Identification of Minimum Impact Sites for Offshore Wind Development in Guernsey's Territorial Waters

by

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Abstract

The Bailiwick of Guernsey is currently heavily reliant on a combination of electricity importation from France and on-island diesel generation, between which, the economic balance varies daily for demand and annually depending on fluctuations in the price of oil.

The States of Guernsey are committed to reducing Guernsey's carbon dioxide emissions by 30% on 1990 levels by 2020 and by 80% on 1990 levels by 2050. In order to meet these targets the States are looking towards an energy portfolio that includes Marine Renewable Energy (MRE).

Working in collaboration with Guernsey's Renewable Energy Team this project addresses a requirement for preliminary mapping for MRE. By combining the use of Arc GIS software and Marxan (a freely available environmental Decision Support Software (DST) which has been adapted for use in this scenario) a planning model has been created that assimilates device limitations, device/receptor interactions and resource requirements in providing an optimal solution to the planning problem of 'energy at minimal impact'.

Due to project constraints and the industrial sensitivity of wave and tidal stream device performance specifications, the planning process was applied solely to the Vestas 112-3.0MW offshore wind turbine. Outputs are successful in providing general minimal impact areas for the potential development of offshore wind farms and the planning framework can be applied to wave and tidal stream technologies as better resource information and device performance specifications become available.

Acknowledgements

I would like to thank Guernsey RET's Mat Desforges and Peter Barnes for their guidance, data and hospitality and also Guernsey's Sea Fisheries Department for their input and time.

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Abbreviations

ABPMER	ABP Marine Environmental Research
BAP	Biodiversity Action Plan
BERR	Department of Business, Enterprise and Regulatory Reform
BGS	British Geological Survey
BLM	Boundary Length Modifier
DECC	Department of Energy and Climate Change
DST	Decision Support Tool
ERP	Energy Resource Plan
GEBCO	General Bathymetric Chart of the Oceans
GEL	Guernsey Electric Limited
GIS	Geographic information System
GREC	Guernsey Renewable Energy Commission
GWh	Gigawatt-hours
HMRG	Her Majesty's Receiver General
LAT	Lowest Astronomical Tide
MaRS	Marine Resource System

MCT	Marine Current Turbines
MMA	Marine Management Area
MMO	Marine Management Organisation
MRE	Marine Renewable Energy
MSP	Marine Spatial Plan
MW	Megawatts
nm	Nautical Mile
ORRAD	Offshore Renewables Resource Assessment and Development Project
PINS	Planning Inspectorate
POL HRCS	Proudman Oceanographic Laboratory High Resolution Continental Shelf Tidal Model
PRIMaRE	Peninsula Research Institute for Marine Renewable Energy
PU	Planning Unit
REA	Regional Environmental Assessment
RET	Renewable Energy Team
SAC	Special Area of Conservation
SAR	Search and Rescue
SEA	Strategic Environmental Assessment
SPF	Species Penalty Factor
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WGS 84	World Geodetic System 1984

1. Introduction

The Bailiwick of Guernsey, situated in the English Channel, 30 miles west of the French Normandy coast is a British Crown Dependency. It is not part of the UK and while it participates in the Common Travel Area it is not part of the European Union.

The Government of Guernsey, with a dual mission to tackle climate change through reducing its greenhouse gas emissions and improve its energy security, established the shadow Guernsey Renewable Energy Commission (GREC), now known as the Renewable Energy Team (RET) which in collaboration with several UK Universities seeks to expand its knowledge of Guernsey's Renewable Resources to influence future energy and policy strategy.

Guernsey is currently heavily reliant on the importation of electricity from France via the Jersey interconnector cable and the importation of oil to fuel the diesel generation at the Vale Power Station. Guernsey Electric Limited (GEL) operates the Vale Power Station for on-island generation. GEL have a licence condition to produce electricity at the lowest cost and the economic balance between importing electricity and on-island generation varies daily depending on demand and annually depending on fluctuations in the price of oil. In 2010 figures showed that an average of 71% of Guernsey's electricity had been provided by the interconnect cable since it was made operational (Guernsey Electricity Limited, 2010).

GEL state that their preferred means of providing electricity is wholly through the interconnect cable. The electricity from the European grid accesses electricity that has been generated carbon free or through low carbon sources, such as nuclear power and renewable energy. This contributes towards Guernsey's target of lowering CO_2 emissions by 30% on 1990 levels by 2020. Vale Power Stations' two diesel generators have surpassed their normally acceptable 25 year life time but due to their intermittent running schedule GEL do not see this as a major issue. Rising electricity demand on Guernsey, however, will leave the Bailiwick increasingly dependent on outside sources if the situation remains the same. GEL plan to increase on-island capacity and have investigated tidal power and the feasibility of an island based renewables industry. GEL did have shares in Marine Current Turbines' (MCT) Seagen, a leading tidal turbine device until recently bought out by Siemens.

Guernsey's energy dependency was highlighted this year by the failure of the Jersey interconnector cable. The cable was damaged on the 29th April and at the time of writing is still not repaired due to the time taken to acquire the vessel and equipment necessary to identify the fault and carry out the repair operation (Guernsey Electricity Limited, 2012). Due to a second fault in one of the France-Jersey interconnect cables even after repair of the Jersey interconnect cable, maximum importation will be restricted to 16MW when Guernsey's maximum demand can be up to 80MW (BBC, 2012). At the time of writing Guernsey is relying solely on diesel generation.

Guernsey RET is working in collaboration with several universities in developing their knowledge of their marine renewable environment. Knowledge gaps have been identified and this report addresses a requirement set by RET of preliminary mapping of suitable sites for MRE with regard to constraints in Guernsey's waters that may affect development. The original requirement of preliminary mapping has evolved to encompass a planning process that can be applied to specific MRE technologies. This project looks primarily at offshore wind in developing a planning process that could later be applied to other MRE technologies.

1.1. Project Aim

To identify sites of accessible resource for offshore wind development with optimal minimum impact to existing environmental and socio-economic receptors within Guernsey's Territorial Waters.

1.2. Objectives

1. *Undertake sensitivity analysis on constraints and develop parameters for Marxan Decision Support Tool (DST) to select optimum minimal impact sites for offshore wind development. Ensure process is repeatable for other MRE technologies.*

   'Optimal sites' are determined based on the following factors:

- Accessible Resource: An extractable resource within the environmental limits of technology being deployed or planned for deployment within the period to 2015.
- Sufficient Resource: The resource meets the device manufacturers' estimates for minimum requirement.
- Least Constraint: Preferential selection will be given to sites that least impact upon environmental and socio-economic receptors.

2. *Using geological data suggest potential export cable routes between optimal sites and identified grid connection points.*
3. *Identify information shortfall and make proposals for field survey.*

1.3. Report Structure

This report initially reviews and compiles background information regarding existing information on Guernsey's planning area, sources of relevant information and planning processes and tools that could be used in the planning process. It goes on to develop a planning process detailed in the methodology that could be applied to individual MRE devices and takes into consideration interaction between device and socio-economic and environmental receptors. Results include output mapping created using GIS that present spatial solutions to the planning problem of offshore wind development and recommended cable routes. The viability of these solutions and the planning process is then discussed and comparisons made. The report concludes with the overarching views on the effectiveness of the planning process and states where information shortfall exists and how the process could be improved.

