled, for shallower water up to ~30m and gravity based for deeper water up to ~70m.

5.6 Water Depths Considerations

Suitable water depth is a critical factor that has to be taken into account during the site assessment exercise. Rotor diameter of a device (16m for SeaGen 1.2 MW) could give some initial indication of the minimum depth for deployment. Nevertheless, the device should not be positioned too close to the bottom, where it would experience inefficiencies caused by friction from the seabed. In addition, it should avoid operating too close to the surface, to prevent the interaction with the turbulent wave zone. Water that is too deep, on the other hand, represents an unfeasible challenge due to increased costs and physical constraints to installation and maintenance. Rotors are generally positioned in the top third of the water column where tidal currents are strongest, therefore maximising the energy capture. The Seagen device has a maximum depth of 38m (MCT, 2012) therefore all calculations have been carried out assuming the depth available is no more than 38m meaning that the power curve for the Seagen could be used. In reality, the majority of the site south of Sark is indicated to be deeper than this and so the chosen Seagen device could not be practically utilised. If and when the technology is developed for deployment in such deep waters, the relevant power curve for that device should be used, applying the same method, to determine the extractable resource.

5.7 Array Spacing

Some assumptions had to be made on spacing the devices within an array. Similarly to the wind turbine spacing methodology, the tidal devices cannot be clustered too close together due to reduced efficiency caused by turbulence and wake effect downstream.

In contrast to the wind industry, tidal technology developers do not yet have sufficient experience with tidal arrays. Some simulations have been done by MCT and a report published by the University of Strathclyde (Goméz, 2008) gives some indication of device spacing rules. The spacing assumption (28 devices or 33.6 MW/km^2 – specific for SeaGen 1.2 MW device) was mainly based on the two proposed arrays (namely Skerries and Kyle Rhea arrays) described on the MCT website (MCT, 2012a). Another value used to support the assumption was based on MCT`s maximum installed capacity scenario for the Big Russel (729 MW/23km^2) published in 2006.

Potential configuration of the devices can be seen in Figures 5:4 and 5:5 .

Figure 5:4 - Single Row Configuration (SeaGen 1.2MW)

Figure 5:5 - Array Configuration (Hammerfest Strom, 1MW)

5.8 Assumptions

In order to carry out the initial assessment of the resource available in Guernsey's waters, the 1.2MW Seagen device was selected as it currently represents the most advanced device, providing the most information with regards to technical details and requirements. This assumption was necessary to carry out the investigation but it should be noted that further assessment could be carried out considering different devices after they have undergone further testing and the relevant details become available.

5.9 Site Selection – Methodology

The site selection criteria has been set according to the recommended methodology for a tidal site assessment, which takes into account tidal resource, water depth, bathymetry data, local environmental constraints, shipping routes and marine archaeology amongst others.

Two zones were assessed: the current and existing 3 nautical mile radius of Guernsey territorial waters and the expanded zone of 12 nautical miles for potential future development.

Sites identified south-west of Guernsey were also eliminated, as the expected significant wave resource available in this area could both clash with other renewable development as well as representing a high-risk environment for the deployment of tidal stream technologies.

5.9.1 Site Constraints

Tidal resource of a minimum of 2m/s (mean spring velocities) and water depth between 20 and 40 metres are the main deployment criteria for the SeaGen 1.2 MW device. Sites with water depths over 40 metres were also considered although these are expected to be utilised at a later stage, when more suitable, deep-water devices are sufficiently tested. Other significant constraints such as shipping, environmental marine reserves, grid access and archaeology were also included in the GIS mapping. The following points summarise the full account of constraints to be considered in a detailed GIS mapping (once the data is made available):

- Tidal resource – at this stage of development, no less than 2m/s mean spring velocities
- Water depth – between 20 – 40m for SeaGen, up to 70 metres for deeper water devices
- Wave/wind resource – installation and operation issues in highly energetic seas around Guernsey should be considered
- Seabed bathymetry – Modern methods of seabed profile analysis are strongly recommended in order to obtain more detailed and updated bathymetry data. Once the potential sites for deployment are identified, more modern methods such as LIDAR and inter-ferometric sidescan SONAR data collection systems, or similar, will be required to explore the bathymetry in sufficient detail

- Environmental
  - Benthic ecology – assessment already carried out by PRIMaRE (2011)
  - Fisheries – impact on local fishing can be obviously viewed as negative. However, the presence of an array could also create an exclusion zone, which could in return serve as a sanctuary for fish and protective area for fish stock recovery.
  - Marine Mammals – slow rotation speed of the blades pose no or little threat to sea mammals, however, an assessment will be required to confirm this.
  - Recreational users
  - The visual impact – significantly lower compared to some other forms of renewable energy (onshore wind, offshore wind)
  - Marine archaeology
- Submarine cable and onshore cable landing impacts
- Safety and navigation – high shipping route density (especially in Little Russel which has been ruled out for tidal deployment for this reason).
- Grid connection – access to the existing infrastructure or the development of new HV cable route(s)

Consultations will also be required with:

- Local fishermen and representative associations;
- Navigational safety authorities;
- Local harbour authorities and ferry companies;
- Other key marine stakeholders

5.9.2 GIS Mapping

The GIS map (Figure 5:6) produced in MapInfo software indicates the unconstrained and suitable sites found within the two identified zones (3nm (nautical mile) and 12nm radius).

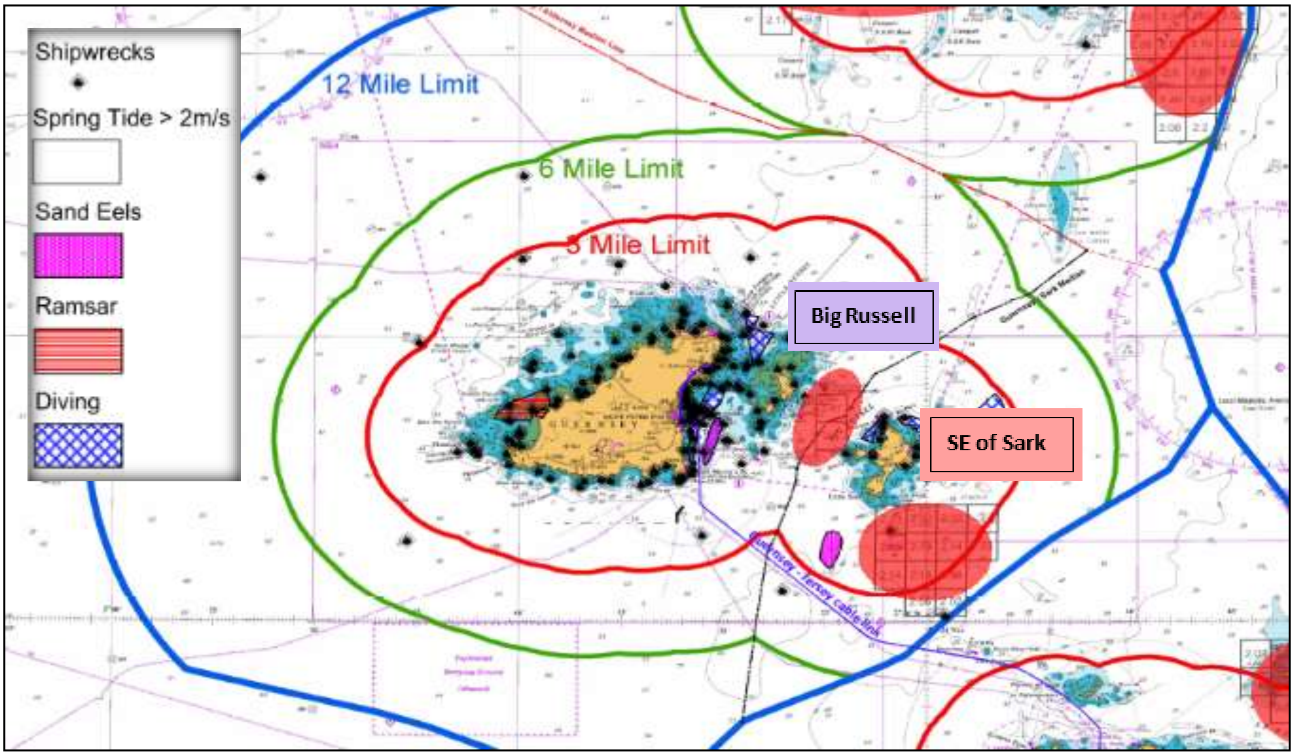

Figure 5:6 - GIS Resource Mapping

5.9.3 Site Assessment - Findings

As shown by the GIS map in Figure 5:6, there are two major potential sites identified in Guernsey territorial waters and the expanded 12 nautical mile zone.

3 Nautical Mile Radius - Big Russel

As it has already been concluded in many reports before, the Big Russel is the most suitable site for its high tidal velocities (2.5 m/s mean spring velocities) and well-suited water depth (20 - 45m). The area of at least 6 km^2 can be utilised for tidal array deployment, perhaps avoiding the centre of Big Russel currently used for shipping purposes. Both sites of Big Russel could accommodate an array consisting of 83 SeaGen 1.2 MW devices, a total of 200 MW of installed capacity within the two arrays. This could result in annual power production of approximately 566 GWh/year (assumed average tidal velocity of 1.5 m/s). This is the equivalent to 140% of the current Guernsey`s electricity demand.

3 Nautical Miles – South East of Sark

Another site identified during the survey is located South East of Sark with mean spring velocities reaching 2.23 m/s and an average of 1.2 m/s. The potential deployment area could be double the size of Big Russel`s outlined arrays, however with lower mean velocities and less suitable water depth (up to 57m). The total installed capacity at this site could reach up to 400 MW (using SeaGen 1.2MW devices) with annual power production of 750 GWh/year (assumed average tidal velocity of 1.2 m/s), representing 190% of Guernsey's current electricity demand. Water depth data, however, is critical and need to be investigated in detail.

Both could connect and feed to the Guernsey-Jersey submarine interconnector or alternatively feed into Guernsey's 33kV onshore electricity network via an on-land landing site and connection station.

Other energetic sites have been identified, such as Little Russel, but consequently ruled out for its unsuitable depth, shipping constraints or other limitations.

12 Nautical Miles – South East of Sark

A deeper part of the site is located partially within the 12nm radius zone which currently does not fall into the Guernsey`s territorial waters but may possible in the future. The deep water (above 40m) is currently unsuitable for SeaGen deployment, but an alternative technology such as Hammerfest or Open Hydro devices utilising gravity-based foundations could be deployed once commercially viable.

5.10 Resource Assessment Methodology

Understanding the variations in resource availability and its general characteristics is highly important in order to accurately assess the tidal energy available. Despite the tidal resource being predictable, it does not represent a constant pattern, but varies across the day, month and year. Spring tides replace neap tides and high tides follow low tides with predictable frequency. The Figure 5:, indicates the local tidal profile of Guernsey area, measured at Site 6 (due south of Herm and to the west of the Fourquies buoy) between 19/12/2009 - 25/1/2010.

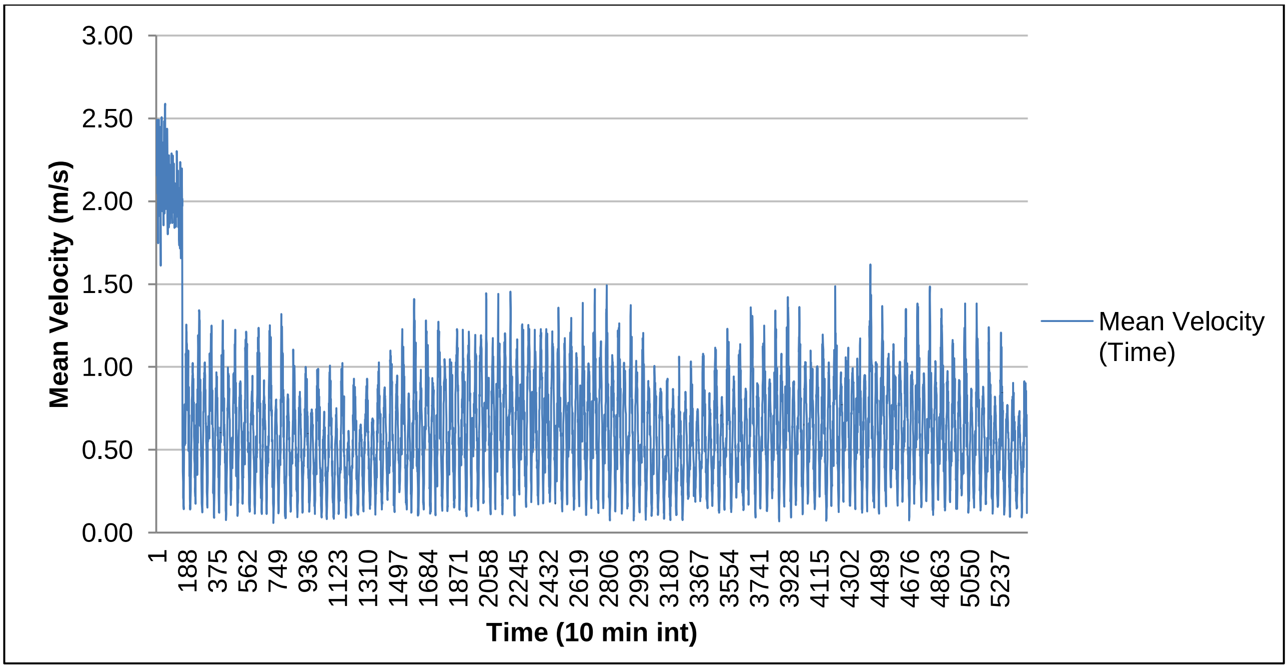

Figure 5:7 - Tidal Profile of the Guernsey Area (Owen, 2010)

On a daily basis, tides generally turn every 6.25 hours. Figure 5: shows the daily variations in tidal velocities for a particular day in December 2009. Data has been extracted and interpolated from the Robert Gordon University (RGU) report.

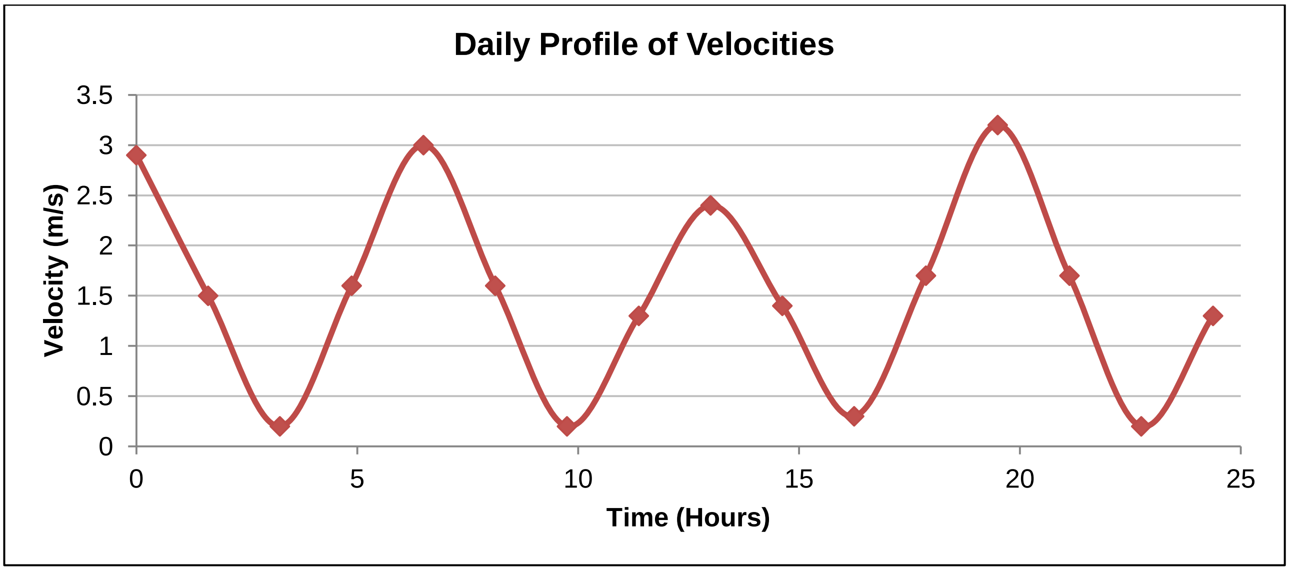

Figure 5:8 - Daily Variations in Tidal Velocities

5.10.1 Errors and Inaccuracy

Even though the methodology of the assessment is believed to be correct and approved by academics, the potential inaccuracy of the provided data introduces an unknown level of error to the calculations and conclusions. It is therefore important to sufficiently explain and understand the possible sources of error.

One of the main obstacles to the time-limited research carried out for this report was the lack of empirical data. The essential data generally used in a tidal assessment are the tidal velocities, local tidal profile and bathymetry data, including water depths. GIS layers for mean spring and mean neap velocities were provided beforehand, but this has proven to only serve as an indication of the resource, not as a figure usable for the power output calculation. Average velocities or actual velocity measurements would be preferred in order to apply these to a specific power curve (for example a 1.2 MW SeaGen device). Also, the GIS layer resolution appears to be too low (2km x 2km), not allowing for the necessary detailed assessment.

The profile of the local tidal resource was found in the RGU report (Owen, 2010) (analysis of the site 6 and 9 measurements) but no numerical background data was obtained within the limited timeframe provided. The data used in the calculations was roughly derived from the graph (Figure 5:) by digitising the picture plot, which inevitably introduced an unknown level of inaccuracy and error. However, it serves as a good indication of the local resource characteristics (i.e. the local variations).

Bathymetry data for the Channel Island was also provided by the stakeholders in form of a GIS layer, again the resolution of 2km x 2km is insufficient. There was also a disparity between the provided GIS bathymetry data and the water depth generated by the Garmin Mapsource software used in the tidal resource mapping report (Owen, 2010). This might, however, be a result of different level of resolution. More modern methods would be required to analyse the seabed in sufficient detail.

The power curve for the 1.2 MW SeaGen device used for the power output estimation at specific velocities had to be digitised in the same manner as the tidal profile plot discussed above. Power curve data is generally rare and developers tend to be protective about the detailed background information.

As a conclusion on the error section, it is important to understand that this report aims to suggest a methodology while using data of limited accuracy. Once the accurate, approved data can be obtained (e.g. velocities for a specific site, detailed numeric data of tidal profile, power curve etc.), the methodology can be re-applied, yielding more reliable results.

5.10.2 Power Curve Application

Power curves represent a useful graphical indication of a device's performance under different velocity regimes. The curve (Figure 5:) also contains some important information regarding cut-in speed, maximum capacity and rated velocity.

Similarly to the tidal profile graph, the power curve for the 1.2MW SeaGen device had to be digitised as no background numerical data was available. The digitised version is believed to be fairly accurate with some space for minimal error.

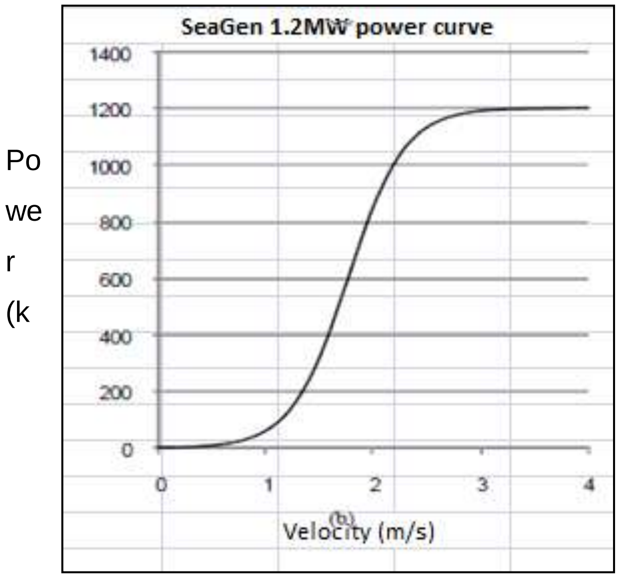

Figure 5:9 - 1.2MW SeanGen Device Power Curve (Hardisty, 2011)

5.10.3 Occurrence Graph

The digitisation of the tidal profile graph (Owen, 2010) has provided necessary information required to derive the annual velocity occurrence graph (Figure 5). The graph expresses how often a particular velocity occurred over a period of time in number of hours per year. The derived values are applied to a specific power curve and an annual power output is calculated.

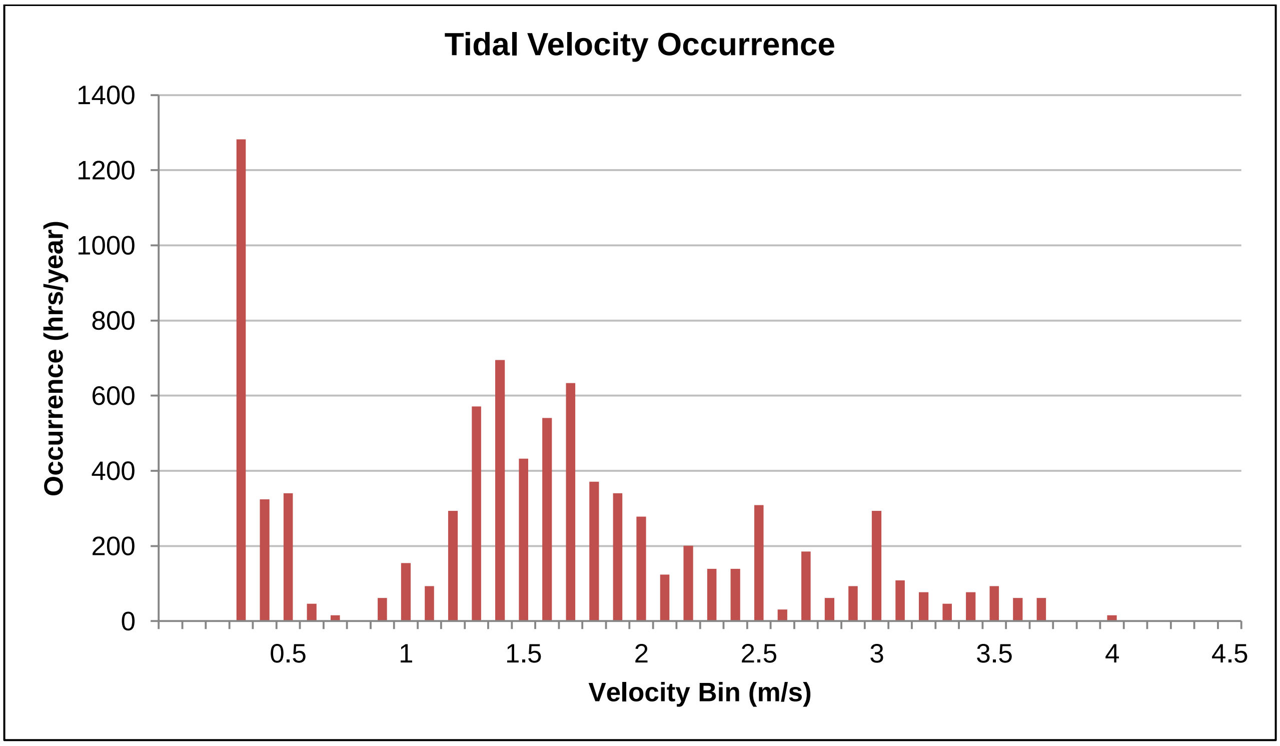

Figure 5:10 - Tidal Velocity Occurrence

5.10.4 Power Output Estimations

The combination of the annual velocity occurrence data and power curve data yields the annual power output of the 1.2MW SeaGen device for a specific velocity regime (1.5 m/s mean velocity for Big Russel, 1.2 m/s for SE of Sark, etc.). The mean velocity value can be changed to match a specific site's characteristics by changing the power output accordingly. For the purpose of the calculation, the availability factor of SeaGen devices was assumed to be 80%, with 20% down time for maintenance and cut-off periods. Table 5:1 shows the power outputs for different velocity regimes.

Power Output in Big Russel (200 MW)		
Mean Velocity (m/s)	**Maximum Velocity (m/s)**	**Annual Energy Yield (GWh)**
0.7	1.84	76.9
0.8	2.10	126.5
0.9	2.36	183.0
1.0	2.63	244.3
1.1	2.89	310.6
1.2	3.15	374.7
1.3	3.41	438.4
1.4	3.68	502.5
1.5	3.94	565.8
1.6	4.20	628.4
1.7	4.46	688.8
1.8	4.73	742.2
1.9	4.99	793.6
2.0	5.25	836.5

Table 5:1 - Output from 200MW Installed Capacity in Big Russel under Different Velocity Regimes

5.10.5 Energy Available vs. Energy Extractable

It is important to understand the difference between the total energy available in the resource and its extractable proportion. The total energy contained in a water column is much higher than what can be practically extracted. This is largely due to the limited cross section of the devices, device efficiency, the Betz limit, capacity factor and the spacing of the devices within the array. The calculations have been performed to compare the two energies available in Big Russel and SE Sark locations. As a conclusion, the extractable proportion of the resource (based on the 1.2MW SeaGen device's technical specification and spacing requirements) is likely to be approximately 10%. This value could increase by improving the outlined limitations (rotor diameter and efficiency in particular). It is important to note that this estimate of energy available is much higher than that found by Alan Owen in the report referenced earlier (2010). Whilst it may be necessary to investigate this further, this highlights the need for empirical data and further analysis, which is currently being looked into by RET.

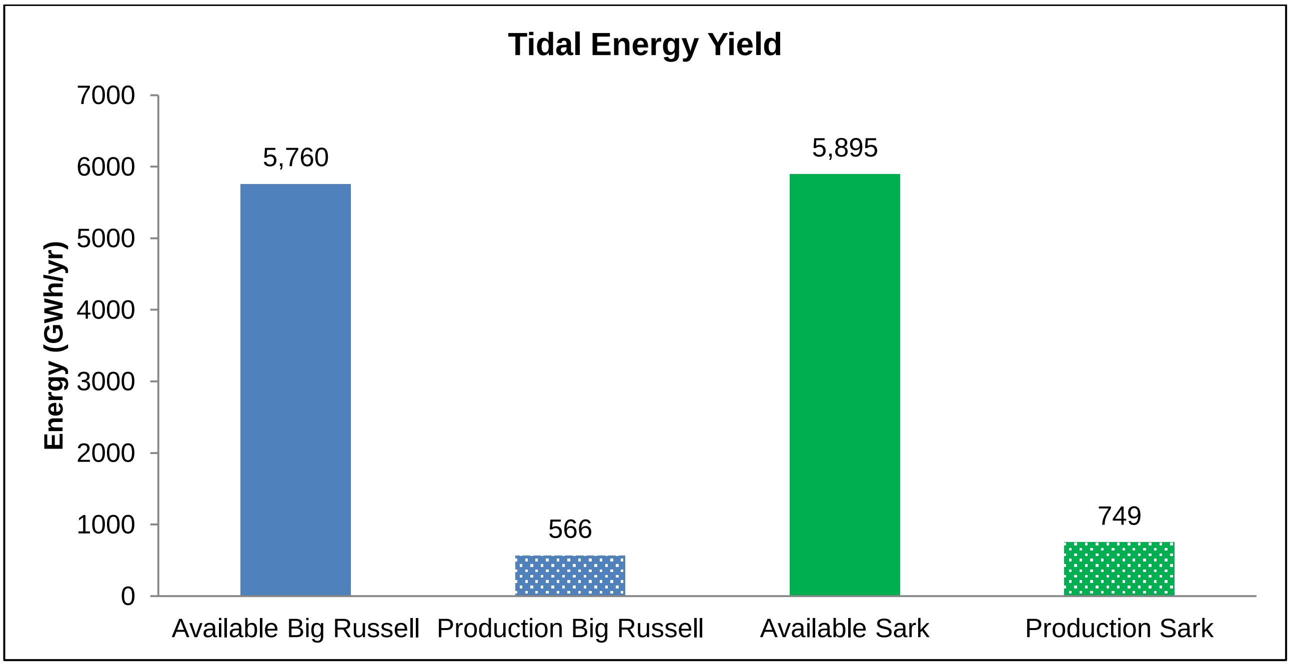

Figure 5:11 - Potential vs. Extractable Energy

5.11 Constraints to Deployment

In addition to the constraints related to the economic feasibility, the high investment risks and the commercial immaturity of some devices, there are several other constraints associated with the physical delivery of an installation or its maintenance.

Installation and maintenance vessels – The availability of installation and maintenance vessels is essential. The specialist nature of these vessels means that the come at a high cost and are often in high demand. The cost of leasing these vessels can represent a prohibitive financial barrier to deployment. The time available for the physical installation is limited to slack tides, often maximum of 30 minutes during each 6-hour tidal interval. The weather and sea conditions have to also be taken into account further limiting the available installation time.

Currently, there is some concern about the limited manufacturing capacity of HV cables due to the high demand from several industries (offshore wind, grid development, interconnectors, onshore networks in particular).

Skilled workers are also required for deployment and as such are in limited supply due to the infancy of the industry. These will have to be sought and contracted correctly and in enough time to ensure their availability.

There is also a lack of available data regarding the tidal resource, and as such it is recommended that this is rectified before more solid plans are made.

5.12 Cost Implications of Tidal Stream Projects

Because of the lack of experience in the sector of tidal stream projects, their cost is entirely based upon estimates. Although many projects and costing analyses have been undertaken for tidal stream devices, most of these are based on R&D projects and thus have higher values (around £10m per megawatt installed) than for commercial projects. The cost range for commercial tidal stream projects is estimated to be between £3.5m and £4.5m per megawatt installed (Committee on Climate Change, 2011). An estimated value of £4m per megawatt installed has been concluded. It is unclear as to whether this value includes the costs of offshore cabling and if so, for what distance; hence, further studies should be carried out on the subject. The value of £4m per megawatt installed is slightly larger than the one estimated by the Committee on Climate Change (CCC) (2011) in Figure 5:7 to allow for a buffer.

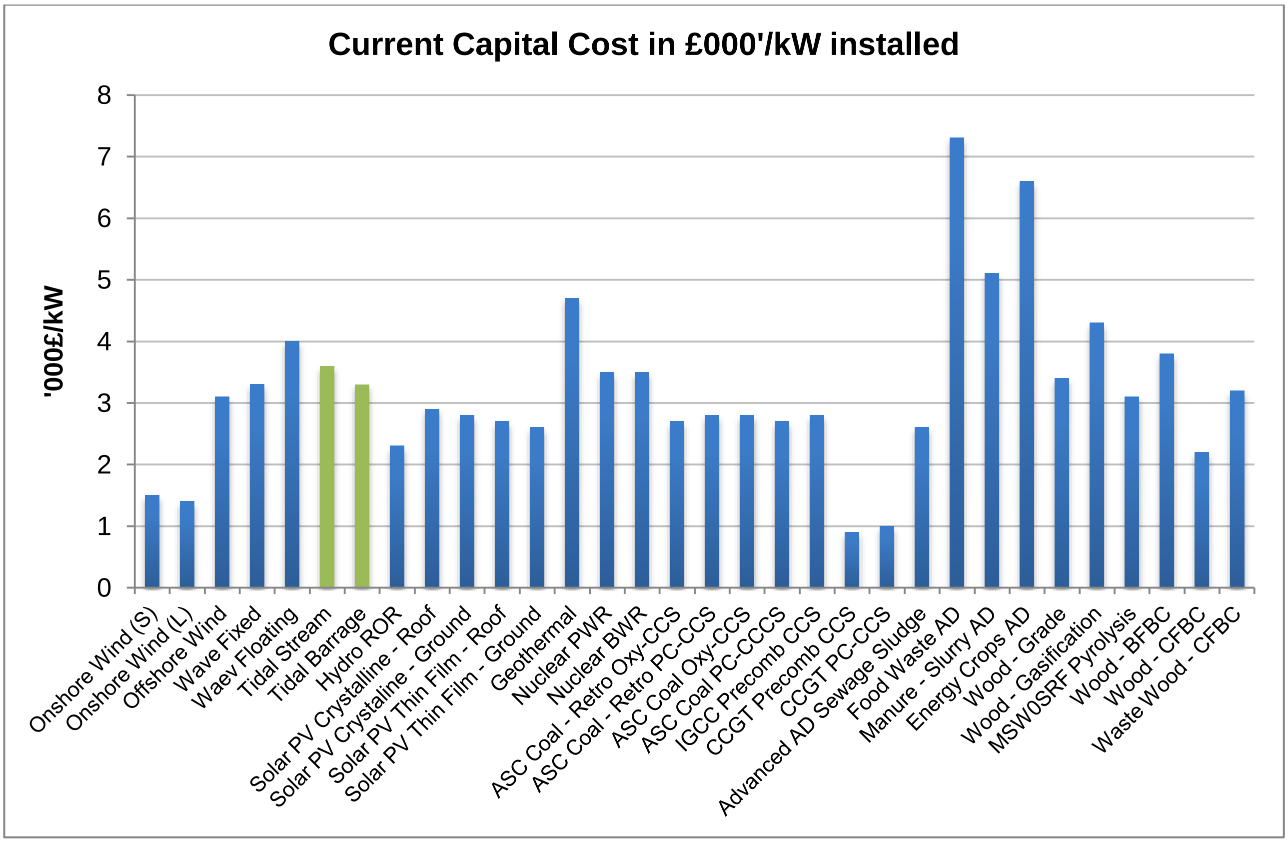

Figure 5:7 - Tidal Stream and Tidal Range Capital Costs (Committee on Climate Change, 2011)

Costs of projects depend significantly upon the industry's learning curve. The CCC (2011) believes that by 2040, the capital expenditure will decrease by 40 - 50%. These reductions are likely to be fairly small at first as new developers enter the industry and technologies then need to prove themselves, but should drop significantly after these initial phase (Redfield Consulting, 2009).

Based on the figures mentioned above, the Big Russel project would have a capital expenditure of around £713m for a capacity of 201MW or £106m to meet a Guernsey base-load demand at 30MW. Further details on the break down of these figures and on their operational costs are discussed in CCC (2011).

5.13 Potential of Research and Development Projects

Another possible route into the tidal industry for Guernsey is to invest in research and development (R&D) projects. These not only bring valuable experience to the global tidal energy sector, but also provide Guernsey with the advantage of a steep learning curve followed by the reduction of the capital expenditure costs. In order for a site to be suitable for the implementation of tidal technologies at a development level, it must incorporate similar characteristics to a site intended for commercial development such as the infrastructure. The difference would lie in aspects such as the grid connection potential, tidal velocity and depth of water (depending on the maturity of the device being tested). Investing in an R&D project would offer the advantage of securing a good relationship with developers by offering them the facilities they require to progress their technology. It may be advantageous to form a contract with the developer to ensure that they will provide a certain amount of generation after the testing period is complete. Guernsey has the unique advantage of having ownership over its territorial waters, minus the seabed, up to 3 nautical miles. This means it has the ability to simplify the leasing application process for developers, which can become a long and drawn out process in the UK.

There are many ways to invest in R&D projects. An example of how this may be carried out is to implement R&D projects in the South East of Sark, providing necessary infrastructure where the resource has been determined as suitable for deployment. This would help ensure that the site could potentially be used in the future for commercial tidal development. However, since there are no current technologies tested for these depths, R&D projects could bring focus to Guernsey if it were to be willing to undertake such a path. This would in turn support the Big Russel as a site for future deployment of commercial arrays with companies such as MCT Ltd or Open Hydro.

5.14 Conclusions and Recommendations

The research conducted during the visit to the State of Guernsey can confirm that the potential of tidal stream and tidal range resource around the island is significant and worth exploiting. The Big Russel, situated between Herm and Sark, appears to be the main focal point, together with another highly energetic site off the coast of Sark (SE). In theory, Little Russel also possesses significant resources, yet its exploitation is practically unfeasible due to the shallow water and high marine activity.

The resource and technology assessment was carried out using data of limited accuracy, which could have introduced an element of error into the final conclusions. However, the suggested methodology of the assessment is believed to be correct and applicable to future works. The realistic installed capacity potential in Big Russel was estimated at 200MW (SeaGen 1.2 MW devices), yielding ~566 GWh/year at 1.5m/s mean velocity. The site SE of Sark could potentially accommodate up to 400 MW of mainly deep water devices (over 40 meters), producing

~750 GWh/year at 1.2 m/s mean velocity. These values are device specific and could increase with increasing rotor diameter and device efficiency.

The main strategy should be to progress with the detailed assessment for the recognised sites as soon as possible, obtaining accurate data of tidal velocities, applying local constraints and utilising modern bathymetry data.

The tidal stream industry is reaching a commercial maturity and it is believed that several devices will be commercially available by the end of the decade. This coincides well with the time required for the necessary infrastructure and port development, environmental impact assessment completion, licensing and financial strategy development and other essential prerequisites to the successful RE deployment.

If Guernsey wished to take the advantage and opportunity of R&D and testing by providing suitable facilities, it should consider entering a joint project with other islands and progress with establishing the necessary incentives (favourable licensing, infrastructure development, EIA). By engaging with a successful developer at an early stage, the Guernsey and other R&D stakeholders are likely to benefit significantly in the future.

Tidal resource in the English Channel represents an opportunity not to be missed and Guernsey, together with other surrounding island should take a full advantage of this possession.

6 WAVE

6.1 Introduction

Guernsey's location in the English Channel, with exposure to the Atlantic Ocean, would suggest that it should have a range of sites suitable for the installation of wave energy converters (WECs). The most important factor in determining the suitability of wave energy generation is to assess the wave resource available locally. This chapter will focus on providing an initial assessment of the wave energy resource based on Met Office data. This initial assessment is intended to be rough resource overview and could be used to inform a more detailed resource assessment using wave buoy data in the future.

Also considered will be environmental and practical constraints in order to identify a suitable site and the scale to which development might be suitable and practical. The resource assessment and proposed site will be used in conjunction with one another to produce an estimate of annual energy yield. This energy yield will be based on the deployment of Pelamis WECs.

6.2 Market Review

The wave energy industry is currently very immature compared to other renewable energy technologies. Because of this there is no real market currently operating with most devices being funded by Government grants and other research and development mechanisms.

6.3 The Resource

Creating a wave resource assessment is the first step in discovering how well an area is suited for electricity generation from WECs. A resource assessment involves taking recorded or previously modelled wave data for a location and analysing it in a number of different ways to find the important characteristics of a site. A model can also be run to predict the conditions at a location near to the original site. This allows an assessment to be made of the likely conditions at a variety of locations with limited data, to help decide where a WEC would be best placed.

6.3.1 Bathymetry

Bathymetry is the underwater equivalent of topography on land and is a measure of depth in a body of water. It is required for a wave model to take into account the affect of shallow water on the wave conditions.

The bathymetry data for the model run for this report was downloaded from General Bathymetry Charts of the Oceans (GEBCO) in grids of 30 seconds (approximately 850m) . The chart below is a contoured representation of this gridded data. The contour labels represent the depth in metres below the average sea level.

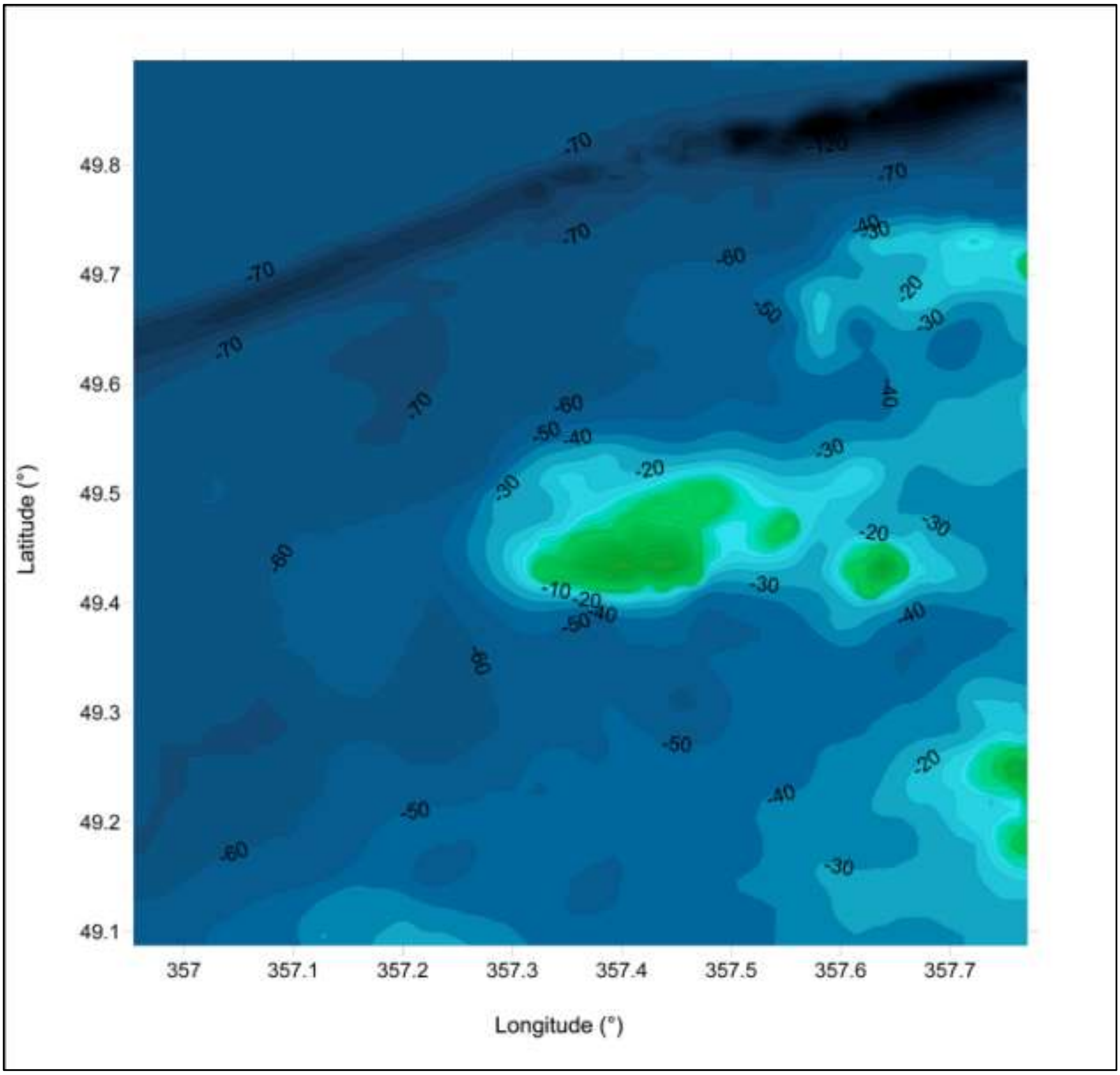

Figure 6:1 - Bathymetric Contour Map (GEBCO, 2012)

Obtaining more accurate bathymetry data is extremely important for creating more accurate wave models. This can be done by using SONAR from a boat or a LIDAR/LADAR survey from a plane.