2. Background

2.1. Need for Renewable Energy in a Policy Context

In the broader context, in spring 2007 member States of the EU agreed to a climate and energy package which signalled the importance of an integrated and long term approach to tackling energy and climate change issues (DECC, 2009). The package includes a target for 20% of the EU's energy consumption from renewable sources by 2020. The UK adopted a legally binding target of 15% of energy consumption to come from renewable energy by 2020. The UK sees this target as a key element of their response to the growing threat of serious climate change and to the need to provide secure, affordable, reliable and sustainable sources of energy into the future (DECC, 2009).

The Bailiwick of Guernsey is not governed by EU or UK legislation however has taken similar steps in adopting energy and emissions targets for 2020 and beyond. In November 2011 the States of Guernsey implemented the Guernsey Energy Resource Plan (ERP) (States of Guernsey, 2011). The ERP is based on an energy vision by 2020 whereby:

- There will be a gradual decarbonisation of Guernsey's energy generation;
- There will be a diversification of energy generation between low carbon and renewables;
- The States will continue to provide a sustainable and secure energy supply for Guernsey; and
- There will be greater transparency in energy decision making to all stakeholders (States of Guernsey, 2011).

Guernsey's maximum electricity demand has shown general growth over the last twenty years, markedly since 2006. It is forecast to continue to steadily grow (Figure 1). The ERP states that 'Energy has become an essential commodity for the economic and social wellbeing of the Island and we (States of Guernsey) need to provide affordable security and resilience of our energy supplies' (States of Guernsey, 2011).

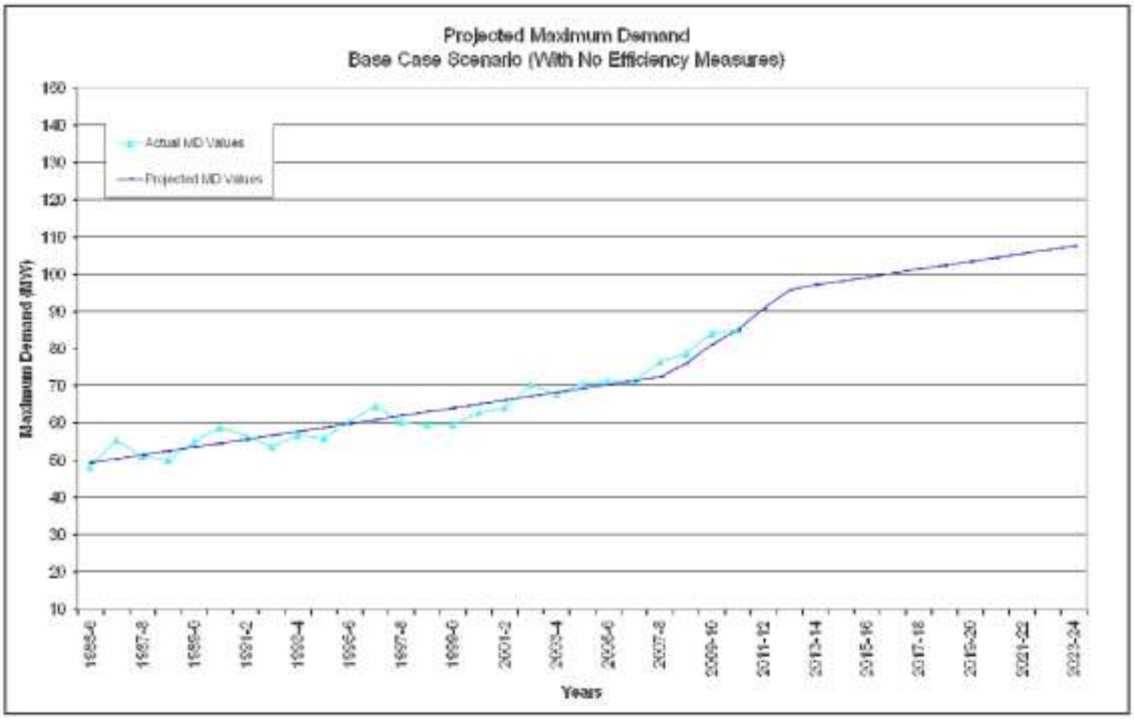


Figure 1: Maximum electricity demand and predictions: source GEL (States of Guernsey, 2011)

The three strategic objectives set out by the ERP are:

1. Maintaining the safety, security, affordability and sustainability of the Island's energy supplies.
2. Using energy wisely, efficiently and not wasting it.
3. Reducing environmental impacts locally as part of our contribution to international initiatives as part of the global community (States of Guernsey, 2011).

Section 9.11. of the ERP states:

'In terms of emission targets the States remain committed to the following targets: to reduce Guernsey's carbon dioxide emissions by 30% on 1990 levels by 2020 (in line with UK targets); and to reduce Guernsey's carbon dioxide emissions by 80% on 1990 levels by 2050' (States of Guernsey, 2011)

The States stance on renewable energy is detailed in section 9.13. of the ERP. So far efforts have focused on developing the framework for licensing MRE technologies, primarily tidal stream technology. However, the realisation that tidal energy will not be commercially viable for at least 5 years has the States looking towards all other renewable options and a potential energy portfolio including offshore wind and wave power (States of Guernsey, 2011).

2.2. Marine Renewable Energy (MRE)

MRE can be split into the broad categories of Offshore Wind, Tidal Stream and Wave energy. Offshore wind energy has been selected as the primary generating technology for this study given its more advanced state.

Offshore Wind

Winds are steadier and stronger offshore than on land, so offshore wind farms deliver a higher power per unit area than onshore wind farms (MacKay, 2009).

The offshore wind industry is still in its infancy as developers strive to de-risk the technology, lower costs and make offshore wind a competitive energy generating technology. In the moving of a well-established technology offshore the industry has encountered several hurdles but also encountered greater freedoms in layout and design. Offshore turbines are generally much larger than their onshore counterparts as there are less transport issues in construction. This is a considerable benefit as power capture is proportional to the rotor area (Twiddel, 2009). The current commercial offshore wind turbine is a 3 bladed horizontal axis wind turbine (HAWT) and although other designs exist such as vertical axis wind turbines (VAWT) and floating designs, which may be a thing of the future, none are yet at a commercial scale.

Development can be divided into shallow and deep offshore wind; shallow depth is considered less than 25-30m. Deep offshore wind is not presently considered economically feasible (MacKay, 2009).

Wave and Tidal Stream

The wave and tidal sector extracts energy from naturally occurring, abundant and clean resources. Globally, it is estimated that there is 180TWh[2] of economically accessible tidal energy and over 500TWh of economically accessible wave energy available annually. The tidal resource is heavily dependent on local seabed geometry, and wave energy relies on areas of sea where the wind can interact with the sea surface over long distances (Adams, 2012).

In the UK wave and tidal stream technologies are moving towards commercial viability, as a result there are now proposals for the first device arrays as developers seek to develop multi-megawatt projects (Adams, 2012). Although there are fore runners in device development there is a large variation in design and as of yet no lead device in either wave or tidal stream has been identified.

2.3. RET Progress in Identifying Marine Resources and Constraints

2.3.1. Halcrow Pre-feasibility Technical Report

In 2009 GREC commissioned Halcrow Group Ltd to provide a brief study into the islands of Guernsey, Herm and Sark with regard to their potential for their development of MRE (Croll, 2009). The report provided technical background for the Regional Environmental Assessment (see 2.3.2). It concluded that the seas around the islands have potential commercially exploitable wave and tidal resources. The report provides a good overview of cable landing options in Guernsey.

2.3.2. Guernsey's Regional Environmental Assessment (REA)

In the UK it is a cross boundary legal requirement to carry out a Strategic Environmental Assessment (SEA) for certain spatial plans and development programmes. Article 3 section 2 (a) of Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment states 'an environmental assessment shall be carried out for all plans and programmes prepared for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use (The European Parliment and the Council of the European Union, 2001). This is subject to the Member State determining on a local level whether the development will have a significant environmental impact.

The Channel Islands, as a Crown dependency, fall outside the legislation of the UK and EU and no SEA legislative requirement exists. The SEA is a useful tool in identifying, documenting and monitoring environmental risk. Guernsey have taken the basic principles and framework of the SEA and completed a Regional Environmental Assessment (REA). It is from this REA that the majority of mapping corresponding with MRE and related constraints in Guernsey's waters originates.

The REA was undertaken to provide a strategic assessment of the potential effects that marine renewable energy devices (wave, tidal stream and offshore wind) will have on the environment of Guernsey, Herm and Sark. The main study area of the assessment was within the 3 nautical mile limit. The REA identifies, evaluates and describes the likely significant effects, both positive and negative, of developing marine renewable energy (GREC, 2010). The REA does not solely look at environmental impacts but also considers impacts on the sea and sea-bed, human beings and their existing health, transportation, resources, industry, culture and landscapes (GREC, 2010). The extent of the REA draws together much of the data required to identify spatial constraints and the RET have created an initial constraints map of the study area within the 3 nautical mile limit (Figure 2). The constraints mapping is a valuable resource in the preliminary mapping of MRE though its scope needs to be expanded to the 12 mile nautical limit, assuming Guernsey and Sark are successful in their plea to extend their jurisdiction (see section 32), and will require further compilation of data relevant to spatial conflict beyond the 3 nautical mile boundary.

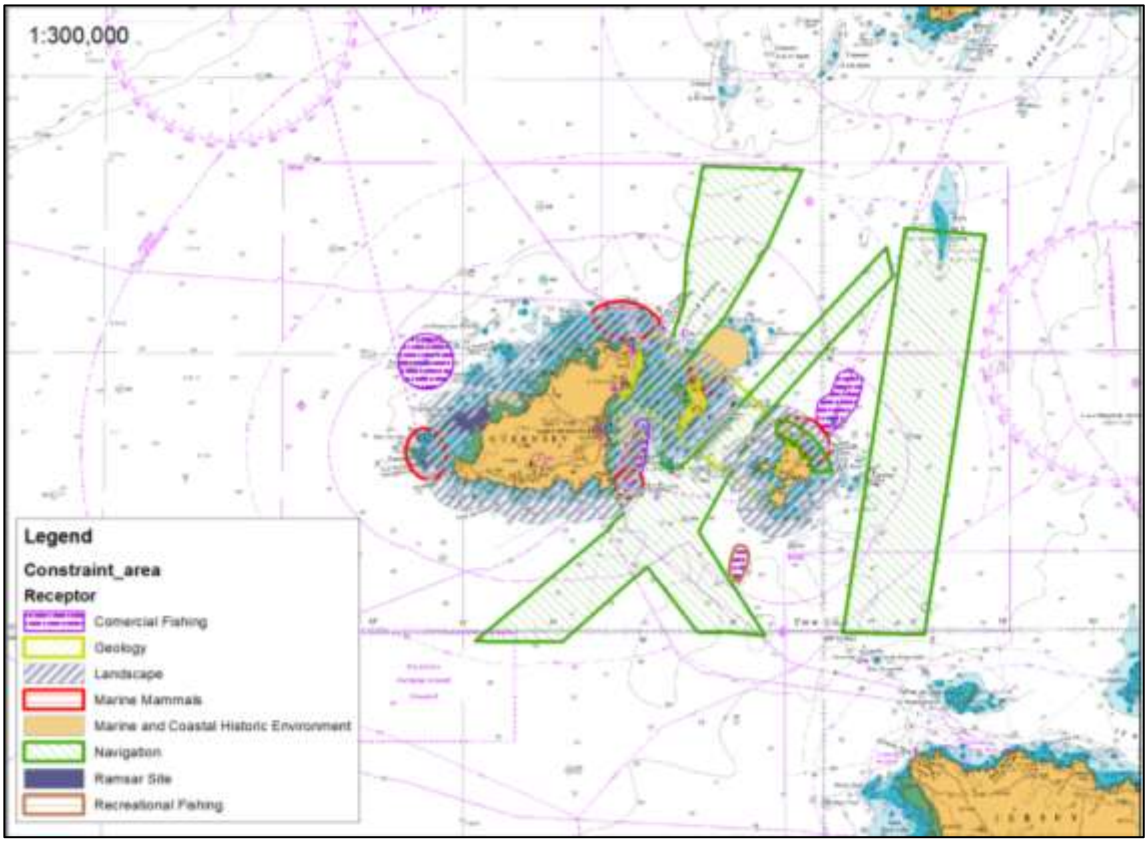


Figure 2: Key Constraints Areas Highlighted in the REA (GREC, 2010)

As well as a constraints map the REA has produced a map of 'potential areas of interest' for the tidal and wave resource. However, to further limit these areas to areas of practical or accessible resource, it is necessary to determine whether constraints are 'hard' or 'soft.' A hard constraint is likely to remove the option of developing MRE within an area where as a soft constraint may allow for the development of MRE bar certain mitigation. The REA suggests possible means of mitigation of negative impact to each sector. A large aspect of this project will be the analysis of constraints and device interaction.

2.3.3. Characterisation of the Benthos in the Big Russel

So far, the Big Russel, which is the main channel between Guernsey and Sark, has been the focus of much of the research towards tidal stream energy extraction in Guernsey. This is due to the high current speeds and shallower water depth. As can be seen with the development of offshore wind in the UK it is economically and practically more viable to initially exploit shallow water regions. The Peninsula Research Institute for Marine Renewable Energy (PRIMARE) in 2011, using towed camera survey, characterised the benthos of the Big Russel to evaluate the risk of damaging key environmental habitats with the deployment of MRE devices. Rocky reefs were the only benthic areas identified as having protection under the Habitats Directive Annex 1 (Sheehan *et al*, 2011). The study concludes that although no UK Biodiversity Action Plan (BAP) species were identified as present in the survey area, it is crucial that this is not taken to mean that these species are not found in the area, only that this study had not identified them. It recommends that once sites are identified for MRE that further monitoring is undertaken at the allocated sites and at control sites (Sheehan *et al* 2011).