6.3.2 Wave Input

Gaining reliable wave data for the site was challenging. The two closest wave buoys to Guernsey are the Channel Lightship and the Jersey Wave Buoy. A wave buoy is a device that floats on the water's surface to measure and record the wave state via a variety of internal sensors. Due to time constraints and other factors, access to reliable data for these two buoys was unavailable for this report. For this reason modelled data was used instead.

UK Met Office modelled data, provided through the University for the location 49.6N, 2.86W, was used for all of the wave resource assessment for this report. The map below shows the location of the model point as well as the Channel Light Ship and Jersey Wave Buoy.

Figure 6:2 - Wave Buoy and Model Point Locations

The data runs from November 2009 till December 2010. Having only a years' worth of data at one point is only sufficient for a fairly coarse resource assessment and is unlikely to properly represent extreme wave states that are important when considering placement of a WEC.

Table 6:1 is a frequency scatter table that represents the probability of any wave state occurring at the model output location. A program was created in MATLAB to extract this information from the Met Office model data. It can be seen that the most common wave state has a period of 5 – 6 seconds and a significant wave height of between 1 – 2 metres.

		Guernsey Sea State Probability							
		Period (s)							
Significant Wave Height(m)		3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11
	0 - 1	1.2	3.4	3.9	4.4	4.9	3.6	1.7	0.8
	1 - 2	0.1	5.5	10.8	9.7	8.2	6.1	4.9	2.5
	2 - 3			2.3	3.7	4.0	3.1	2.5	2.0
	3 - 4				0.2	0.6	1.5	1.0	1.0
	4 - 5					0.1	0.9	1.0	0.2
	5 - 6						0.1	0.2	0.0
	6 - 7								0.1

Table 6:1 - Sea State Probabilities for Met Office Model Point

The power of a wave can then be approximated using the following equation:

$$P = H^2 \times T$$

Where:

P = Power (kilowatts per 1 metre wave front)

H = Height (metres)

T = Period (seconds)

Table 6:2 shows the power of the different wave conditions that occur at the site. It can be seen that as the wave height and period increases so does the wave power. Having sea conditions with high wave power is generally desirable for a WEC as can be seen later in the chapter on energy yields.

	Wave Power (kW/m) Period (s)								
		3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11
Significant Wave Height(m)	0 - 1	0.0	1.1	1.4	1.6	1.9	2.1	2.4	2.6
	1 - 2	7.9	10.1	12.4	14.6	16.9	19.1	21.4	23.6
	2 - 3			34.4	40.6	46.9	53.1	59.4	65.6
	3 - 4				79.6	91.9	104.1	116.4	128.6
	4 - 5					151.9	172.1	192.4	212.6
	5 - 6						257.1	287.4	317.6
	6 - 7								443.6

Table 6:2 - Wave Power Matrix

Figure 6:3 is a wave rose that describes the direction and magnitude of the waves at the location. It is presented in the nautical convention, which shows the direction in which the waves are travelling towards. It can be seen that the predominant swell arrives from the South West with waves of a much smaller magnitude coming from the North East.

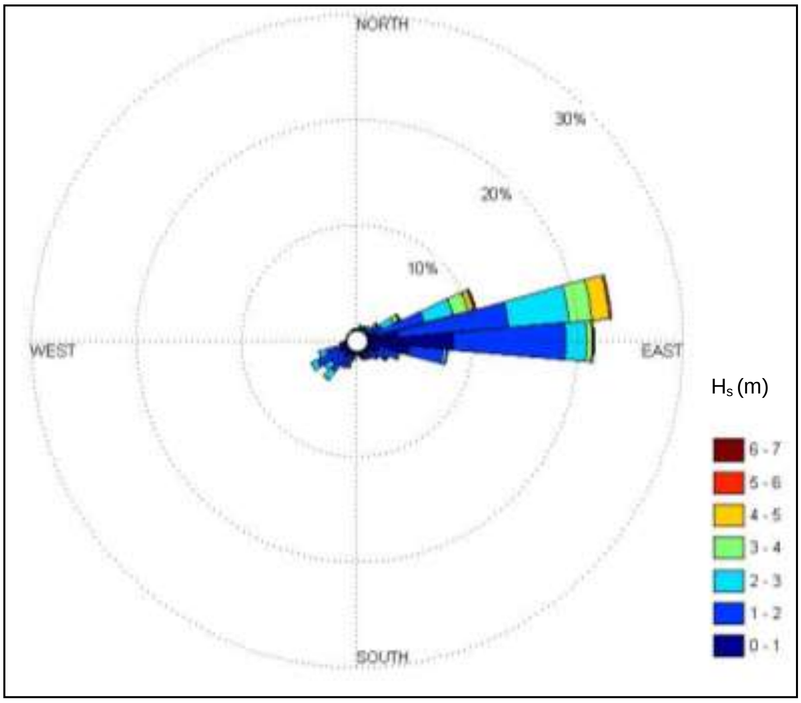

Figure 6:3 - Met Office Model Point Wave Rose

6.3.3 The Wave Model

The open source wave modelling program, SWAN, was used to create a map of the wave resource in the area from the analysis done on the Met Office modelled data. The SWAN model that was created for this report is fairly coarse and assumes constant wave parameters along the Western and Northern edges.

In order to increase the accuracy of the model a model calibration should be carried out. This involves comparing the model output to recorded wave data. Different aspects of the model are then changed until the outputs begin to reflect the recorded conditions more closely. Due to the lack of recorded data this could not be undertaken.

The wind and tide conditions also need to be taken into account when running a wave model. This means that in addition to a wave buoy, a reliable wind record needs to be used in future models. Calculating the tidal height can be done relatively easily but due to the extremely strong tidal currents in the area further work may need to be done in this area.

Figure 6:4 is a visual representation of a SWAN model run. The model inputs were a wave height of 1.5m and period of 5.5s, which is representative of the most common wave state experienced. The colours represent the different levels of power in the waves measured in kW/m.

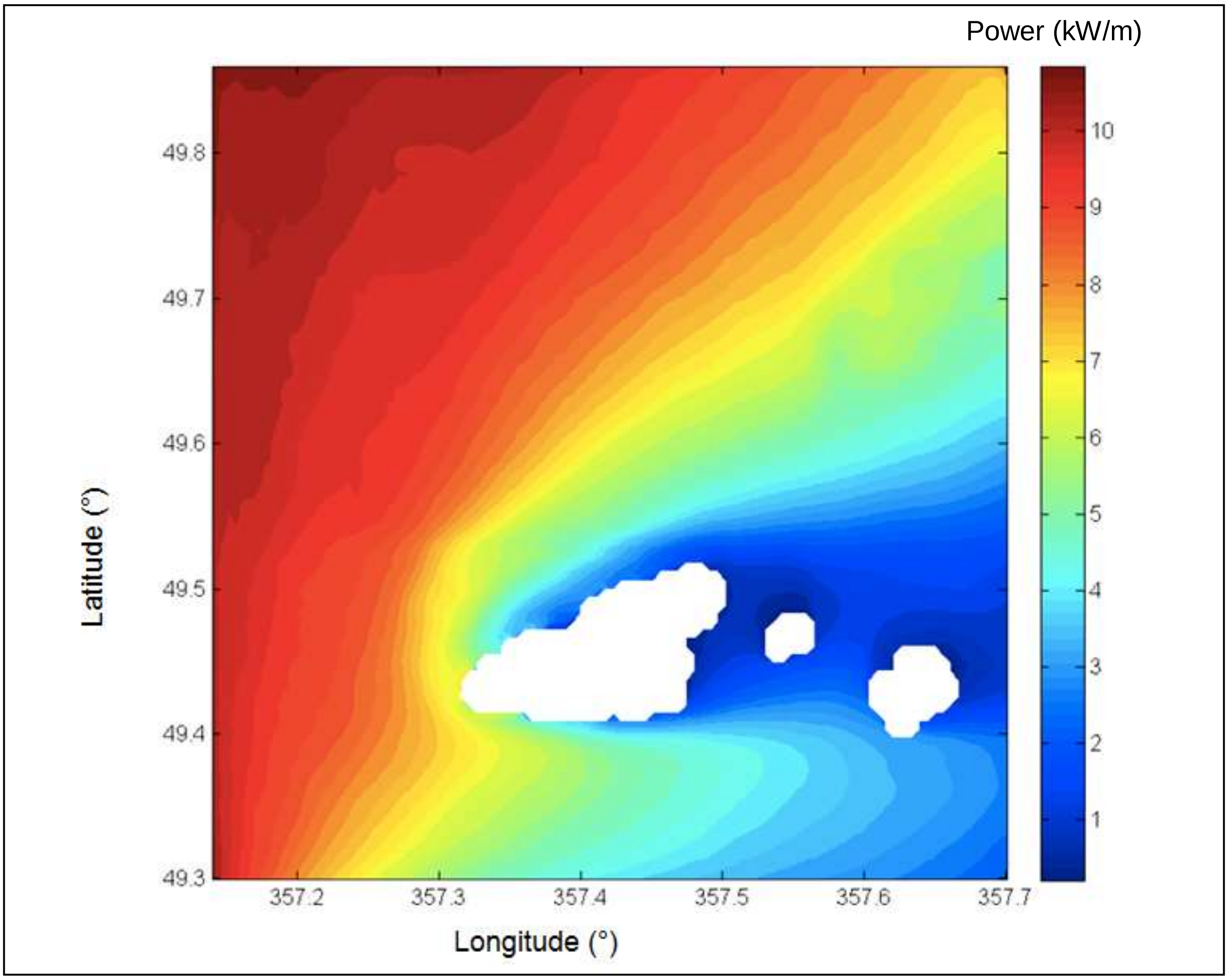

Figure 6:4 - Wave Energy in kW/m

It can be seen that the locations with the highest wave energies are generally to the west of the island. This is to be expected because these locations have no obstructions between them and the Atlantic Ocean, as well as generally being in deep water. The bathymetric map (Figure 6:1) can be compared to the wave energy map (Figure 6:4) to get an idea of the effects that change in water depth have on the wave power, at a given point.

The low resolution of the bathymetry grid and lack of recorded data means that the model is unreliable for outputting accurate wave energies for near shore sites so using the data taken from the Met Office model location is preferable. It does however give a clear representation of the relative energies of the waves at different locations near the island and will help advise on the best locations for WECs.

6.4 Site Constraints

The most suitable sites have been considered based on environmental, seabed, shipping and bathymetry constraints as well as the available resource. In this section of this report the various constraints considered and their influence on the placement of a wave farm are discussed.

6.4.1 Depth

In order to avoid significant loss of energy yield due to wave interaction with the seabed, the site has been constrained to outside the 50m-depth contour, based on admiralty chart data. This depth was compared against data obtained from the General Bathymetric Chart of the Oceans (GEBCO). The comparison revealed some discrepancy, with the GEBCO data indicating that the greater than 50m zone lies within the three nautical mile limit on the resource rich west coast. This highlights the need for bathymetric surveying for a detailed resource assessment. For the purposes of this report the admiralty bathymetry was considered suitable. The 50m zone is indicated in Figure 6:5 as the blue shaded area to the west and south of the island.

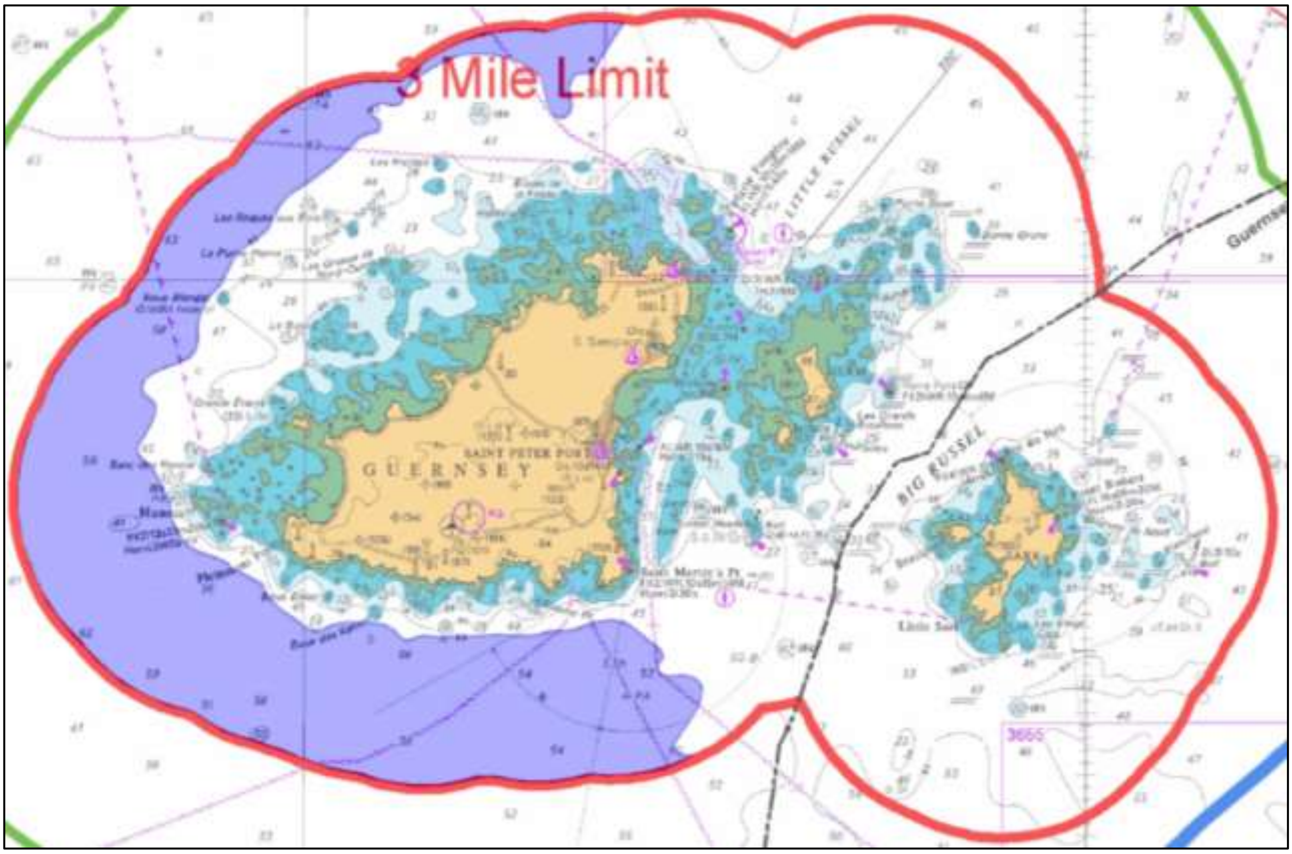

Figure 6:5 - 50m Depth Constraint

6.4.2 Shipping

Shipping is a major concern for the deployment of Wave Energy Converters (WECs). As the seaways around the islands are notoriously busy, it was considered essential that shipping movement maps be produced in order to ascertain the areas less heavily traversed by shipping traffic. This would minimise the disruption to traffic and the likelihood of collision. In order to do this it was important to obtain Automatic Identification System (AIS) data, which is used to track the positions of vessels, as well as other information such as unique identification, course and speed. Digimap Guernsey operates an AIS data logging service and was able to provide data so that the shipping movements could be mapped. Due to the size of the data sets it was only practical to map the movements over 1 month, August was chosen, as suggested by the harbour master, as this is the busiest month (see Figure 6:6 - AIS Constraint Mapping).

The AIS data revealed that the area to the west of the island is the clearest in terms of traffic, it stands that this area is also suitable in terms of the resource which can be seen in the resource assessment section of this document.

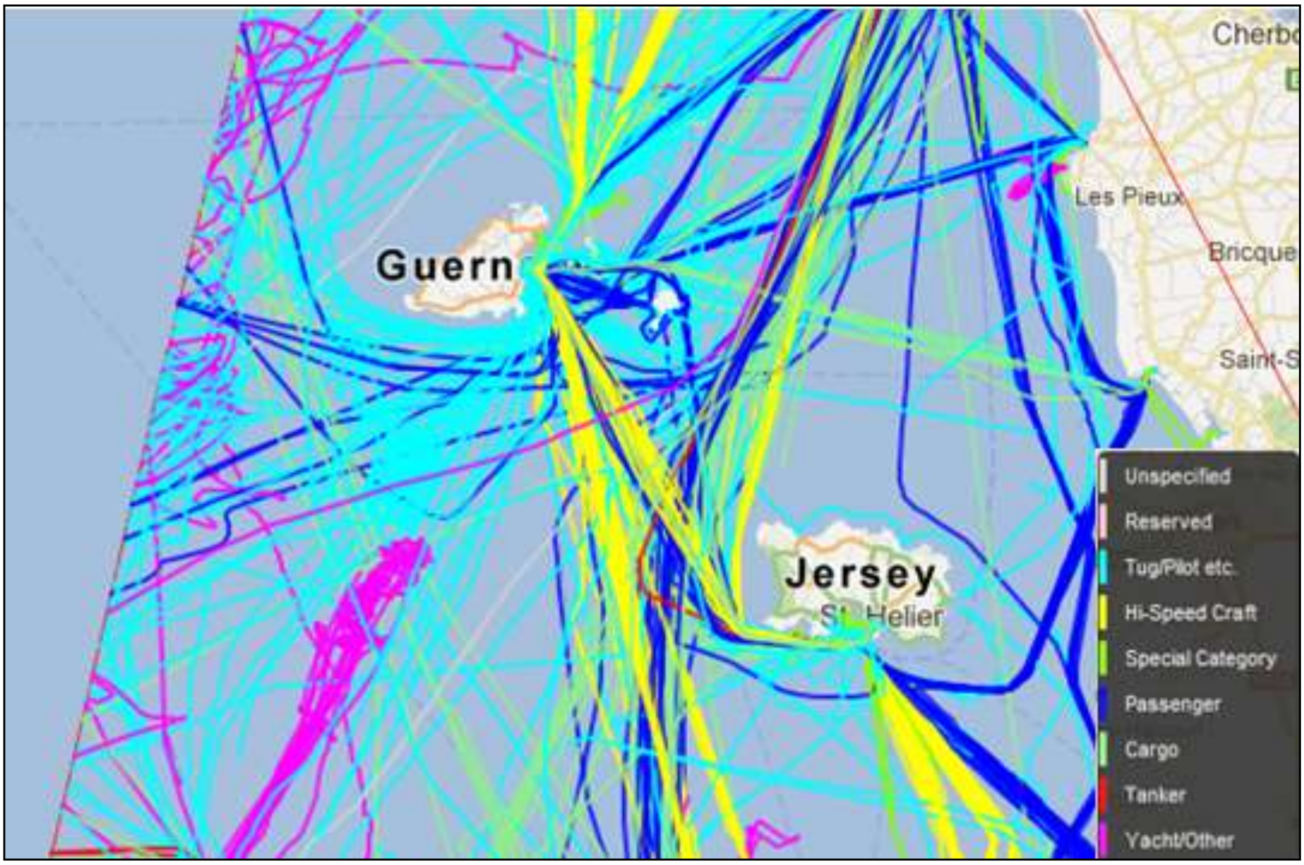

Figure 6:6 - AIS Constraint Mapping of Shipping Movements (August 2011)

6.4.3 Other Constraints

Other constraints to the development of wave farms in Guernsey waters were considered, these included:

- Ramsar Sites;
- bird breeding areas;
- marine mammal areas;
- historic coast;
- commercial Fishing and Angling;
- known wrecks;
- the locations of other renewable energy technologies proposed in this report and by the Guernsey Renewable Energy Team.

When taking these constraints into account it was confirmed that the greater than 50m zone to the west of Guernsey remains relatively unaffected. There are two wrecks that will need to be avoided when spacing devices however.

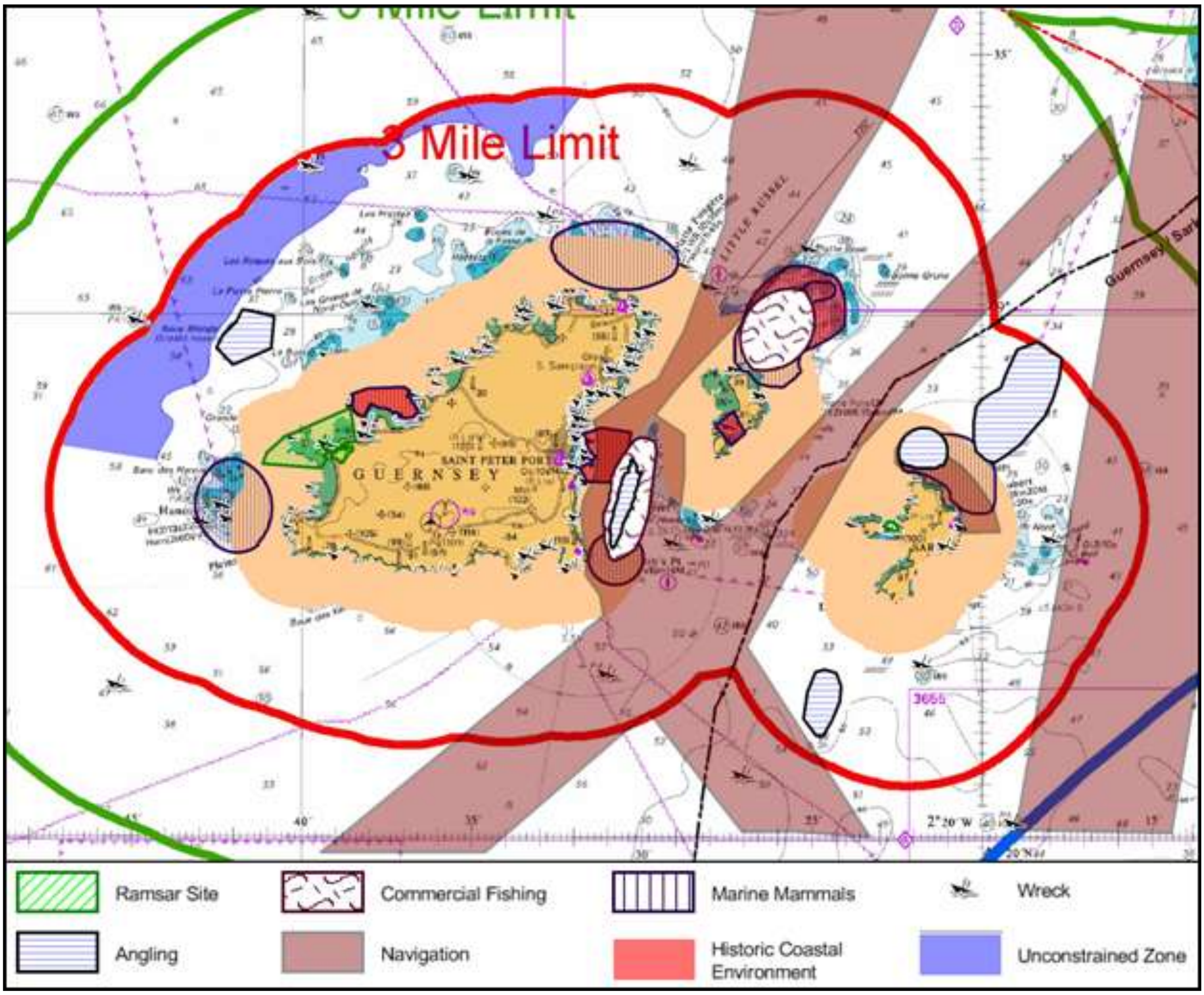

Figure 6:7 - Site Constraints

6.5 The Device

Devices can generally be categorised into three main design types. These are summarised below:

Oscillating Water Columns (OWC)

Waves cause the water column to rise and fall, which alternately compresses and depressurise an air column. The energy is extracted from the resulting oscillating airflow by using a Wells turbine

Overtopping Devices (OTD)

Ocean waves are elevated into a reservoir above the sea level, which store the water. The energy is extracted by using the difference in water level between the reservoir and the sea by using low head Kaplan turbines

Wave Activated Bodies (WAB)

Waves activate the oscillatory motions of body parts of a device relative to each other, or of one body part relative to a fixed reference. Primarily heave, pitch and roll motions can be identified as oscillating motions whereby the energy is extracted from the relative motion of the bodies or from the motion of one body relative to its fixed reference by using typically hydraulic systems to compress oil, which is then used to drive a generator (Harris, Wolfram, & Johanning, 2004).

In order to provide a possible energy yield for a wave farm in the region identified by constraint and resource mapping, it is necessary to consider a specific device. Due to the commercial infancy of the wave sector, most developers consider the specifications of their devices as commercially sensitive and do not publish them. Without device specifications, and especially the power matrix of the device, it is not possible to produce an energy yield. It is for this reason that the theoretical wave farm be modelled using the Pelamis WEC, classed as a wave activated body. Due to the near-commercial nature of the device, Pelamis do publish their power matrix, which can be seen in Table 6:3.

		Period (s)							
		3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 10
Significant Wave Height(m)	0 - 1			14	18	19	17	14	11
	1 - 2		44	90	115	119	108	90	73
	2 - 3		109	220	282	285	254	211	178
	3 - 4			408	489	477	426	355	300
	4 - 5			544	684	668	616	515	427
	5 - 6				750	750	744	685	575
	6 - 7					750	750	750	743

Table 6:3 - Pelamis Power Matrix (kW) (Pelamis Wave Power, 2009)

As the consideration for the construction of wave farms in Guernsey waters is a comparatively long term one against wind and tidal technologies, it is important to point out that the use of Pelamis in this report does not constitute a recommendation of the device for future deployment. It is yet to be seen which of the devices in development will prove the most reliable choice, due to the infancy of the sector. It is recommended that close attention is paid to the development and deployment of devices, particularly in reference to their survivability at sea, before any device choices are made.

6.6 Energy Yield

In order to obtain an energy yield it was important to consider the number of devices it is practical to install in the unconstrained area identified in the constraint mapping. In order to achieve this it was decided that, to minimise resource interference between devices, the devices should be arranged so that the oncoming wave in the predominant direction should pass only two devices. The devices were also arranged so that there were no two devices in line with one another in the direction of the predominant wave. A buffer zone of 300m was applied around the device to further reduce wave resource competition and to prevent clashes between devices.

The layout of the devices can found in Figure 6:8. The red circles represent the exclusion zone surrounding each device. Some of the devices are in waters slightly shallower than the recommended 50m, which was considered acceptable on the advice of Lars Johanning, industry expert and academic of the University of Exeter.

Also shown on the map is the suggested location of the subsea cable to service the wave farm (shown as a blue dashed line). The suggested layout allows for 37 devices, each rated at 750kW, meaning an installed capacity of 27.75MW.

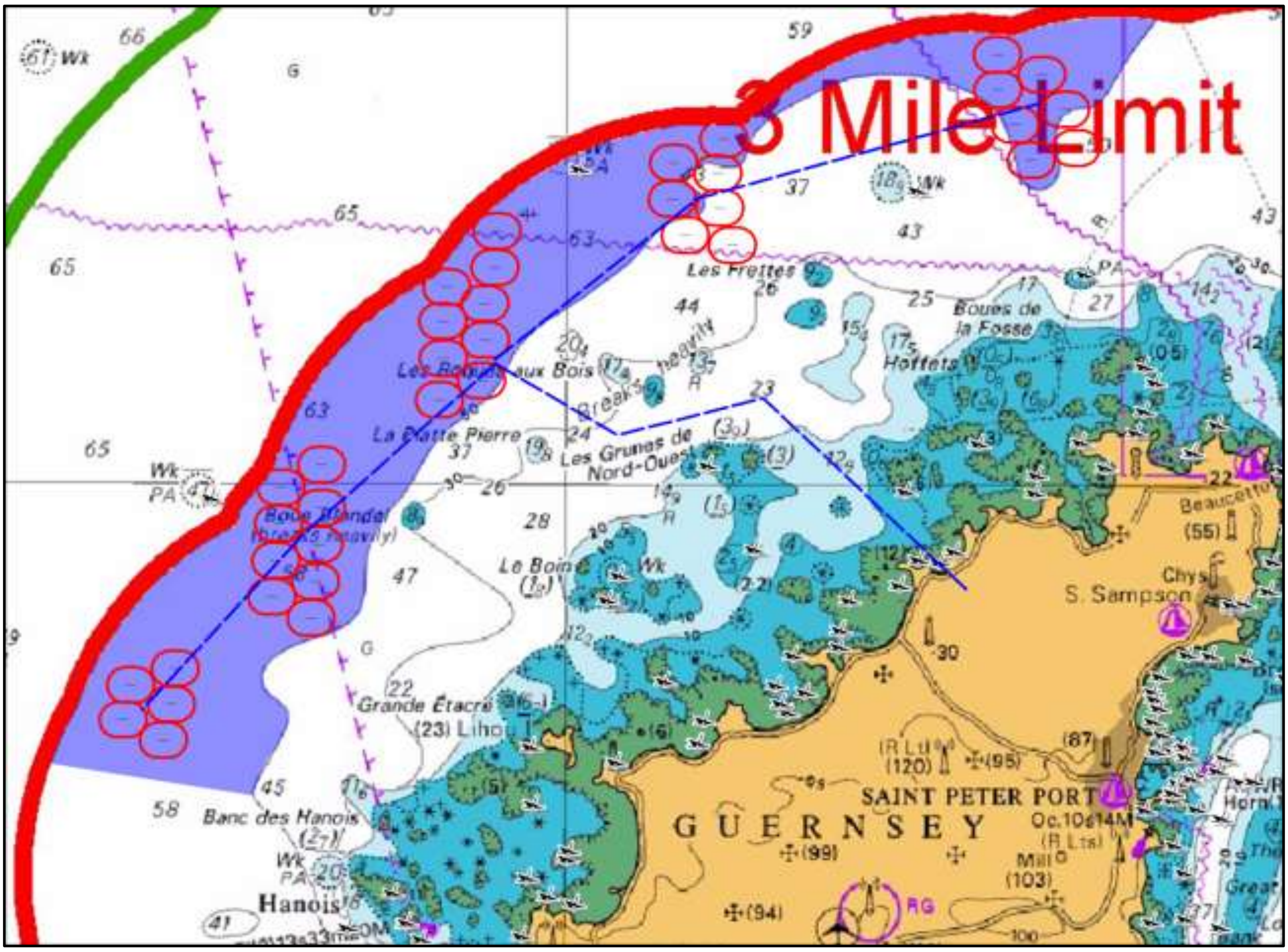

Figure 6:8 - Site Layout

In order to obtain an annual energy yield it was necessary to compute the proportion of time throughout the year that each sea state occurs. A probability scatter table was produced using the Met Office wave data for the output location closest to the proposed site for the year 2011.

	Period (s)								
Significant Wave Height(m)		3 - 5	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11
	0 - 1	1.2	3.4	3.9	4.4	4.9	3.6	1.7	0.8
	1 - 2	0.1	5.5	10.8	9.7	8.2	6.1	4.9	2.5
	2 - 3			2.3	3.7	4.0	3.1	2.5	2.0
	3 - 4				0.2	0.6	1.5	1.0	1.0
	4 - 5					0.1	0.9	1.0	0.2
	5 - 6						0.1	0.2	0.0
	6 - 7								0.1

Table 6:4 - Annual Sea State Probability Table (%)

The energy yield for each sea state was calculated as:

$E = S_p \times 8760 \times P_p$

Where:

E = Energy (kWh)

S_p = Sea state Probability

8760 = Number of hours in a year

P_p = Power for corresponding sea state from Pelamis power matrix.

The overall annual energy yield was the sum of the energy yield from each sea state. Using this methodology it was found that each device would yield around 1.1GWh per annum and the whole array would yield around 40.58GWh per annum.

This figure leads to a capacity factor of ~16%. Capacity factor is the ratio of actual energy generated in contrast to the energy generated if the device operated at its rated output for all hours of the year. On the website for the Pelamis device (Pelamis Wave Power, 2012a), a target of between 25-40% is set for the device. Whilst the anticipated capacity factor is not in-line with this, due to the modelled nature of the estimation, it is advised that further data is obtained before making any final conclusions regarding the resource.

6.7 Mooring Options

The two major requirements for a WEC mooring are to withstand the environmental and other loadings involved in keeping the device on station, and to be sufficiently cost effective so that the overall economics of the device remain viable.

Wave energy conversion devices will require differing mooring designs to best suit the device and the seabed characteristics. The design of the mooring should be considered as an integral element in the overall system design as it will contribute to the device efficiency and thus its financial viability.

Mooring design will need to be based on the specific seabed characteristics at the WEC device location. In general, the seabed in areas of high-energy seas tends to be hard rock or mobile shoals of pebbles/shale. Where the seabed is hard rock it is possible to use piling to provide a secure anchor point. Where this is not possible drag anchors may be the better option.

In order to assess the required moorings for the array a map of the sediment found in the area was consulted. As can be seen in Figure 6:9, 11 of the devices will be over hard rock and require piling. The remaining devices can use drag anchor mooring systems. It may be possible in the array for the devices to share mooring points (Pelamis Wave Power, 2012), reducing the overall cost of mooring the array.

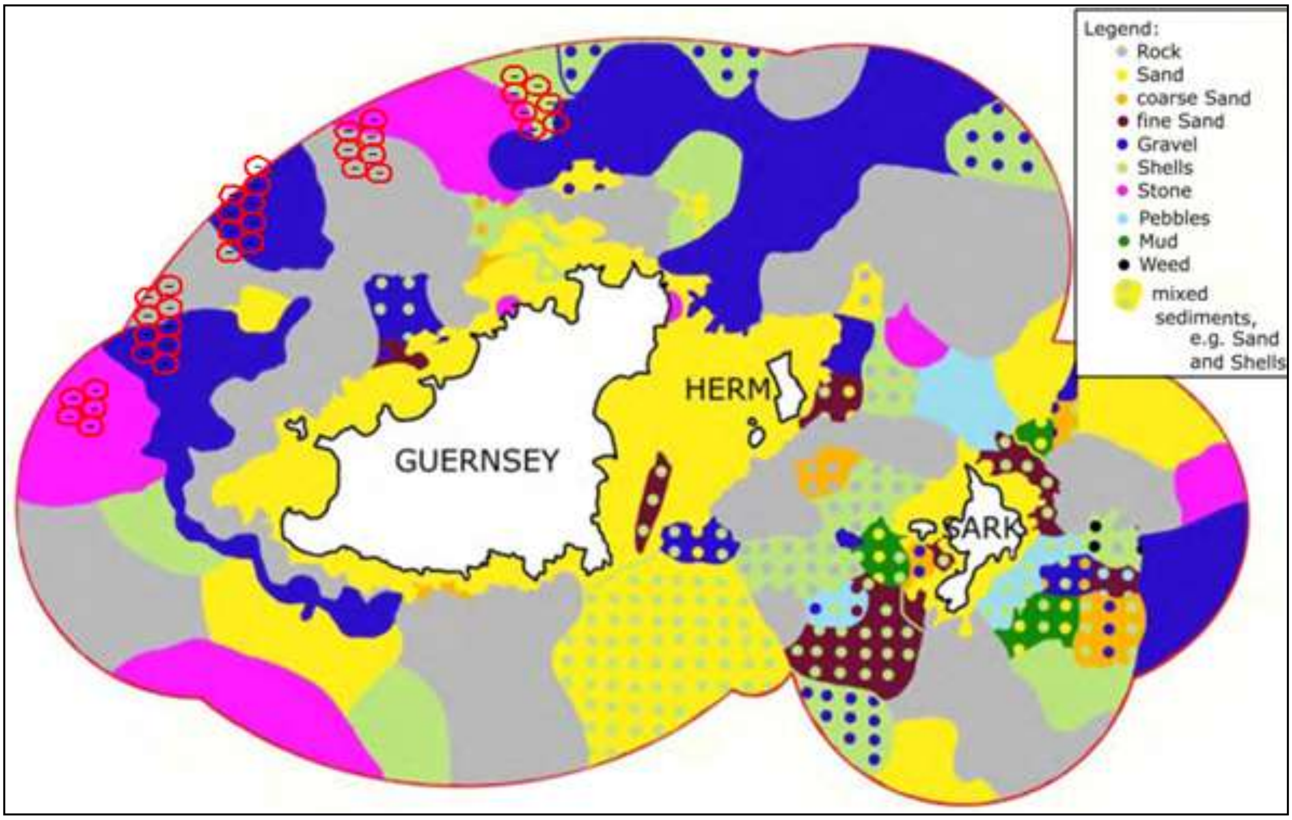

Figure 6:9 - Sedimentology Map for Mooring Specification (Alan Redman, 2011)

6.8 Conclusion and Recommendations

This initial review of the wave power potential in Guernsey has revealed that, despite the constraints, there is potential to deploy up to 28MW of WECs within the three nautical mile limit from Guernsey.

It is concluded that there is potential for WEC deployment in the water surrounding Guernsey. This chapter has provided an initial feasibility study and it is stressed that significant further analysis regarding the resource and site suitability must be carried out before strategic decisions are made. In order to carry out this further work, this report has found that certain data is required. It is recommended that a subsequent resource assessment be carried out using data available from the Channel Lightship and the Jersey Wave Buoy. Should the resource still prove attractive at this stage it is recommended that a detailed resource assessment is carried out by deploying wave buoys and detailed bathymetric survey is also undertaken. It is also suggested that the use of onshore radar wave measurement might provide an attractive alternative to wave buoys.

Pelamis has been used in this study to enable the resource to be quantified in terms of a theoretical energy yield. It is important to stress the infancy of the sector and that most devices are still in development. Close attention should be paid to the development of WEC devices so that the best performing device can be deployed at the site. It is for this reason that the exploitation of wave energy is regarded as a longer-term proposition when considered against offshore wind and tidal technologies.

The design wave, that is the maximum wave size that a WEC is likely to encounter, should be modelled also to further determine the suitability of the site.

Due to the unusually strong tidal currents in the area an assessment of the possible effects that these will have on WECs would need to be performed.

The onshore affects of WEC deployment have not been quantified and it is recommended that work is carried out to determine the onshore affects associated with the reduction in wave height. Previous work in this area for Wave hub in Cornwall has shown this impact to be minimal, though in this case the proposed device locations are closer to shore.

The work in this chapter has been focused within the 3nm limit. Should the limit be extended to 12nm it is recommended that subsequent resource assessments be carried out to determine the maximum and practical exploitable resource.

7 OFFSHORE WIND

7.1 Introduction

The States of Guernsey are considering the potential for implementing offshore wind to help meet its renewable energy targets and have already conducted a pre-feasibility study. Offshore wind energy is currently the most economical and mature marine renewable energy technology, which has resulted in its rapid growth, with an annual increase of 56% from 54MW to 2,860MW installed globally from 2001 to 2010 (Dvorak, 2011). It is therefore a key technology to consider for reaching renewable energy targets, especially in the short to medium term.

The purpose of this report is to provide a critique of the offshore wind initial feasibility report for Guernsey, which was produced by the States Commerce & Employment Department. This is followed by further research not included in the initial feasibility study such as locating other potential sites for deploying offshore wind farms around Guernsey and a general continuation of the initial study.

7.2 Offshore Wind Feasibility Study Review

7.2.1 Introduction

A feasibility study for offshore wind around Guernsey was conducted by the Commerce and Employment Department in July 2011. This study begins with a review of this report including an overview of the key observations made. Additional information and analysis was then included to expand upon what had already been covered and to include areas not considered in the report.