2.3.4. Tidal Resource Modelling

A report on tidal resource modelling within Guernsey's territorial waters was drafted in 2010 by Dr Alan Owen of the Robert Gordon University; the paper will be published in 2012. This draft report details the methodology employed in assessing the Guernsey tidal current resource location, magnitude, sensitivity to device depth and cut-in speeds, and possible landfall for power transmission (Owen, 2010). Mapping provides information on the average available energy in GWh/year over grid squares of 1km^2.The input data for the software is taken from the Admiralty tidal stream atlas, Admiralty tidal diamond data and local anecdotal tidal vector sketches. The report firstly looks at the raw resource, without considering technological or practical limitations, in this scenario the resource is seemingly plentiful however when the technological limitations of leading tidal stream devices are applied there are very few feasible areas of development, the main limiting factor being depth. This study does not take into account spatial constraints, though in combination with the more recent REA this report is very useful in identifying the key areas of spatial conflict for tidal energy extraction.

2.3.5. Prefeasibility Study for Offshore Wind

In addition to the REA, the RET undertook a pre-feasibility study for offshore wind development. Two potential development scenarios were devised for the purposes of the study, a minimum development scenario of 12MW and a maximum development scenario of 30MW. The study focused on Guernsey's territorial sea which extends to the 3nm limit though consideration was given to the potential for future expansion to the 12nm. It was concluded that there was only one potentially suitable deployment zone within the 3nm limit which is off the north-west coast of Guernsey.

2.3.6. Exeter University Renewable Energy Report

Exeter BSc Renewable Energy Students in collaboration with Guernsey RET completed a Renewable Energy Feasibility Report in June 2012. The report assessed the suitability and feasibility of deploying macro-marine renewable energies off the coast of Guernsey (BSc Renewable Energy Final Year Students, 2012). This report provides a very good overview of all aspects of MRE deployment from licensing to technological constraints. The report incorporates a wealth of relevant background information from previous studies and up to date facts and figures. The report also suggests potential sites of suitable deployment for MRE technologies that will be comparable to this study's output.

A similar report was completed by Cranfield MSc students in 2011; however, it looked at the potential for MRE in the Channel Islands as a whole. This report also suggested potential sites for wave and tidal stream arrays off Guernsey's coast and is useful in presenting the operating depth ranges of several leading technologies (Abercromby *et al* 2011).

2.4. Example Mapping of Renewable Resources in the UK

2.4.1. The BERR Renewables Atlas

The current version of The Atlas of UK Marine Renewable Energy Resources commissioned by the Department for Business, Enterprise and Regulatory Reform (BERR) in 2007 and led by ABP Marine Environmental Research (ABPMER) was intended to support the strategic environmental assessment of tidal and wave energy in UK waters. The Atlas gives us a good overview of the wave, tidal and off shore wind resources in the UK, including the territorial waters of the Channel Islands. The Atlas represents the most detailed regional description of potential marine energy resources in UK waters (including the Channel Islands) ever completed to date at a national scale, and is used to help guide policy and planning decisions for site leasing rounds (ABP Marine Environmental Research, 2011). The Renewables Atlas has been completed using computer models. Datasets for wave and wind have been derived from data spanning 3.5 - 7 years. The Renewables Atlas provides tidal current data in m/s averaged over grid squares of roughly 3km^2. The wave and wind data is of smaller scale averaging information over grid squares of roughly 12km² (ABP Marine Environmental Research, 2008).

The Renewables Atlas is available as an interactive map online and it is possible on request to download the GIS layers from ABPMER. A supporting technical report is also available for download explaining the information sources and methodology in the creation of the maps (ABP Marine Environmental Research, 2011).

Although the Renewables Atlas is an excellent source of information for the renewables industry it doesn't provide great enough resolution to accurately plan developments. For this, individual site surveys and monitoring would be required. A key recommendation put forward by the renewables industry for the improvement of the mapping would be to include constraints (ABP Marine Environmental Research, 2008). The technical report addresses this as follows:

'The GIS architecture that underlies the project database can easily be developed to incorporate additional data layers, which often already exist, providing information on a range of potential constraints to deployment. Suggested layers include existing infrastructure (cables, pipelines, oil and gas installations, implemented renewable developments, aquaculture), activities (navigation, leisure, fishing), geophysical (detailed bathymetry, seabed sediments/geology), and environmental considerations (designations, flora and fauna) This information would enhance understanding of potentially exploitable resource areas, and if combined with information about renewable technologies has the potential to deliver quantitative analysis of the relative merits of deploying different technologies in specific spatial locations (ABP Marine Environmental Research, 2008).' This project will address this recommendation on a local scale and a project database will be used to aid the planning process in selection of optimal, low impact sites for MRE.

2.4.2. Agence des Aires Marines Protégées

The French Agency for Marine Protected Areas shared recent GIS mapping with the RET on energy, including existing proposed offshore wind farms as well as existing infrastructure. Separate maps also show protected areas, areas of sensitive habitats/species, major and minor navigation routes and areas of importance to commercial fisheries. The mapping can be used to understand MRE development on a regional scale. Interestingly the maps show a proposed French wind farm development site on the eastern side of Sark's 12nm boundary (Figure 3). There may be scope for a joint approach to development in this area which will be considered in the discussion of planning solutions.

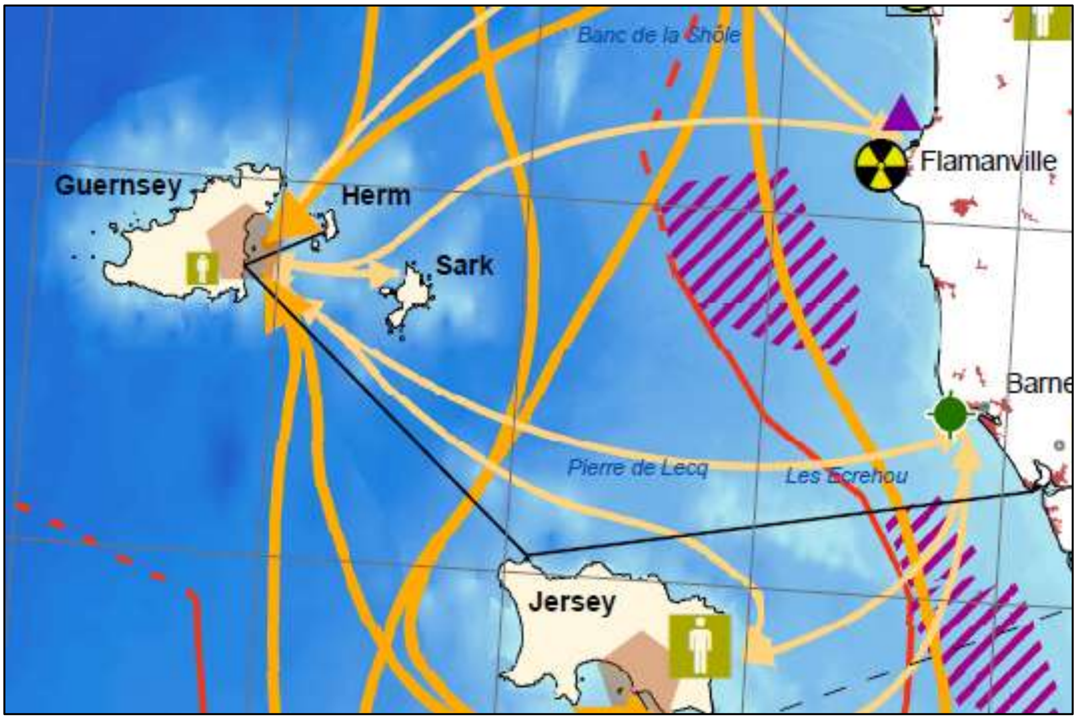


Figure 3: Excerpt from Golfe Normand Breton GIS Mapping (Agence des Aires Marines Protegees, 2012). Purple Diagonal Striped Areas Represent Proposed Wind Farms, Yellow Arrows- Navigation

2.5. Marine Planning

2.5.1 The Marine Management Organisation (MMO)

The Marine Management Organisation (MMO) was formed following the Marine and Coastal Access Act 2009. The MMO have the key task of Marine Planning for English waters. Their objectives include:

- The design of a planning process suitable to deliver marine plans
- Stakeholder engagement to integrate and balance all the current marine and future activities into a comprehensive plan
- To deliver a marine plan for each marine plan area
- To monitor and review plans on a regular basis (MMO, 2012).