7.2.2 Key Observations

The key observations are set out here to provide an overview of the report:

- Two offshore wind deployment scenarios considered, both 2-3 miles off the North-West coast of Guernsey:
  - The first site was 12MW (4 x 3MW turbine)
  - The second site was 30MW (10 x 3MW turbines)
- Turbine selection:
  - The report concluded that the 3MW Vestas V90 turbine is the most favourable due to deployment rates and a successful track record.
- Wind speed data:
  - An initial study was undertaken showing favourable results particularly for a far offshore location, however this analysis was very crude and further study is needed.
- Environmental impacts:
  - Visual impact assessment is a particular issue with the sites selected in the study;

  - Environmental impacts require further research;
  - Study of public attitudes required;
- Current and possible future territorial limits:
  - Guernsey and Sark have legal jurisdiction of waters to 3nm;
  - The Crown currently has ownership of the seabed, though negotiations regarding this are being investigated.
  - Special areas of legislation (e.g. fisheries) extending to 6 or 12nm;
  - Guernsey and Sark have applied to the UK Crown for a long-term lease of the seabed to 3nm-expected to pass in timescale for marine renewables;
  - Right to lease the waters and seabed out to 6 or 12nm is being looked into;
  - Expansion of the territorial water will allow further locations to be considered off the coast of Guernsey to site an offshore wind farm.

7.2.3 Areas for Further Review

Following the review of the feasibility study a number of areas for further review were considered, which are included in the remainder of the offshore wind section of the report.

This includes:

- In depth wind speed analysis by comparing airport wind speed trends with wind speeds measured at the Chouet anemometer, this would then be extrapolated to the potential offshore wind site, taking into account roughness factor and hub height, as recommended in the study;
- Further site selection due to visual impacts on current sites selected;
- Continuation of turbines review;
- Continuation of foundations review;
- Continuation of infrastructure review;
- Environmental impact review and identification of environmental studies to be carried out.

7.3 Turbine selection

7.3.1 Brief Analysis of Feasibility Study

The turbines listed on the feasibility study have little background or technical information included. It appears that the 3MW Vestas V90 turbine is the most favourable due to deployment rates and a successful track record.

The suggested 12MW installation is unlikely to be financially viable due to the lack of economies of scale associated with installing, commissioning and operating the array. Much of the surveying and especially installation vessels can have very expensive daily hire rates. Some, such as floating cranes can cost £270,000/day (The Crown Estate, 2010). This necessitates that the capacity be much bigger than 12MW to spread the relatively fixed installation and surveying cost across many turbines, and reduce these costs with relation to the cost of the turbine, see Figure 7:1.

7.3.2 Turbine Size

The turbine selected in the feasibility report was the Vestas 3MW turbine. This may be viable for a site close to land where the visual impact would be a significant issue, however larger turbines may be more cost effective where these impacts are less significant.

Offshore wind farm developers are continuously looking for larger wind farms to increase cost effectiveness and maximise capacity, benefitting from economies of scale. Between 30-50% of the capital cost for an offshore wind farm goes towards the WTG (Wind Turbine Generator) (Accenture, 2012) therefore there has been a drive to increase WTG size to reduce cost per MW installed. This is because the remaining capital cost would only marginally increase to support a heavier structure and higher capacity electrical systems, despite the turbine cost increasing with capacity. Consequently WTG manufactures are currently developing 5MW-7MW wind turbines.

It is recommended that 5MW turbines should be reviewed alongside 3MW turbines for potential sites far offshore; this would not include the sites suggested in the feasibility study. Larger turbines should not be considered if the project is proposed for the short term due to lack of track record. If the project is considered for deployment around 2015-2020 or later then larger wind turbines are likely to have been installed with a sufficient track record to provide confidence in their reliability.

Greater energy yields are attainable from bigger turbines with larger swept areas. As seen from Equation 1, the instantaneous power available in the wind is proportional to the cube of the swept area, thus larger turbines with greater swept areas will produce considerably more power.

Equation 1 obtained from Boyle (2004).

(Equation 1)

P = power (Watts)

p = air density (Kg/m^3)

A = swept area (m^2)

V = velocity (m/s)

Turbines larger than 3MW will have a shorter installation time per MW installed capacity. Additional benefits of installing bigger turbines are the economies of scale as such turbines have fewer foundation and ancillary service requirements per MW of installed capacity. Guernsey's feasibility study disregarded turbines of greater than 3MW as a feasible option due to the lack of a present reputable track record. However, these larger turbines are currently only a few years away from commercial maturity. The first phase of deployment isn't planned to start until 2015, and if Guernsey wish to use the existing harbour facilities for installation it is unlikely deployment will start until 2020. By 2020 it is likely that there will be many larger turbines available with reputable track records, and these should be investigated.

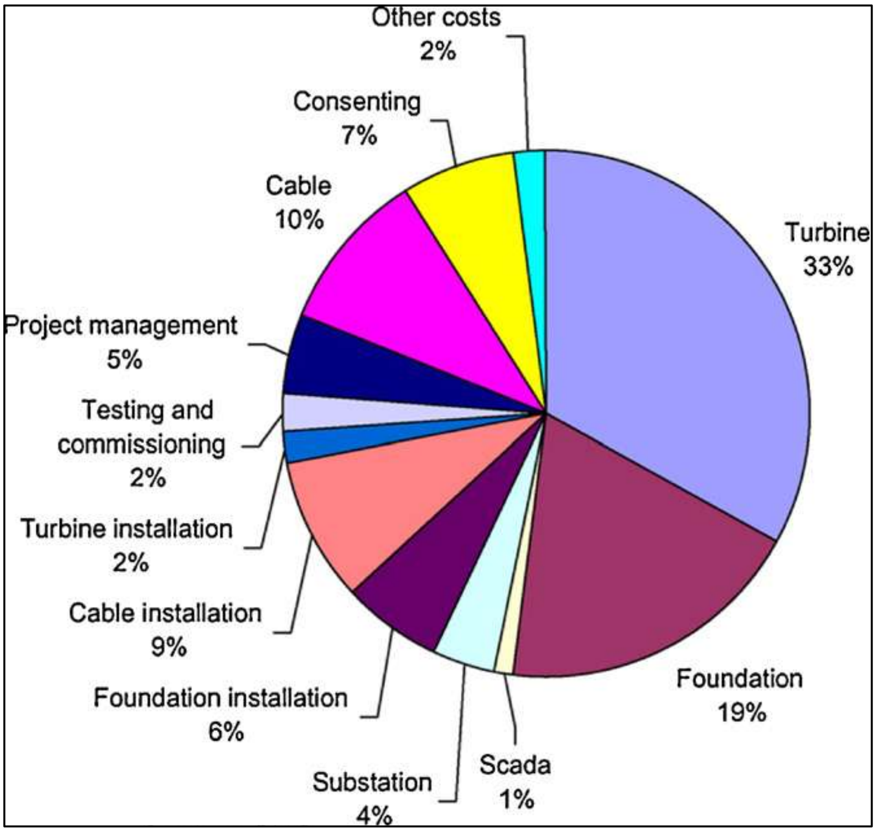

Figure 7:1 - Capital Cost Breakdown of for an Average Offshore Wind Farm (O'Keeffe & Haggett, 2012)

7.3.3 Site Specific Turbine Selection

Figure 7:2 shows the wind speed distribution has been predicted by this study (see Section 7.8 - Offshore Wind Resource).

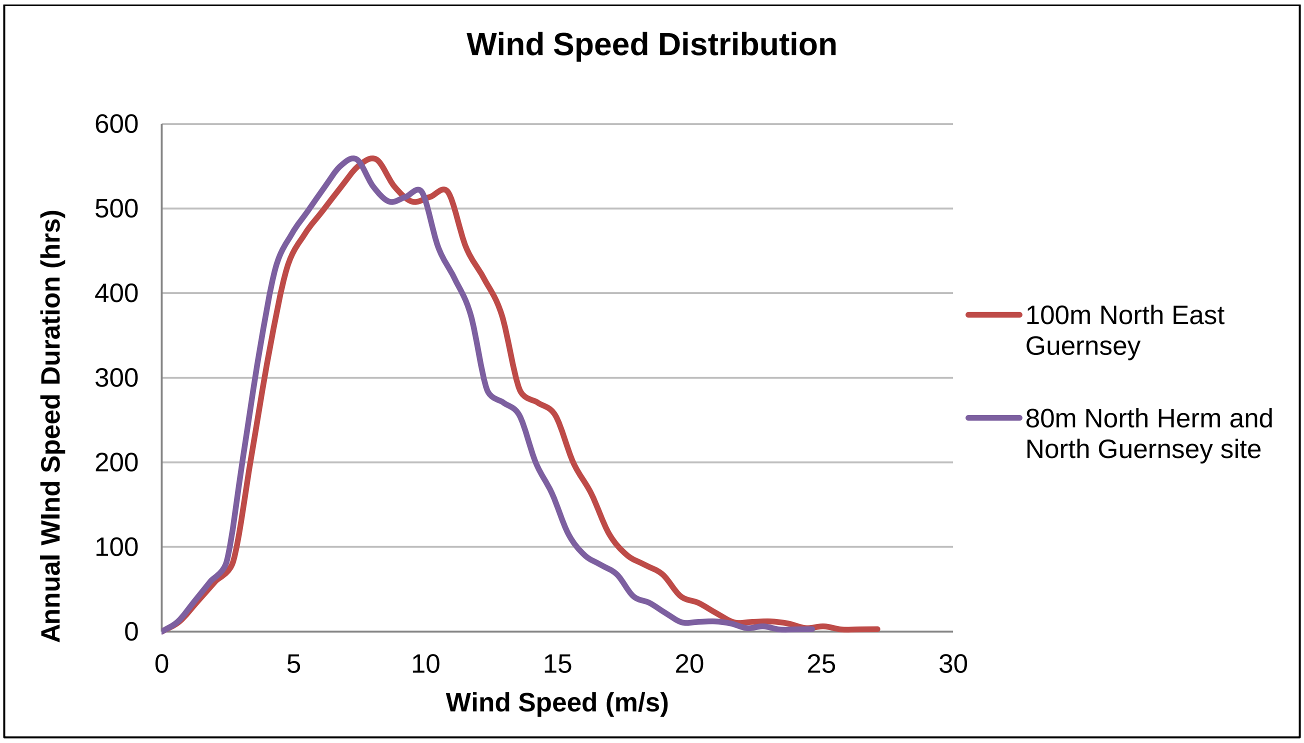

Figure 7:2 - Wind Speed Distribution

Ideally the selected turbine should reach rated capacity at lower wind speeds to maximise energy yield over the course of the year.

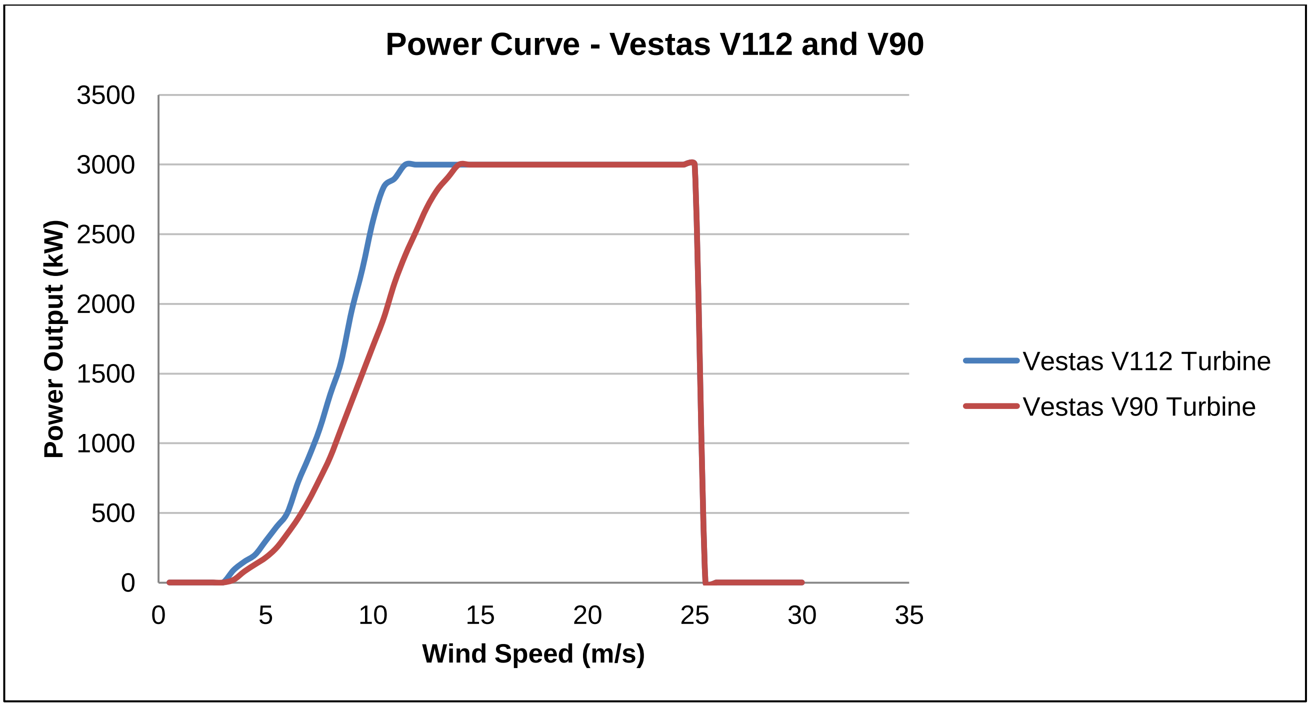

Figure 7:3 - A Power Curve Comparison of the Vestas V112 and V90 Turbines

When comparing Figure 7:2 and Figure 7:3 it appears that the Vestas V112 turbine would have the greatest energy yield in comparison to the V90. This is because it is able to reach rated power at lower wind speeds due to its larger swept area. Despite this the Vestas V90 turbine has been selected for the two 30MW wind farms (North Guernsey and North Herm) due to its successful track record and to minimise visual impact as these sites are close to shore. The REpower 5M was chosen for the North East Guernsey site as REpower is one of the only turbine manufacturers who have a track record with 5MW wind turbines, see Table 7:1.

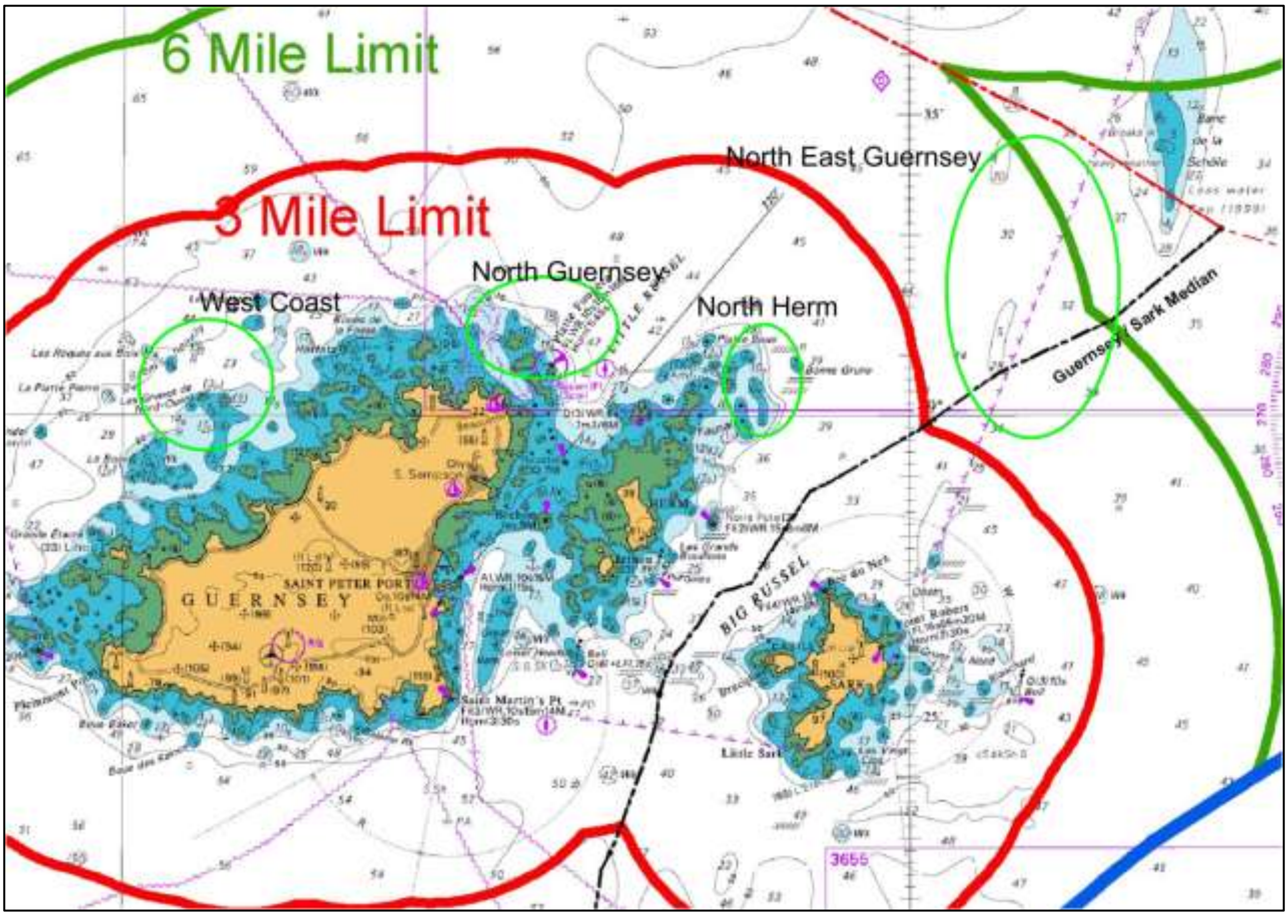

Figure 7:4 - Selected Installation Sites from GIS Mapping

7.3.4 Recommendations

It was not possible to obtain the power curve for the Bard 5.0 turbine; this would have been useful for comparing the REpower 5M against the Bard 5.0 wind turbine, as these are the main manufacturers with track record of a 5MW offshore wind turbine.

Manufacturer	Turbine model	Rotor swept area (m^2)	Capacity (MW)	Cut in speed (m/s)	Cut out speed (m/s)	Track record (1-5) [1= No track record, 5 = excellent track record]	Foundation type
Vestas	V164	21,124	7	4	25	1, prototype as of quarter four 2012, full scale production to start at quarter one 2015	Tripod or jacket structure
Vestas	V90	6,362	3	3.5	25	5, Well established, 1300 turbines currently installed	Monopile or gravity anchor
Vestas	V112	9852	3	3	25	Unknown	Mono pile or gravity anchor
REpower	5M	12,469	5	3.5	30	4, 44 turbines currently operational offshore since 2004	Tripod, jacket structure or gravity anchor
Siemens	SWT6.0 154	18,600	6	3.5	25	2, 2 turbines currently under testing by Dong Energy off the Gunfleet Sands offshore wind farm	Tripod or jacket structure
Bard	5.0	11,689	5	3	25	3, 16 turbines currently installed in the North Sea	Tripod, jacket structure or gravity anchor

Table 7:1 - Wind Turbine Selection

7.4 Foundations

7.4.1 Review of the Feasibility Study

In RET's feasibility study monopile foundations were suggested as they are the most common foundation type with the least technological risk that can be implemented in these depths (20-30m). The monopile foundations must be drilled due to the hard rock seabed in the area of the proposed array. Drilled foundations have a number of benefits including a shorter required pile length due to the strength and high level of stability of the rock. However it should be noted that drilling for the installation of piles is an extremely expensive operation and generally in offshore wind projects it is avoided where possible. A cheaper potential option when considering the seabed characteristics is the use of gravity base foundations.

7.4.2 Transition Pieces and Towers

Transition piece and towers are generic for most wind turbines. An area not considered in the review is the potential to use concrete towers as opposed to steel towers. These can have benefits over installation in that they can be installed in many small segments so do not need large specialised barges to transport them. They are also not so vulnerable to the volatile price of steel and there is the potential to recycle concrete reducing the energy/CO_2 content in construction (concrete requires large amounts of energy in production) (Gifford, 2007).

7.4.3 Further Analysis of Foundations

For this study a further analysis of foundations has been conducted with regards to the sites proposed by RET and the sites found by this study. The foundations must cope with wind/hydrodynamic loading and complex dynamic behaviour from the wind turbine.

In order of importance, the following are of prime consideration when deciding what foundation options are most feasible:

- The geology and seabed conditions
    - Depth of water column
    - Soils and morphology
    - Hydrodynamic and wind loading
- The size of the wind turbine under consideration
- The installation window dependent on tidal conditions
- The design and type of deployment vessel

7.4.4 Depth of Water Column and Foundation Choice

Conventional gravity base installations were only tested in depths of up to 15m (Huddleston, 2010), however recently much of the Round 3 wind farms installed on the UK coasts have utilised gravity foundations in depths of up to 35m (Renewable UK, 2010). Monopiles are the most common foundation type and are generally suited to depths of up to 30m (Huddleston, 2010). Jacket and tripod structures are suitable up to a depth of 50m (Huddleston, 2010) but are more expensive.

7.4.5 Seabed Conditions

The geology and seabed conditions are of greatest importance when selecting the foundation type and installation vessel required. From the feasibility study it has been determined that the seabed off the west coast of Guernsey is primarily formed of the hard rock Granodiorite (GRET, 2011). It is likely that a high-resolution marine geophysical and geotechnical survey (Huddleston, 2010) will be required to confirm this. A geophysical survey would identify the underlying bathymetry and areas of potential archaeological significance. It would also identify the seabed characteristics, for example sediment types, homogeneity of the foundation soil and morphology of the seabed (BSH, 2008). This is important to identify the strength and size of the foundations required to keep the turbine stable under various forms of loading, and for safe deployment of turbine installation vessels such as jack-up barges. The potential wind turbine sites that have been identified are situated on three main seabed geology types; sand, gravel, and rock.

7.4.6 Environmental Loading and Structural Support

Apart from the geotechnical and geophysical site investigations, when designing the foundations both normal and extreme environmental loading conditions must be investigated. Extreme environmental conditions denote the maximum wind wave and tidal loading. The determination of maximum loads must be representative of the operational life of the turbine, thus estimates should include maximum 50-year gust and wave conditions (BSH, 2007). A safety factor must be applied due to uncertainty in predicting maximum environmental loading.

The direction of the loading must also be taken into consideration, if the tidal current and wind direction act in opposite directions this will increase the turning moments. During the design phase a balance must be struck between installation expenditure and structural stability of the foundations.

7.4.7 Turbine Size and Foundation Choice

Typically turbines with capacities of below 5MW in size will use monopile foundations, turbines of 5MW and above generally use jackets or tripods in steel or concrete gravity foundations, (The Crown Estate, 2010). Larger turbines are subjected to greater loading conditions, thus the weight and size of monopiles that would be required to provide such structural support would not be technically feasible.

7.4.8 Turbine Installation and Vessel Choice Dependent on Environmental Factors

Adverse environmental loading conditions due to significant wave heights, tidal currents and wind loading can significantly delay the installation process and create narrow ‘weather windows’ within which deployment vessels are permitted to operate. Depending upon the vessel design, different installation vessels are able to operate under different loading conditions. Thus, vessels must be carefully selected upon the results of detailed environmental load forecasts with particular consideration to vessel cost and operational capabilities. Further to this, it may be more economical to select a vessel that has a more expensive daily hire rate but is able to operate in adverse environmental loading conditions and hence facilitate a faster installation.

The two foremost vessels for the installation of an offshore wind farm are jack-up barges or purpose built wind turbine installation vessels (WTIVs) (URAZ, 2011). Both vessel types have multipurpose capabilities and are used for transportation, installation of foundations, wind turbine assembly and construction (Ortiz). WTIVs are often able to install faster than jack-up barges as WTIVs have higher transit speeds, higher deck loads, greater lifting capabilities and often use of dynamic positioning systems which can speed up jack-up times (Ortiz). Therefore a purpose built

WTIV may utilise weather windows for installation more effectively than a jack-up barge system; this is especially important for Guernsey that has a significant tidal current and thus narrow installation windows. However a full economic analysis would be required because WTIVs with dynamic positioning systems are considerably more expensive than jack-up barges. A typical WITV may cost around £130,000/day (The Crown Estate, 2010). Thus accurate weather and sea state forecasts are very important to avoid delays due to weather limitations that can be very costly.

7.4.9 Further Considerations and Design Options

A full hydrodynamic survey will be required to identify whether or not loading conditions due to both waves and tidal flows are too great for the installation of a gravity anchor foundation, as such foundations are prone to scouring. Sloped sandy surfaces must be levelled by dredging before installation can commence. It is possible to install jacket and tripod foundations on sloped hard rock however if the slope is too great the surface must be planed.

7.4.10 Potential Installation Site Characteristics

Turbine size (MW)	Site ID	Site	Depth (m)	Seabed geology
3	1	North Guernsey	16	Half sand and half gravel
3	2	North Herm	10	Sand
5	3	North East Guernsey	35	Sand and rock

Table 7:2 - Potential Installation Site Characteristics

Monopile foundations would be suited to sites North Guernsey and North Herm because of the shallow depth and the medium size of the turbine. The North East Guernsey site would suit either gravity base foundations or jacket/tripod structures. At the NE Guernsey site the water is approximately 35m deep, and the large 5MW turbines require greater structural support than that provided from a monopile foundation. A gravity anchor would be preferable for Site 3 due to the cost implications of installing a jacket or tripod structure, however due to the sand experienced at the site scouring is an effect that must be properly considered and mitigated against.

7.4.11 Recommendations

To design the turbine foundations, 50-year extreme hydrodynamic and wind loading surveys must be performed to identify the maximum loads that will be exerted on the structure. Accurate sea state and weather forecasts are required to effectively deploy wind turbine installation vessels by reducing the chance of weather limitations. There is a strong tidal regime in the vicinity of all the potential installation sites; thus ideally the selected wind turbine installation vessel should have the ability to operate during strong tidal currents. It is recommended selecting a vessel such as the Wind Carrier 1 or 2 that can operate in currents of up to 2.5m/s (URAZ, 2011).

7.5 Infrastructure and Deployment Capabilities

7.5.1 Electrical Infrastructure

Offshore wind farms have intricate electrical systems that require complex reactive power and load flow studies for correct system design. The key electrical components within a typical offshore wind farm are listed below.

- Export cable
- Array cables
- Offshore substation
  - Transformers
  - Switchgear
- Onshore substation
  - Reactors
  - Capacitors
  - SVC (Static VAR Compensator)
  - Transformers
  - Switchgear
  - Harmonic filter

All electrical components must meet distributed generator requirements for which Guernsey follows those set out by the UK such as those stated by the UK G59/2-1 engineering recommendations. These set out the standards and technical requirements for "the connection of generating plant to distribution systems of licensed DNOs" (Energy Networks Association, 2011).

7.5.2 Export Cable

The export cables connect the offshore array with the onshore substation. These are high voltage AC cables therefore the voltage may be stepped up via an offshore substation to minimise cable power losses. The array cables interlink the turbines to the offshore substation. The offshore substation steps up the voltage produced by the turbines from 33kV to typically 132kV to minimise cable losses, and control the flow of reactive power. Switchgear is required to create an open circuit in the event of a fault, or when the electricity produced does not meet the standard specified by the grid code.

Cable losses for the potential NE Guernsey array may be more significant because the export cable is much longer than that of the 30MW array. The line impedance of the export cables connecting to the 30MW wind farms are unlikely to incur significant power loss as the wind farms are very close to the onshore substations.

It was suggested in the feasibility report that rock armour would be used for cable protection; however, although, this is a commonly used cable protection method it is costly. Another proven cable protection method, which is cheaper than rock armour, is using a flexible concrete mat that is manufactured using a steel cage.

Figure 7:5 - Subsea Cable Covered in Concrete (Cable Concrete, 2004).

7.5.3 Onshore Substation

The onshore substation is designed as a power-conditioning device for injection into the grid. Reactors and capacitors create and absorb reactive power to maintain a power factor close to unity. Reactors absorb reactive power produced from the export cable under no load, and the harmonic filter. Capacitors produce reactive power for the export cable under heavy load and the onshore and offshore transformers. The SVC is capable of producing or absorbing excess reactive power prior to grid injection. The harmonic filter is required to remove unwanted AC frequencies produced from the connection of the wind farm to the electrical network.

It may not be economical to install an offshore substation for the smaller capacity 30MW wind farms due to the high capital expenditure associated with an offshore substation, approximately £50 million (The Crown Estate, 2010). Further investigation would be required to calculate the financial benefit of installing an offshore substation for a 300MW wind farm.

7.5.4 Deployment and Installation

It is unlikely that Guernsey will be able to provide the port infrastructure capabilities to facilitate an offshore wind farm; however Guernsey's port facilities may be able to provide O&M duties. Nearby deep water ports would be considered for installation as explained in the RET Feasibility Report produced by Halcrow Group Limited:

Port	Distance (nm)
Cherbourg	52
Portland Port	86
Plymouth	88
Portsmouth	106
St Malo	52

Table 7:3 - Return Distances from St. Peter Port (Halcrow Group Limited, 2009)

7.5.5 Access to Supply Chain

The sizes of the potential wind farms found in this study are either 30MW or 300MW. An issue with the smaller 30MW offshore wind farm is the ability to obtain a supply order for the desired turbines as offshore wind manufacturers have a reputation of rarely supplying small projects. The ability to supply turbines for a wind farm is clearly an important issue, which must be addressed when considering the development of such a project.

A potential solution to this is to combine the project with a nearby French offshore wind farm. This has a number of benefits including:

- Access to supply of turbines;
- reducing supply chain risk;
- nearby dedicated O&M facilities and O&M teams;
- availability of spare parts;
- economies of scale.

There are however potential issues with this including:

Competition for spare parts and O&M services;

- risk of relying on the other project to be fully consented before being able to consent own project to enable shared turbine supply contract;
- limiting turbine type implemented to those used in the French project which may not be the optimal model or size for the characteristics or consenting constraints (such as visual impacts) of the Guernsey wind farm.

Nearby French offshore wind farms are shown in Table 7:4:

Name	Size (MW)	Distance from Guernsey (miles)	Planning stage
Neoen	100	35	Early/concept
Les Grunes	100	34	Early/concept
Des Minquiers	200	49	Early/concept
Cherbourg	400	45	Early/concept
Saint-Brieuc	500	31	Early/concept

Table 7:4 - Offshore French Wind Farms in Planning (4C Offshore, 2012)

In addition to the proposed projects shown there are some other sites under discussion including one between Sark and the Normandy west coast.

Figure 7:6 illustrates the location of the different offshore wind farms in planning listed in Table 7:4:

Figure 7:6 - Locations of Planned French Offshore Wind Farms (4C Offshore, 2012)

Figure 7:7 shows the nearby French ports to Guernsey. The largest port is Cherbourg and is the likely installation port for all of these offshore wind farms unless a high level of investment is provided for a closer port.

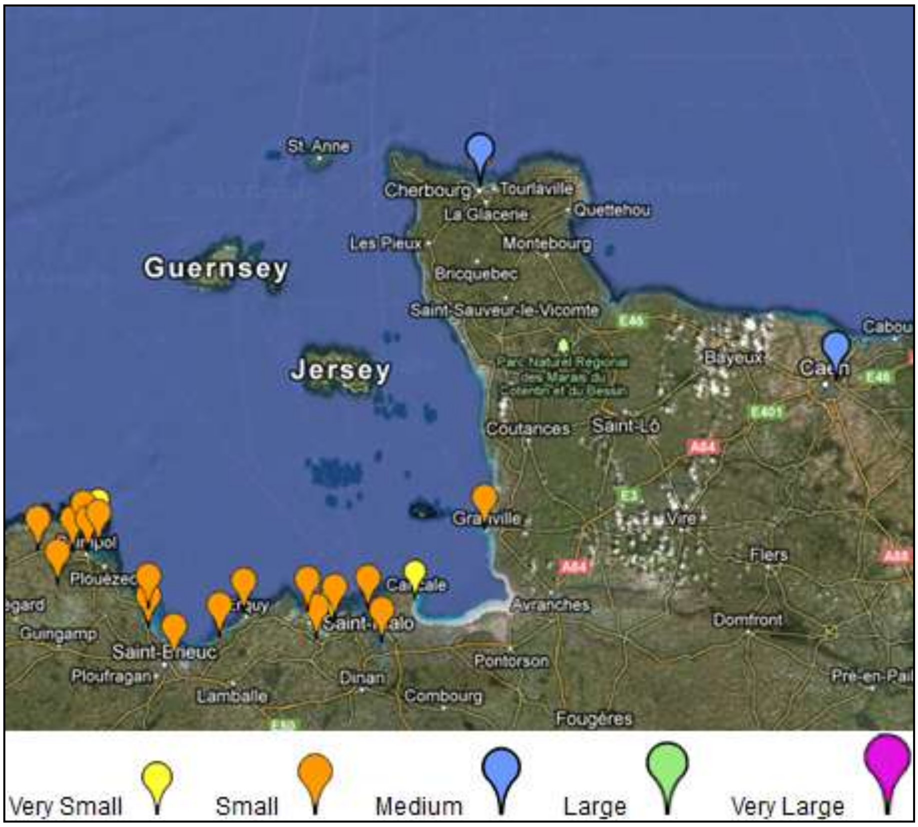

Figure 7:7 - French Ports Near Guernsey (World Port Source, 2012)

Due to the early planning stage and lack of published information regarding developments, further analysis is not possible in this study. As more information becomes available about each site, it will be possible to review what types of turbines are being considered as well as the planning constraints associated with each site. These can then be compared against the Guernsey offshore wind farm site if it is decided to pursue a site for potential development. The risk of sharing a project with one of the French wind farms, the economic benefits of doing so and the suitability of the likely turbines can then be reviewed to determine whether it is advantageous to combine a project or not.

7.6 Market Review

7.6.1 Current

At present there is an EU-wide drive to reduce carbon dioxide and greenhouse gas emissions to combat climate change (O'Keeffe & Haggett, 2012). EU mandated targets have driven the rapid installation rates of offshore wind farms across the continent. Offshore wind development is concentrated in Europe with the region accounting for over 70% of the total global installed capacity (Aldock , 2008). The key countries fuelling this drive for offshore wind power are “the United Kingdom, Denmark, Holland, Sweden and Germany” (Esteban & Diez, 2011). Wind power is one of the most mature hence it is also one of the least expensive marine renewable technologies. As of 2010 there were 2GW of installed capacity of offshore (Esteban & Diez, 2011) and 198GW onshore wind (Zwaan, Rivera-Tinaco , Lensink , & Oosterkamp , 2012). Although there are obvious differences between offshore and onshore wind power, much of the innovation and experience within the onshore industry can also be utilised by the offshore industry.

7.6.2 For the Future

The global offshore wind market is set to grow at a rate of 31% per year to a total of 37,900MW by the year 2020 (Aldock , 2008). 38% of this growth is expected to arise from developments in both the UK and Germany. The increasing deployment of offshore wind is likely to be accompanied by cost reductions as a result of economies of scale, innovation and technological improvements in all stages of the supply chain.

In the mid 2000s the cost of offshore wind power was approximately £1.5million/MW (Gross , Heptonstall, & Greenacre , 2010). The expectation was that costs would fall, however they have since risen to £3.1 million/MW by 2012. The reason for rising costs is due to fluctuations in commodity prices, lack of competition, supply chain constraints and increasing deployment depths (Gross , Heptonstall, & Greenacre , 2010). The costs now appear to have plateaued, and it is predicted that costs will decrease by 20% to approximately £2.5 million/MW by 2025 (Gross , Heptonstall, & Greenacre , 2010).

7.6.3 Guernsey

Guernsey is tied into a take or pay clause contract (See Section 3.5 – Interconnector) to buy 16MW of France's electricity until 2023. GEL have entered into a long term contract for purchasing electricity from France from 2013 – 2023. Despite the name the "take or pay" element of this contract is not seen as a barrier to renewable development before 2023 because although it does set out that GEL should "take" or purchase some electricity from France there is still sufficient flexibility available to GEL to allow some on-island generation and to sell some electricity back into the market or to Jersey. This will allow on-island renewable generation in this period. As Guernsey's base load demand is 25MW, without an energy storage solution or export capacity an installation greater than 9MW would, at times, be producing more electricity than required. Thus the deployment of the array may require suspending until 2023 to fully utilise the wind farm. By the time Guernsey has adequate infrastructure to facilitate an offshore installation it is likely that the costs per MW of installed capacity will have decreased. At the same time, the costs of on-island generation and importing electricity from France are likely to increase. The culmination of increasing prices of conventional generation and the decreasing price of offshore wind may push the technology towards grid parity. This is discussed in detail in Section 12- Scenario Analysis of this report.

7.7 Offshore Wind Site Selection

Siting an offshore wind farm is heavily dependent on a number of constraints, which need to be mapped to give an indication of suitable sites. This was done in the feasibility study, which looked primarily at the West coast for suitable sites. However, this could potentially cause concern for tourists and Guernsey residents due to the recreational nature of this part of the island. Further study into public perception is being carried out for RET, and this should be considered before any final statements are made. For this report further sites have been considered up to 12nm from Guernsey, Sark and Herm based on the premise that the States territorial waters will be expanded from the current limit of 3nm to 12nm.

Constraint data was received from RET (unless otherwise stated) and are as follows:

- Wind resource - using UK Marine Energy Atlas;
- Bathymetry using shipping chart information from which a maximum depth of 35m at low tide was considered;
- Fishing - long line, netting, angling, potting and trawling both commercial and recreational, although fishing is not considered to rule out a potential site;
- Sightings of marine mammals;
- Visual impact (1nm buffer around each island);
- Major shipping routes using charts from the St Peter Port harbour master;
- Historic environment (ship wrecks and other areas of historic interest);
- Sub-sea cables;
- Ramsar sites;
- Recreational diving;
- Geology (not considered a constraining factor);
- Dredging (not considered a constraining factor).

Constraints that were not possible to obtain include:

- Communication Fresnel zones;
- Radar;
- Aviation;
- In depth environmental constraints.

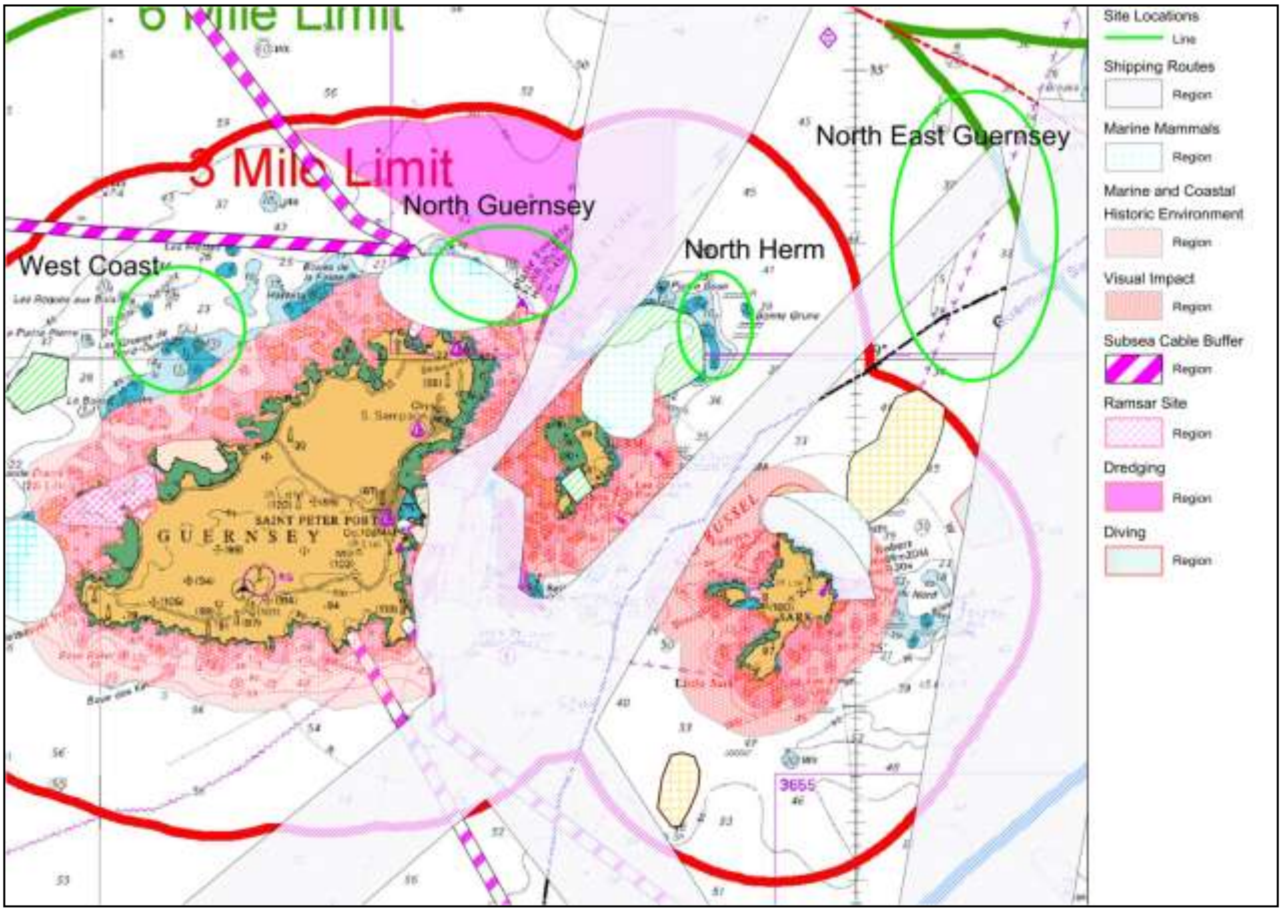

Figure 7:8 - Map of all Constraints

The Figure 7:8 shows all the constraints mapped onto a Raster image of the Bailiwick.

The new potential sites that were identified are as follows:

- North Herm (10 x 3MW turbines)
- North Guernsey (10 x 3MW turbines)
- North East Guernsey (60 x 5MW turbines)

7.7.1 North Guernsey Site

North of Guernsey is a potential site for a 30MW array. Situated approximately 2.5km from the nearest point of land on Guernsey, it is also the closest to the feasibility site and the Chouet met mast. It has the following advantages:

- The proximity to the shore should allow for less cabling and electrical losses;
- It is situated near to an electrical substation;
- It is in a relatively shallow location (average of 20m at low tide).

And the following disadvantages:

- It is close to the shore in a remote location unspoilt by industrialisation, which is a popular area for recreation and tourism. Therefore there is a potential for visual impact;

- It is near to sightings of marine mammals.

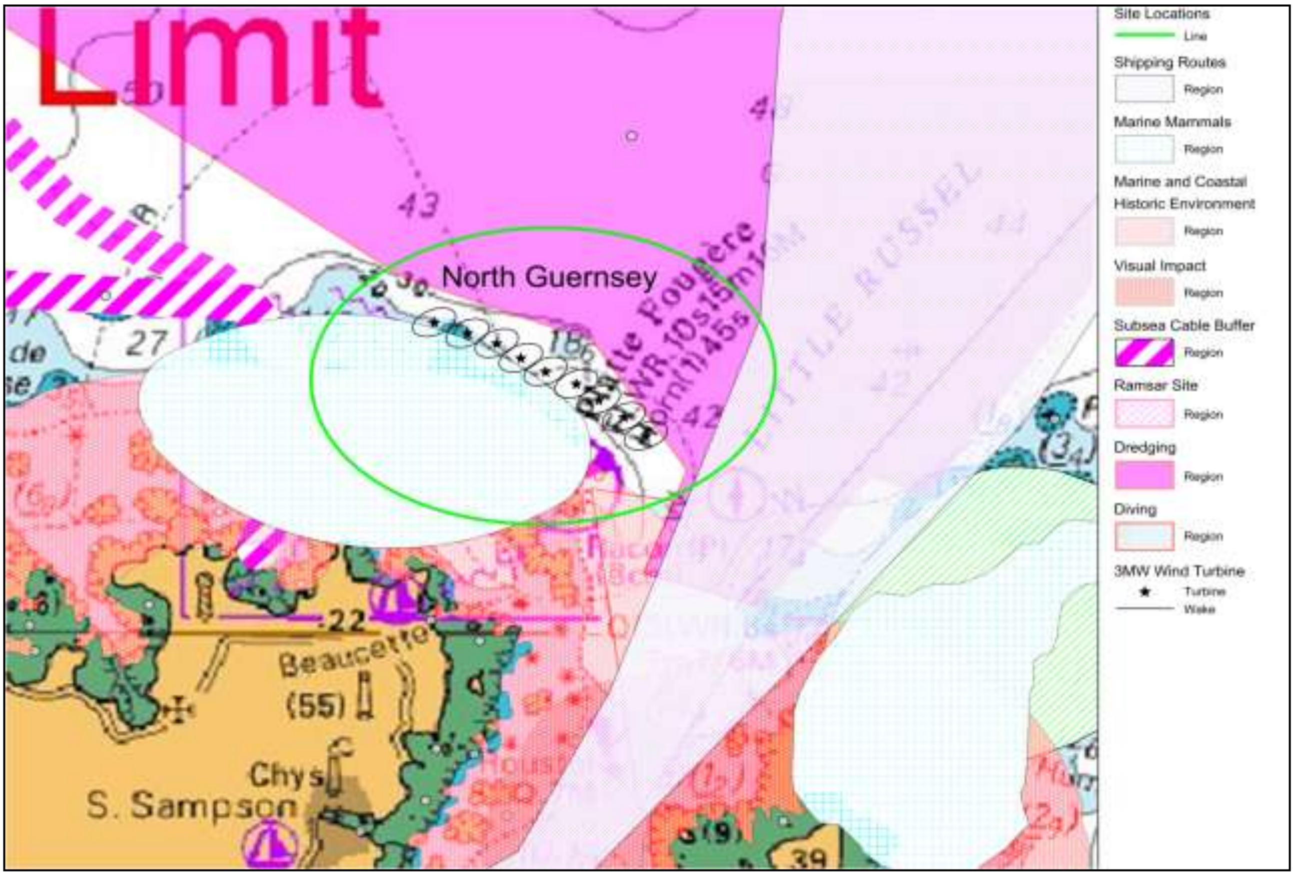

Figure 7:9 - North Guernsey Site and Constraints

7.7.2 North East Guernsey

Another potential site is to the North East of Guernsey. This could potentially accommodate up to 300MW of capacity. Situated 14km away from Guernsey, it is the largest potential site identified in this report. It has the following advantages:

- Potential to utilise a larger resource;
- Much lower visual impact due to distance from land;
- Reduced predicted cost per MW installed due to higher capacity factor and use of larger turbines.

Disadvantages of this site are:

- Much higher cabling and infrastructure costs;
- It is intersected by a busy shipping route;
- It is the deepest site considered at about 32m at low tide.

The environmental mapping data did not cover this area so this is a requirement for further study.

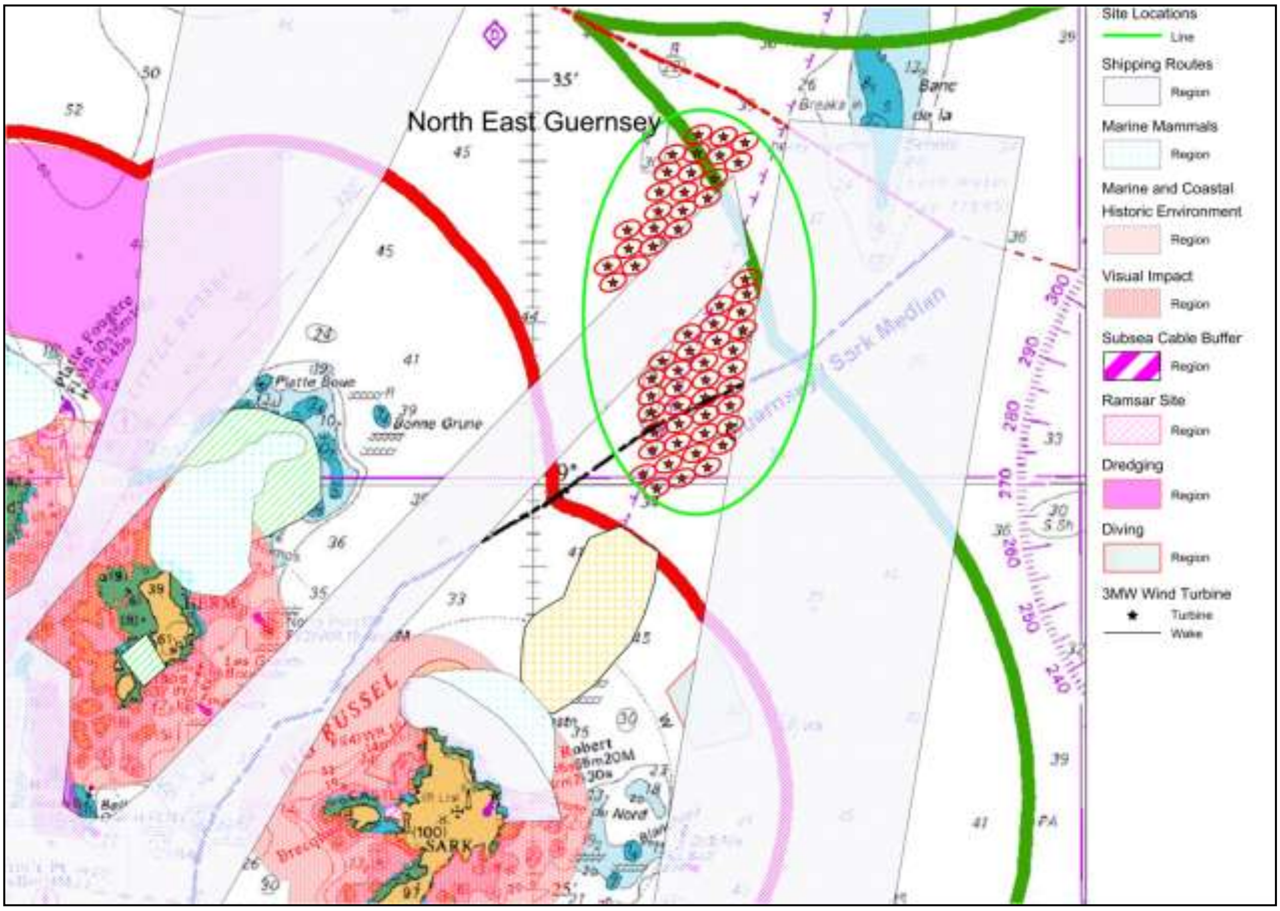

Figure 7:10 - North East Guernsey Site and Constraints

7.7.3 North Herm Site

Another 30MW potential site was found North East of Herm. It is about 7.5km from Guernsey and 4.5km from Herm. It has the following advantages:

- Shallowest waters of any site at about 15m depth on average at low tide;
- Shorter cabling distances than 300MW site;
- Limited anticipated visual impact from land as greater distance than the North Guernsey site.

And the following disadvantages:

- This site may receive some sheltering from the prevailing wind direction by the island of Guernsey;
- It is close to sites of historic interest;
- It is close to marine mammal sightings;
- It is further away than the North Guernsey site therefore increasing the cost of cabling.

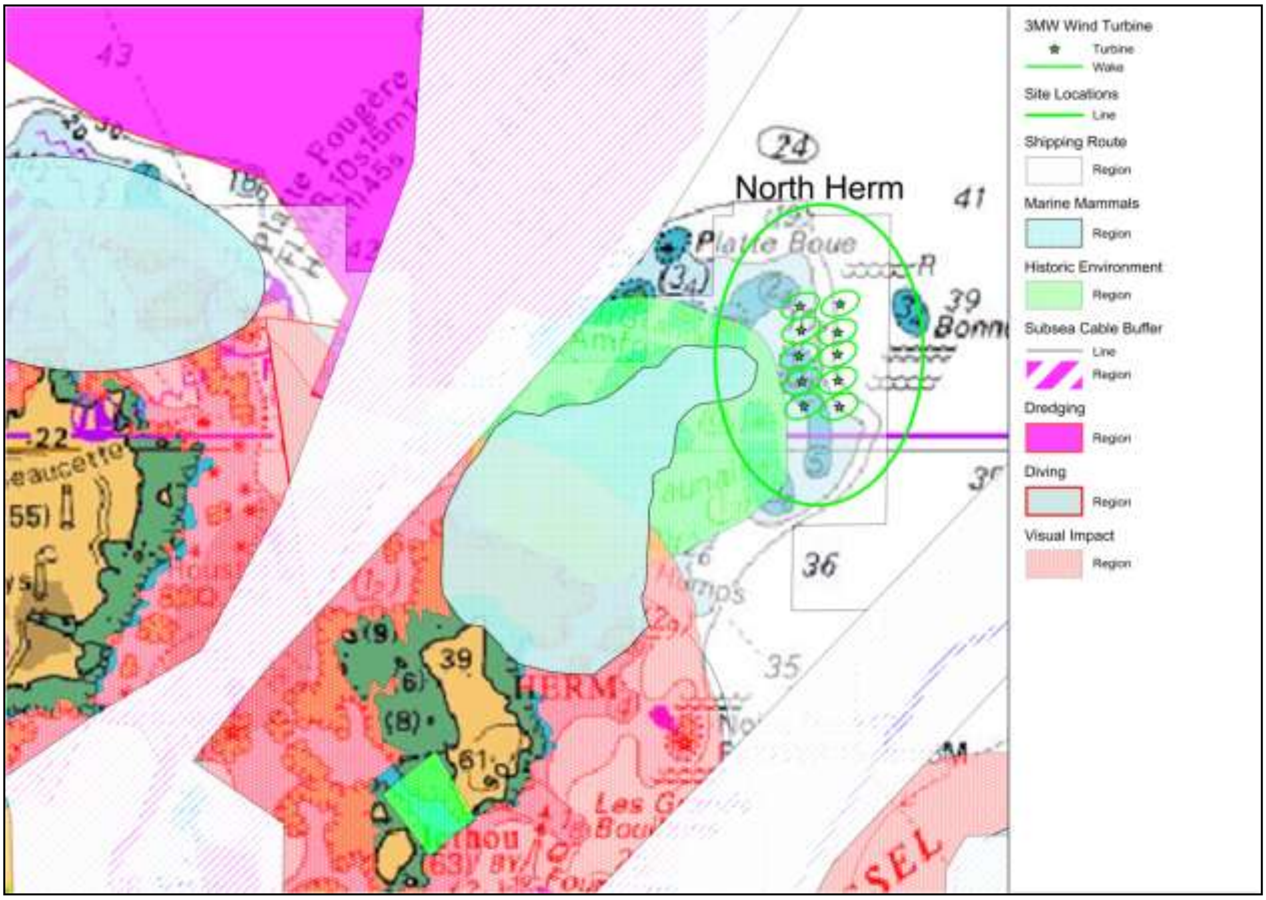

Figure 7:11 - North Herm Site and Constraints

7.7.4 Site Selection Conclusions

Each of these sites requires further study to deem their feasibility. This will include:

- Obtaining detailed bathymetry data;
- Obtaining detailed geology data;
- Undergoing the assessments detailed in the 'Environmental Impact Assessment' section;
- Gaining a further understanding of shipping routes;
- Gaining access to communications, radar and aviation data.

This will also help to assess the possibility of further potential sites.

7.8 Offshore Wind Resource

7.8.1 Prefeasibility Study Wind Resource

The feasibility study carried out by RET looked at wind speed estimates using the following sources:

- Airport met office data
- Channel Lightship data
- European Wind Atlas Data
- UK Marine Energy Atlas

Using primarily the European Wind Atlas data, an average wind speed of 8.5m/s at 80m height was assumed. Using the historic Airport data the following wind rose was created:

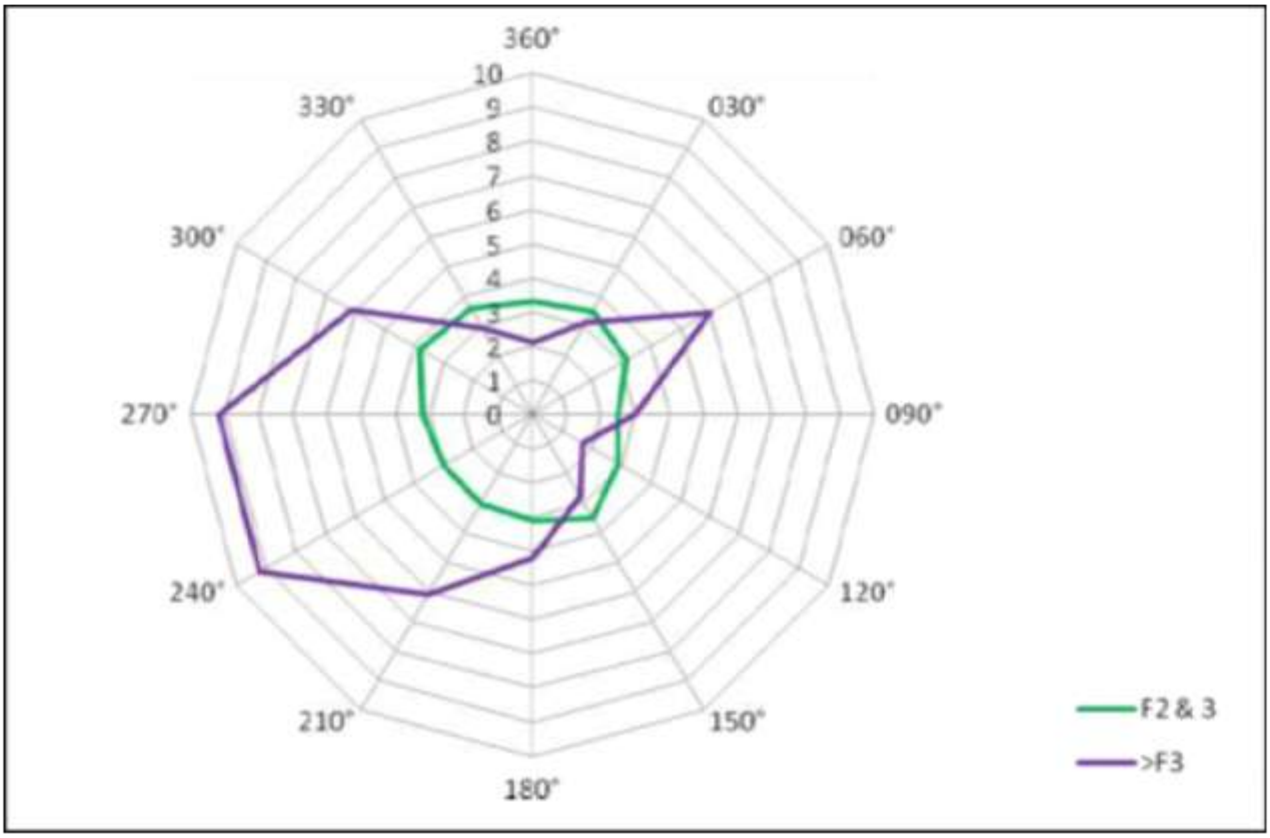

Figure 7:12 - Wind Rose from Guernsey Airport (Dept. Commerce and Employment, 2011)

This shows a prevailing wind direction of WSW, W and ENE.

In the recommendations for further work the following point was made:

- Use a 'Measure, Correlate, Predict' analysis using data from a met mast in an exposed location on the North West coast to create a more accurate prediction for wind speeds at the proposed sites.

After this report was produced a met mast was set up in the North Western peninsula of Chouet in order to record one-minute resolution wind speed data that could be directly compared with equivalent airport data. It was recommended that at least two years of data be collected to do the analysis.

As this location is exposed it was deemed to be a reasonable estimate of near-shore wind speeds. This assumption has been used in this report.

7.8.2 New Wind Resource Assessment

To gain a better understanding of wind resource further analysis has been undertaken. This has been broken down into two sections; near-shore, westerly exposed locations and an offshore location specified in the 'Site Selection' section as 'North East Guernsey'. An assumption based on the airport wind rose has been made that the most frequent wind direction for high power winds is from the WSW.

7.8.3 Guernsey Airport and Chouet Met Mast Data

For both cases wind speed data was taken from the Guernsey Airport and the Chouet met mast over the period of six months at a one-minute resolution. These could then be plotted against each other to create a correlation equation as shown in Figure 7:13.

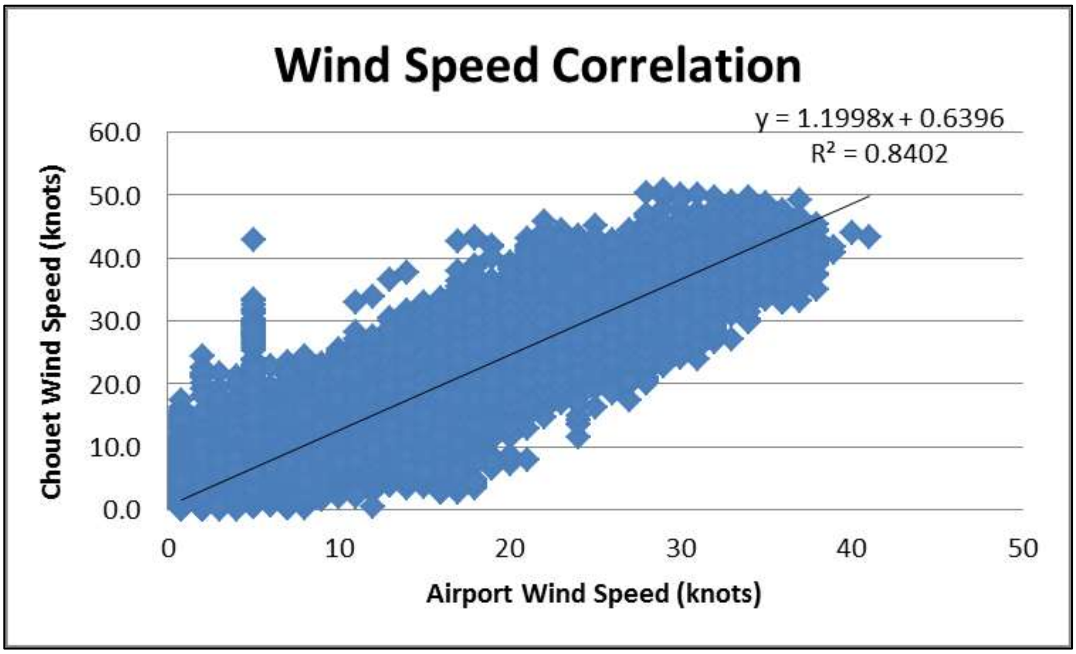

Figure 7:13 - Wind Speed Correlation

This correlation equation was then applied to Airport data over two years to give an approximation of Chouet output for the same period.

The Chouet met mast is situated at 10m above ground level. It is necessary to extrapolate this to the hub height of the wind turbines being considered, in this case 80m and 100m. This is done by applying a wind speed gradient equation:

Where:

v = Velocity at new height (m/s)
v_0 = Velocity at original height (m/s)
H = New height (m)
H_0 = Original height (m)
Z_0 = Roughness coefficient length

Roughness coefficient of length is assumed to be equal to that of seascape as that is the predominant surface close to the met mast. However, for a more accurate figure a more thorough approach to obtain the roughness coefficient should be made.

This led to anticipated two year Chouet met mast averages for 10m, 80m and 100m hub heights of 7.0m/s, 8.4m/s and 8.6m/s respectively.

7.8.4 Atlas of UK Marine Renewable Energy Resources

Wind resource was also calculated for the offshore scenario 'North East Guernsey'. This was done by using the UK Marine Energy Atlas to work out a conversion factor that could be applied to the converted Chouet data. This assumes that the wind regime at this site is the same in terms of spread but of a greater magnitude.

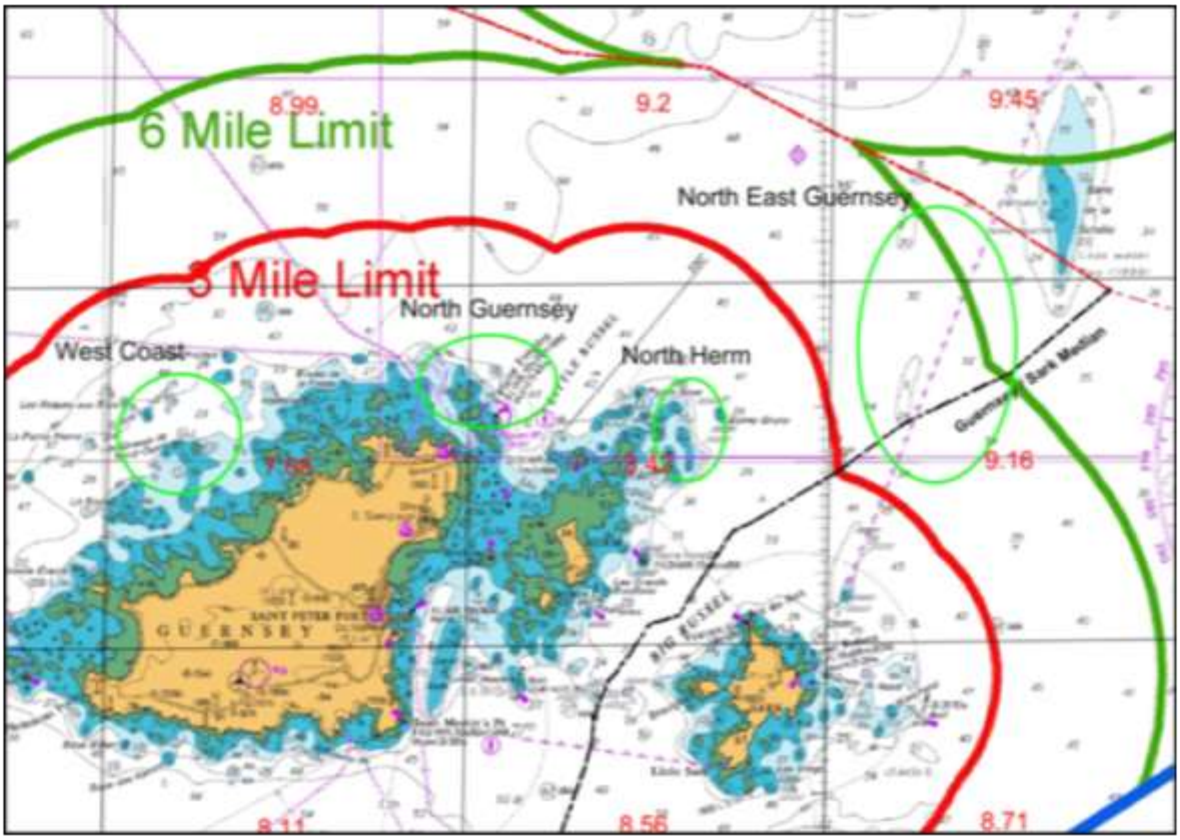

Figure 7:14 - Map of Possible Sites and Wind Speeds at 100m around Guernsey (m/s).

Figure 7:14 shows the proposed sites circled in green and the UK Marine Energy Atlas figures labelled in red. An average of the two squares that the North East Guernsey site is located in was found and compared to the average of the Chouet data. This was used to calculate a conversion factor, which was applied to the correlated Chouet – Airport data.

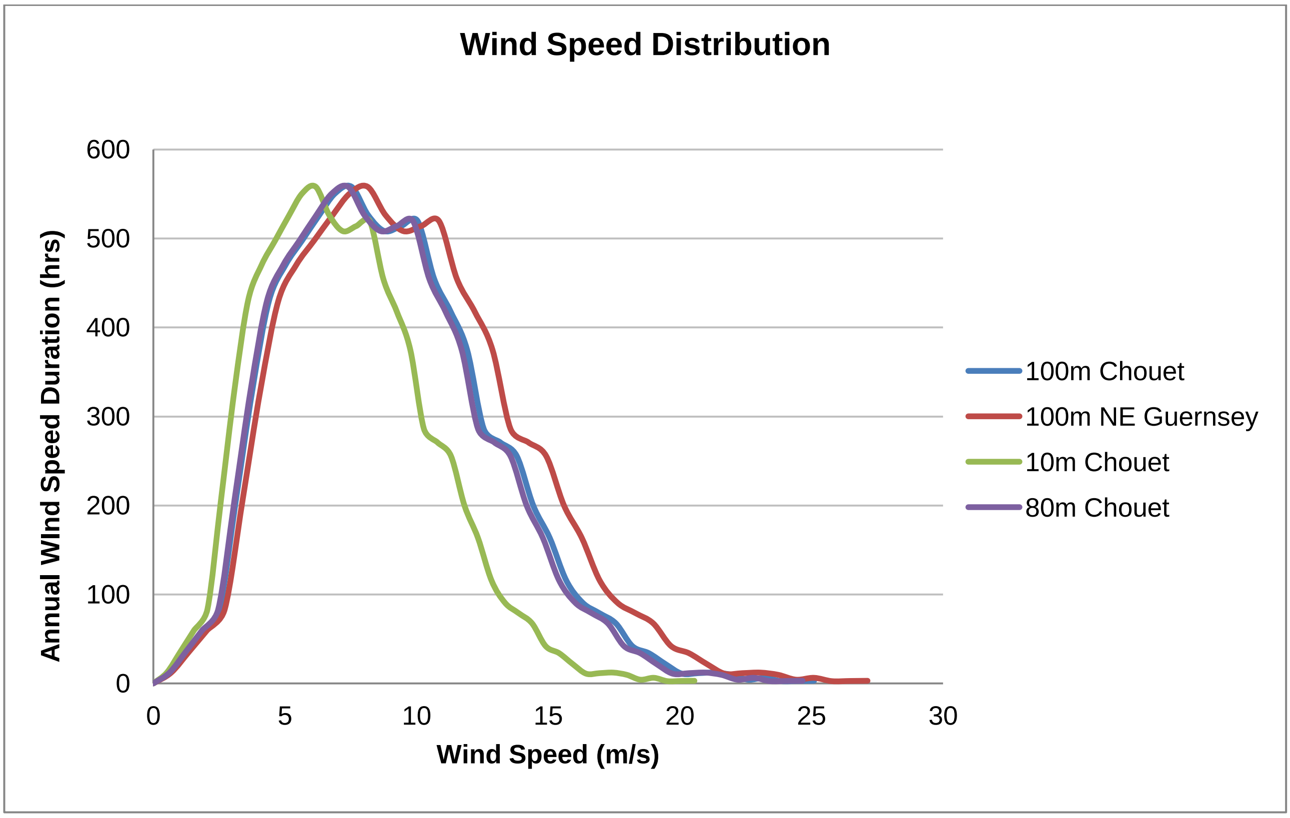

Figure 7:15: Wind Speed Distributions for Four Scenarios

Figure 7:15 shows the wind speed shift that is predicted to occur between the Chouet met mast and the NE Guernsey offshore location. The average wind speed for the offshore location at 100m height was found to be 9.3m/s.

7.8.5 Wind Resource Conclusions and Recommendations

This brief analysis has estimated that the average wind speed at the near-shore North West Guernsey sites, at 80m height is approximately 8.45m/s, which is the same as the central estimate given in the feasibility study. The offshore sites cannot be as easily compared as the feasibility study calculated average wind speed values for 30nm towards the English Channel and this report considered a more technically feasible site 6nm to the North East of Guernsey. For the North East Guernsey site an estimated average of about 9.3m/s was found at a 100m height, less than the English Channel estimate (that was based on Lightship Station data) but worthy of further study.

The analysis in this report relies heavily on the following assumptions:

- There is a linear correlation between the Chouet met mast and Guernsey Airport wind speeds;
- Surface roughness at Chouet can be predominantly described as seascape;
- The Chouet site is representative of the near shore sites identified;
- The UK Marine Energy Atlas has reliable wind speed data;

- It is possible to apply a conversion factor to Chouet wind data to extrapolate to a site with a higher wind speed average;
- Two years of Airport data is indicative of historic data.

It should be noted that the wind regime at the various near shore sites cannot be guaranteed to be the same as the Chouet met mast. Also, the wind regime at the offshore site cannot be guaranteed to be a simple conversion factor increase of the Chouet met mast. As the sites are at a distance and have a variety of sheltering and funnelling effects produced by land masses it is reasonable to assume that in fact they will be subject to a somewhat different wind regime. Thus this analysis can only be taken as an indicator of wind resource in the area and further study is of course required.

Based on this information it is suggested that the following points are looked into:

- Use the Chouet met mast to compile two years of data;
- Consider predicting long term Chouet data by finding a correlation equation with long term airport or lightship station data if considered appropriate (i.e. if there is sufficient correlation);
- Apply parametric statistical analysis to smooth out biases in raw data;
- Use this to do a preliminary financial analysis of the proposed sites;
- If there appears to be a business case for a site it is likely that onsite data will need to collected before finance can be made available. This can be done by using a met mast or SODAR technology and correlated with the Chouet met mast for long term predictions.

7.9 Turbine and Array Energy Production

Turbine energy yield calculations are based on the near-shore wind regime with 3MW Vestas V90 turbines at 80m hub height and the offshore wind regime with 5MW Repower turbines. Turbine power outputs are stated by the manufacturer:

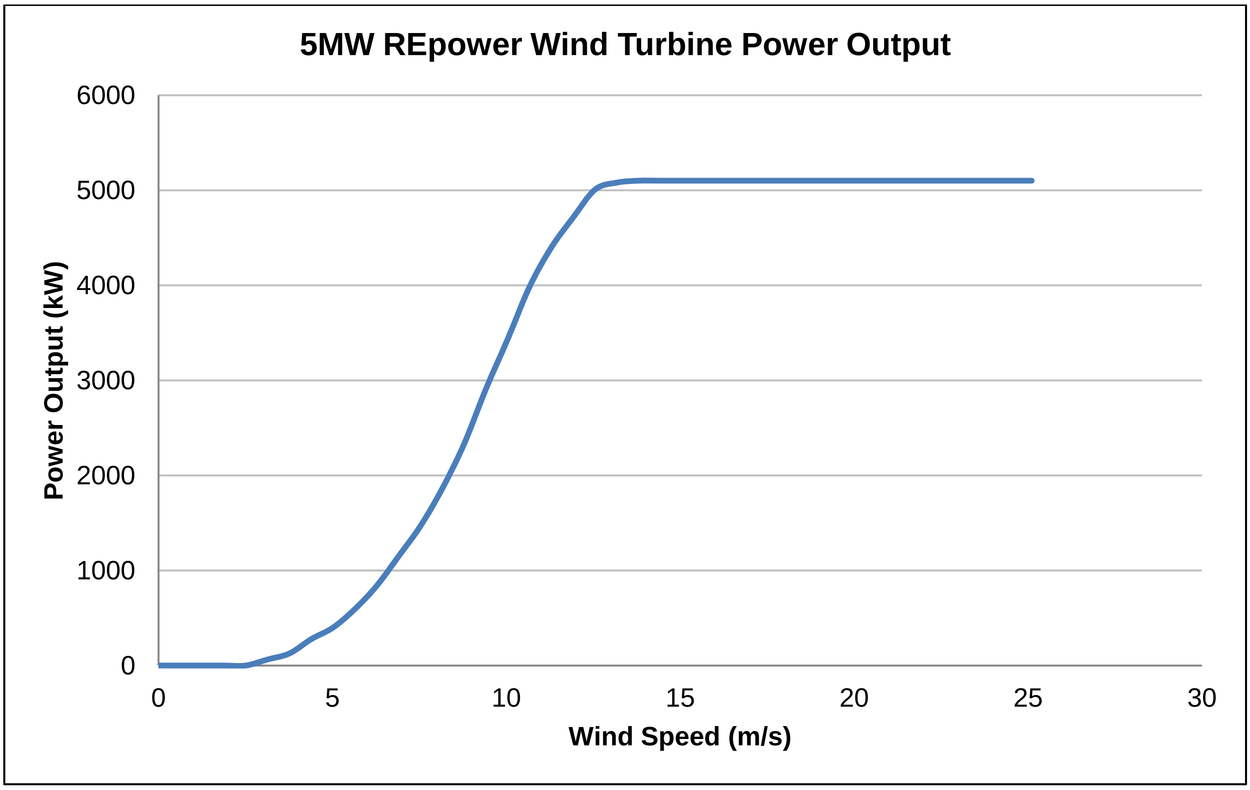

Figure 7:16 - 5MW REpower Wind Turbine Power Output

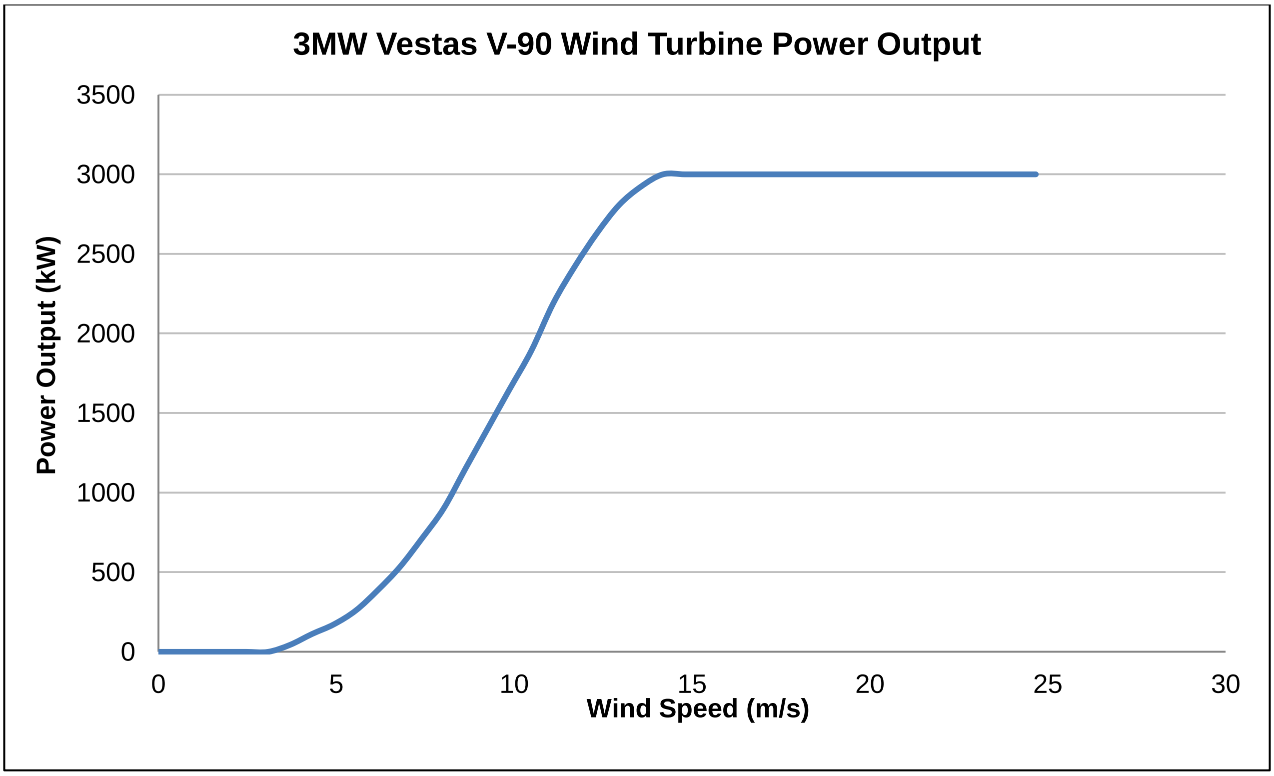

Figure 7:17 - 3MW Vestas V-90 Wind Turbine Power Output

The annual wind speed durations found in Section 7.8 - Offshore Wind Resource are then multiplied by the power curves to calculate the energy yield per turbine at each site.

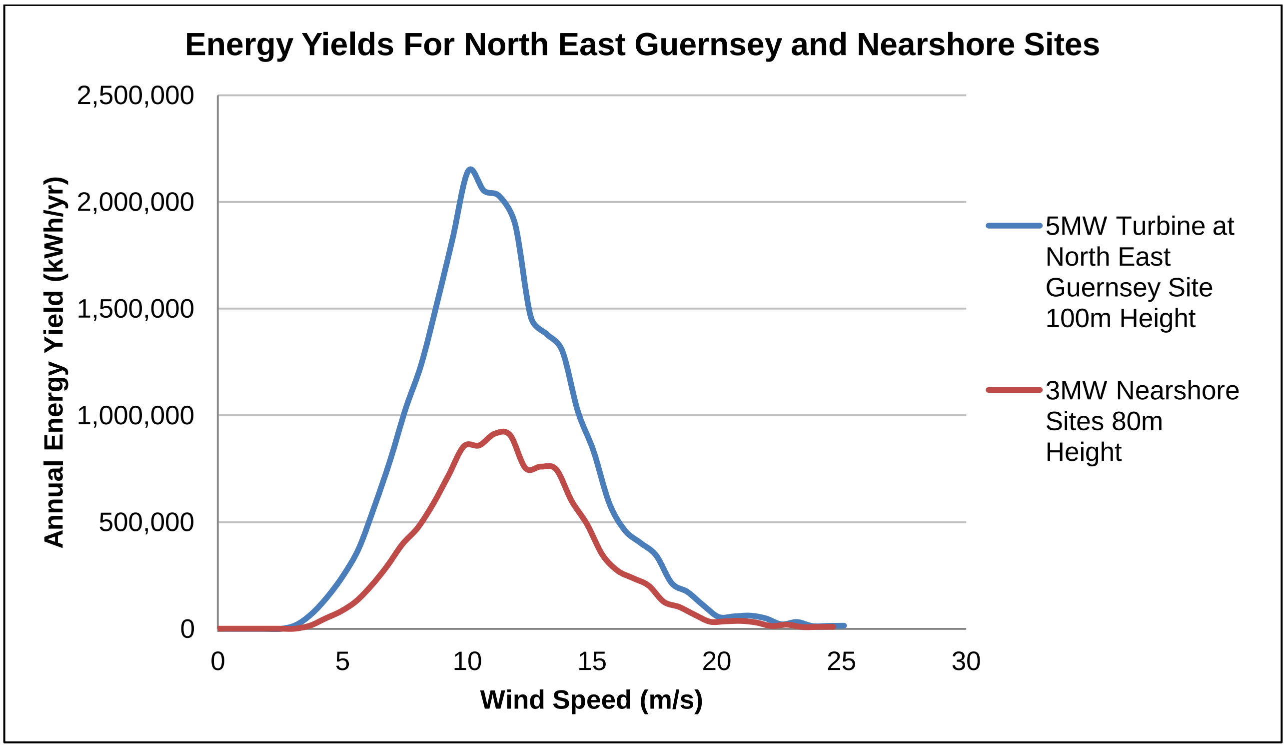

Figure 7:18 - Energy Yields for North East Guernsey and Nearshore Sites

Annual energy yield for an 80m high 3MW Vestas wind turbine at near-shore 30MW sites were found to be approximately 11GWh. For a 5MW REpower turbine at the offshore 300MW location an annual energy yield was found to be approximately 22GWh. This does not take into account losses from the array or cabling.