Currently planning is underway at two of the eleven identified English sites, the East inshore and the East offshore areas, the MMO aims to complete planning by 2021 (MMO, 2012). Marine planning has come about due to the increased demand of marine activities and site designations. Similar to ABPMER the MMO are developing an online interactive map consisting of multiple GIS layers, which is available on their planning portal (MMO, 2011). Unlike the Renewables Atlas which looked at the raw resources of wave, tide and wind the MMO's map displays designations and information on marine use, such as protected environmental areas, cable routes, fishing intensity etc. This interactive map unfortunately does not currently provide much information on the UK waters surrounding the Channel Islands.

2.5.2. UNESCO Marine Spatial Planning Initiative

In 2009 UNESCO finalised a guide that lays out a 'Step by Step Approach to Marine Spatial Planning (MSP) toward Ecosystem-based Management.' The guide aims to provide an operational framework to maintain the value of marine biodiversity while at the same time allowing sustainable use of the economic potential of the oceans (Douvere, 2009).

The report provides a comprehensive overview of MSP and provides a logical framework for guidance in achieving goals and objectives for marine areas. Designed to aid professionals responsible for the planning and management of marine areas and their resources, it could be very useful tool for Guernsey's RET. This project could contribute to an MSP for Guernsey however it is a small part of the overall initiative. The initiative directly aids this project in its identification of current conflicts and compatibilities among human activities. The report's human use conflicts and compatibility matrix (Figure 4) could be used to support interactions analysis of Guernsey's planning zone.

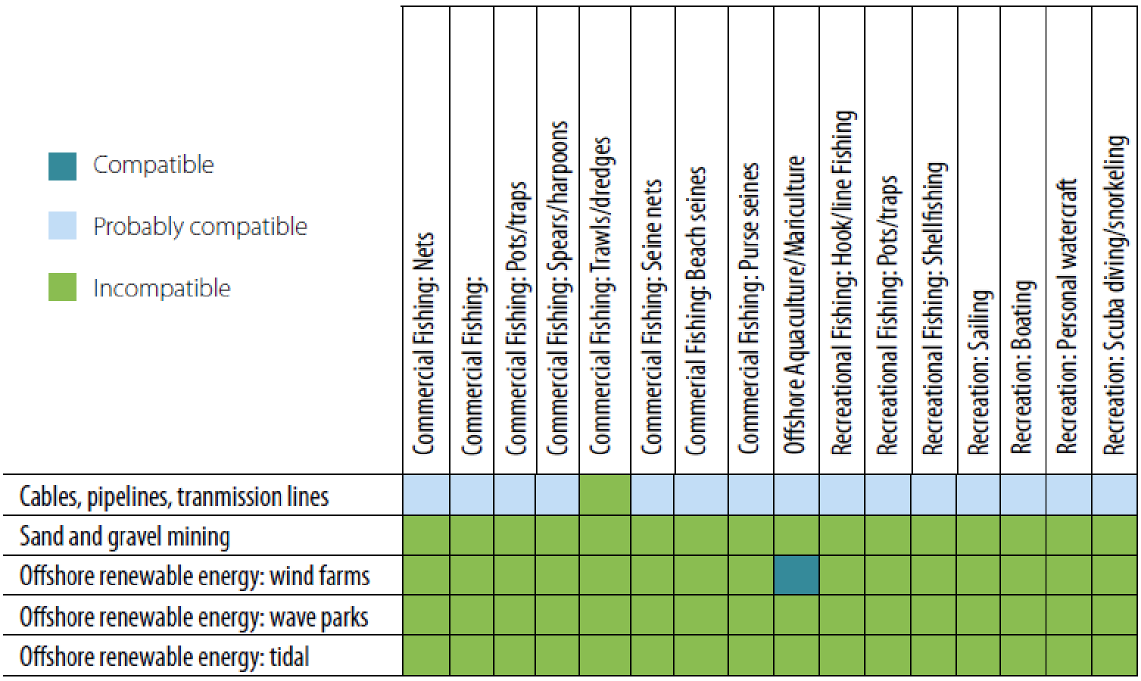


Figure 4: Segment of UNESCO's Human Use and Compatibility Matrix (Douvere, 2009)

2.5.3. The Offshore Renewables Resource Assessment and Development (ORRAD) Project

In 2010 the South West Regional Development Agency commissioned the ORRAD report, a broad scale regional assessment of the South West of England’s potential to support the development of offshore renewable energy projects up to and beyond 2030 and the economic benefits to the region such development would bring (PMSS, 2010). The identification of the development potential involved four key stages:

Stage 1- Mapping of the realisable resource from 2010-2030 for each technology type.

Stage 2- Application of spatial constraints likely to exclude development from resource areas.

Stage 3- Expert Analysis of other constraints, which may restrict the development potential of resource areas.

Stage 4- Assessment of the capacity capable of being installed in those identified potential development areas of lower constraint.

The wind, wave and tidal resource were assessed by broad technology types rather than with reference to specific devices. Technology groups were derived from resource parameters and installation depths. For example wind technologies were grouped as:

- Shallow water wind (installed 0-30m water depth at Lowest Astronomical Tide (LAT).
- Intermediate water wind (installed 30-60m below LAT).
- Deep water wind (installed 60m below LAT and deeper) (PMSS, 2010).

The ORRAD report predicts future technological development in its grouping. Currently the world’s largest offshore wind farm in development. As an example of the current wind technology, the London Array is being constructed in 25m water depth (London Array Ltd, 2012). The current monopile technology used in the majority of developments is unsuitable for deeper water as the thickness of the pile increases exponentially in order to handle the loads applied by the turbine thus becoming economically unfeasible.

The deepest installed turbines are located 12 miles offshore in depths of 45m in the Moray Firth at the Beatrice Demonstrator Site (Talisman Energy, 2005). The EU funded project set out to prove the commercial benefits of operating a deep water wind farm at this site. The turbines use a ‘jacket quadropod’ substructure which comprises a 4 legged lattice frame connected to the seabed with steel piles.

Deep water development is also currently limited by the functional limits of installation vessels. The largest of the ‘Jack Up Barges’ necessary for piling are restricted to around 45m LAT (Jack-up Barge, 2012).

Although the ORRAD report had a scope of 20 years and made large assumptions on the development of the offshore technologies, its GIS outputs are split into resource zones for 2010-2015, 2015-2020 and so on, highlighting the resources that are currently accessible or likely to soon become accessible. The mapping is small scale at 1:1,325,000 and is inappropriate for developers though a useful guide for decision makers at regional level (Figure 5).