7.9.1 Energy Production of an Array

Wind turbines in an array are subject to three main losses from the calculated yield given above. These are array losses (due to interference of the wind regime from near-by turbines), electrical losses (from transformers and cabling) and down time (due to maintenance). Figures for this study are based on averages from the Danish Wind Energy Association and are equal to those given in the feasibility study. Array losses depend on the turbine rotors, the layout of the wind farm and the turbulence intensity with a range of about 5-10% loss. Electrical losses range from 1-2% and losses from soiled blades account for another 1-2%. For this study a total loss is assumed to be 14%. It is advised that further study be carried out in this area, which is specified below.

The energy yield calculations are based on ten 3MW turbines for the near-shore scenario and 60 5MW turbines for the offshore scenario. Assuming losses given above this result in an energy yield of 94GWh/yr and 1268GWh/yr for the near-shore and offshore sites respectively.

7.9.2 Wind Energy Yield Conclusions and Recommendations

Yield calculations are required to assess the economic feasibility of the project and therefore require reliable data. It is recommended that more accurate power curve data is obtained from turbine manufacturers to enable more accurate yield calculations.

7.10 Economics

The cost of an offshore wind farm depends on numerous variable factors such as turbine and foundation types, method of deployment and the distance from the shore. The variability between each development makes defining the cost of this technology difficult without extensive individual analysis of all aspects involved during design, construction and operation stages. Appendix B highlights the main costs associated with an offshore wind farm.

The types of turbines recommended for the 30MW sites are the Vestas V90 model, and for the 300MW site the REpower 5M turbine model. This choice is due to the potential negative visual impact from the shore of the 30MW sites as the Vestas V90 model has a 144m max tip height, compared to the 163m maximum tip height of the 5M model which would be more suited further from the shore to maximise energy yield where visual impact is not such a concern.

Using the Crown Estate Document 'A Guide to an Offshore Wind farm' (2010), the cost breakdown of a 500MW wind farm is outlined, resulting in the following estimated £/MW installed figures:

Wind Farm Process	Cost/MW Installed	Cost for 500MW	Cost for 300MW
Development and Consent	£120,000	£60m	£36m
Wind Turbine	£1,200,000	£600m	£360m
Balance of Plant	£900,000	£450m	£270m
Installation and Commissioning	£800,000	£400m	£240m
Operation and Maintenance	£60,000	£30m	£18m
Total	**£3.08m**	**£1540m**	**£924m**

Table 7:5 - Offshore Wind Cost Breakdown (The Crown Estate, 2010)

These figures can be assumed to be relevant for a 300MW wind farm but are not a suitable representation for the cost for 30MW, where alternative case studies of wind farms of a similar scale would be a more accurate indication of expected cost.

RWE site statistics for North Hoyle 60MW wind farm (2003) show that this £80m project has a total cost of £1.3m/MW installed. This cost is likely to be more comparable to the Guernsey 30MW sites, at North Herm and South Herm. It should however be taken into account that this wind farm was commissioned in 2003 and cost factors which are not related to wind farm size such as exchange rate and price of steel have changed since then.

Guidelines for cost per MW installed in the existing feasibility report are as follows:

Site Name	Cost (£m/MW)
Rodsand 2	2.0
Ormonde	3.0
Lincs	2.7
Borkum West	2.9
Global Tech 1	2.9
Dudgeon	2.3

Table 7:6 - Costs per MW Installed (Garrad Hassan, 2010)

Table 7:6 leads to a future cost assumption of between £2.5M to £3M/MW installed.

The distance from the shore defines how much cable is required, with an additional offshore substation needed for greater distances. This needs to be studied further as the increased cost of installing a substation for a wind farm further from shore may not outweigh the cost of extra cabling which is dependent on factors such as the cost of copper.

Due to economies of scale, it is more likely to be cost effective to develop the 300MW site 14km North East of Guernsey.

7.11 Conclusion

From an appraisal of RET's feasibility study into offshore wind power it is advised that the 12MW site on the west coast is probably not suitable. This is due to both the lack of economies of scale and the visual impacts that may be experienced on the west coast of Guernsey. Three further potential sites were identified, namely, North East Guernsey, North Herm and North Guernsey, with rated capacities of 300MW, 30MW and 30MW respectively. These sites were identified from detailed GIS mapping taking account of relevant site constraints. A wind farm of up to 30MW should be considered in the shorter term, as this could be a good starting point for Guernsey to accelerate some of the benefits identified in Scenario 2 - 'Base Load' Renewables (Section 12.3).

Wind speeds at all three sites were calculated from correlating wind data from Guernsey Airport with wind speed data from the Chouet met mast. These speeds were then extrapolated to the required hub heights. All three sites boast a considerable wind resource. The 10 Vestas v90 turbines at the North Guernsey and North Herm sites would yield approximately 94 GWh/year and 60 REpower 5M turbines at the 300MW site would yield approximately 1268GWh/year.

At present Guernsey does not have adequate port infrastructure to facilitate the installation and commissioning of an offshore wind farm. The wind farms would have to utilise harbour and port facilities in France where the planning for several French wind farms is already underway.

The 300MW site rests on the ability that Guernsey will be able to extend its territorial waters to at least 6 nautical miles.

It is the recommendation of this report that there is enough significant potential for offshore wind around Guernsey to make further research advisable.

8 ENVIRONMENTAL SCOPING STUDY

8.1 Introduction

By using the Regional Environmental Assessment Report for Marine Energy (RET, 2011) as a baseline study, the following section aims to indicate the key environmental impacts that could be caused by deploying offshore devices. By identifying these impacts at an early stage, they can be mitigated against effectively and fully understood by the time any devices are installed. It also allows for an indication as to where the key areas of further study should be in the future, if plans for offshore devices are taken further.

8.2 Scoping Study

8.2.1 Offshore Wind

Being the most commercially advanced of three technologies considered, the potential impacts of offshore winds are better known and can therefore be better estimated. There is still a high level of uncertainty as the offshore wind sector is still burgeoning but most issues can at least be scoped, if not completely understood at this stage.

Visual Impacts

One of the most vivid concerns for the local people will be the visual impact of an offshore wind farm. This concern has already been well documented by the local press and such it is important that this report addresses those worries. This was already considered in the site selection, with the potential sites being located away from the more popular, recreational North and Western edges. Also, the turbines for the smaller, near shore sites have been specially selected to minimise visual impacts.

Figure 8:1 shows a realistic image of a 30MW site at 3km distance. As can be seen, the impact is minimal and, especially with weather effects taken into account, should be negligible.

Figure 8:1 - A View of a 30 MW Wind farm at 3km (10 x 3 MW Vestas V90 turbines)

Whilst the 300 MW site is farther from shore, there are a greater amount of turbines and therefore the visual impact must be assessed independently. Figure 8:2, shows a realistic image of a 300 MW site from 6km viewing distance. As can be seen, again with weather effects taken into account, the visual impact should be negligible.

Figure 8:2 - Realistic Image of 300 MW Offshore Wind Farm at 6km (30 x 5MW REpower 5M turbines)

There will also be visual impacts during construction due to large vessels and cranes being necessary to install the turbines and ancillary works. With appropriate public awareness these impacts should be negligible as they will only be present for a limited time.

Birds

Unlike wave and tidal power devices, the wind turbines are structures that stand above sea level. The construction, deployment and maintenance of these devices suggest that they will create greater impacts as a result. The main impact that is currently associated with wind power, both offshore and onshore, is avian collision. There has been much research in this area in the last twenty years and collision has been most likely caused by poor visibility rather than the positioning of the structures (Allison, Jedrey, & Perkins, 2008). The noise and vibrations caused by the turbines allows the avian species to be aware of them before they encounter them. However, one issue that has arisen from offshore wind is that the location of a wind farm, if chosen poorly, could cause a bird to change migration route (Masden, Haydon, Fox, Furness, Bullman, & Desholm, 2009). Research is currently being carried out to determine the extent of the impact that this would cause to the bird and whether it has a detrimental effect. It has been established that majority of the Guernsey coast has been identified as being breeding areas for avian species (RET, 2011). In consideration of this, the location of the wind farms needs to be explored to establish whether they would have a negative impact on the breeding sites closest to the wind farms. Due to the method of constructing an offshore wind farm, disturbance to coastal and marine populations are unavoidable, however this can be kept to a minimum when considering innovative methodology. In addition, the foundations and bases of the turbines have potential to become new marine habitats leading to potential new feeding grounds for the avian population

Fish and Seabed Communities

The method of anchoring or fixing the turbines to the seabed will determine the potential impact on marine environment, with positive impacts including habitat creation due to the introduction of new structures on the seabed and fishing restrictions causing population increase at the site.

Wind turbines can be detected by fish up to 16km away but cause no significant behavioural reactions until within a few metres of the structures (Mathias H. Andersson, 2011). They produce no serious damage to hearing organs (EWEA, 2008) and so commercial fish should not be affected due to WTG noise. COWRIE and several Sea Fisheries Committees have researched habitat disruption, fisheries biology and management and the potential for positive impact of habitat enhancement. From this research guidance has been provided for turbine manufacturers as to the levels of electromagnetic disturbance that would potentially impact on sensitive marine species, so turbine design can help to mitigation of these impacts (Huddleston, 2010).

Coastal Processes

The type of turbine foundation used has been found to affect the potential impact on coastal processes. Gravity-based foundations present the largest negative potential impact for scouring of the seabed, for which scour protection should be used. There is no evidence to date that seabed morphology is negatively affected beyond the process of local scouring around the turbine structures (Huddleston, 2010).

Historic Environment

Each wind farm has individual aspects to consider depending on the features of the location. The historic issues to be considered such as heritage sites can be complex and cumulative requiring individual study (Huddleston, 2010).

Vibrations

Two methods have been considered for the construction of the foundations: drilling or use of gravity base foundations. Drilling would result in many impacts of different levels. Firstly, it would cause irreparable damage to the seabed and potentially destroy small habitats. The underwater vibrations caused by the drilling could create areas in the sea that the marine ecology would choose to avoid, thinking it to be dangerous. In an extreme case, this could result in populations relocating and thus impacting the fishing industry. Secondly, around the coast of Guernsey there are many shipwrecks that have historical value. If the location in not considered efficiently or the vibrations are too great, damage could be caused to these. The gravity base foundations require much less invasion of the seabed, making its impacts much less. However, mitigation for both methods can be seen in the form of new habitats at the base of the turbines.

Onshore Flora

The island of Guernsey is roughly four by five miles in size, because it is so small it is likely that it acts as one ecosystem rather than a landmass made up numerous ecosystems. This was enhanced by the numerous site visits carried out during the data collection period. At each coastal site the same set of flora was found varying only slightly. Considering this, when choosing the site for an onshore substation and considering impacts on flora it is likely that the same impacts will occur at numerous potential sites. As a result these impacts can transcend to impacts on feeding sites on land.

Impacts of Onshore Construction

The main impacts to consider for construction of onshore substations are on local housing and traffic. Guernsey is quite densely populated so it is unlikely that a site would be chosen that would not be in the near vicinity of a house or publicly used building. Noise and visual impacts will be an issue during this period and measures will need to be considered to keep impacts and disturbances to a minimum. Traffic will most likely be caused on the island when transporting necessary materials and tools to the chosen site. There are times of year, such as the summer season, in which the island is likely to be most populated caused by tourism. It would be advised that these periods in the year are discounted when considering when to build the onshore substations as it will cause minimal traffic and the issue of noise will be of concern to fewer people.

Shipping and Navigation

Offshore wind farms have the potential to impact upon shipping routes. As this was considered in site selection as a constraint, this can be scoped out. Shipping routes are also a soft constraint, meaning that minor routes can be changed in order to accommodate offshore wind sites.

8.2.2 Tidal and Wave Power

The potential impacts of tidal stream technologies and wave devices cannot be accurately estimated at this stage, but as the industries develop and more devices are tested for longer periods, the potential impacts can be better understood. Most of the impacts for these technologies will be very similar, and as such have been considered simultaneously. The following issues are the key areas for further study for deployment of these technologies in Guernsey.

Visual Impacts

As wave and tidal devices have few components above water, the visual impacts of these devices are minimal, especially when at the distances identified in this report. The main visual impact would come during construction where cranes and large vessels are required for installation. This impact should be scoped out, however, as by making the public aware when this may occur and the fact that it will only be for a limited time there will be a negligible effect experienced onshore.

Shipping

The two main locations that have been suggested in the tidal power chapter of this report are in the Big Russel and the south east of Sark. As stated in the REA, the Little Russel hosts the majority of all nautical routes of importance such as ferries for both tourism and cargo, but the Big Russel, while only hosting a few routes, is still an area of importance in this context. The suitable choice of device and the spacing of the array could mitigate the impacts related to this. The construction and deployment period would need to be planned carefully to ensure that the device causes minimal traffic and other machinery needed to deploy it.

Ecology

Secondly, the ecology around the islands of Herm and Sark are rich and diverse showing presence of puffins (Figure 8:3), seals and occasionally dolphins. These species are important to consider for conservational reasons as well as allowing opportunities for tourism such as boat trips for sightings. For both of these reasons these areas need to be disturbed as little as possible to ensure that the presence of the devices does not become a detrimental feature. For tidal power, from the two locations suggested, it is probable that the location off the south east of Sark would have fewer if not smaller impacts.

Figure 8:3 - Photograph Taken off the East of Herm in the Big Russel Showing the Presence of a Group of Puffins. Photographed by Emma Jolly, 2012

Foundation Construction

Four methods of foundations and mooring have been considered in this report: gravity base, pile mounted, floating and hydrofoil induced down force. Similarly to that of offshore wind, pile mounted and gravity based moorings have been suggested as the most suitable methods for this resource. The impacts from these are most likely to be similar to those mentioned in the previous section. However, because of the different location to that of offshore wind a further study into the seabed in the suggested location would need to be carried out to establish the level of impact caused, whether it is positive or negative.

Fishing

Finally, the impacts concerning angling and commercial fishing have been considered. Because of the nature of the device and the methodology of deployment it is likely that any impacts associated with fishing both commercially and recreationally will be minor and sporadic. Once deployed, the device will be stationary and traffic from shore to the device will only occur for maintenance reasons. Due to the infancy of the industries it is not possible to predict how often maintenance is likely to be carried out and for what length of time.

Protected Areas

There is currently only one fairly small Ramsar site present on the island of Guernsey, which is situated on the west of the island. Because of its location it is likely that the construction and deployment period for a wave device would cause some minor impacts to this site, namely disturbance from noise and visual impacts. The different devices considered would have different impacts in this location due to their operation. For example the design for oscillating water columns allows the devices to be located offshore or built into the coast (Heath, 2012). Due to the Ramsar site and avian breeding areas it would be advised that for the west of the island, the coastal land is touched as little as possible to reduce negative impacts.

Fish

The advantage of the presence of wave and tidal structures is that they cause an exclusion zone that can be used as a sanctuary by fish species. This would allow certain species to thrive and as a result create a new feeding ground for avian species that does not intercept with angling and commercial fishing areas.

Marine Mammals

Currently there is not enough information concerning marine mammal areas to fully identify the potential impacts. There are sites around the island of Guernsey where there have been various sightings of different marine mammals such as seals and dolphins. It has not yet been determined how common these species are to these areas. Currently, it is suggested that these species are present in these sites seasonally rather than throughout the whole year (RET, 2011). It needs to be determined whether they use these sites for breeding, feeding or both. Alternatively the sites could be part of a migration route. Further study needs to be taken to establish how important these sites are and whether they need to be considered as constraints when finalising the location of the devices.

Cultural Heritage

The historic impacts of these locations are both in relation to onshore and offshore features. Offshore, around the whole island, there are shipwrecks that are scattered. Off the west of the island two wrecks have been identified. These would need to be investigated further to determine their stability and structure to see whether they would cause damage to the devices. These sites also need to be preserved for their historical value.

Onshore there are many forts and castles around the coast. These have qualities such as heritage and historical value that means they should not be disturbed if possible to maintain their value. To connect any of the devices to the island, cables and substations would need to be built in the most suitable locations. The construction period of these connections suggests that there will be some short-term impacts. Once the connections are established there are not likely to be any impacts related to them other than maintenance.

8.3 Recommendations for Further Study

Many of the impacts that are associated with marine energy devices are very similar across the different resources. The main differences concern construction and or deployment as the different methodologies differ. Wind power is the resource that has continuous visual impact, as it is visible above the sea level. However, because of the maturity of wind power as a technology the impacts associated with it can be more predictable and allow for greater mitigation. In contrast, wave power is still considered a very new technology and research is still being carried out to identify the different impacts that can be associated with majority of devices, especially concerning marine flora and fauna. From the information provided by the REA and by referring to research that has been completed on this matter, this report has tried to outline the key features that need to be considered when deploying a marine technology.

It would be advised that a full and complete survey is carried out to identify all species present in the coastal waters at all times of the year and what specific locations are of importance to their survival, i.e. feeding and breeding grounds. To follow this it would be advised that a similar survey is carried out on the avifauna present on the island and identify clear migration routes that are used throughout the year. The information received from this will allow the planning process to run more efficiently in the sense that clear and specific constraints can be considered.

Finally, a study should be carried out to identify the location and structural integrity of all ship wreckage in the coastal waters. This will be helpful in identifying locations that should be avoided as well as broadening the island's historical heritage.

9 ENERGY EFFICIENCY AND ON-LAND RENEWABLES

9.1 Introduction

To ensure the study of Guernsey's renewable energy potential, on land technologies need to be considered. The installation of on land technologies and energy efficiency measures interlink with macro marine renewables as the island's base load demand can be reduced and a proportion of the islands energy demand met, reducing the installed capacity of the marine technologies required or increasing the amount of electricity that can be exported from the marine technologies overseas. The technologies that are to be considered in this section are as follows:

- Energy Efficiency Measures;
- Micro generation;
    - Solar PV;
    - Solar Thermal;
    - Heat Pumps.
- Landfill gas (LFG);
- Energy from Waste (EfW);
- Anaerobic digestion (AD).

Due to land constraints, visual impact and a widespread public attitude onshore wind has not been included in this study.

9.2 Energy Efficiency Measures

Improving the energy efficiency, of both current and new build properties can provide vast energy savings to the consumer and offers the potential to substantially reduce the islands base load energy requirement. This interlinks closely with the marine renewable energy proposals as a reduced base load can either reduce the required installed capacity of the marine devices, if supplying the island, or allows a greater amount of the electricity produced to be exported to overseas countries.

The energy efficiency of properties can be improved by three different options that can be implemented in an order of cost and effectiveness. The three primary efficiency measures are to increase the education of the community on how to save energy, improving the insulating performance of the building fabric of the dwellings and by improving the efficiency of the appliances used within the dwelling.

9.2.1 Education

Educating the community on energy saving measures, either through campaigns or awareness programmes, can significantly reduce the energy consumption of a dwelling without significant financial investment. This can involve simple measures such as turning lights off when the room is not in use, installing switchgear that turns off electrical appliances at the mains when switched into stand by mode to energy consumption monitoring equipment installed at demand centres. Campaigns can be set up to offer advice and the government could potentially offer such devices to the consumer at cost price.

9.2.2 Insulation

Improving the insulation performance characteristics of building fabrics within the existing housing stock can substantially reduce the property's heating requirements. This can be achieved by either cavity wall insulation where suitable, or external/internal wall insulation, being the more costly option as well as increasing the loft insulation. Approximately 40% of Guernsey's housing stock is constructed with cavity walls, equating to approximately 10,000 dwellings. If 50% of houses with cavity walls invested in insulation, based on Energy Savings Trust's estimations of energy savings per property of 550kg/year, the island could reduce their annual CO_2 emissions by 2,750 tonnes. This would cost each dwelling between £100-350, paying back in a maximum of three years (Energy Saving Trust, 2012a). For loft insulation, Energy Savings Trust estimates a minimum saving of 110kg/CO_2 per year per property. If 50% of the housing stock were to improve their loft insulation to 270mm, the minimum amount of CO_2 saved annually is estimated at 1,375 tonnes. This would cost each dwelling between £100-350, paying back in a maximum of two years (Energy Saving Trust, 2012b). If, as stated, the uptake was 50% of houses with cavity walls (5,000 dwellings), this could mean £3.5m spent on energy efficiency measures in Guernsey; a great opportunity for local businesses.

In terms of new build dwellings, defined requirement standards of insulation need to be raised and implemented. In the UK the building regulations for new dwellings are implemented at the design stages whereby the dwelling is required to comply with the code for sustainable homes. A policy such as the Code for Sustainable Homes should be implemented within the Guernsey planning policy framework to ensure dwellings are built to meet the energy efficiency requirements, reducing their reliance on energy, thus the reducing the CO_2 emissions of the dwelling.

The commercial sector accounts for 40% of electricity usage on Guernsey (La Société Guernesiaise, 2008), therefore inefficient commercial buildings should also be evaluated and targeted as, again, there could be potential for a large market for energy efficiency measures to be installed. This would further present a superb opportunity for local businesses to supply and install these proposals.

9.2.3 Energy Efficient Products

Energy efficient appliances should be promoted when replacing old appliances. Based on the Energy Saving Trust's calculations, energy efficient appliances could save approximately 90kg of

CO_2 per year, per house. Considering 50% uptake of all domestic properties, this offers annual CO_2 reductions of 1,125 tonnes of CO_2 per year.

9.2.4 Policy Implementation

In order to achieve mass deployment of the energy efficiency measures, a review into the current policy is needed to reduce the initial financial outlay of such installations. Suggested policy measures would require little or no financial investment by the Guernsey government.

The first option would be to develop a programme such as the UK's Green Deal, which is a zero interest loan that pays for the initial investment of the energy efficiency improvements. The loan would increase annually by the inflation rate to ensure that the Guernsey government does not lose capital. This could be available for low-income occupants to help aid the implementation of both insulation and energy efficient appliances.

The second option would be directed towards insulation; the government could set up a non-profit department that offers the installation of insulation at cost price. This would therefore decrease the cost of the initial installation, increasing the number of occupants that could afford the initial financial outlay. Having a specialist department also means that the implementation of such a scheme will meet installation standards and can guarantee technology performance, increasing the consumer confidence.

9.3 Micro generation

9.3.1 Domestic Solar PV

This study aims to assess the possible implementation of solar PV on the island for both domestic and commercial properties. Guernsey currently has no renewable energy policy specifically targeted at the promotion or installation of solar PV and no financial incentives, except an export tariff, to encourage a significant deployment of PV technology. This low rate of expansion has ensured that, at present, there is only one company on the island that is able to offer PV installation services.

Methodology

In order to assess the potential and economic viability of significantly expanding the deployment of PV on the island, a resource appraisal and financial model has been created. An ideal model, based on south facing roof spaces and localised conditions, will be used under the conditions of a $4kW_p$ system situated on an average sized domestic property. The cost effectiveness of this model will illustrate whether it is financially prudent to deploy PV on a mass scale and therefore the resource assessment and financial model will be conducted considering the following assumptions:

Assumptions

- 4kWp system – based upon the area of a standard roof;

- Installation costs of £8,500;
- Domestic electricity price of 15p/kWh;
- Electricity price inflation of 6% per annum;
- Standard rate of inflation of 3% per annum;
- Initial export rate of 7.2p per kWh;
- 50% utilisation of the electricity produced from the system;
- Annual solar PV resource of 4010kwh per annum - PV GIS estimate (European Comission, 2012)
- 1% annual degradation of the panel's output efficiency;
- A new inverter installed after 10 and 20 years with a present value of £1,000.

Results

Appendix C shows that such a PV system, installed within the parameters described earlier, will payback in 16 years, however in real present values the system does not payback over the lifecycle of the proposal, and in fact will cost the client £284 to implement.

Should there be a large-scale deployment, solar PV has the potential to contribute a significant proportion of the island's electricity demand. If 20% of the residential properties situated on the island were to uptake a 4kWp system it has been calculated that 20GWh of electricity would be generated saving approximately 10,000 tonnes of CO_2 annually (based on 0.5kg of CO2/kWh of electricity produced).

Discussion

The initial analysis indicates that solar PV does not provide an economically viable investment for the residents of the island; with an export rate of £0.072/kWh solar PV becomes cost neutral if not investible. This indicates that solar PV will become an economically viable investment in the short to medium term as energy prices continue to rise, especially as electricity prices reach £0.20 per kWh, and technology costs continue to fall. Therefore, policy makers may wish to consider the removal of relevant industry barriers in preparation for this watershed.

Current barriers and further work required

In terms of external barriers and further work required there is currently a shortage of skilled workers and installation companies required for the installation and maintenance of solar PV on a mass scale. This could result in the local workforce not capturing the potential macro benefits of the industry. The industry would then be reliant upon engineers from the UK and France, thus reducing the self-sufficiency and sustainability of the industry on the island and increasing the cost of the installation due to travel. In terms of installation, registered installers should have to abide by a set standard and certain industry regulations, such as the Micro generation Certification Scheme (MCS) in the UK. This would ensure installation standards are high; ensuring the lifespan of the system last the expected 25 years. Furthermore, in terms of policy, current Guernsey planning regulations deem that a PV system cannot face a public highway. To eliminate this barrier a policy should be incorporated to ensure PV could be installed under permitted development rights, reducing the planning barrier currently in place prior to installation.

9.3.2 Commercial Scale PV

Methodology

The use of PV on commercial premises has great potential for deployment upon the island. The demand profile of commercial premises, with a set base load requirement, can be matched to a PV system increasing the utilisation factor of the electricity produced.

As with the domestic system a resource assessment and financial appraisal has been conducted based on a 4kWp system. The same assumptions have been used with regard to PV for commercial properties as with domestic. The only exception is the utilisation factor, which has been set at 90% in order to reflect the realistic generation and demand profile interactions.

Results

Based upon the financial modelling, incorporating PV into commercial buildings proves a far more economically viable option showing a payback of 12 years with an NPV of £5,490. It would therefore seem wise to push PV for commercial usage however, there are currently barriers restricting development that need to be overcome.

Current Barriers and Further Work Required

Firstly, the island should consider the introduction of leasing arrangements considering freehold and leasehold properties over the lifespan of the installation. In addition, there needs to be a source for supply of components, expertise and maintenance. The industry needs to be encouraged on the island to increase competition, improving quality and reducing cost. Finally, the proposed standards of installation would need to be formalised and published. These would provide a minimum quality of installation, thus ensuring installations are of a high standard and live up to expectation.

Discussion

Commercial solar PV offers islanders an immediate opportunity to invest in renewable energy technologies. While presently there are several barriers to large-scale uptake of PV systems, the removal of these barriers and subsequent learning curves will have the knock on effect of removing barriers to the domestic solar PV industry.

9.3.3 Heat Pumps

The island should consider electrification of the heating network, in conjunction with the expansion of installed electrical generation capacity. This would open the way for heat pumps to be utilised in domestic properties to supply the necessary heating energy requirement. Due to the nature of assessment of heat pumps requiring an individual assessment of a property, it is difficult to assess the energy and carbon savings on offer. This section will, therefore, consider the barriers currently hindering the installation of heat pumps and the most suitable approach for deployment.

With regard to properties in Guernsey, they can be characterised as having poor energy efficiency, akin to older housing stock seen in the UK. These properties are exposed to poor air tightness, limited sealing of the building fabrics, and minimal insulation. As heat pumps operate most effectively with low grade heating systems, improving the air tightness of the building structure and improving insulation is essential before a heat pump should be considered. If installed without these improvements, a lower COP will be achieved making heat pumps less cost effective, due to their dependency on electricity. In terms of current properties, heat pumps are difficult to retrofit because they work best with low grade heating systems compromising of under floor heating.

Heat pumps are, therefore, ideally suited to new build properties where low grade systems can be incorporated into the building design e.g. under floor heating and the dwelling can be constructed to be air tight and energy efficient. Approximately 80 new build properties were constructed in 2010, a typical figure for Guernsey's annual level of property expansion and, therefore, there is not a huge demand for heat pumps on a new build scale.

Heat pumps can be installed with a radiator based system although it will require the exiting temperature of the heat pump to be increased to approximately 55 degrees centigrade to supply the required internal temperature of 21 degrees centigrade in the living areas and 18 degrees centigrade elsewhere. This will inherently reduce the COP of the heat pump effectively reducing its efficiency, which again will reduce the financial viability of potential investment to ordinary homeowners.

Current Barriers and Further Work Required

As with solar PV, there are no current incentives for installations, which are likely to be required for deployment on a mass scale if policy makers are keen to expand the sector in the short term. In addition, there is no current policy for installation standards, which would be recommended for quality assurance purposes and to ensure property assessments are conducted to check that the building fabric is efficient and suitable for a low grade heating system.

An area where further work is required is to promote heat pumps as there is a lack of skilled labour and maintenance workers necessary for an emerging industry to grow successfully. This can be done via training courses and education to increase the knowledge and understanding required to install heat pumps successfully.

Conclusion

Due to the potential expansion of renewable energy generation, electrified heating systems may be deemed preferential to traditional methods. Therefore, serious consideration should be given to improving the energy efficiency of future dwellings to maximise the yield of heat pumps, as well as tackling the other barriers that are currently restricting their deployment.

9.3.4 Solar Thermal

Introduction

Solar thermal technology can provide up to a maximum of 70% of a households annual hot water requirement. Currently two types of solar thermal technology are prevalent, ‘evacuated solar thermal’ tubes, and ‘flat plate collectors’. Typically evacuated tube systems have higher efficiencies and a more stable generation profile as a result of the resource response characteristics, but ultimately have a higher purchase cost by comparison to flat plate collectors. Therefore when compared in terms of both efficiency and cost the two systems will yield approximately the same energy contribution per unit price. Designing the appropriate system to be installed must therefore be considered on a case-by-case basis, accounting for the aesthetic, structural, demand centre and special externalities.

Methodology

An assessment of a domestic solar thermal system installed on the island will be conducted using a generic ideal model. This will be deemed as a basic representation for what can be achieved at an island level. This will be scoped around an ideal $3m^2$ south facing evacuated tube system, complete with all associated plumbing and cylinder requirements, considered optimal for a 3-4 bedroom dwelling.

The energy yield calculations are based on the British SAP (Standard Assessment Procedure) methodology, localised to Guernsey by available resource. Using this data, a full financial assessment will be performed. In an effort to gain a true representation of what solar thermal technologies can achieve within the domestic thermal demands of Guernsey, two separate models have been created to individually represent the displacement of both gas and electricity based heating source methods. It should also be noted that the financial models include zero subsidies or external financial resource, reflecting both the lack of political incentive and inability to transport heat for external sales.

Results

The financial appraisal (see Appendix D) indicates that utilising solar thermal technology, as a co-heating measure, displacing traditional gas heating, is not financially viable, presenting a payback of 18 years; in real present value the proposal does not actually payback over the estimated lifespan of the project.

When assessing the solar thermal system (see Appendix E) where the baseline displaced heating system mechanism is driven by electricity the payback period is lowered to 14 years and will be capture a financial profit of £682 in present terms.

Discussion

Although both financial appraisals show that solar thermal technology is not currently investable without subsidy or incentive packages, there is a scenario where this rejection does not hold true.

As previously noted, the modelled installation cost has included all associated plumbing arrangements inclusive of installation of a suitable hot water cylinder. Properties in which a suitable cylinder already exists, suitable to house the required thermal heat exchanger, or that require the replacement of the cylinder irrespective of solar thermal will effectively be able to take advantage of solar thermal technology with a net discount of £1000.

Current Barriers and Further Work Required

The following practical and financial limitations will need to be considered alongside direct financial analysis, as an aid to assessing the practicality of solar thermal installations on the island:

- The supply chain limitations;
- Standards - both regulatory and construction for installation;
- Education regarding the adaptation of human behaviour in order to optimise the system utilisation and by extension maximise the financial return from the system;
- Education and training regarding installation, maintenance training and supply chains would need to be expanded and reinforced;

Both technologies would require policy and financial support to incentivise uptake of the technologies, as presently they are likely to be unattractive to anyone without a dutiful belief in sustainability.

9.3.5 Overall Micro-generation Recommendations

Building a supply and service industry for small scale maintenance and installation that is sustainable yet suitably scaled to the scheduled island uptake will not only capture macro economic benefits for the island but allow maximum financial benefit to the clients.

9.3.6 Anaerobic Digestion from Cattle Slurry

Anaerobic digestion is the process in which organic material is decomposed by a microbial culture in an oxygen-deprived environment. The primary product of the reaction is biogas, a mixture of methane and carbon dioxide with trace amounts of hydrogen sulphide, ammonia, and nitrogen. The biogas can be used as a fuel in a Combined Heat & Power (CHP) generation plant to generate both heat and electricity, through the use of an engine or small gas turbine depending on the size of the digester.

Methodology

The main livestock on the isle of Guernsey is the Guernsey cow, with an approximate population of 2,700 in 18 dairy farms. This relatively large population indicates a suitable level of slurry to act as the primary secure feedstock for a small to medium size anaerobic digestion plant.

While animal slurries are a comparatively poor feedstock for producing biogas, anaerobic digestion of it is still widely practiced as a safe waste management solution for excreta and organic contaminants. This can produce soil-enriching elements, water and biogas, which can be used to generate electricity and heat.

To gain a sensible appraisal of the technology, as many variable factors have been acclimatised to island specific data, however in order to estimate energy yield and feasibility several technology and resource properties have been assumed in line with industry standards.

This study has assumed that 50% of all slurry produced will be available to the AD plant; the fuel resource will consist of 10% dry matter allowing 35% conversion efficiency into energy.

Results

Analysis of the resource potential indicates that a medium scale AD plant is capable of yielding 945,000 kWh per annum from cow slurry, effectively covering the electrical demand of 236 homes (assuming an annual electrical demand of 4,000 kWh per home).

1m^2 of biogas is equal to 21MJ of energy, 21MJ = 5.83kWh
1 dairy cow (weekly) = 0.33 m^3 of slurry - 0.165m^3 available per week
1 cow = 47kg of slurry per day
1 cow = 0.047 tonnes * 20m^3 of biogas per tonne = 0.94 m^3 biogas per day
0.94m^3 * 5.83kWhs per day = 5.48 kWh per cow per day

Assume 50% of slurry lost

2.74 kWh per cow per day
Assume 35% efficiency = 0.959 kWh per day per cow
2,700 cows = 2,589 kWh per day
365 days per annum = 945,095 kWh per annum

Sizing the digester
0.33 m^3 (slurry)/2 = 0.165m^3 *2700 = 446m^3 of slurry per week
Digester volume = slurry (m^3/yr) * (retention time (days)/ 365)

=23192 * (28/365)

= 1779.1 m^3

Further Considerations

While AD presents a relatively simple method of generating energy from a resource presently generated on the island, there are many further considerations that must be considered during the design stage of any proposal:

- *Location:* The specific location of any AD plant will be a trade off between several practical aspects; including the minimisation of resource transportation requirements, permitting considerations, distribution of secondary sales and available land.
- *Secondary Sales*: The anaerobic process of turning cow slurry into electricity will produce waste items, including heat and digestate, which could be potentially utilised as a further form of income generation. The aspects of management and transportation of these secondary sales must be taken into at the design stage to maximise the financial return of any proposal. The digestate has a nitrogen fertilizer equivalent of £330 per tonne in the UK.
- *Environmental Considerations:* The island of Guernsey is classified as a 'Nitrate Venerable Zone' and thus all future proposals should communicate fully with relevant stakeholders, linked to Guernsey's 'manure management plans', at the design initiation stage to ensure compliance and an acceptance as part of Guernsey's future.
- *System Type:* Further to the identification that the system must incorporate a storage facility of a minimum 1780m^3, there are major decisions to be made about system type dependant on their generation profile aspirations and initial upfront financial constraints. It should be noted that within this study all financial models have been based on a generalised CSTR system, due to its generic utilisation within slurry fuelled AD systems.

Financial Analysis

The following financial analysis has been based on a 120kW Continuous Stirred Tank Reactor (CSTR) plug-and-flow AD system, with an initial capital cost based on the assumption of £325 per m^3 of retained slurry resource and an annual operational cost of £47 per tonne (SLR Consulting, 2011).

Item	Value
Annual Recoverable Yield	3300 tonnes
Average Daily Resource	79.9 tonnes
Average Daily Volume	63.7 m^3
28 Retention Volume	1779.1 m^3
Installation Capital Costs	£578,307
Annual Operational Costs	£155,000

Table 9:1 - AD System Snapshot and Costing Estimate

Table 9:2 indicates that while the return on investment may be preferential to current traditional investment opportunities it may not be of a magnitude that could attract investment from external sources, with a return in current terms of just £140,600 on the initial £580,000 capital investment.

Initial Investment	**£578,300**
System Payback	20.3 Years
Project Profitability	£790,322
NPV	£140,652
IRR	4.2%

Table 9:2 - AD Headline Financial Figures

When taken in the context of Guernsey's aspirations and the financing parameters required to execute the permitting and construction of an anaerobic digestion generational facility the business model analysed above may not be suitable.

Discussion and Further Recommendations

Improvements to the projects finances, and by extension suitability, should be prioritised.

One area, which would be worth exploring, would be running the AD plant alongside suitable putrescible waste recovery and recycling. If seen as an adjunct to recycling, a greater amount of better quality feedstock could be utilised therefore increasing methane production. This would increase electricity yield and therefore profitability. It is therefore recommended to conduct a feasibility study as to how recycling and waste management regimes can best be run alongside AD.

Conclusion

AD from cow slurry not only provides a marginal financial opportunity for investors, but also offers a method of energy generation particularly attuned to a source of indigenous pride. The Guernsey cow, surviving of the land of Guernsey, providing electrical and heat energy to the local population could provide a further layer to the concept of localism while simultaneously leading the islands conscientious to examine further aspects of sustainability and willingness to house renewable energy technologies.

9.3.7 Energy from Waste

Waste disposal is one of the key problems facing the island and the future development of its infrastructure. Currently the main route for waste disposal is landfill, and there is one site on the north of the island. It is expected to reach capacity and be decommissioned by 2022.

One solution to the waste management issues was the construction of a waste incineration plant, which was scoped by SITA in 2012. However plans for this development contradicted public opinion and therefore the project never came to fruition. As such the problems for the future of waste management remain.

One opportunity for energy generation is utilising landfill gas for electricity production. After the landfill has been fully utilised it is capped and wells are sunk down into the waste. As methane is produced through anaerobic decomposition it is pumped under slight negative pressure to a gas engine, which will drive the generator to create electricity. These engine systems are highly scalable and modular, the system provided by Jenbecker being placed in a shipping container for example.

Gas extraction for combustion requires the landfill site to have certain criteria such as tanking and capping. The current site at Mont Cuet opened in 1998 does not conform to the traditional design of cells and capping associated with sites on which methane extraction is anticipated in the future. By subdividing a site into smaller cell units, it also allows for methane production as each individual subdivision is completed and capped. This is an important consideration when considering landfill gas as an energy production resource as it allows for gas exploitation much earlier in the landfill's scheduled life.

Given the island's outlined situation there are several possible scenarios that could account for the future of waste disposal on the island. Some of these provide the opportunity for supplementary energy generation alongside the waste disposal route and others can contribute to concurrent energy generation measures such as AD.

New Landfill

The creation of a new landfill site would allow for a continued waste disposal route, albeit one that is not in line with Guernsey's move towards sustainability. If a new site were to be outlined and commissioned it would be essential to design it in line with the best available scheme for methane extraction. Currently this involves separating the site into individual cells; tanking the cells with a suitable membrane to ensure collection of leachate; and when full capping the site in an airtight manner. This could be utilised alongside the islands wish to increase recycling to 70% by 2025, and would therefore increase the scheduled lifespan of the site. Ultimately it only presents a short-term solution.

There are however some key issues that are present with this solution:

- It is not a progressive method of waste disposal;
- Land space is at a premium on Guernsey and has mostly been exploited; as such it is doubtful that there would be sufficient space to site a new landfill;

- There are key environmental concerns;
- Concerns for social and domestic amenity in the surrounding local area including but not limited to visual impact, odour and loss of socioeconomic income.

Waste Export

One scenario for the disposal of municipal waste is to not commission any further infrastructure domestically, and instead ship the waste internationally to a country, which has the facilities to process it. This is the currently accepted scenario for the future of Guernsey, with waste set to be shipped to Jersey and be incinerated. This contractual arrangement will incur an unspecified cost related to the tonnage, and therefore, it can sensibly be assumed, render the operational costs of waste disposal higher.

These contractual arrangements with Jersey do not represent the best value to Guernsey with regard to waste disposal for two reasons. Firstly it is a costly measure atop an already expensive waste management policy. Secondly it contracts the amount of food waste in the mix to be exported. If more of the putrescible waste from the domestic and commercial sectors could be separated and incorporated into the production of energy through anaerobic digestion there would be greater financial advantages.