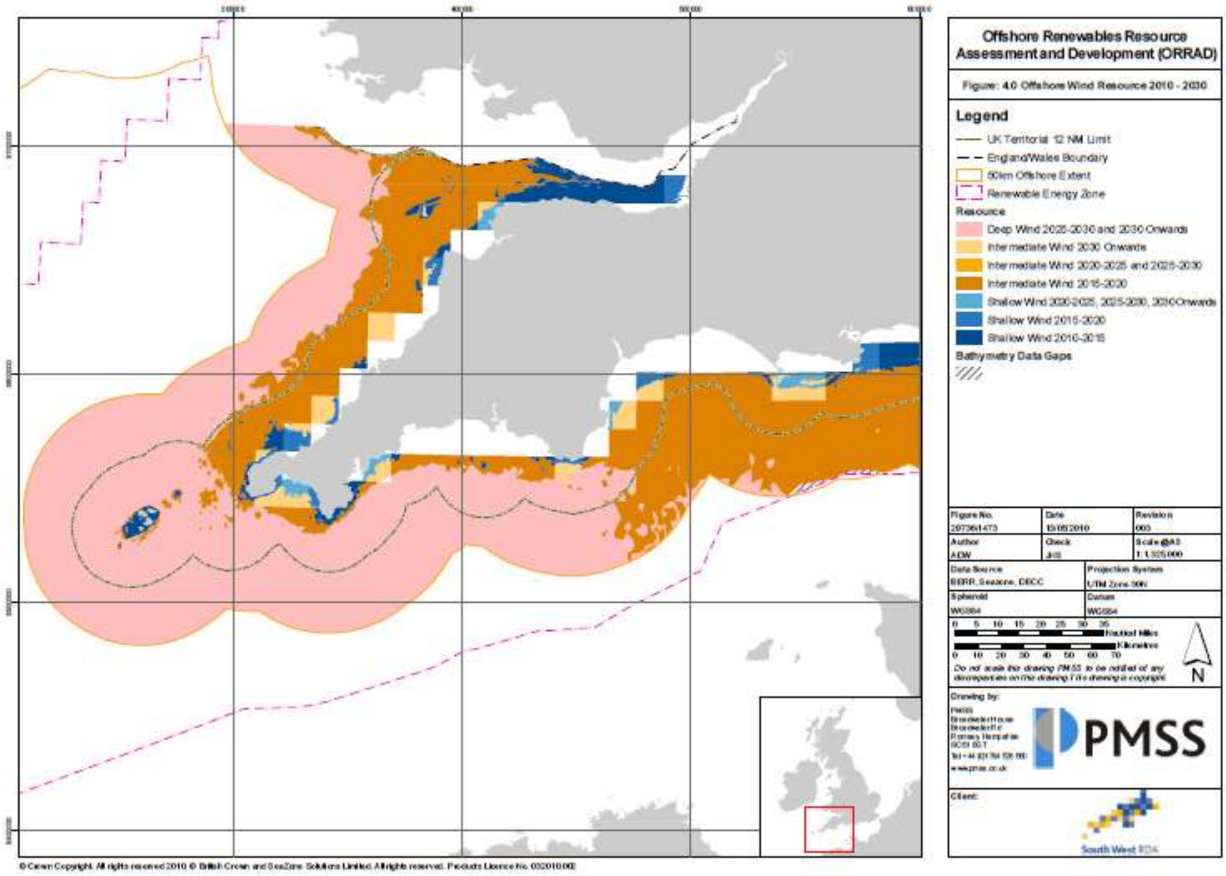


Figure 5: Offshore wind Resource 2010-2030 (PMSS, 2010)

The ORRAD report's analysis of 'hard' and 'soft' constraints presents a good general overview of socioeconomic and environmental receptors that should be taken into consideration when planning offshore renewables development and will be referred to for guidance in this planning process.

2.5.4. The Dorset C-Scope Project

The C-Scope project, which has recently come to an end, was a 3 year pilot marine planning project funded by the European Union Interreg IV Seas Programme. The project saw collaboration between Dorset Coast Forum and the Coordination Centre for Integrated Coastal Zone Management in Belgium (Smith, 2012).

C-Scope had three main objectives in Dorset:

1. Creating a pilot Marine Plan for a 1000 km2 area off the Dorset Coast referred to as a Marine Management Area (MMA).
2. Developing a GIS-based tool (Coastal Explorer Planning) for planners, developers and consultees.
3. Producing iCoast, a map-based website for locals and tourists to access coastal and marine information, and which encourages sustainable use of the coast (Smith, 2012).

The project involved an in depth study to contribute to the marine plan that involved stakeholder participation, coastal and marine policy, economic impact assessment, forecasting of future marine activity and seascape character assessment. The planning process compiled various sectoral interaction tables rating interactions as positive, neutral or at conflict (Figure 6).

YOUR SECTOR → / OTHER SECTORS ↓		OTHER SECTORS AND SUBSECTORS								
		Renewable Energy			Subsea cables and pipelines				Inshore fisheries	
		Offshore Wind	Wave	Tidal	Electricity	Oil/Gas Pipelines	Outfalls	Telecomms	Scallop Dredge	Demersal trawl
Renewable Energy	Offshore Wind		Positive						Neutral	
	Wave	Positive							Conflict	
	Tidal	Positive							Conflict	
Subsea cables and pipelines	Electricity	Positive							Conflict	
	Oil/Gas Pipelines	Neutral							Conflict	
	Outfalls	Neutral							Conflict	
	Telecomms	Positive							Conflict	
Inshore fisheries	Scallop Dredge	Competition								
	Demersal trawl	Competition							Neutral	
	Pelagic trawl	Competition							Neutral	

Figure 6: Example Screen Shot of C-Scope User Interaction Table (Smith, 2012)

In addition, detailed multibeam seabed survey was undertaken to map seabed formations and contribute to sediment transport models and habitat mapping (Figure 7).

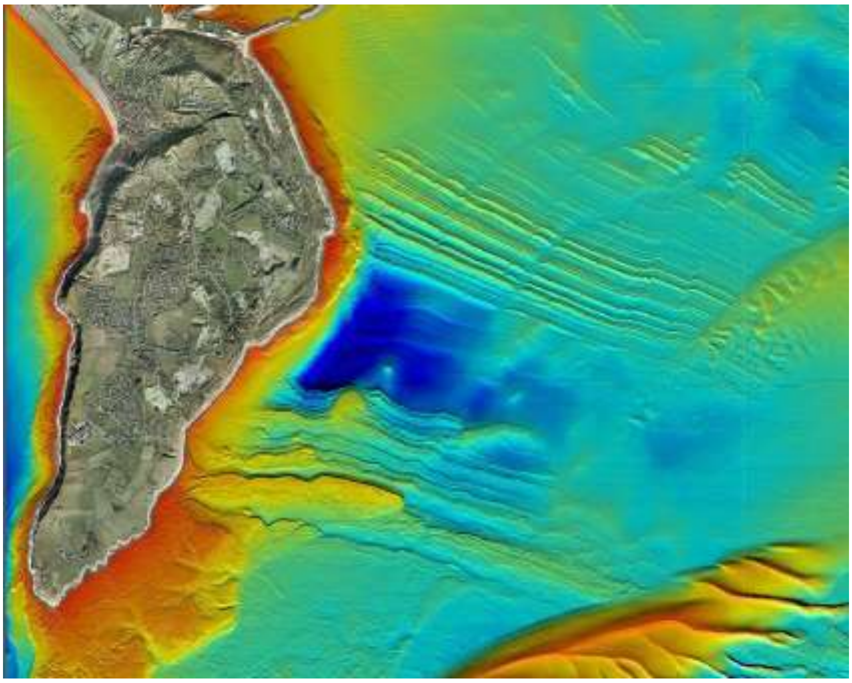


Figure 7: Multibeam Sonar, Seabed Survey Imaging. Source: C-Scope Project (Smith, 2012)