The best case for waste export could follow some of the contractual arrangements being mooted between the UK and Scandinavian nations. The concept behind the negotiations is that the municipal solid waste could be bought at a premium per tonnage by Sweden and then they incinerate it to generate energy. This scenario would allow a significant offset of the costs associated with waste disposal and, if suitable contracts could be formed, allow for the retention of a large proportion of the island's putrescible waste therefore providing an extra feedstock for anaerobic digestion.

Retrofit the Current Landfill

One further possibility is to assess the feasibility of retrofitting the main site at Mont Cuet in order to facilitate gas extraction and utilisation. This has already been ruled out after cost benefit analysis was carried out.

Incineration

Incineration of municipal solid waste to generate energy would be one cost effective mechanism by which the island could contribute to both its energy and waste disposal needs. Currently it does not appear viable on the island due to considerable public opposition. It may however be an option in the future when the realities of the current infrastructure problems become apparent to the population.

10 INFRASTRUCTURE AND INTEGRATION

10.1 Introduction

Infrastructure and Integration spans the necessary investment in the electrical grid, gas grid, transport network, ports and energy storage. It is vital that these systems and networks are invested in to ensure that they are capable of managing changes to the energy landscape of Guernsey.

The development and maintenance of infrastructure on Guernsey is the responsibility of The States of Guernsey. In order to establish a holistic approach to planning across States Departments, the States Strategic Plan (SSP) has been devised. Infrastructure is one of the areas where a resource plan is due to be developed, alongside Energy, Strategic Land Use and Population. Each Department is preparing a register of assets by June 2013 in order for the Infrastructure Resource Plan (IRP) to be developed. As part of the SSP, Key Performance Indicators (KPIs) have been developed in order to monitor progress towards long-term targets. The primary KPI for infrastructure is a measure of investment as a percentage of (Gross Domestic Product) GDP. Over the past ten years, seven years have fallen below the target of 3% of GDP spent on routine capital expenditure.

Guernsey Electricity Limited is responsible for the integration requirements of new electrical generation or changes to electrical demand on the island.

10.2 Electrical Grid Infrastructure

The public electricity supply company, Guernsey Electricity Limited, owns the electricity supply infrastructure and operate the electricity supply services of the island of Guernsey. Electricity has traditionally been generated using diesel generators and gas turbines, however, a subsea cable that connects Guernsey and Jersey to the European grid was commissioned in 2000 through a joint venture between Guernsey Electricity and Jersey Electricity meaning up to 80% of the electricity consumed on the island is now imported (Guernsey Electricity Limited, 2005).

10.2.1 Electrical Infrastructure

Three bulk supply points, Les Amballes, Bellegreve, and Kings Mills, connect the 33kV transmission network to the 11kV distribution network, which is sectored using a primary distribution ring of 14 substations and six individual radial secondary systems. The island's power station is connected at 11kV at Vale (Guernsey Electricity Limited, 2005).

10.2.2 Subsea Cable

A single 90kV cable, rated at 60MW, connects Guernsey to Jersey, and two 90kV cables with a combined power rating of 145MW connect Jersey to France. In Guernsey the cable lands at

Havelet Bay and is stepped down to the 33kV transmission system near Les Amballes at Barker's Quarry (Guernsey Electricity Limited, 2005).

Supply contracts between Guernsey Electricity, Jersey Electricity and EDF provide for a minimum of 16MW to be transmitted through the cable to Guernsey - which Guernsey is obliged to buy while the cable is in operation. For technical reasons, the cable must operate at a power level of at least 5MW. Extra electricity may be imported through short-term power-purchase agreements (Guernsey Electricity Limited, 2005).

10.2.3 Local Generation Plant

Slow-speed diesel generators, with total capacity of 65.3MW, provide local base-load generation, comprising three 12.2MW Sulzer RNF-68, and two Sulzer RTA-58 (rated at 14.2MW and 14.5MW) generators. One 11MW Alstrom Cyclone and two 19.5MW Thomassen gas turbines provide peak-lopping and emergency generation and have a total capacity of 50MW. The three 12.2MW slow-speed generator sets are due to be decommissioned, following an extended operational life of 35 years, in 2014, 2015, and 2017 respectively (Guernsey Electricity Limited, 2005).

The slow-speed generators can operate efficiently between 75% and 100% loading levels, and are capable of being run at as low as 50% of their rated output. The gas turbines are inefficient but are relatively cheap. They can respond extremely quickly to fluctuations in demand and can provide fast black-start capacity in emergency situations (Guernsey Electricity Limited, 2005).

A 17MW medium-speed Wärtsilä diesel engine is due to be commissioned in 2013 and the power station has space allocated for a further 17MW medium-speed generator set. The medium-speed generators offer faster response times so are better for tracking demand.

The spectrum of generation plant allows for a large degree of flexibility in the generation output as the governable engines can be brought online individually to meet the electricity demand and output can be varied to a large degree.

10.2.4 Security of Supply

Guernsey has a policy of maintaining enough generation and electrical import capacity to supply the maximum load in the event of the two largest generators being unavailable which is known as the 'n – 2' policy (Guernsey Electricity Limited, 2005).

10.2.5 Regulatory Framework and Long-Term Strategy

Guernsey Electricity is regulated by the Office of Utility Regulation and is obliged to source the cheapest available electricity (Channel Islands Competiion and Regulatory Authority, 2001), so renewable electricity projects in Guernsey will compete with electricity imports from France. Presently, no policy mechanisms support renewables in Guernsey, though it is understood that the proposals and discussions are underway to implement policy for the support of renewables.

A further cable is to be installed between France and Jersey, and the possibility of a second cable to Guernsey is being examined. It is understood that future supply contracts with EDF, worth around €1bn, will guarantee large quantities of imported electricity that will be sourced from 30% hydroelectric and 70% nuclear generation.

10.3 Grid Integration of Renewable Energy Generators

Typically renewable electricity projects under 3MW capacity would be connected to the 11kV network, incurring connection costs of £20,000 - £60,000. In order to determine whether or not such connections are possible, the local demand and the new fault level of the point of connection (PoC) substation must be examined, along with the power ratings of lines and transformers, the voltage range, harmonics, and power factor. Excess electricity that cannot be consumed by the substation group must be exported to the 33kV network for distribution around the wider network, so the reverse power capability of the local bulk supply point (BSP) transformers must also examined in this case (British Wind Energy Association, 2012).

Typically, medium sized projects (up to around 50MW) would be connected to the 33kV network and would incur connection costs of the order of £120,000 - £150,000 (British Wind Energy Association, 2012). In Guernsey there is no high voltage transmission backbone so excess electricity cannot be exported to a higher voltage grid to be distributed around a wider network - though export through the subsea cable is considered in Section 10.3.2.

Electricity cannot generally be economically stored in large, grid-scale quantities so electricity generation should ideally match the demand. The local generation plant and the huge pool of generators accessible through the subsea cable are capable of tracking demand changes reasonably efficiently. Renewable generation, however, is often intermittent or unpredictable and island electricity distribution systems have fairly low base-load requirements, with lower load and generation diversity than larger networks such as the European Grid. Since the output of a renewable electricity project is often ungovernable, the amount of renewable generation that can be connected to a system is limited by the amount of output that can be utilised in real-time.

10.3.1 The Base Load Scenario

This section considers the base load renewable energy strategy that, on the assumption that the thermal ratings of lines are sufficient and voltage and local fault-levels are acceptable, requires no major infrastructure changes.

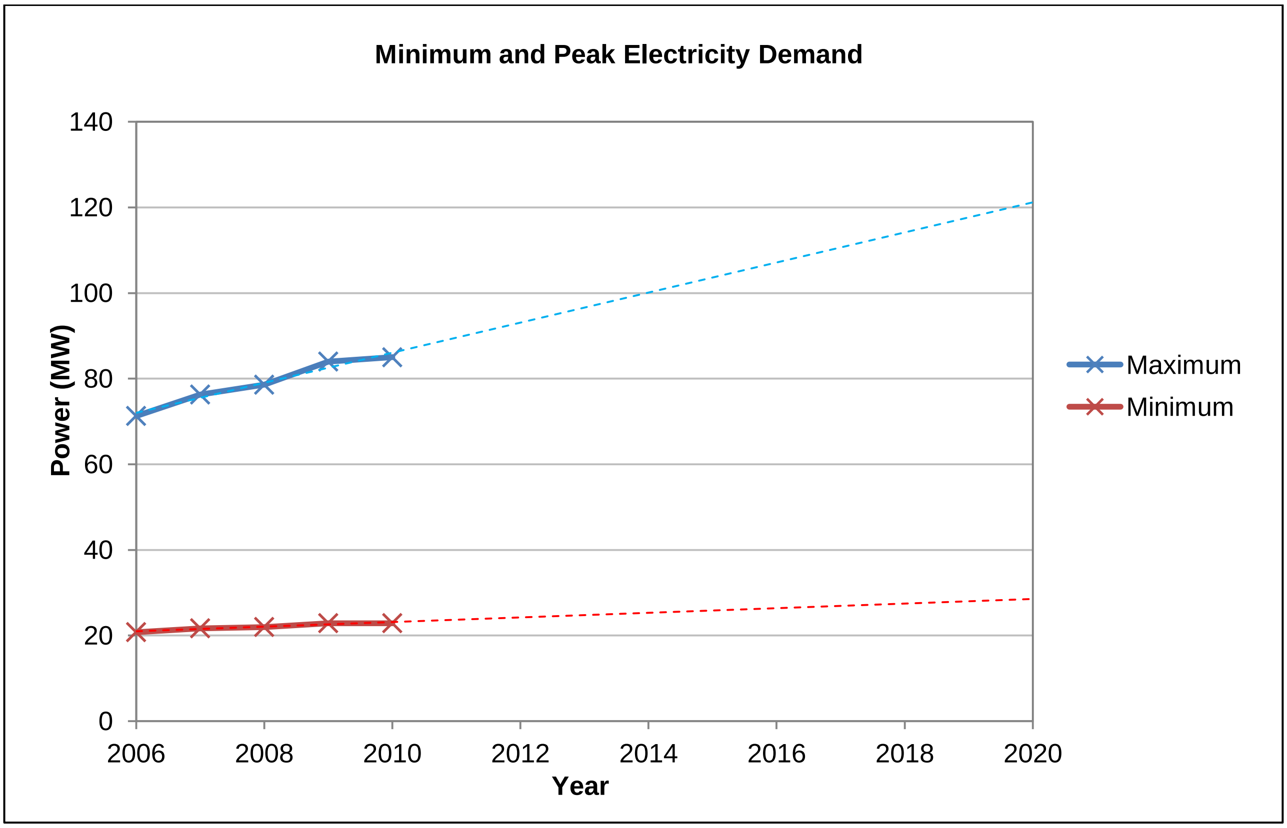

Figure 10:1 - Maximum and Minimum Electricity Demand (Guernsey Electricity Limited, 2011)

The minimum and maximum demands are plotted in Figure 10:1 for the years 2006 through 2010 and the linear demand trends are also projected to 2020. Based on the data available, the maximum amount of renewable generation that can be connected with 100% utilisation within Guernsey is the minimum demand (28.5MW for 2020), minus the minimum required import (16MW), which equals 12.5MW. This 2020 estimate of maximum renewable generation does not, however, consider the time-varying nature of electricity demand and renewable output, or other factors that may affect the level of minimum electricity demand over the period such as fuel switching to electricity for domestic heating or electric vehicles loads that may emerge.

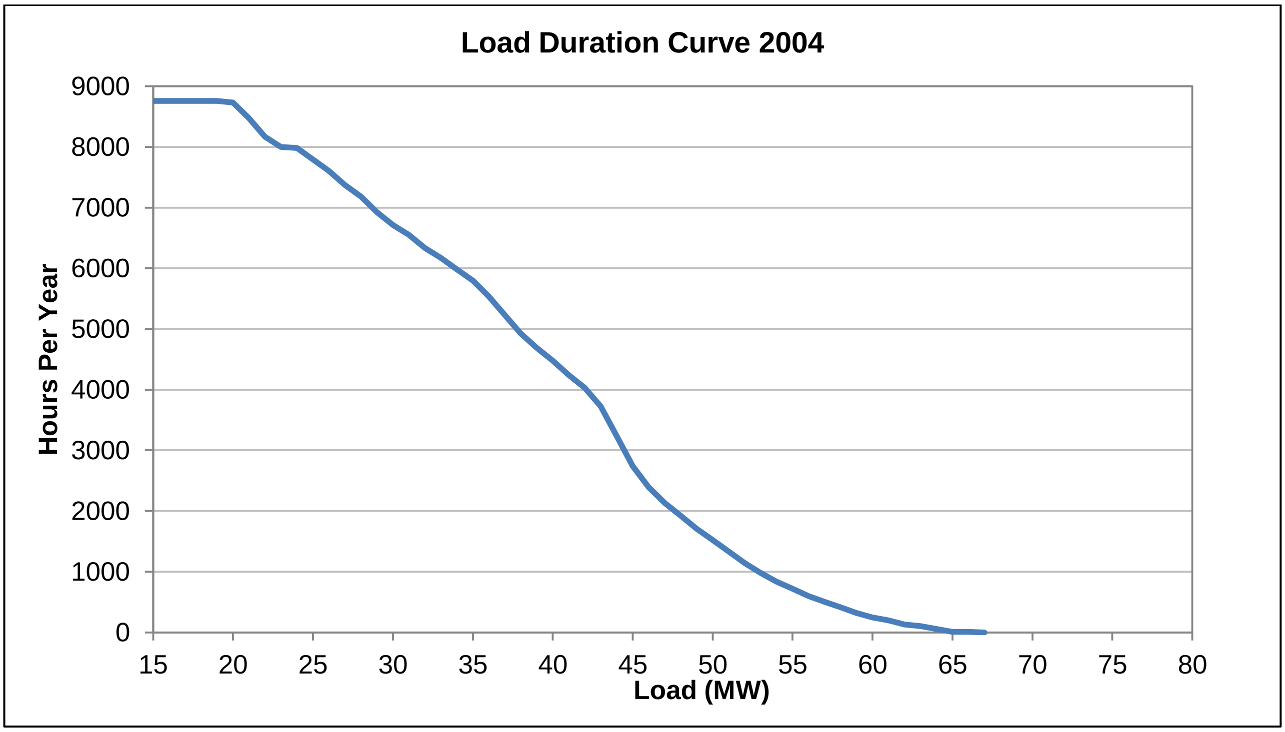

Figure 10:2 - Load Duration Curve 2004 (Guernsey Electricity Limited, 2005)

It can be seen from the 2004 load-duration curve plotted in Figure 10:2 that the base load is around 20MW, but for the majority of the time the load is greater than 30MW. It may, therefore, be viable to connect more capacity than the base load and to displace a greater amount of locally generated electricity, while maintaining a reasonable utilisation of renewable generation capital. The probability of renewable output exceeding demand is dependent on the amount of capacity installed above the base load demand, and by the probabilistic nature of the generation and demand processes.

Probabilistic models representing the amount of time that various loading levels and the amount of time that various renewable output levels are expected to occur can be used to estimate the quantity of renewable output that can be utilised. The utilisation factor can then be used to optimise the level of renewable capacity through financial modelling. This is discussed further in Appendix F.

It is anticipated that the minimum loading level of the Guernsey electricity distribution system is expected to increase beyond that projected in Figure 10:1. This will be due to an anticipated shift in heating fuel from gas and oil to electricity, and the potential uptake of electric vehicles. This anticipated change in base-load will essentially mean that more renewable generation can be connected. Industry sources have quoted a figure of around 30MW (approximately twice the capacity determined though projected minimum demands and 100% utilisation) as a reasonable level of renewable generation for the Guernsey electricity grid, though precisely how this figure has been derived is unknown – this would need further work to test this.

10.3.2 Beyond the Base-Load

It may be possible to increase the level of renewable generation projects, beyond that which is found to be objectively attractive for the base-load, by incorporating energy storage facilities or by exporting surplus electricity to Jersey and Europe.

Of all of Guernsey's potential renewable energy resources, tidal generation has perhaps the greatest acceptable and economical potential; however, base load demand levels present a significant technical barrier to potential capacity.

The generation of electricity from tidal streams is intermittent and variable but predictable. It is temporally regular so energy storage systems may be particularly effective for buffering the generated tidal energy between tidal cycles to smooth the output, absorbing surplus generated energy to be released at times of high demand. This is known as load shifting.

Such an approach may increase the level of tidal generation that can be integrated into Guernsey's electrical grid and may displace a greater amount of local diesel generation.

Wind, wave and solar power are potentially subject to long unpredictable levels of poor power output so high levels of deployment of these technologies would require considerable backup generation (which is not a problem on Guernsey) or energy storage systems if generation significantly exceeds the base-load. The necessary energy storage requirements will need to be calculated. This is beyond the scope of this report; however is an area in which future work could be carried out.

Various energy storage options for Guernsey are briefly discussed in Section 10.4, Energy Storage.

It is technically possible for power to be exported to Jersey through the subsea cable and on to France. A contractual framework exists between Guernsey and Jersey for the exchange of generation support between the islands but at present no framework exists to support export to France. It may be possible therefore, to aggregate the Guernsey and Jersey base-loads for sizing renewable energy generation, which could increase the potential base-load renewable capacity to 30MW - 50MW. This depends on the projected minimum combined demands of Guernsey and Jersey and the economics of such energy supply contracts.

Export of electricity to the European Grid will be essential if a large amount of Guernsey's potential renewable energy resource is to be exploited, however, the politics and economics of such an arrangement are uncertain. Cables could also feasibly connect Alderney and Sark, perhaps en route to France, which will increase the potential market and would offer better balancing capability and higher base-load levels.

10.4 Energy Storage

Utility-scale quantities of energy can be stored mechanically, chemically or thermally (Evans et al, 2012). Various energy storage technologies that are suitable for storing large quantities of energy are now considered. Figure 10:3 shows the capital cost per kW installed, and the levelised capital cost per kWh of storage capacity. The size of the bubble is proportional to the potential capacity in MW of projects using the technology. The practicality of integrating each storage technology into Guernsey's electrical system for the purpose of load shifting is now considered.

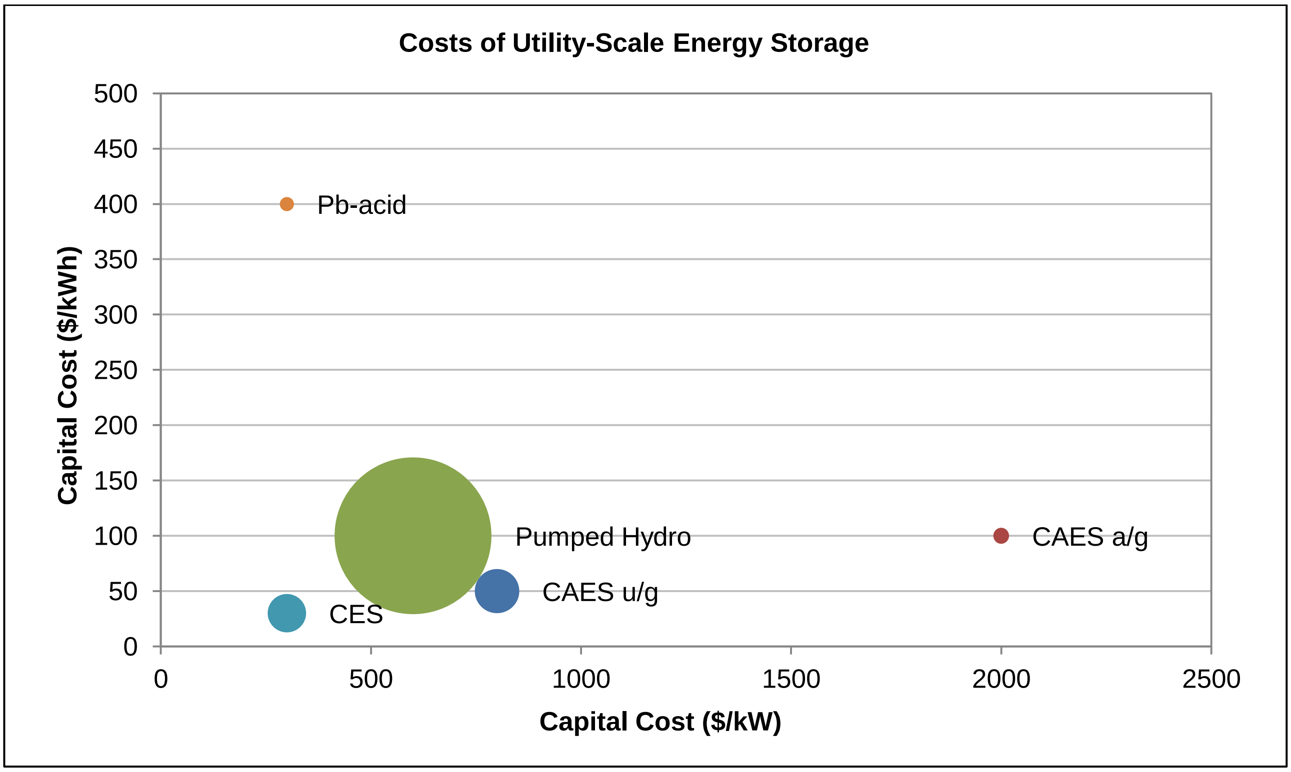

Figure 10:3 - Costs of Utility-scale Energy Storage (Source data: Evans et al, 2012)

10.4.1 Mechanical Energy Storage

Mechanical storage technologies store energy in the form of kinetic or potential energy. Flywheels are kinetic mechanical storage devices but are unsuitable for load shifting since they have a limited power due to mechanical constraints, the cost of storage capacity ($/kWh) is high and the devices have a high rate of self-discharge. Flywheels are far more suitable for smoothing out high-frequency fluctuations in demand (Evans et al, 2012).

Pumped-hydro and compressed air energy storage (CAES) store energy in the form of gravitational, and elastic, potential energy respectively and these technologies can be the most cost-effective demonstrated method of storing large amounts of energy. Pumped hydro schemes use reaction turbines that can be operated in pumping mode to pump water to high potential energy levels, which can be released back through the turbine to generate electricity (Evans et al, 2012). The energy storage method is efficient and has low self-discharge rates; however, pumped hydro schemes require a large amount of land with a suitable topology for storage and discharge of large quantities of water, which is unavailable in Guernsey.

CAES uses compressors to compress air up to pressures of around 70bar. Diabatic CAES systems are the only demonstrated systems and use heat exchangers to extract the heat generated during compression. The compressed air is then run through gas turbines with natural gas to increase the efficiency of gas turbines. Adiabatic CAES uses insulated storage vessels and requires no natural gas input but is only in the developmental stage and has not been demonstrated (Hartmann et al, 2012; Evans et al, 2012). Compressed air can be stored above ground in pressure vessels or below ground in air-tight caverns. Above ground CAES has very high capital cost and a smaller capacity than underground CAES (Evans et al, 2012). The economics of underground CAES, which can achieve high capacities for reasonable costs, is heavily dependent on the availability of suitable underground caverns. In Guernsey the cost of excavating such structures in the local granite stone is prohibitive.

10.4.2 Electrochemical Energy Storage

Electrochemical energy storage relies on reversible electrochemical reactions to convert electrical energy to chemical energy and vice-versa. Lead-acid batteries are the most economical secondary battery technology that is suitable for grid scale storage, with reasonable efficiencies and capital costs per kW. However the electrodes degrade so the cycle life-time of lead acid batteries is low at around 1,000 cycles, leading to high levelled costs per kWh of capacity (Evans et al, 2012). Safety is also a concern and potentially increases costs since extremely high short-circuit currents may occur in grid-scale battery banks. The energy density is also low, at around 40Wh/kg, requiring large areas of controlled storage space.

Redox flow batteries such as vanadium and hydrogen-bromine store chemical energy in liquid electrolytes rather than in the electrodes. The electrolytes are stored externally meaning that increasing tank size can increase capacity, and power output by increasing the electrode area (Evans et al, 2012; Joerissen et al, 2004). Flow batteries have many advantages over standard batteries, with potentially higher round-trip efficiency, large capacities, and high cycle lifetime, however, they require around 1.75m^2 of electrode and 2.1m^2 of electrode separator material per kW of capacity, and 6kg of vanadium oxide is required per kWh of storage which costs around €16.3 per kilogram (Joerissen et al, 2004). These figures make vanadium flow batteries expensive, and grid-scale facilities require large electrolyte storage tanks and electrode areas.

Fuel cells differ from batteries in that they have solid electrolytes separating the reactants, which permit proton exchange, and they consume reactants. Fuel cells are expensive and are ideally suited to direct fuel combustion using methane, natural gas and hydrogen (Evans et al, 2012). Electrolysis of hydrogen is not particularly efficient and energy density is low unless the gas is compressed. This means hydrogen fuel cells are not presently a suitable energy storage technology for large applications.

10.4.3 Thermal Energy Storage

Cryogenic energy storage (CES) and high-temperature thermal energy storage (HT-TES) systems use electricity to decrease or raise the temperature of thermal mediums which may be used to drive heat engines, or to raise steam to run gas turbines (Evans et al, 2012). HT-TES systems are more suitable for concentrated solar thermal systems which buffer solar thermal energy in molten salts that is used to raise steam at the required rate.

CES looks to be a promising technology for large grid-scale grid energy storage and uses electricity to drive liquifactors that liquefy air under pressures of up to 150bar. The liquefied air is then expanded through gas turbines to generate electricity. The systems are expected to be operable with round-trip efficiencies of around 50%. This efficiency is low, however the cost of these systems is expected to be around half the cost per kW, and a third of the cost per kWh than pumped hydro storage (Evans et al, 2012). Systems could achieve efficiencies of around 70% if using low-quality waste heat from thermal processes (Brett, 2012). The energy density of CES systems is also extremely high at around 200 Wh/kg, which is comparable to expensive Na-S (sodium-sulphur) batteries, and is two or three times greater than lead-acid batteries (Evans et al, 2012). CAS is a developing technology, but a demonstration plant has been in operation in Slough, UK since 2010. The site was developed through a multimillion pound collaboration between Highview Power Storage, Scottish and Southern Energy, BOC/Linde and the University of Leeds, with significant funding from DECC (Brett, 2012). The state of this should be monitored as it perhaps offers the only potentially economic energy storage technology for balancing Guernsey's renewable generation.

10.4.4 Discussion

No mature energy storage technology is suitable for shifting intermittent renewable output on the island of Guernsey; however, CES looks to be the best potential option. CES systems could be used to increase the local utilisation of the potential renewable energy resources on the island and support tidal generation. There seems to be good scope for maximising the efficient use of CES through cooling loads, if data centres are to be a significant future load on the island, and though the usage of low-quality process heat.

A detailed stochastic financial analysis, using the best possible future projections of load profiles, is required in order to determine how much if any storage capacity is economical for a specific level of renewable generation.

10.5 Port Infrastructure

10.5.1 Overview of Current Infrastructure

The process of installing and maintaining offshore marine energy devices requires the use of a variety of vessels. The operability of these vessels is dependent on their accessibility to suitable ports.

There are two main harbours on the island of Guernsey: St Peter Port Harbour, situated on the east of the island and St Sampson's Harbour, located to the north of St Peter Port. Each port has facilities to harbour a number of vessels in marinas and on mooring pontoons and each can facilitate refuelling for all vessel types (Guernsey Harbours, 2012).

For ships that are too large to moor in the ports themselves there are anchorage points situated to the east of each of them, outside the protection of the harbours. These points are for ships exceeding the maximum size of the ports, which is 130m length and 5m draft for St Peter Port and 80m length and 4.5m draft for St Sampson's Port.

St Sampson's Port is also restricted by the fact that it is a 'Not Always Afloat But Safe Aground' (NAABSA) port as during low tide the port is dry. This is unsuitable for some modern vessels and can cause damage to any ship that is not suited for resting out of the water.

10.5.2 Current Infrastructure Plans

As of 2012, a project to replace four of the freight cranes in the harbour was started. Costing £13.8 million, the project is expected to take two years and will improve the freight handling facilities at the port (BBC, 2012b).

Beyond the current work there is currently a consultation process being carried out by Moffatt & Nichol on behalf of the Guernsey Harbour Authority. This consultation will provide a master plan for the two ports. This plan will outline the suggested infrastructure changes in line with consultations with the port users, including but not limited to, the fisheries, the Guernsey Yacht Club, freight services and the oil tanker services. It is expected that the cost of the upgrades suggested in the report will total in excess of £100 million. This master plan is expected to be completed by September and for the suggestions to be finished shortly after 2020.

10.5.3 Infrastructure Requirements

Throughout the process of developing offshore marine renewables a number of vessels will be involved covering all areas of the process including surveying, foundations, cable laying, device installation and operations and maintenance (O&M). In order for these ships to operate as intended, they will require access to port facilities for mooring and refuelling.

Alongside providing space for the vessels, storage space is required for the offshore technologies themselves. For example, when installing offshore wind farms, the turbine parts are shipped from the manufacturer to a port near to the installation site. The parts are then loaded onto installation barges and then shipped to the site. As such significant onshore storage space is required to store the technologies during installation as well as equipment for maintaining the vessels once the installation has been completed.

Another example of harbour space that would be required is for the maintenance of wave devices. In the event that a significant amount of maintenance needs to be carried out on a wave device, such as the Pelamis, it may need to be towed into dock. It should be noted however that the Pelamis does not require the quay or pontoons to be the full length of the device although ideally the waters should be sheltered (Pelamis Wave Power Ltd., 2011).

10.5.4 Recommendations for Base-load Scenario

Developing offshore renewables to cover the base load of the island is a relatively small-scale task, in comparison to the task involved in the export scenario. The ports are more than adequate to harbour surveying and the smaller O&M vessels for all the technologies. They are, however, too small to accommodate the larger scale vessels and to store any of the offshore technologies during installation or maintenance.

Due to the comparatively lower capital cost of installing the technologies compared to expanding the port infrastructure at this scale, it isn't worth investing into upgrading the port infrastructure specifically for renewable energy technologies. As this is the case, it is recommended that the larger vessels use either French or UK ports. This does increase the running costs of the vessels as they are required to travel a further distance to reach a suitable port, as well as the port berth leasing cost so that the ship is able to dock at the selected port(s). The following ports have been identified as suitable for usage by ships involved in offshore marine energy projects:

- France
  - Cherbourg (45nm)
  - St Malo (55nm)
- UK
  - Portsmouth (110nm)
  - Plymouth (90nm)
  - Portland Port (75nm)

All the above ports are within reasonable distance for the operating range of the various vessels required during the construction of offshore marine projects.

10.5.5 Recommendations for Export Scenario

Unlike the base load scenario, significantly more investment would go into the offshore projects in the export scenario. As this is the case, it makes more sense to include port developments suited towards developing offshore renewables into the harbour master plan.

As part of this process it is essential that RET is included in the consultation process for the development of the plans. It has already been identified that the ports need to support larger vessels, particularly cruise ships and oil tankers. These plans could be modified to include the needs of those vessels used to install and maintain marine renewables at little extra cost.

If, however, the ports are not developed to suit larger vessels then, as mentioned in the base-load scenario, the French or UK ports should be considered.

10.6 Transport Infrastructure

10.6.1 Overview of Current Infrastructure

Transport accounts for 25.1% of total emissions in Guernsey (States of Guernsey, 2011b). In 2010, there were 87,553 vehicles registered on the island, of which 63,710 are private vehicles (States of Guernsey, 2011b). Motoring is a high energy user; in 2010 approximately 34 million litres of petrol and diesel were imported to Guernsey, which accounted for approximately one third of the island's total energy emissions.

It is considered that aviation is outside the scope of this report and, to a certain extent, commercial transport is also considered in this manner. These businesses are predominantly run by external organisations whose management internationally would have to implement any changes to the local fleets or operation. This is not an area that should be ignored by Guernsey but would be a later project.

The public transport network in Guernsey consists of 33 buses (BBC, 2011b) operated by CT Plus, a subsidiary of the HCT Group on behalf of the Environment Department. CT Plus is a social enterprise that reinvests money from their commercial contracts into community projects. The operation of the public transport network is carried out on a short-term contract basis of 2-3 years.

The Electric Vehicle Company (EVC) has been based on the island since 2005 with the aim of selling new electric vehicles and converting pre-owned vehicles where engines have become uneconomical to repair (EVC, 2012). The majority of the products are exported to either France or the UK and there has been little interest in electric private vehicles on the island. An open day has been held to raise awareness of EVs but EVC did no business as a result of the day. The Environment Department used an EV in the past but it was returned to EVC after a short period.

10.6.2 Current Infrastructure Plans

The current bus fleet is approximately ten years old and has been deemed fit for purpose for current operations. It is expected that within ten years a new fleet will be purchased. Approximately two years ago EVs were discussed as a future option and the cost was considered to be prohibitive.

CT Plus is considering the use of a biodiesel mixture in the short term. There has been some interest in biodiesel generation on the island and a company (Island Waste Oils Limited) has been established and has applied for planning permission for their initial processing plant.

CT Plus is also considering an education strand to their business in accordance with their social enterprise status. This education programme will be focused on the environmental benefits of using public transport and encouraging bus use.

There are no current plans to promote private electric vehicle purchase either by EVC or the States.

10.6.3 Recommendations

It is inappropriate for the transport issues to be discussed in relation to 'minimum' and 'maximum' renewable deployment and the proposals are therefore discussed predominantly on a timescale basis. In the short term, work being carried out independently by CT Plus on fuel usage reduction and biodiesel should be supported by the Environment Department. This will require minimal infrastructure change although fuelling points in the bus garage will be altered and this may tie in with a new bus garage if this is carried forward by the Environment Department.

The education programme should also be supported and the Education Department should consider following its development and where possible, integrating with other suggestions made in the Public Consultation section of this report.

Another commercial fleet that should be investigated is the hire car fleet on the island. There are three hire car companies on the island: Hertz, Europcar and Avis. These are all international organisations and as such it would be initially challenging to electrify this fleet. However, Hertz operate a Channel Islands branch and it is important to consult them on the purchasing processes that are in place. The hire car business is one where the turnover of stock is noticeable higher than the bus fleet and this is an area where progress could be made in a reasonably short period.

In the longer term, there is work that must be carried out in order to consider major restructure to the transport network. There has been little work carried out on the feasibility of electrifying either the public or private transport network and it is important that a study is completed covering all option, similar to the work of Chang for Saint Paul island in 2008. Initially, a further investigation into the costs of electric buses should be undertaken by the Environment Department and it is suggested that this is carried out in association with EVC. Discussions should be initiated with the three bus companies who have provided electric or hybrid buses in the UK under the Green Bus Fund: Volvo/Wright, Optare and Alexander Dennis. It is unlikely that the public network could be entirely electrified due to the fact that the current fleet would cover more miles than the range of an electric bus each day and would therefore require charging throughout the day; this is impractical.

Without further investigation to the operation of the bus timetable, it is impossible to give further information.

Further work must involve key stakeholders, including EVC, the three fuel companies on the island (Channel Island Fuels, Esso and Rubis) and the hire car companies based on the island. It is vital that Guernsey Electricity are integral to this process as any long term infrastructure changes must be supported by their network. It is suggested that the Environment Department and Guernsey Electricity undertake this study alongside any strategic plans currently in development.

In an ‘export’ scenario, there is potential that the wide scale electrification of vehicles on the island may provide an additional storage capability that may be useful in balancing the intermittency of large-scale renewable energy generation. In addition to this, DECC have suggested that EV charging may assist in balancing some excess overnight renewable energy generation (DECC, 2010). Alongside this additional storage capability will become the more complex operational duties of Guernsey Electricity’s balancing team. The feasibility and operational considerations for this should be discussed with Guernsey Electricity and may require further work in the form of a Master’s thesis or consultancy report, as a progression of the work previously discussed. However, as an initial assessment, it has been calculated that if a quarter of the private motor vehicles were electrified, there would be a storage capacity of 255MWh accounting for the fact that a car battery should be left 50% charged. This is equivalent to a quarter of the average daily electricity demand on the island. Calculations and assumptions are shown in Appendix G.

A major challenge to electrifying the public transport network is the short contract lengths offered by the States for the operation of the bus services. In order for long term plans to be developed and implemented, a level of certainty is required. This may be possible to overcome due to the fact that the buses themselves are state-owned and infrastructure may be developed independently of the bus operators.

If the private transport network is to be electrified it is likely that it will occur in phases and will be part of a far longer-term strategy involving public awareness and education programmes by the Environment Department in association with EVC.

11 DEVELOPMENT OF PUBLIC CONSULTATION

11.1 Introduction

The success of any planned large renewable energy project depends in part on how willing the public are to see it developed. To increase the acceptability of a project it is important to not only have a strong public consultation procedure, but also for there to be a good knowledge base within the community. When people have a good understanding of the issues involved relating to energy, within a local and global context and they are already engaged in adopting efficient and sustainable practices in their homes and workplaces they are more willing and likely to respond favourably to new initiatives.

Steve Morris (States of Guernsey Energy Policy Advisor) has said, on the subject of energy issues, that ‘one of the things that needs to be done is to start getting islanders to understand ‘energy’ more than they currently do,’ (Sustainable Guernsey, 2012). He goes on to say that a major part of reducing Guernsey’s carbon footprint is for the people of Guernsey to control their energy usage and that they can’t be expected to do this if they do not understand energy issues.

Guernsey aims to be ‘a Centre of Excellence for research and educational aspects associated with renewable energy’ (Guernsey Renewable Energy Commission, 2011). In order to facilitate this aspiration, effective preparatory work can be done with the public and within education and training. The links that the Renewable Energy Team (RET) has already established with universities can be used to assist with this.

A benefit of renewable energy projects (both micro- and macro-) is that they require skilled people. It is hoped that by bringing renewable energy projects to the island there will be a diversification of industries. Commerce and Employment have already identified diversifying the industries in Guernsey as an objective (States of Guernsey Commerce and Employment Department, 2011). The main industry at the moment is primarily financial services.

11.2 Current Situation

11.2.1 Public Consultation

In the past, as seen with the planned energy-from-waste incinerators, members of the public have felt that plans have not been particularly transparent and that a decision had already been reached about projects before any consultation had occurred. Guernsey Electricity Limited’s (GEL) planned wind farm also encountered problems with the public when plans for the project were leaked.

Yvonne Burford (now a Guernsey Deputy) completed a master’s thesis on ‘Public Attitudes to the Possibility of Near-Offshore Wind Power in Guernsey – W*hat are they and what influences them?*’ She did this by distributing a postal questionnaire to a randomly selected sample obtained by use of the Guernsey phone book. 210 people responded to the questionnaire that showed that 71.9% of people were in favour of wind farms in general and 65.7% were in favour of the construction of them locally. The latter is the same percentage as in favour of local wind farms on mainland UK (66% (Vaughan, 2012)).

Guernsey Tomorrow is a document that was created by the States of Guernsey; it was an initiative that gave people the chance to voice their opinions on the type of place they would like Guernsey to be. 61 people were asked how strongly they agreed with the statement that the States should 'encourage the domestic installation of green alternative technologies and maximise energy from micro-renewables,' (Strategic Land Planning Group, 2010). 79% of people said that they agreed or strongly agreed.

Every three years the Young People's Survey asks Guernsey students in years six, eight, ten and twelve their attitudes and opinions on a variety of subjects including health, sex and employment. In 2007 survey students were asked to answer the open ended question 'If I were chief minister…'. Of the 4000+ responses, concern for the environment was the most frequent observation with the responses reflecting a concern for, and commitment to, their island and a desire to play their part in making Guernsey an even better place in which to live. Just over 20% of year sixes responded by saying they would do something about the environment (Figure 11:1).

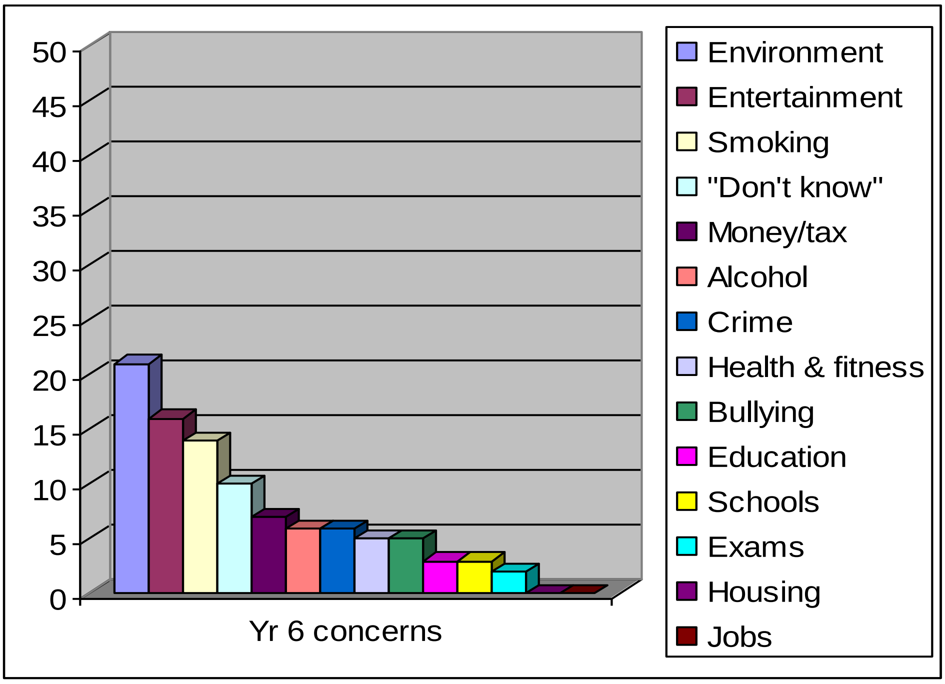

Figure 11:1 - Year 6 Responses to 'If I were chief minister…' (Source: Young People's Survey 2007)

A few years ago GEL commissioned Island Analysis to conduct a short survey in to people's opinions about energy on Guernsey; this survey also included questions about renewable energy.

On the 3rd April 2012 Renewable Energy Team (RET) held an open day to give the public a chance to learn about macro-marine renewable energy in relation to Guernsey, with members of the team being available for discussion.

In autumn 2012 a student from University of Exeter will commence a PhD research project on the topic of 'Public Engagement with Marine Renewable Energy: a Guernsey case study.' The briefing for the topic states that the student will use Guernsey as a 'living laboratory to understand public understandings and acceptance,' (University of Exeter, 2012). This should provide the Renewable Energy Team with a better understanding of what issues need to be addressed in order to increase the acceptability of renewable energy on Guernsey.

11.2.2 Education

Renewable energy and sustainability are currently taught in science and geography lessons throughout secondary school and in environmental science in the sixth form. RET is starting to work with schools to promote renewable energy awareness by developing educational resources in conjunction with Elizabeth College. GEL worked with schools to teach students about energy soon after the cable was laid between Guernsey and Jersey. As well as government departments and GEL helping in schools, the Planet Guernsey Conference in 2008 worked with sixth formers to raise awareness of climate change and its impacts in Guernsey. Posters were produced showing the students' thoughts on climate change and what actions students suggested their school, island and Guernsey people could take and do to highlight the issues. One of the outcomes was that students wanted schools to 'create more awareness of climate change, teaching in more detail and starting from an earlier age' (Planet Guernsey Conference, 2008).

11.2.3 Raising Awareness

Work is already being done to raise awareness of environmental issues on the island. Sustainable Guernsey is a website that frequently posts news stories about issues relating to sustainability both on the island and elsewhere. It is regularly updated and advertises events that are happening to get people involved in environmentally friendly events locally. Guernsey Climate Action Network (G-CAN) did a similar thing to Sustainable Guernsey; they brought people together and also held events that promoted sustainability; for the most part the group now seems to be largely inactive.

In 2007 Andrew Casebow (Climate Change Secretary of La Société Guernesiase and vice-chairman of Guernsey Renewable Energy Forum (GREF)) compiled and edited a book entitled 'Planet Guernsey – Towards a Sustainable Future' that was published by Guernsey Climate Change Partnership. The book detailed the evidence and the impacts of climate change in Guernsey, the consequences that future climate change might have and detailed opportunities of how to respond.

In 2010 E-Si (a renewable energy company in Guernsey) launched a competition entitled 'What's the payback?' The campaign was to see if people on the island were aware of what the payback for renewable energy is and to promote debate of the 'deep issues planet earth faces at this time in history,' (E-Si, 2010). Also in 2010, E-Si hosted a micro-renewable energy exhibition in St. Peter Port that saw members of RET and GEL attending.

Guernsey Renewable Energy Forum (or GREF) is a stakeholder group that consists of environmental specialists on the island and other interested parties. The forum acts as an independent group to discuss and share information about renewable energy.

11.2.4 Politics

As mentioned earlier public consultation on renewable energy projects has been an issue in the past. Some people have felt that it has been approached using a decide-inform-defend procedure whereby the public have merely been informed and not been involved in the decision making process. This has led to the desire to create a strong public consultation strategy, as this will be key in developing any project.

The Regional Environmental Assessment (REA) is a technical assessment of the environmental impacts that could arise as a result of deploying tidal and wave devices in the waters around Guernsey and Sark. During the preparation of the REA a consultation process was undertaken, with stakeholders providing numerous responses, these were then compiled into a report. One response stated that insufficient time had been allocated to make a fully considered response. Paul Fletcher (CEO of E-Si Ltd.) was one of the people who responded to the document and placed a strong emphasis on the importance of public understanding. He wants the government to 'ensure that all bodies and the public are educated in what renewable energy may mean to them,' (Commerce and Employment, 2011).

The Guernsey Energy Resource Plan, produced in 2011 as part of the States Strategic Plan, looks at how the island will be powered in the future. It is based on energy aspirations for 2020 whereby the States want to see 'a gradual decarbonisation of Guernsey's energy generation' and it 'sets out key objectives which will affect future energy decisions,' (States of Guernsey, 2011). At its first presentation in 2009 only the States of Guernsey noted it. After some small modifications it was adopted in February 2012. The document went for consultation to various stakeholders in 2011, including the Housing Department, RET and Guernsey Gas. There was quite extensive feedback from these bodies, which included constructive proposals with suggestions for inclusion or modification. Some raised issue with the lack of information on energy efficiency measures and a methodology for reducing demand within the plan. It was also suggested that this document be considered as a work in progress that should be regularly reviewed and updated and others highlighted that they were aware that renewable energy projects would become more feasible as energy prices increase. RET provided many constructive suggestions.

The RET Communications Strategy – 2012 outlines the key messages that the team are looking to communicate to the public whenever contact is made. Stakeholders are identified as well as the method and timing of the information to be released to these different groups.

The Scrutiny Committee has developed a document entitled Public Engagement Strategy. The role of the committee is to scrutinise the departments of the government to ensure that they are performing the role that they are supposed to. The Public Engagement Strategy document identifies 'best practice guidelines', (Scrutiny Committee, 2012) for the committee to follow when engaging with the public. However, as the States of Guernsey do not currently have a corporate public engagement policy, it provides a good structure for public engagement in general. A spectrum of engagement methods are recommended that include informing, consulting and acting together with stakeholders. A stakeholder is considered to be anyone - individual, group or organisation - who can affect or be affected by the work. It is considered important that stakeholders have an opportunity to involve themselves in reviews and feel connected to processes.

Recently the Public Services Department have been consulting on the Guernsey Ports Master Plan. This involved consulting with stakeholder groups including community organisations and associations, with them being invited to feedback sessions. The public are also being invited to help shape the future development of Guernsey's harbours. The Public Services Minister Paul Luxon considered that it was important for islanders to be engaged in the development of the Ports Master Plan, for them to find out about the issues being addressed and the ideas being put forward. Also he stated that the department wanted to hear from more of the islanders so that the master plan can reflect their views. This is an indication of a newer trend in consultation with the process being used to engage the public in the development of a new project and with a desire to find out the views of the public so that their views can be reflected.

11.3 Education Suggestions

The National Curriculum in the UK primarily covers energy and renewable energy in science lessons in secondary schools (sustainability and climate change occur within geography). Teaching in Guernsey loosely follows the same curriculum. It is recommended that a review of the curriculum be undertaken with regards to identifying, and then reconsidering, when and where knowledge of energy and in particular renewable energy is being taught and developed. Sixth form students raised the issue, at the Planet Guernsey Conference, of whether it is being taught from a young enough age. This process should identify if more time, or depth of teaching, needs to be dedicated to the subject. This is recommended particularly in the context of Guernsey's aspirations with regard to developing its marine renewable energy resources and becoming a Centre of Excellence for Renewable Energy, but also within the wider context of developing understanding of the inter linking issues regarding energy.

The following are some recommendations for what should be included in science teaching at secondary schools:

- Different ways of generating electricity (fossil fuels, nuclear, renewable);
- The advantages and disadvantages of these;
- An understanding of in which circumstances energy is used, and of how much energy is consumed by these various activities;
- And exercises to come up with a rough idea of each student’s personal energy use and how this relates to the average value (this also relates their learning to real life and makes them aware of the importance of taking ownership of their energy use as well as moral implications such as being responsible for your actions).

It is also recommended that the social implications, locally and globally, are also addressed in a considered way.

For learning to be effective it is important that students are engaged with what they are being taught and one way of achieving this is by having interesting ways for them to learn. Science particularly lends itself to using practical teaching aids, for example, using a homemade waterwheel for an experiment. This could be implemented by taking advantage of the relationships that RET has already established through the projects being undertaken with UK universities. Students at the universities could create practical teaching aids or experiments to be used in Guernsey schools. Not only could teaching resources be created, but university students could possibly also assist with classroom activities. Visiting lecturers or experts to the island could also speak on the subject of renewable energy.

A questionnaire was prepared that was intended to be distributed by all secondary schools to their students. Unfortunately, due to the short amount of time available to complete it, and with many students taking exams, only two schools were able to distribute it. This has meant that only a few students responded, not enough to analyse the results. In the future it is recommended that a similar questionnaire be distributed to gauge students’ awareness of renewable energy. A copy of the created questionnaire can be found in Appendix H.

It is important to encourage students to continue to study science and engineering after compulsory education has been completed. Currently there are roughly 800 students from Guernsey studying at higher education institutions in the UK. To incentivise and encourage more students to study for a science, technology or engineering degree at university it may be possible to utilise some of the philanthropic good will of the Guernsey residents by setting up a fund to support them in their studies. These young people would be bringing back high level skills and expertise that will support Guernsey's vision to be a Centre of Excellence in Renewable Energy.

Education is not just about what is learned at school or university, learning occurs throughout a person's life. There have been successful awareness programs organised by the Guernsey's Education Department through Lifelong Learning, which have been run in schools, and youth organisations that have highlighted issues and aimed to effect lifestyle choices such as drug and alcohol use and political awareness. A similar approach could be used with energy and sustainability. These approaches usually use a worker employed by another organisation or a charity and could potentially include workshops run by university students.

An idea for educating younger people outside of school is the implementation of renewable energy in playgrounds. Figure 11:2 shows one example of this but could also include other ideas such as roundabouts that generate electricity as they turn. Equipment like this could be considered for the Folk Museum's playground that is currently in need of refurbishment.

Figure 11:2 - Energy Seesaw (inhabitat, 2010)

Young people should have the opportunity to train and achieve relevant and up to date vocational qualifications on the island after leaving school. E-Si is an employer requiring skilled workers, but there was not appropriate training available on the island. Instead Guernsey College of Further Education have needed to send people to Southampton on a weekly basis to obtain the requisite skills in electronics, which is pertinent to the renewable energy sector. This highlights the need for appropriate vocational training courses to be developed and made available on the island. This is something that the Housing Department also brought up in its response to the consultation on the Energy Resource Plan. It identified two areas of need: firstly, by ensuring the College of Further Education provided appropriate training, that gives new entrants the understanding and skills about modern practices and the new technologies being used within the construction sector to improve the sustainability and performance of buildings. Secondly it suggested, ‘that there are opportunities, and perhaps incentives, to reskill the existing workforce,’ (Housing Department, 2011). There could be vocational training to be a renewable energy installer or technician. Also programmes could be developed with a BTEC qualification, such as the one in Sustainability Skills offered by Edexcel, that could be pursued by young people and adults. It is a scheme which has been found to be effective in the UK with those young people identified as ‘Not in Education, Employment or Training’ (NEETs).

If they were to be set up on Guernsey, the Guernsey Training Agency (GTA) could potentially be a provider for teaching the non-practical side of these courses, as it is already used by students visiting the island who are doing projects in conjunction with RET.

11.4 Raising Awareness Recommendations

11.4.1 Government

Raising awareness of the issues to do with energy and sustainability amongst key members of the Islands’ population is regarded as being essential, as is having a solid understanding about renewable energy. This could be achieved by developing and providing a high quality training programme, overseen by RET. It is important for those in government, both politicians and civil servants and others in positions of leadership in Guernsey, including those within the parishes, to demonstrate a good understanding of the issues and to act as role models in the way they use energy and adopt efficiency measures to reduce their own and their organisation’s energy consumption. This group holds positions of considerable influence and so it is important that they have a good understanding and appreciation of the issues to do with energy. This education and awareness programme could involve the use of outside sources such as university lecturers or through links with organisations such as the Energy Saving Trust and the Carbon Trust to deliver the training. The training could be on going and also involve a pack of information for reference and further information, with access to the RET team encouraged and facilitated.

It is suggested that a working group is set up by the States to identify clearly what the short, medium and long-term goals of the States are with regard to energy matters, sustainability issues and carbon reduction targets within the context of the (Carbon Reduction) targets agreed to and adopted by the States of Guernsey.

In 2009 Tribal Helm were appointed to carry out a fundamental spending review within the States of Guernsey. This identified where the government was losing money through inefficient processes, including energy usage. Again the States needs to ensure they are leading by example and following through with any recommendations made with regards to energy use in government buildings. A similar thing could be done with public buildings such as libraries, hospitals etc., making energy audits mandatory so that employees are aware of how much energy is being used and where savings and more efficient use of energy could be adopted.

11.4.2 Public Organisations - Energy Champions

All government employees should receive training and participate in awareness raising programmes at work; a methodology could be developed for this. Additionally one or two people from each department of an organisation with an interest in sustainability could volunteer or be invited to train to become an Energy Champion for their department. It would then be possible for these individuals to act as role models about energy use within their department of their organisation; this would reinforce the learning from the training programme. Energy Champions would also act as motivators and be a point of reference and source of information and guidance to their colleagues, with the capability to signpost them to other sources of information when appropriate. This would help to ensure that workplaces are being used in the more energy efficient ways. These Energy Champions should receive a very good level of awareness raising and training, as potentially they will be very influential in passing on their knowledge and good practice to others. Initially this will be at work but also as newly learnt behaviours are likely to be adopted within the home then this knowledge is likely to then be further disseminated within their communities. The Energy Champions would benefit from further support and meetings with their opposite numbers from other departments; this would support the cascading effects of knowledge and practices.

11.4.3 Communities

Another outcome from the Planet Guernsey Conference, 2008 was that students wanted to ‘Encourage community schemes to reduce the impact instead of relying on individuals’.

People within their local community could group together to invest in energy efficiency schemes or a renewable energy project for a community building such as a village or town hall, hospital, school or doctors surgery. The group could then use the money that is received from selling power to the grid and/or the money that is being saved through reduced energy bills to reinvest back in to the community.

Earlier in this report the use of Energy Champions has been identified as a strategy that could be used throughout government premises to encourage and facilitate efficient energy use and help to raise awareness in the workplace amongst their colleagues within departments. This is a method that could be used in all workplaces, interested individuals within companies, organisations and schools (both teachers and pupils), sports clubs, public services etc. could also become Energy Champions within their organisation or community group. A similar training scheme to the one identified for the government could be provided or facilitated by RET that could be held at the Guernsey Training Agency.

11.4.4 Building on Success

There have already been successful events held to raise awareness about sustainability and so it would be advisable to build on the work that has already been done. One such event was the open day held by RET on the 3rd April this year. Rather than being a one off event it could be part of a series of public exhibitions or talks hosted by RET. This could include bringing in outside speakers to talk to the public such as renewable energy technology manufacturers, suitably experienced project managers, members of organisations such as the energy institute or academic lecturers. There are many inspiring well-informed speakers.

As mentioned previously Andrew Casebow's book 'Planet Guernsey – Towards a Sustainable Future' looked at the effects that climate change was having on Guernsey. As a follow up to this successful awareness raising campaign he is writing a second book due to be released later this year, entitled 'Planet Guernsey – Riding the Storm'. This new book will look at energy security as well as population change, food and water security and environmental change. The plan is also to engage young people by holding a competition whereby young people write and illustrate sections to be included in the book. If he can secure enough funding Andrew Casebow would like to publish enough copies that each household could have its own copy.

It is suggested that a variety of communication methods are adopted including websites, social media and webinars as well as posters, monthly newsletters and regular meetings. These should reflect the different lifestyles of islanders to ensure these awareness programmes are effective at reaching diverse groups within the population.

11.5 Public Consultation Procedure

Public consultation can encompass a variety of ways of engaging with the public. The Scrutiny Committee's Public Engagement Strategy outlines the different levels of engagement (high, medium, low) that can be used depending on the desired outcome. In the earliest stages of the consultation a high level of public engagement is needed to develop a strong project that has been informed by the opinions of the public. Towards the end of the project less engagement is needed, as developers will be informing people of progress rather than developing a plan. Throughout the project there should be an email address available for people to leave comments as well as by using comment cards and this should be made clear at all meetings and in all press releases.

It will be important to engage the media at an early stage and throughout the project ensure that any information being released to the public is accurate and well informed. Several media outlets that could be used are: BBC Radio Guernsey, The Guernsey Press, Sustainable Guernsey and thisisguernsey.com. On the websites it will be useful to include positive news reports about other renewable energy projects and sustainability news happening elsewhere to get people enthused about the projects that will be happening on their island.

11.5.1 Stakeholders

Before public consultation can take place the stakeholders will need to be identified. These include but are not limited to:

- Fishermen;
- Shipping and Navigation;
- Sustainable Guernsey;
- E-Si (and any other renewable energy companies);
- Guernsey Electricity Limited;
- Environment Department;
- Tourism and Recreation;
- Community organisations and associations;
- Water sports participants;
- And the press (radio, TV, newspapers etc.)

Some of these may need to have access to more information than the public and be kept more involved with project development.

11.5.2 A Proposed Framework

Below is a proposed framework for a public consultation procedure on marine renewable energy projects.

Phase 1 – Pre-project Proposal

- Ongoing awareness raising, education and public engagement to take place as soon as possible, after strategies and programmes for these have been agreed. It is suggested that a preliminary survey could be conducted early on, which will be used to gauge the level of awareness of energy issues and sustainability and levels of understanding of renewable energy, which would help to inform this process.

Phase 2 – Project Proposal

At this stage it is essential to have a high level of public engagement so that people feel their opinions have been taken in to account from the very beginning.

- Prepare briefing document to be used by members of RET and other people in contact with the media with key points (from RET Communications Strategy and project specific details).
- Set up a website about the project that includes regular news updates, information about the developers and devices and relevant statistics such as the amount of houses that the generating plant will power and CO_2 savings.

- Brief the stakeholders individually about the project and receive feedback from them.
- Anticipate any questions that may come from the public/media and have answers prepared.
- Public meetings, forums and drop in sessions to be held in St. Peter Port and the parishes, with particular attention being paid to those parishes that would be most likely to be affected by the proposed project. Advertise these meetings through the media (radio, newspaper, online) and leaflets/posters. This will give residents the chance to ask questions and express their concerns. This will highlight issues that might need to be dealt with. It may also help show individuals or groups of people that will be likely to resist the project early on.
- Once the public meetings have happened the initial plans can be made. These can then go back to meetings, after which the consultation phase will begin (this will be announced at the meetings). People will have three months to leave feedback through the public consultation section of the Guernsey government website, by filling out comment cards that can be found in public places (i.e. doctors surgeries, local shops etc.) or by communicating directly with RET.

Phase 3 – Post-consultation

- Once all feedback has been gathered there may need to be changes made to the project proposal based on this.
- From the public meeting and feedback it might be possible to identify individuals who are very positive about the project. RET could take advantage of this by using these people to increase acceptance of the project. A few people within each parish could keep in contact with RET on a weekly basis and be used (as well as the media) to update people on progress with the project.
- At this stage there should be a meeting where members of stakeholder groups are invited to hear the revised plans. As mentioned previously there may be information that the public are not privy to released at this point. It may be necessary to have non-disclosure agreements arranged so that any sensitive information cannot be released.
- After the stakeholder meeting again meet with each group individually to get feedback on the new plans.
- Following a revision of the plans a public exhibition could be held (similar to the one held by RET on the 3rd April 2012). This would be a less formal setting for people to see the new plans and with members of RET and the team developing the project, on hand for the public to speak to. It may also be useful to have a comments book where people are able to say how they feel about the revised proposal particularly in comparison with the original plans.

- At this stage it may be that individuals against the plans have formed in to opposition groups. It will be important to keep in contact with these groups and to minimise any damage that they may cause to progress of the project. This may be by opening a dialogue with them and inviting said groups to a meeting just for that group. RET must be prepared to react quickly to any action or negative news stories released by these groups. Looking at previous cases where opposition groups have formed and researching the websites of similar groups will give an idea of issues that might be brought up.
- It is essential that a good relationship is maintained between RET and people in the media to ensure that opposition groups do not have a chance to develop a rapport with them.

Phase 4 – Project Confirmation

- It may be deemed necessary to revise the plans once again as an outcome of the exhibition and stakeholder feedback.
- Once the project has been confirmed, leaflets should be distributed to all the households with the final plans and a timeline of important dates for the project. There should also be a more comprehensive pack of information available from RET for those that want it.
- There may be another public exhibition to showcase the final plans and again give people a chance to ask questions. This should be as engaging as possible and also family friendly to encourage younger people to take an interest in the project.
- It could also be good to run workshops at the Guernsey Training Agency that members of the public of all ages could attend. These could be run by RET in conjunction with the developers, universities or E-Si with an aim to educate about renewable energy and sustainability.

Phase 5 – Construction

- Informing members of the public if and when a phase of the construction is potentially going to impact them. Regular press releases to update public on how the construction is going. Perhaps emphasising when interesting developments are occurring (i.e. delivery of wind turbine bases) to get people talking about the project and possibly going to watch the unloading.

Phase 6 – Project Completion

- Family event held on or around day of completion to celebrate. All encouraged to go particularly including stakeholders, RET, developers and the media.

Phase 7 – Post-Project Completion

- Regular press releases to update public on operation of the generating plant.

11.6 Conclusion

A public consultation procedure is crucial to the effective deployment of a renewable energy project. It can aid in the speed of the delivery of the project as well as helping secure funding. By following a scheduled and thought-out procedure, RET can ensure that the public stay well informed, involved and educated on any project.

The first step of preparing the ground is the most critical for a successful outcome of the public consultation procedure. A change in public knowledge and awareness of the underlying issues will need to be engineered, alongside the development of an appreciation of the potential benefits of the proposals to Guernsey.

Government can facilitate learning and change by empowering people and making it easier and to act individually, in the workplace and in their communities. This could be achieved by appointing a person or team with the specific responsibility of developing and coordinating enabling strategies. Their remit would include raising public awareness and enhancing energy education. These strategies would assist Guernsey and its people to reduce their carbon emissions by demand reduction through efficiency measures and micro-generation.

Setting an example with their own actions will provide leadership for what people can do both individually and collectively. Engaging the public by empowerment and demonstrating commitment will communicate the priority that the States place on energy issues, providing a favourable context for its marine macro renewable energy proposals.

12 SCENARIO ANALYSIS

12.1 Introduction

In order to investigate how Guernsey's marine renewable potential could be best realised, three energy scenarios have been considered within this chapter. These scenarios are:

- Scenario 1: a baseline scenario that assumes no renewable energy projects are installed and the current mix of imported and self-generated electricity continues
- Scenario 2: assumes a small uptake of marine renewable technologies, generating enough electricity to meet Guernsey's base load of 30MW
- Scenario 3: assumes a large uptake of marine renewable technologies to supply Guernsey's electricity needs as well as providing an export potential

To fully understand each scenario and the possible implications of deploying them, each one will be modelled and analysed in more detail.

12.2 Scenario 1

12.2.1 Overview

This scenario considers the case if Guernsey continues to obtain all of its electricity from on-island generation and imported electricity via the interconnector from France. The import from France currently makes up 78.6% of Guernsey's electricity and is under contract until 2023.

On-island generation currently makes up for the short fall in Guernsey's electricity supply (21.6%). This 115MW of capacity is generated by five 2-stroke, slow speed diesel generators, with a total rated capacity of 65.3MW, and 3 gas turbines with a total rated capacity of 50MW (Guernsey Renewable Energy Commission, 2011). In the year ending 31st March 2011, 18.4 million litres of diesel were consumed solely for on-island generation alone.

Scenario 1 is based on Guernsey continuing to use the current energy model to meet its electricity demand, exploiting the cheapest source depending on time of year and replacing generation capacity with modern equivalents as and when required. There have been several assumptions made in making recommendations of the viability and sustainability of this model, these being:

- Cost to the consumer increases at 5.5% per year; this reflects the trend in Guernsey's electricity price rises and is consistent with global trends in energy costs;
- Guernsey continues to utilise oil as its primary generation fuel;
- Energy use rises at 0.4% per year;
- Inflation averages 3% per year.

These assumptions are made for reasons discussed in Section 12.2.2 - Challenges of Scenario 1.

Under Scenario 1, Figure 12:1 gives a projection of energy cost to the consumer until 2042.

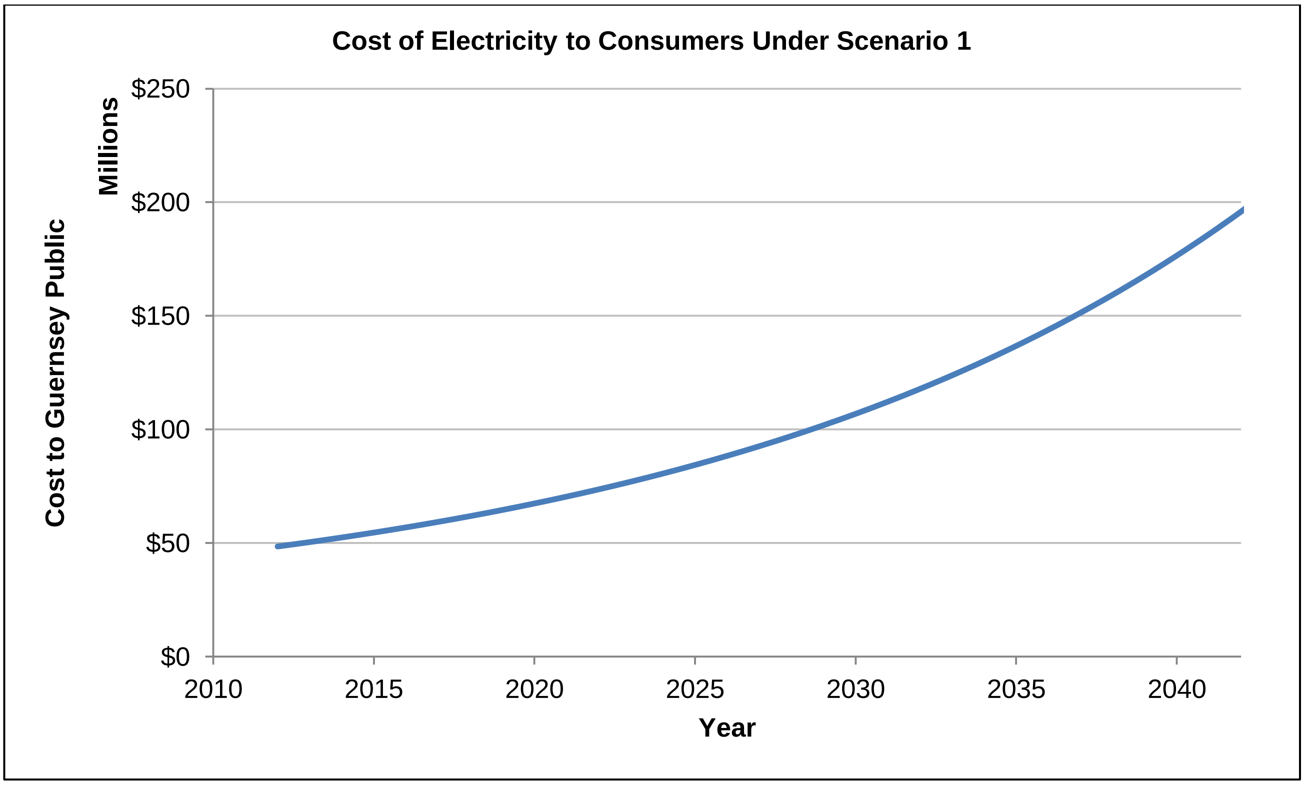

Figure 12:1 - Cost of Electricity to Guernsey Public under Scenario 1

This cost projection is reliant on variable assumptions. This highlights one of Guernsey's clear challenges -being heavily reliant on European political situations and global oil prices; this variation can be significant. The following discusses the reason for some of these assumptions and ultimately the challenges of sticking to this scenario.

12.2.2 Challenges of Scenario 1

Security of energy supply is one of the major drivers for countries who have adopted renewables programmes. Guernsey is heavily dependent on imported electricity from France through the interconnector, which leaves Guernsey's electricity supply vulnerable, on both a security and cost aspect. This security vulnerability was highlighted recently by the fault in the interconnector, which has forced Guernsey to rely solely on its, more costly, on-island generation.

For Guernsey the cost of imported electricity is also a concern. Francois Hollande, the new French president has already stated that he plans to reduce French nuclear capacity from 75% to 50% of French demand by 2025 (New York Times, 2012) which the French professional association for the electricity industry anticipated will increase the price of French electricity (World Nuclear News, 2011). As the bulk of Guernsey's imported electricity is sourced from French nuclear power this is likely to increase the cost. In addition to this if other mainland European countries struggle to meet their emissions targets for 2020 and 2050 then low-carbon nuclear electricity from France may be in increasing demand and this will also result in an increase in cost of Guernsey's imported electricity.

For energy security, Guernsey relies on Guernsey Electricity's oil based generation portfolio. Guernsey Electricity operates an 'n-2' policy, this means they ensure that two generators (including the interconnector) can be lost and Guernsey Electricity can still generate Guernsey's maximum demand. A 4-stroke medium speed diesel engine, rated at 17MW will be commissioned by February 2013 to allow this policy to continue to operate as demand increases. It will cost in the region of £10M (Guernsey Electricity Limited, 2012).

The cost of on-island generation depends on the global price of oil. It is projected that this will continue to rise at least to 2030, Figure 12:2 produced by the United States Energy Information Administration. This also shows three scenarios, a high price case, a low price case, and a middle price case referred to as reference.

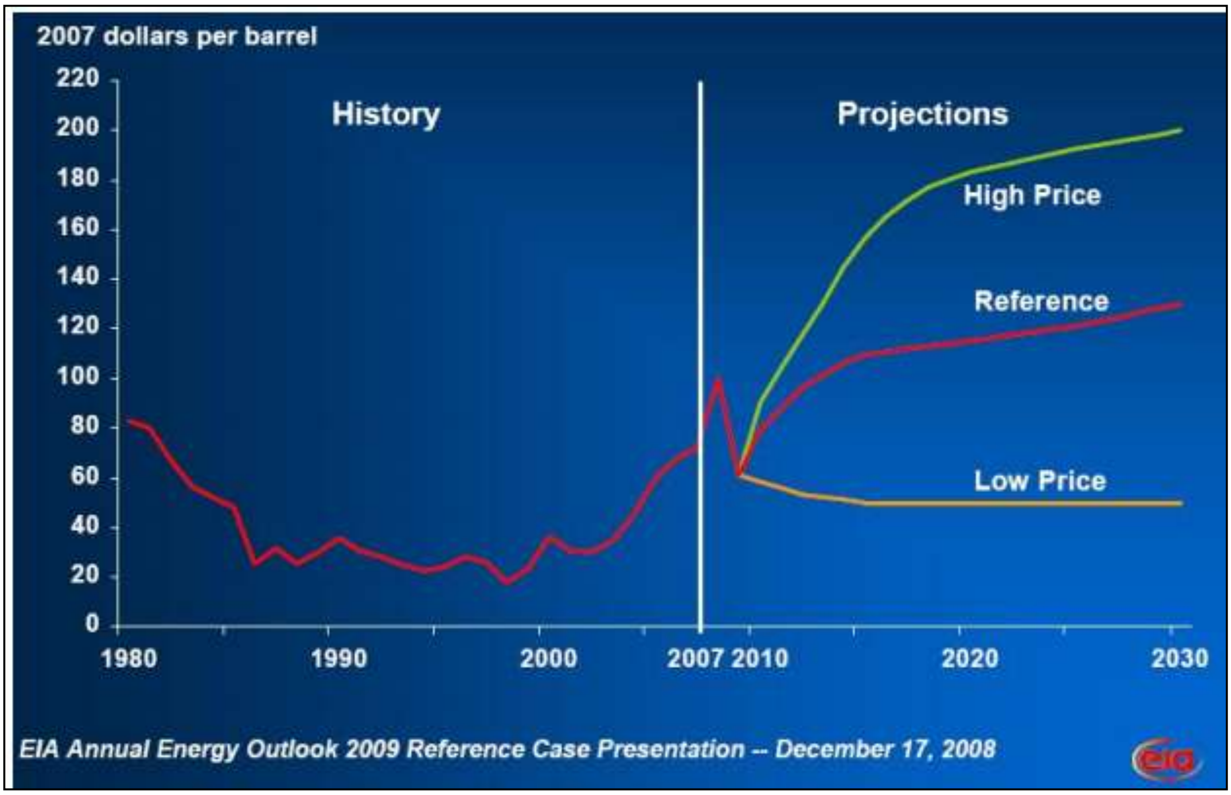

Figure 12:2 - Annual Energy Outlook 2009, with Projections to 2030 (United States Energy Information Administration, 2008)

For the year ending 31st March 2011, the price of oil was $87.50/barrel (equivalent to £0.35/litre) (BP, 2012). Both the reference and high projections predict a significant increase in oil price by 2030. The reference case predicts an oil price of $130/barrel, whilst the high case predicts a price of $200/barrel, representing a 49% and 129% increase respectively. This increase in cost will be reflected by an increase in electricity bills to consumers on Guernsey. The low price suggests a decrease in oil price, down to $50/barrel, a 31% drop. However, the current price of $87.5/barrel is above the value it was predicted to be at this stage by this lower scenario and so it is felt the 2030 predicted low price is unlikely to become a reality.

Global energy markets will continue to pressure governments to turn to a cheaper reliable energy source that is not as volatile as the current fossil fuel market. With oil prices expected to continually increase and more emphasis being placed on CO2 neutral fuels. The Office of Utility Regulation (OUR) had to take measures against these price rises and increased tariffs by 8.5% in April 2010 and a further 5.5% in April 2011 (Guernsey Electricity Limited, 2011). It is possible that the cost of both self generated and imported electricity may in fact drop but this seems unlikely, and certainly in the case of oil, a price drop is only predicted in the most optimistic of predictions.

The extent of these challenges is an area that must be investigated and assessed by Guernsey, however it is clear that the current 'non-renewables' Scenario 1 is not only insecure but also potentially very expensive and provides few benefits.

12.3 Scenario 2: Base Load Renewables

This scenario describes development of renewable energy for on-island use only. Without a cable to export power to France and no access to UK or French support mechanisms the installed capacity will only cover Guernsey's base load electrical demand. In 2011, this stood at 22.9MW but will be closer to 30MW by 2020 (Guernsey Electricity Limited, 2011). This is the point from which it is most likely that any renewable capacity will begin to enter the system.

Scenario 2 models base load as being met by a single offshore development, this is due to economies of scale and subsequent cost to Guernsey. There are two potential options for supply of this base load from offshore technologies; tidal stream and offshore wind. The reasons behind this choice come down to the technologies for both tidal and offshore wind options being more mature than wave energy, and are therefore more technically and financially viable.

As stated, Scenario 2 assumes no appropriate export option exists and therefore as such that the development of deployment would be for provision of base load and would be sized as such. The option for generating revenue under this scenario involves Guernsey supplying the required financial support. There are two principle methods of accomplishing this, either by grant funding or some form of incentive, the cost of either being footed by Guernsey's population. This investment will have a series of different viabilities depending on technology, capacity, the time of entering the market and the cost of other electricity generating options. As highlighted either tidal or offshore wind generation are currently the most suitable and due to economies of scale it will require an either or approach.

Under current regulation Guernsey Electricity is obliged to provide electricity to the consumer at the cheapest possible price. This will have to be changed if any offshore renewables are to be developed, with the decision being verified by the long-term benefits of developing an offshore renewable programme.

12.3.1 Tidal Power

The sea surrounding the island of Guernsey has one of the largest tidal ranges in the world; with a tidal capacity of 30 MW exploiting just a small proportion of this. A further study into the different arrays and potential locations are looked into in Section 5- Tidal.

Tidal power, not being as mature as offshore wind, will have higher capital costs but is more dependable as a source of predictable output, making it the more appropriate technology for base load generation. Tidal follows a sinusoidal flow pattern, making it intermittent but predictable. Even though it is capable of generating a constant source of power for extended periods of time, it still suffers from intermittency issues as tidal flow is not constant and will have periods of zero flow.

Technologically, a tidal array of 30MW can be implemented as soon as 2020, this will give enough time to obtain the required licensing and meet necessary infrastructure and supply chain timeframes. Nevertheless, from a purely financial perspective suggests 2030 as an appropriate year for deployment ensuring that the savings outweigh cost to the Guernsey public. It is important to emphasise however that this does not monetise the value of reducing CO_2 emissions, energy security and other advantages.

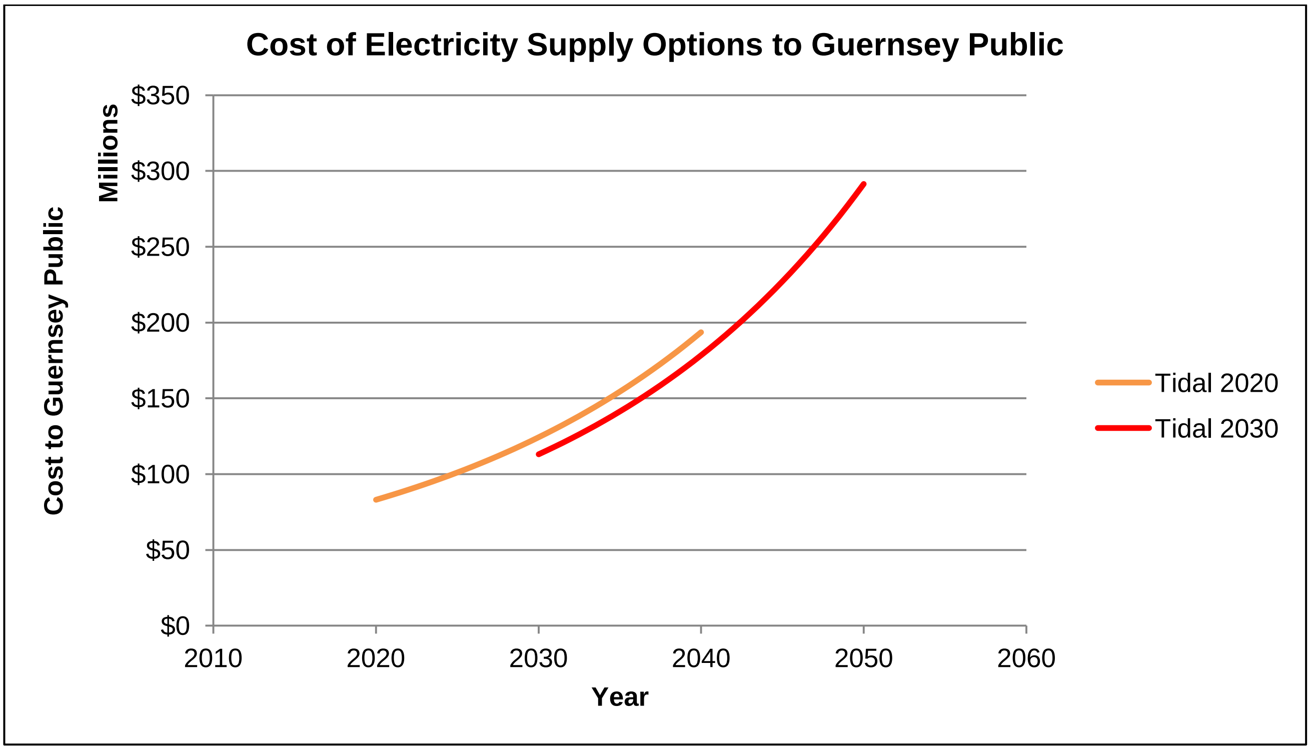

Figure 12:3 - Cost of Electricity Supply Options to Guernsey Public

The current cost of tidal stream technologies is estimated to be approximately £4m/MW. By 2030, a 30MW installation would make economic sense with a cost of around £3.3m/MW. This deployment would require an additional 1p/kWh in addition to 2030 price. Yet the overriding benefits need to be considered and taken with due merit, making tidal electricity of more value than offshore wind.

12.3.2 Offshore Wind

Offshore wind, as a technology, is relatively mature in comparison to tidal power.30MW of installed capacity could be technically installed and readily available by 2018 giving enough time for all legal and environmental procedures to be carried out. The potential sites are shown in Section 7 - Offshore Wind.

Although wind power is considerably cheaper per installed MW than tidal power the greatest draw back the technology faces is its reliance on an intermittent and unpredictable wind source. This makes it less dependable for securing a steady demand profile, as it is not possible to accurately predict future generation.

Development of offshore wind will be a far more financially viable option yet does not have the same overall benefits as a tidal development. Offshore wind has a current estimated cost of £2.5m/MW at deeper, remote sites meaning shallower, near shore wind sites are likely to be more in the region of £2m/MW. This means that certain offshore wind developments could be financially beneficial if deployment occurred in 2018. This does not consider the implications of requiring the maintenance of backup capacity, however the potential savings means that this should be still be a viable option. An offshore array of 30MW would require a subsidy of approximately 2p per kWh on the 2020 average price of electricity; yet, at current rates of electricity price inflation this represents a good long-term investment for Guernsey’s public. There are clear challenges associated with an intermittent generator such as offshore wind, as discussed previously, which de-values this generation slightly but an investment in 2020 would still be viable.