The C-Scope project sought to answer the following planning questions in creating the marine plan and basic MapInfo GIS functions:

1. What takes place where? (Figure 8)

2. Where is there competition for marine space?

3. What management already exists to address this competition?

4. Where is the competition most intense?

5. Where are there potential synergies between sectors?

6. Where is human marine activity most concentrated?

7. Where are the most sensitive marine habitats?

8. What practicable resources are within the MMA?

9. Where does current and future human marine activity interact with sensitive marine habitats? (Smith, 2012)

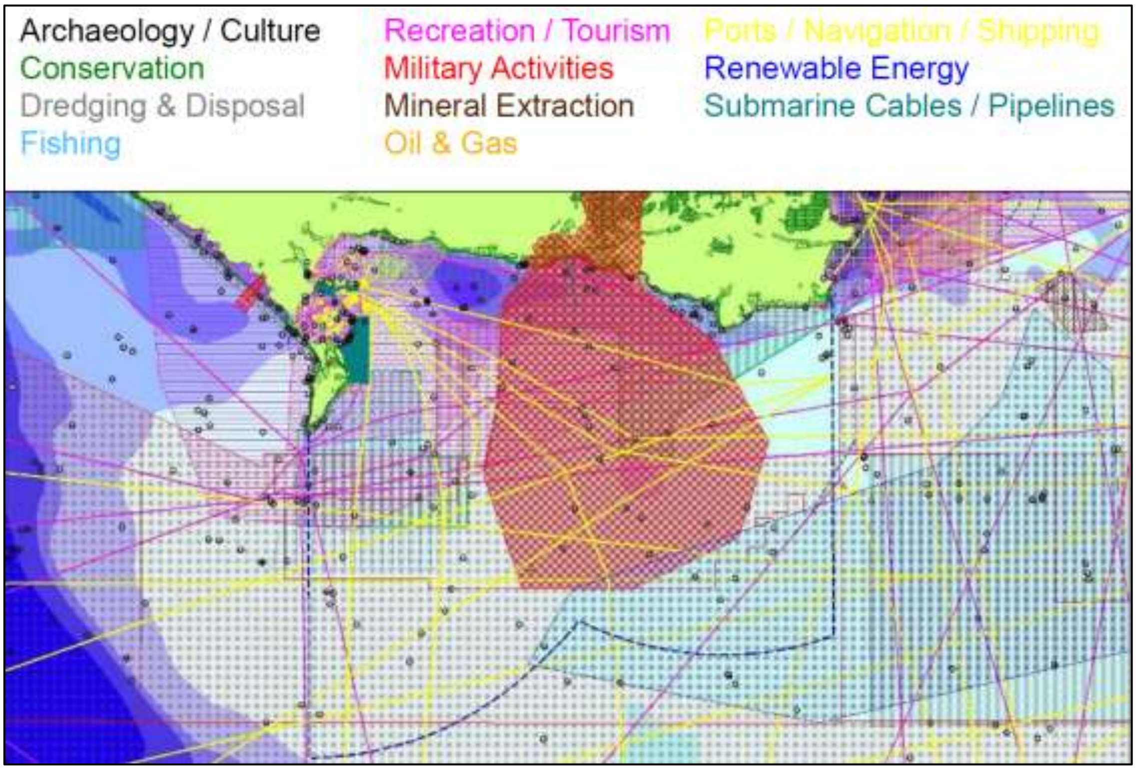


Figure 8: Dorset C-Scope, What takes place where? (Smith, 2012)

Royal Haskoning completed an 'Offshore renewables capacity study' for the project which addressed current and emerging marine renewable energy technologies and their potential operating conditions as well as constraints mapping (Figure 9) to identify potential areas for further offshore renewable energy development in Dorset waters (Trendall *et al* 2010).

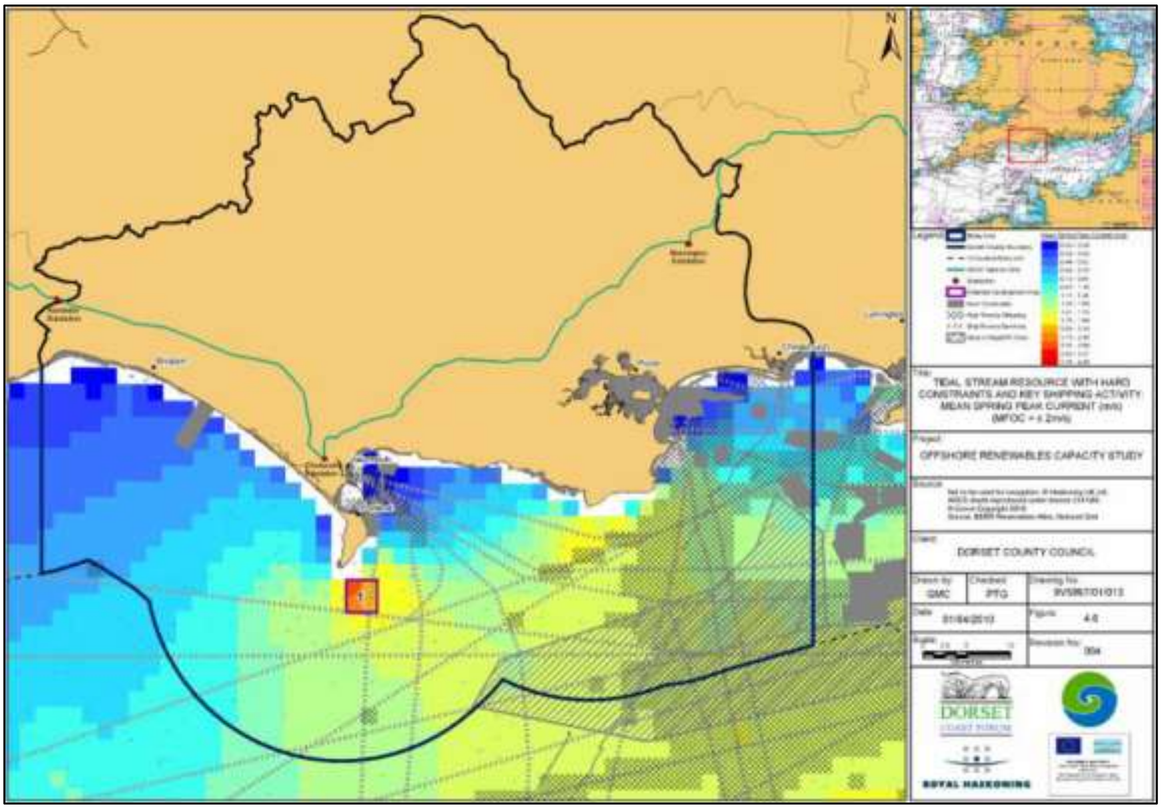


Figure 9: C-Scope- Example Constraints Mapping for Tidal Energy (Trendall *et al* 2010)

2.6. Example of UK Development Planning for Offshore Wind

In the UK, The Crown Estate releases areas available for seabed leasing for the development of offshore wind. In 2009 The Crown Estate ran a competitive tender process and awarded Round 3 zones to different developers. In parallel they undertook a Habitats Regulations Assessment required under UK Habitats Regulations (Duggan, 2012) .