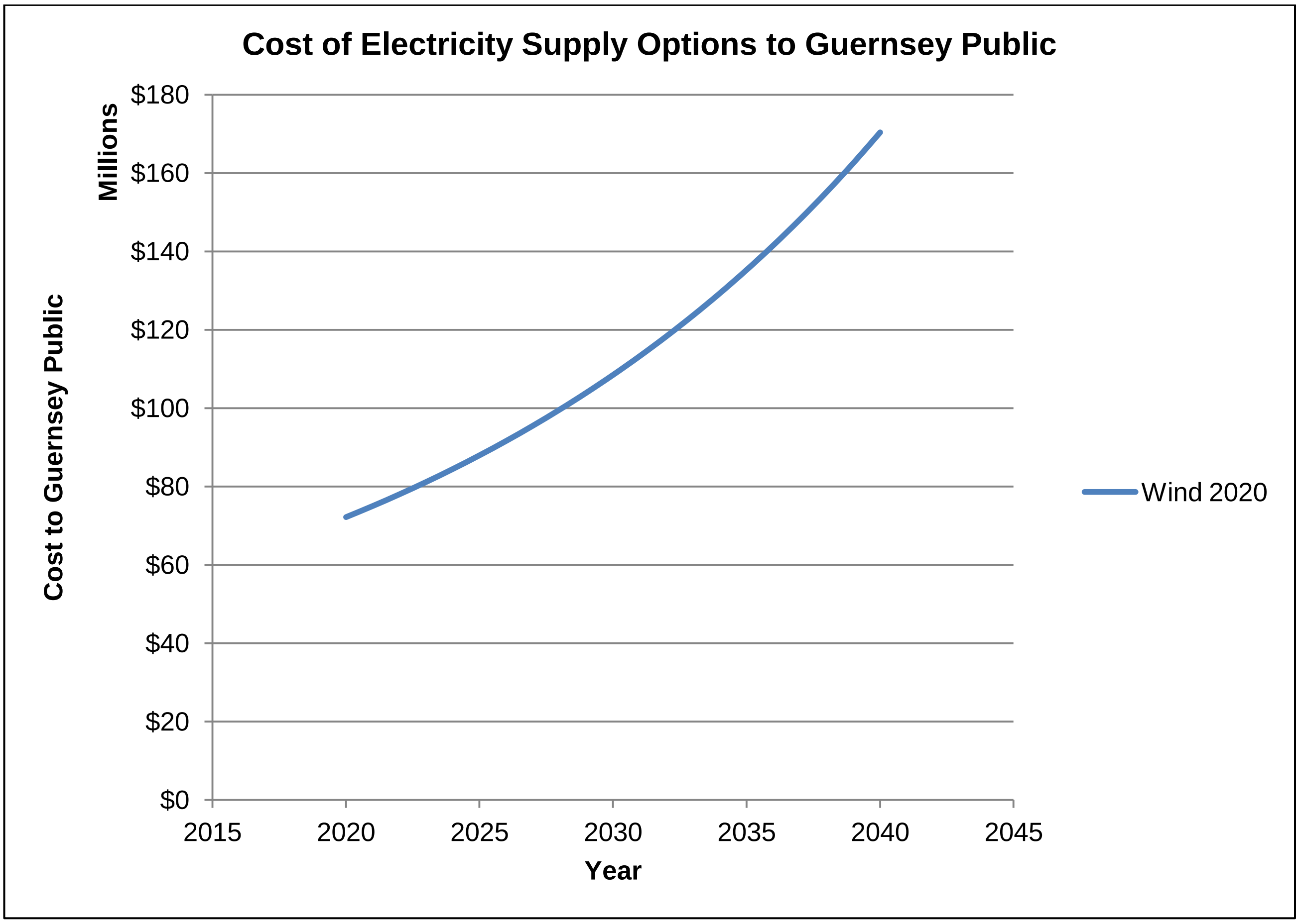

Figure 12:4 - Cost of Electricity Supply Options to Guernsey Public

12.3.3 Conclusions and Recommendation

There are numerous considerations and assumptions that these projections are based on and many factors that would change the viability of the non-export scenario. Energy price rise is the biggest factor and this is highly susceptible to frequent and substantial fluctuations, which need to be taken into account when considering the next section.

It is clear that due to the small size and population of Guernsey that any self-funded deployment would be a significant financial undertaking and would result in one of the most significant £/capita development programmes anywhere in the world. Although offshore wind may well prove the most feasible and profitable solution in the short term, the overriding advantages stemming from tidal energies predictability adds to the argument for tidal technologies. In the absence of legally binding targets the prolonged development timeframes may prove acceptable.

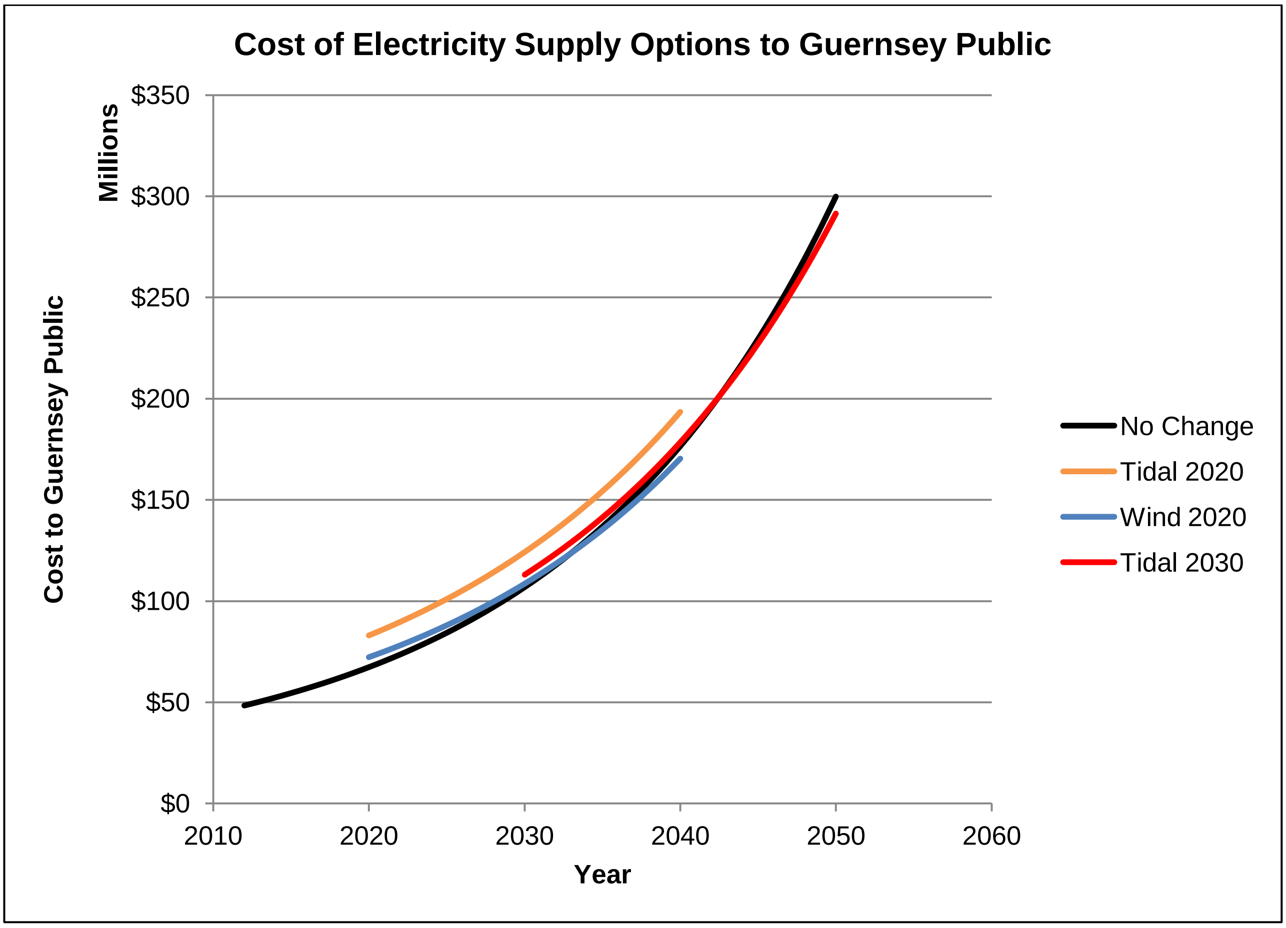

Figure 12:5 - Cost of Electricity Supply Options to Guernsey Public

Currently the ‘take or pay’ contract (see Section 3.5 - Interconnector) Guernsey Electricity has with EDF for imported electricity means that a 30MW development prior to the contract end in 2023 is likely to be rendered unfeasible. This is due to the contract committing Guernsey to pay for 16MW at all times. However, a staged build up to 2023 may be viable. This could be looked at as a future study. GEL have entered into a long term contract for purchasing electricity from France from 2013 – 2023. Despite the name the “take or pay” element of this contract is not seen as a barrier to renewable development before 2023 because although it does set out that GEL should “take” or purchase some electricity from France there is still sufficient flexibility available to GEL to allow some on-island generation and to sell some electricity back into the market or to Jersey. This will allow on-island renewable generation in this period.

If Guernsey wishes to achieve renewables capacity in the immediate future without use of an outside subsidy, offshore wind is the most financially feasible option currently available. The intermittent and unpredictable nature will result in a higher cost to run backup generation at times, however not excessively.

The substantial advantages of tidal power would mean that viability in 2026 could be reasoned. However, more effective modelling and predictions need to be made to assess this. The drawbacks with tidal power lie in the immaturity of the technology, a single leading technology hasn't been established as of yet and there are still no proven tidal array projects.

RET and the States of Guernsey will need to look fully into whether such a route is appropriate and if the substantial benefits of becoming an early adopter can be reasoned for against such a cost. One of the greatest enablers for such a scenario would be the development of energy storage capacity.

12.4 Scenario 3: Export

Scenario 3 assumes that export is possible to a European country, with the primary options being either France or the UK. It is also assumed Guernsey can gain revenue from the export countries support mechanism. Currently this is not possible without a change in the UK or French energy policy.

There are extensive challenges and consideration as to if and how this would work, with the benefits for selling to either country being weighed up.

UK

Currently a sales agreement with the UK would be the most financially desirable option with its current support for offshore technology. Under the proposed support of five Renewable Obligation Certificates (ROC) (~£200/MWh) for tidal or wave technology and two ROCs (~£80/MWh) for offshore wind then development, from an economic perspective, would be possible under a much reduced timeframe. The timeframes for development clearly mean that ROCs will no longer be the mechanism of support when sites are developed however, it is anticipated that the Contract For Difference (CFD) scheme will provide similar levels of support.

The additional subsidy and use of ROCs makes offshore wind deployment for sale to the UK feasible immediately, depending on the method by which export is to be achieved.

France

Exporting to France seems a much more obvious answer especially considering the existing infrastructure. However, it has the same challenges in setting up any arrangement and also provides much less in the way of subsidy.

The available rates for the proposed installed technologies are shown below:

- Offshore Wind: €130/MWh (~£105/MWh)
- Wave/Tidal: €150/MWh (~£121/MWh)

Scenario 3 assumes that maximum capacities for offshore wind, tidal and wave are installed and the electricity exported to France. Capacities are largely dependent on the state of the technology and available infrastructure; these variables are described in detail within the technologies' respective sections.

12.4.1 Offshore Wind

Offshore wind has a combined maximum installed capacity of 390 MW from four sites, with a predicted generating capacity of 1500 GWh/year. This would be based on the four sites outlined in Section 7 - Offshore Wind.

12.4.2 Tidal Power

The main tidal resource is found in two sites, the Big Russel and South Sark. The Big Russel has a maximum installed capacity of 202MW whilst South Sark has an installed capacity of 403 MW. The combined capacities are 605MW with a predicted generating capacity of 1316GWh/year. (See Section 5 - Tidal)

12.4.3 Wave

As wave energy technology is relatively immature in comparison to wind, there was a limited range of available devices that have been proven to work. The Pelamis has undergone extensive testing and after a device was installed and connected to the Portuguese grid it was seen as the market leader in the wave energy sector. With an array of Pelamis devices within the three-mile territorial limit the maximum installed capacity was given as 27.75MW and a predicted generating capacity of 40.58 GWh/year was calculated, see Section 6 - Wave.

12.4.4 Conclusions and Recommendation

Exporting renewable electricity is perhaps the most exciting and financially rewarding strategy if appropriate agreements can be reached. It is clear that under Scenario 3, revenue will be generated from the sale of electricity to primarily France or the UK, although other countries could be considered. There are extensive challenges and consideration as to if and how this would work, with the benefits for selling to either country being weighed up.

An effective way of accessing the subsidy of either country needs to be achieved if any substantial deployment programme is to take place. Under an export model, uptake of technology can be potentially achieved earlier, especially under current UK subsidies. If these agreements can be achieved then Guernsey could well be on its way to becoming a leading green energy supplier and providing itself with a secure and profitable generation portfolio.

The possibility and implications of acquiring such an agreement require detailed research with a wide range of possible variations.

If Guernsey manages to gain access to a market that could give the generator an attractive tariff, above the average market electricity price, it can make all renewable energy technologies considerably more viable in comparison to a ‘no subsidy’ scenario. Deployment rates will be considerably reduced if a financial tariff could not be accessed. As detailed in the economics for Scenario 2, without a subsidy offshore wind will become financially viable in 2019. This date could be greatly reduced under a regime similar to the UK’s ROC arrangement. Once a proven, secure payback is achieved for any of the technologies, funding will become considerably easier to secure.

This scenario is the most attractive of the three in respect to energy security, energy diversity and as a financial structure. As well as these advantages it also allows Guernsey play its part in lowering the UKs emissions target under the Kyoto Protocol.

13 RECOMMENDATIONS

Below are listed the key recommendations from this report. Using these recommendations, further projects can be formed to help develop upon the work and research that has already been carried out for RET. For further explanation, see the page number associated with each recommendation.

Tidal

1. Obtain empirical data for tidal currents around Guernsey; especially in the areas of significant resource identified in this report – the Big Russel and South East of Sark (p31);
2. Further investigate the development of a commercial R&D opportunity in Guernsey's waters (p31);
    a. A more detailed assessment of the potential sites will be required, in addition to the empirical data such as tidal velocities and up to date bathymetry measurements;
    b. Initial contact with developers to gauge interest in this project;
3. Obtain accurate and more detailed bathymetric data for the territorial waters surrounding Guernsey (p31).

Wave

4. Obtain more detailed bathymetric data (p33);
5. Develop upon the initial wave resource assessment carried out (p45);
    a. Use currently deployed devices to obtain resource data, such as the Channel Light Vessel or the Jersey Wave Buoy;
    b. If still indicative of a good resource, deploy Guernsey's own wave buoy or radar wave monitoring system;
    c. Finally, a bathymetric survey plus environmental surveys will be required before testing can begin.

Offshore Wind

6. Further wind speed analysis should be carried out – by combining and correlating data at Chouet Met Mast with Guernsey Airport data the most accurate conclusions can be drawn (p48);
7. The potential visual impacts of an offshore wind farm, particularly a near shore site, should be assessed, especially to gauge the public perception of such a project (p48);
8. The business case for an offshore wind farm should be thought out and investigated – this will include a detailed economic assessment and statistical analysis and modelling (p48);
9. The potential expansion of the limit of territorial waters should be discussed (p48);

10. Further data is required to develop the site selection process – this includes detailed bathymetric measurements, geology data, telecommunications and radar links and aviation data (p67);
11. If any offshore wind sites are selected for further development, an environmental assessment will need to be carried out – this will include environmental impact investigation, geophysical and geotechnical surveys as well as looking at turbine and foundation selection and hydrodynamic and wind loading surveys (p48);
12. For the larger 300MW offshore wind farm site, outside of the 3nm boundary, environmental mapping is required (p65).

Environmental Scoping

13. For all technologies, an environmental scoping study is required (p78);
14. A study should be carried out on the marine mammals around the island to explore their breeding, feeding and migratory habits (p82);
15. A survey of all the species in and around the coastal waters, throughout all the year, should be carried out (p85);
16. Find out the location and structural integrity of shipwrecks around the areas of consideration (p85).

Infrastructure and Integration

17. Finalise the policy mechanisms that would support renewable energy despite the obligation to source the cheapest power (p100);
18. RET should feed into the consultation for the expansion of the harbour (p109);
19. Further investigation into the electrification of the transport network and how this might be approached (p111);
    a. Explore the potential electrification of hire cars and public transport;
    b. Study the potential for electric cars to act as a storage facility for renewable energy.

Development of Public Consultation

20. Engage with the public at all levels and ensure education is at the heart of future plans (p117);
    a. Review how energy and renewable energy is taught in schools;
    b. Use links with universities to further the profile of renewable energy amongst young people;
    c. Use a questionnaire to gain understanding of the current level of knowledge of renewable energy;
    d. Extend ‘Lifelong Learning’ to energy and sustainability

21. Upskill workforce ready for the potential deployment of renewable energy (p117);
22. Develop a working group in the government to identify clear goals for energy and sustainability (p120);
23. Raise energy awareness in public buildings, workplaces and within the community (p120);
24. Adopt a framework for public consultation throughout all stages of renewable energy from pre-project proposal through project proposal, post consultation, project confirmation, construction, project completion and post-project completion (p122).

Scenario Analysis

25. Initially, due to economies of scale, to meet the baseload either tidal or offshore wind should be selected; both may be integrated at a later stage (p130);
    - **a.** Study the benefits and relative timescales of commercialisation, especially for tidal, to make a decision on the optimum choice;
26. Consider a phased approach due to the cable contract until 2023 (p133);
27. An export scenario is the most financially viable, however it requires access to UK or French subsidies – maintain work in obtaining access to these (p136).

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APPENDIX A - Tidal Range

Introduction to tidal range technologies

Tidal range technologies, as opposed to tidal stream devices, utilise the potential difference in head of sea water between low and high tides. In principle, the water accumulated during the high tide is locked behind the sluice gates and released through hydroelectric turbines once the tide retreats and head reaches sufficient height. Potential energy can be extracted both during flood and ebb tides although the last method usually yields better results.

There are two principal technologies currently designed to utilise tidal range resources: tidal barrages and tidal lagoons. Only tidal barrages so far have been developed on a commercial scale – e.g. the 240MW La Rance barrage in Northern France and the 254MW plant in South Korea – although very little is known on the subject. Tidal barrage resembles a dam that spans across a bay or a river estuary. The sluice gates allow the water to move in an out of the enclosed area, directing the flowing water towards the hydroelectric turbines. The issues often raised with respect to tidal barrages are mainly related to the environmental impacts as the structure is likely to have a considerable effect on the bay`s habitat.

Figure A:1 shows the basic components of a tidal barrage.

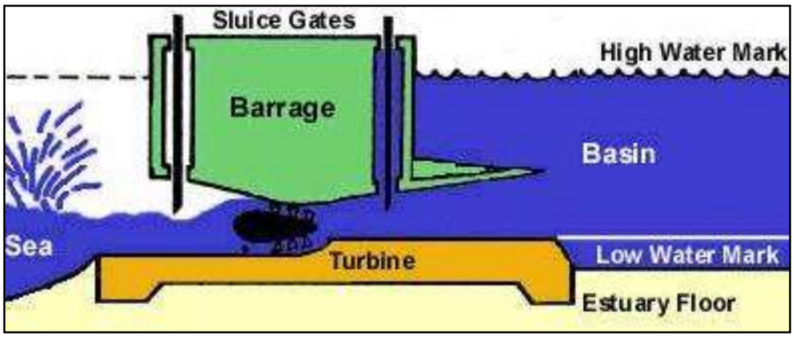

Figure A:1 - basic components of a tidal barrage

Tidal lagoons are based on similar principle as tidal barrages as far as the technology is concerned. The difference lies in the fact that tidal lagoon impound only a proportion of the water in the bay, causing lesser environmental intrusion and offering higher sitting flexibility. Tidal lagoons can also be situated further offshore which could reduce the negative impact on the bay`s habitat and visual amenity. Multi-cell impoundment structures, such as the one pictured in Figure , could represent a tidal range option applicable soon in the future. Increased load factor (about 62%) and longer time of generation adds to the attractiveness of the solution. Each cell can release it potential energy in controlled and scheduled manner, dispatching power in response to demand price signals (source: Tidal Electric)

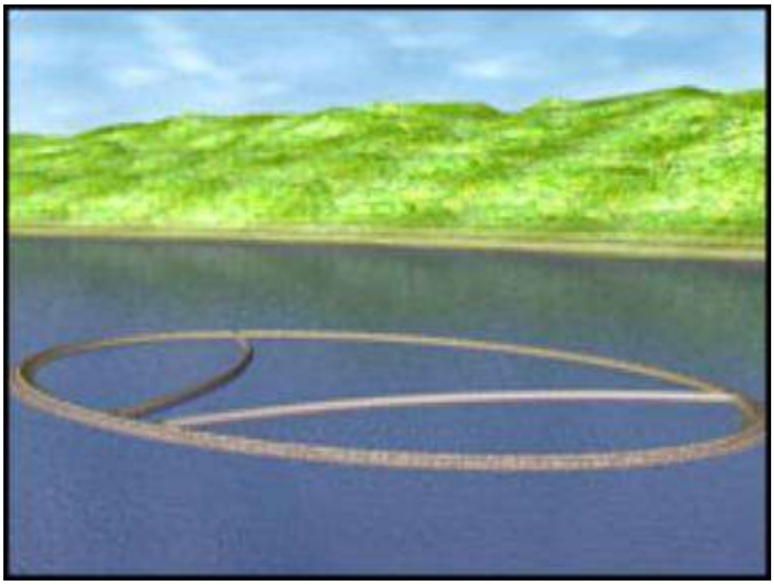

Figure A:2 - Tidal lagoon technology

Tidal range resource at Guernsey

Tidal range resource around Guernsey, although barely mentioned in previous reports, has been briefly assessed using basic equations, GIS mapping and general industry guidance. It should be highlighted, that the resource is significant (up to 8.8 m spring tidal range off the southern coast of Guernsey, 8.2 m in southern bays), yet its exploitation has to be carefully considered. Environmental, visual and social impacts have to be thoroughly assessed and mitigation suggested. Tidal barrage, suggested in the assessment below, is the only proven technology available at the moment. Tidal lagoons or tidal fences, however, could become more optimal and more environmentally benign solutions in decades to come.

Methodology and Findings

The following case study equations have been applied to estimate the tidal range energy potential (Wikipedia, 2012):

Example calculation of tidal power generation

Assumptions:

- The tidal range of tide at a particular place is 32 feet = 10 m (approx)
- The surface of the tidal energy harnessing plant is 9 km² (3 km × 3 km)= 3000 m × 3000 m $= 9 \times 10^6$ m^2
- Density of sea water = 1025.18 kg/m^3

Mass of the sea water = volume of sea water × density of sea water

= (area × tidal range) of water × mass density

$= (9 \times 10^6 \text{ m}^2 \times 10 \text{ m}) \times 1025.18 \text{ kg/m}^3$

$= 92 \times 10^9$ kg (approx)

Potential energy content of the water in the basin at high tide = ½ × area × density × gravitational acceleration × tidal range squared

$= ½ \times 9 \times 10^6$ m^2 × 1025 kg/m^3 × 9.81 m/s^2 × (10 m)^2

$=4.5 \times 10^{12}$ J (approx)

Now we have 2 high tides and 2 low tides every day. At low tide the potential energy is zero.

Therefore the total energy potential per day = Energy for a single high tide × 2

$= 4.5 \times 10^{12}$ J × 2

$= 9 \times 10^{12}$ J

Therefore, the mean power generation potential = Energy generation potential / time in 1 day

$= 9 \times 10^{12}$ J / 86400 s

= 104 MW

Assuming the power conversion efficiency to be 30%: The daily-average power generated = 104 MW * 30%

= 31 MW (approx)

Tidal range values summarised in the Table A:1 were obtained from the provided GIS dataset. "R" value has been calculated and represents the mean tidal range for south cost of Guernsey (Moulin Huet and Petit Bot bays).

Tidal range values for southern bays				
Tide (source: GIS)	value 1	value 2	value 3	R
Neap	3.85	3.88	3.9	
Spring	8	8.05	8.12	
Average	5.925	5.965	6.01	5.967

Table A:1 - Tidal range values for southern bays

Table A:2 contains individual calculations of potential energy, installed capacity and power output for the two specific sites (Moulin Huet and Petit Bot).

Power calculations								Installed cap	30 % eff	12hrs/day
Location	surface A	R (m)	m (kg)	h (m)	PE (J)	E (J)/day	Power (W)	Power (MW)	Inc.eff (MW)	GWh/year
Site 1 (Moulin Huet)	1.057	5.967	6464435833	2.98	1.892E+11	378382822633	4379430.82	4.38	1.31	5.75
Site 2 (Petit Bot)	1.008	5.967	6164760000	2.98	1.804E+11	360841897080	4176410.85	4.18	1.25	5.49
g (gravity)	9.81						total	8.56		11.24
q (density)	1025									

Table A:2 - Calculations of potential energy, installed capacity and power output for the two sites

Figure A:3 indicates the potential locations of tidal barrage/tidal lagoon located on the south coast of Guernsey.

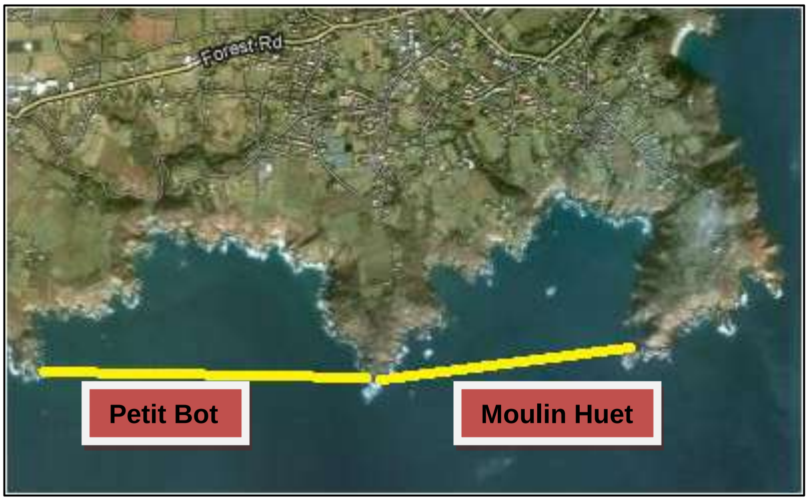

Figure A:3 - the potential locations of tidal barrage/tidal lagoon located on the south coast of Guernsey

Rough Cost Order

The costs of tidal range projects are not well known and understood as of yet. They can vary significantly depending on their design and location. The capital costs are a result of the direct costs added to the habitat compensation costs which increase significantly with the size of the plant and can constitute up to 50% of the total final cost. These can be taken into account in the design and operation of the plant though the costs are likely to be similar to those of conventional designs. These costs are likely to rise in the future in line with the development of coastal regions (CCC, 2011). The sites chosen for the installation of tidal barrages in Guernsey are unlikely to have considerable ecological impacts; hence the maximum proportion of the capital cost represented by habitat compensation is estimated at 20%. Mitigation measures will concern more the tourism industry, especially on the Eastern site.

The direct costs of tidal barrages comprise the costs of civil works (which account for the major part), turbines, electrical connections and site licensing and preparation. The civil works' costs comprise mainly on-site labour, supervision and construction equipment and services as well as construction and installation materials. The purchase of turbines often turns out expensive as the designs usually include more than one; however there is potential for cost reductions in the future through ameliorated production processes. As an example to the cost break down for tidal barrages, a theoretical 2GW plant has been imagined by (CCC, 2011) – see below. The model does not include any major grid reinforcement.

Tidal barrages have a capital cost in the range of £2.8m to £4m per megawatt (see figure below). The most likely value is estimated to be £3.3m/MW and has been included in the model below. It is unclear as to whether this includes any habitat compensation costs; further studies will have to be undertaken on the matter for the sites identified as suitable for tidal barrages in Guernsey. Operational costs represent less than 1% of the capital expenditure, a low proportion equivalent to those of hydropower plants. An overall cost reduction is estimated at 8% by 2040 (CCC 2011).

Tidal barrages have a long lifespan of up to 60 years which is likely to make projects economically viable. However, too little is known on the actual costs linked to tidal barrages and proper scoping measures must be studied and taken into account before any further cost analysis can be carried out. There might be some strong opposition from the tourism industry for the implementation of barrages in the South coast. For all these reasons, no detailed financial analysis has been carried forward and no further considerations have been made on the subject for this report; however, tidal barrages remain an option for Guernsey to explore and further analysis could be undertaken based on the tidal stream model once all the parameters are known.

Capacity	Annual Energy Generation
MW	MWh/yr
8.56	11240

Total Capital Cost	
k£/MW	k£
3300	28000

Fixed Annual O&M Costs		Variable Annual O&M Costs	
%	k£	£/MWh	k£
0.9	254	0.2	2.248

Capital Cost Break Down (based on figures for hypothetical 2GW UK barrage)		
Component	%	k£
Site prep / licensing	12	3390
Turbines	27	7600
Civil Works	53	15000
Electrical Works	3	900
Balance of Plant	5	1400
Total	100	28000

Conclusions

As outlined above, tidal range resource is significant and its utilisation could become a part of the Guernsey`s renewable energy strategy. A detailed assessment of the resource potential would be required to confirm the findings. So far, the brief assessment has identified two bays located on the south coast of Guernsey (Moulin Huet and Petit Bot) which could potentially accommodate about 4.4 and 4.2 MW installed capacity, yielding 11.24 GWh/year in total. Careful analysis of environmental, social and visual impacts has to be undertaken and suitable mitigation suggested.

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APPENDIX B - Offshore Wind Farm Cost Breakdown

Cost Item	Details
Environmental Surveys	• Benthic surveys, pelagic surveys, ornithological surveys, sea mammal environment surveys • Ornithological and mammal surveying craft, onshore environmental surveys
Coastal Process Surveys	• From the shore and on the seabed
MET Station Surveys	• MET station structure • MET station sensors • MET station auxiliary systems
Sea Bed Surveys	• Geophysical surveys • Geophysical survey vessels • Geotechnical surveys • Geotechnical survey vessels
Front End Engineering Design Studies	• By an experienced consultancy/manufacturer
Human Impact Studies	• Questionnaires • Tourism Research • Job Creation
Nacelle	• Nacelle bedplate • Main bearing • Main shaft • Gearbox • Generator • Power take-off • Control system • Yaw system • Yaw bearing • Nacelle Auxiliary systems • Nacelle cover • Small engineering components • Fasteners • Conditioning monitoring system
Rotor	• Blades – Structural composite materials – Blade Root – Lightning protection – Hub Casting – Blade bearings – Pitch system – Hydraulic pitch system – Electric pitch system – Spinner – Rotor auxiliary systems – Fabricated steel components

Tower	• Steel • Personnel access and survival equipment • Tuned damper • Electrical system • Tower internal lighting
Balance of Plant	• Electrical systems
Cables	• Export cable • Array cable • Cable protection
Turbine Foundation	• Foundation structure • Transition Piece • Crew access system • J tube • Scour protection • Sacrificial Anode
Offshore substation	• Electrical system • Facilities • Structure
Onshore substation	• If upgrade is required, where and what impacts this may have on the local area

(The Crown Estate, 2010)

APPENDIX C - Domestic Solar PV 4kWp Financial Appraisal

Life of Project (years)	25
Annual Production (First Year kWh)	4,010
Utilisation of the Free Electricity	50%
Annual Production Decrease	1%
Revenue Generation Tariff (£)	0.00
Revenue Export Tariff (£)	0.072
Energy Savings (£)	0.1500
Energy Price Increase	6%
Installation Costs (£)	8,500
Inflation	3.00%
New Inverter Year 10 and 20 (£)	1,000

Year End	Present	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	
End of year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
Production (kWh)		4010	3970	3930	3890	3850	3810	3769	3729	3689	3649	3609	3569	3529	3489	3449	3409	3368	3328	3288	3248	3208	3168	3128	3088	3048	
Energy Price		0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.43	0.45	0.48	0.51	0.54	0.57	0.61	
Generation Tariff		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Export Tariff		0.07	0.07	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.13	0.13	0.14	0.14	0.15	

Cash In	8,500

Income																											
Revenue	0	445	463	481	500	520	541	563	586	609	634	659	686	714	743	773	804	836	870	905	942	980	1,020	1,061	1,104	1,148	
Outgoings																											
CAPEX	8,500																										
Operating Costs/Replacement Parts	0	0	0	0	0	0	0	0	0	0	1,305	0	0	0	0	0	0	0	0	0	1,754	0	0	0	0	0	
Cash Flow	-8500.00	445	463	481	500	520	541	563	586	609	-671	659	686	714	743	773	804	836	870	905	-811	980	1,020	1,061	1,104	1,148	15,531
Cumulative Cash Flow	-8500.00	-8,055	-7,592	-7,111	-6,610	-6,090	-5,549	-4,985	-4,400	-3,791	-4,462	-3,802	-3,116	-2,403	-1,660	-887	-84	753	1,623	2,528	1,717	2,697	3,717	4,778	5,882	7,031	7,031
Discount Rate	0.05																										NPV
Discounted Cash Flow	-8500.00	425	421	418	415	412	409	406	403	400	-420	394	391	388	385	382	380	377	374	372	-318	366	364	361	358	356	-283
Discounted Cumulative Cash Flow	-8500.00	-8075	-7654	-7236	-6821	-6409	-6001	-5595	-5193	-4793	-5213	-4819	-4428	-4040	-3655	-3273	-2893	-2516	-2142	-1771	-2088	-1722	-1358	-997	-639	-283	-283

NPV	-£283.47

APPENDIX D - Solar Thermal 3m^2 Financial Appraisal (Gas)

Life of Project (years)	25
Annual Production (First Year kWh)	1,438
Utilisation of the Free Electricity	100%
Annual Production Decrease	0%
Revenue Generation Tariff (£)	0.00
Revenue Export Tariff (£)	0.000
Energy Savings (£)	0.1200
Energy Price Increase	6%
Installation Costs (£)	4,000
Inflation	3.00%

Year End	Present	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	
End of year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
Production (kWh)		1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	
Energy Price		0.12	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.26	0.27	0.29	0.30	0.32	0.34	0.36	0.38	0.41	0.43	0.46	0.49	
Generation Tariff		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Export Tariff		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Cash In	4,000																										
Income																											
Revenue	0	173	183	194	206	218	231	245	259	275	292	309	328	347	368	390	414	438	465	493	522	553	587	622	659	699	
Outgoings																											
CAPEX	4,000																										
Operating Costs/Replacement Parts	45		180		180		180		180		180		180		180		180		180		180		180		180		
Cash Flow	-4000.00	173	3	194	26	218	51	245	79	275	112	309	148	347	188	390	234	438	285	493	342	553	407	622	479	699	7,307
Cumulative Cash Flow	-4000.00	-3,827	-3,825	-3,631	-3,605	-3,387	-3,336	-3,092	-3,012	-2,737	-2,626	-2,316	-2,169	-1,822	-1,634	-1,243	-1,010	-572	-287	206	548	1,101	1,508	2,130	2,609	3,307	3,307
Discount Rate	0.05																										NPV
Discounted Cash Flow	-4000.00	165	3	168	21	172	38	176	55	180	70	185	84	189	98	193	110	198	122	202	134	207	145	212	156	216	-502
Discounted Cumulative Cash Flow	-4000.00	-3835	-3833	-3664	-3643	-3471	-3432	-3256	-3201	-3021	-2951	-2767	-2683	-2494	-2396	-2203	-2093	-1895	-1773	-1571	-1437	-1230	-1085	-874	-718	-502	-502
NVP	-£501.76																										

APPENDIX E - Solar Thermal 3m^2 Financial Appraisal (Electricity)

Life of Project (years)	25
Annual Production (First Year kWh)	1,438
Utilisation of the Free Electricity	100%
Annual Production Decrease	0%
Revenue Generation Tariff (£)	0.00
Revenue Export Tariff (£)	0.000
Energy Savings (£)	0.1500
Energy Price Increase	6%
Installation Costs (£)	4,000
Inflation	3.00%

Year End	Present	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	
End of year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Total
Production (kWh)		1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	1,438	
Energy Price		0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.25	0.27	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.43	0.45	0.48	0.51	0.54	0.57	0.61	
Generation Tariff		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Export Tariff		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Cash In	4,000																										
Income																											
Revenue	0	216	229	242	257	272	289	306	324	344	364	386	409	434	460	488	517	548	581	616	653	692	733	777	824	873	
Outgoings																											
CAPEX	4,000																										
Operating Costs/Replacement Parts	45		180		180		180		180		180		180		180		180		180		180		180		180		
Cash Flow	-4000.00	216	49	242	77	272	109	306	144	344	184	386	229	434	280	488	337	548	401	616	473	692	553	777	644	873	9,674
Cumulative Cash Flow	-4000.00	-3,784	-3,736	-3,493	-3,416	-3,144	-3,035	-2,729	-2,585	-2,241	-2,057	-1,671	-1,441	-1,007	-727	-239	98	646	1,046	1,662	2,135	2,826	3,380	4,157	4,801	5,674	5,674
Discount Rate	0.05																										NPV
Discounted Cash Flow	-4000.00	206	44	211	64	215	82	220	99	225	115	231	131	236	145	241	159	247	172	253	185	258	197	264	209	270	682
Discounted Cumulative Cash Flow	-4000.00	-3794	-3750	-3539	-3476	-3260	-3178	-2958	-2859	-2633	-2518	-2287	-2156	-1920	-1775	-1534	-1375	-1128	-955	-703	-518	-259	-62	202	411	682	682
NVP	£681.98																										

APPENDIX F - Base Load Modelling

If a stochastic process can be assumed to be random and stationary then a static stochastic model based on time-invariant probability distributions may be employed (Montgomery & Runger, 1994). If such assumptions are invalid then dynamic stochastic models may be employed (Box & Jenkins, 1970), or a model can be constructed piece-wise using multiple static distributions for each period of time that the process can be assumed to random and stationary (Brinkworth, 1977).

Clearly the demand for electricity on Guernsey is neither random, nor stationary, since daily load profiles follow characteristic diurnal variation patterns, loading levels vary periodically throughout the year, and there are also long-term trends in electricity consumption (Guernsey Electricity Ltd., 2005).

Long-term trends in the loading data can be identified through least squares methods (Amato at al, 1986) and through knowledge of loading changes to the network. Once long-term trends are identified they can then be used to normalise the loading data to result in a time-series that is stable in the mean over long periods.

The seasonal variation in electricity demands and RES-E output can be handled by assuming the processes to be stationary over the period of one month, modelling each process using a series of static probability distributions - one for each month, or the seasonal variation can be modelled using a periodic function which is used to evaluate the stochastic residuals of the deterministic seasonal model (Amato at al, 1986).

It is possible to apply the assumption that the demand process is diurnally random, since the tidal, wave and wind processes can be assumed to be uncorrelated to the diurnal variation in electricity demand - which is determined largely through behavioural patterns of the consumer.

Given the monthly empirical probability density functions for RES-E generation, , and for electricity demand, , the joint probability of coincidental generation, g, and loading level, l, for month (or appropriate period), m, is given by:

The aggregated joint coincidental utilisation outcomes of each generation and loading level can then be calculated to estimate the amount of RES-E generation that can be utilised over each month of length, d:

This method may be used to derive a stochastic model of RES-E generation and loading level coincidence on the Guernsey grid with financial outputs, but will require the following cases to be considered in the calculation of RES-E utilisation - rather than the simple case presented here - since each case has an associated financial value:

- Total electricity imports displaced through RES-E
- Total local electricity generation displaced through RES-E
- Total RES-E output that can be exported to Jersey - or other consumers - (As discussed in section 2.2, Beyond the Base-Case)

Historical and projected electricity grid loading data is not available for the present study so the aforementioned model cannot be evaluated.

APPENDIX G - Electric Car Storage Potential

Car	Mercedes A Class	
Storage	36	kWh
50% storage	18	kWh
90% charging efficiency	16.2	kWh
Total Guernsey Fleet	1020	MWh
Quarter Guernsey Fleet	255	MWh
Annual Electricity Demand	400	GWh
Average Daily Demand	1.10	GWh
Average Daily Demand	1100	MWh

APPENDIX H - Renewable Energy Questionnaire for Secondary Schools

Renewable Energy Questionnaire

***1. Which year are you in?**

- ◯ Year 7
- ◯ Year 8
- ◯ Year 9
- ◯ Year 10
- ◯ Year 11

2. Please tick the appropriate answer from the following statement:
The amount of energy in the universe is:

- ◯ Increasing
- ◯ Staying constant
- ◯ Decreasing

3. Which of the following are renewable energy sources?

- ☐ Hydropower
- ☐ Oil
- ☐ Tidal
- ☐ Wind
- ☐ Solar
- ☐ Coal
- ☐ Geothermal
- ☐ Natural Gas
- ☐ Wave
- ☐ Nuclear

4. Name two advantages of renewable energy sources over others:

1) __________

2) __________

5. Which renewable energy source would be the most efficient in a warmer country such as Spain or India? Explain your answer

____

6. What do you know about renewable energy in Guernsey and the Channel Islands?

____