The developer with the rights then decides where to locate the development within the zone. They do this based on survey work and studies to help them understand the most appropriate locations and also take into consideration engineering, economic and environmental factors. Then they undertake an EIA and detailed consultation on the wind farm. An application is then submitted for development consent to the National Infrastructure Directorate within the Planning Inspectorate (PINS). Based on all of the evidence including information from stakeholders PINS will carefully weigh up the benefits of the project against environmental impacts and make a recommendation to the Department of Energy and Climate Change (DECC). The final decision rests with the DECC Secretary of State (Duggan, 2012).

It can be expected that Guernsey could similarly ask a developer to do the detailed survey work and studies required to identify the best location for the final site. However the RET with a seascape area of interest of roughly 2175km^2 could make significant headway in collaboration with Universities on identifying and analysing areas of best resource, which a developer could then narrow down.

2.7. Application of Decision Support Tools (DST)

2.7.1. Marine Resource System (MaRS)

The Crown Estate in the UK manages the seabed out to the UKs' 12nm limit and provides the leases for wind farm and wave and tidal development (The Crown Estate, 2012). They have developed a DST called 'Marine Resource System' (MaRS) which is GIS based. It is designed to enhance marine resource analysis and ultimately identify areas with potential for development in UK waters. MaRS helps to identify and resolve possible planning conflicts in a transparent, evidence-based manner (Hook, 2011). As well as assessing the suitability of sites for specific projects by identifying areas of opportunity and constraint, MaRS can undertake analyses that are more complex – for example, it can identify how different activities would interact in a particular area and provide statistics showing the value of the area to a competing industry (Hook, 2011).

MaRS provides the main model processing function in which datasets are selected to add to models. Datasets are prioritised individually according to UK government and/or industry-approved policy and the information within the datasets can be reviewed and easily fine-tuned to make the focus more precise.

Looking at the example of how MaRS was applied to the Offshore Transmission Network Feasibility Study (Hook, 2011), two models were run, an exclusion model and a restrictions model. The results were combined to produce the final output. The exclusion model contains 'hard' constraints data which must be avoided when planning cable routes. The restriction model includes information regarding 'soft' constraints such as environmental areas (Statutory and non-Statutory), technical parameters and other users and obstacles.

The model datasets are prioritised by applying weights and scores. Weights are used to prioritise the level of importance of each dataset and scores to prioritise the attributes within the datasets. The weights and scores are multiplied to give a final value of importance to each parameter (see Table 1). For the full range of restrictions and exclusions in the Offshore Transmission Network Feasibility Study see Appendix 1.

Table 1: MaRS Example Restrictions Datasets, higher W*S= more constraint

Dataset Name	Buffer (m)	Weight	Score	W*S
The Crown Estate Assets				
Active Cable inside UK Waters	250	1000	100	100000
Inactive Cable inside UK Waters	250	700	70	49000
Active Pipelines in UK Waters	250	1000	100	100000
Inactive Pipelines in UK Waters	250	700	70	49000
Dredging Option - Aggregates	2000	1000	100	100000
Tidal Leases - Live	n/a	1000	100	100000
Wave Leases - Live	n/a	1000	100	100000
UK Offshore Wind Activity	n/a	1000	100	100000
Aquaculture Leases - Pending	250	1000	100	100000
Regulated Fishery Orders	n/a	500	50	25000
Dataset Name	**Buffer (m)**	**Weight**	**Score**	**W*S**
Environmental[24] #				
MCZs	n/a	700	70	49000
Areas of outstanding Natural Beauty AONB	n/a	600	60	36000
National Scenic Areas (NSA)	n/a	600	60	36000
Special Areas of Conservation (SAC)	n/a	1000	100	100000
Special Protection Areas (SPA)	n/a	1000	100	100000
Sites of Special Scientific Interest (SSSI)	n/a	700	70	49000
Ramsar Sites	n/a	1000	100	100000
Heritage Coast	n/a	700	70	49000
Local Nature Reserves (LNR)	n/a	600	60	36000
Local Authority Nature Reserve (LANR)	n/a	600	60	36000
National Nature Reserve (NNR)	n/a	700	70	49000
National Parks	n/a	600	60	36000

The final output mapping of summed solutions highlights locations with more overlapping datasets (GIS polygons) with high weightings as less suitable for a potential cable route. In effect MaRS identifies areas of high constraint which should be avoided in the planning process.

The range of datasets and parameters available to The Crown Estate make the MaRS DST an effective tool that can be tailored to all forms of offshore development. Unfortunately the tool is for internal use only and unavailable for use in this scenario. However the Offshore Transmission Network Feasibility Study's description of the MaRS methodology is very useful for reference as a comparison process.

2.7.2. Marxan

As MaRS is unavailable for general use it was decided to look to Marxan as a DST that could be adapted for use in this study.

Marxan is software that has been designed to provide decision support for environmental reserve system design. Originally created for the Great Barrier Reef Marine Park Authority, since its release in 1999 the use and application of the tool has grown exponentially (Ardon *et al*, 2010). The need for such software stems from the problem a conservation planner faces in identifying the optimal reserve system when faced with a large number of potential sites. The 'problem' itself is a complex relationship between social, economic and ecological factors. Marxan when given a set of selection criteria will present the best solution for what is known as the 'minimum set problem', where the goal is to achieve some minimum representation of biodiversity features for the smallest possible cost (McDonnel *et al*. 2002 cited by Game & Grantham 2008). The rationale is that cheaper or less socially disruptive reserve networks are more likely to be implemented (Game & Grantham 2008). The cost used in Marxan could be total monetary cost required for purchasing sites or when actual site cost is unavailable, reserve area may be used as a surrogate for cost assuming the larger the area the more costly it will be to implement and manage. Cost can also be any relative social, economic or ecological measure of costs (Game & Grantham 2008).

In this case the traditional use of the software will be adapted to aid optimal site selection for MRE. As opposed to 'a minimum representation of biodiversity features for the smallest possible cost', the minimum set problem becomes 'a minimum target of accessible marine energy for the least possible cost/negative impact (to both environmental and socioeconomic receptors)'. Marxan has been chosen for use in this project as it is the world leading Environmental DST; it is freely available and can be used in conjunction with GIS software.

3. Methods

3.1. Initial Trial Planning Process

This section discusses the initial idea for the planning process and the method used in testing its effectiveness. The trial formed the basis for the methodology detailed in subsequent sections.

Figure 10 shows an output map from the Dorset C-Scope Project which inspired the design of the planning process that follows.

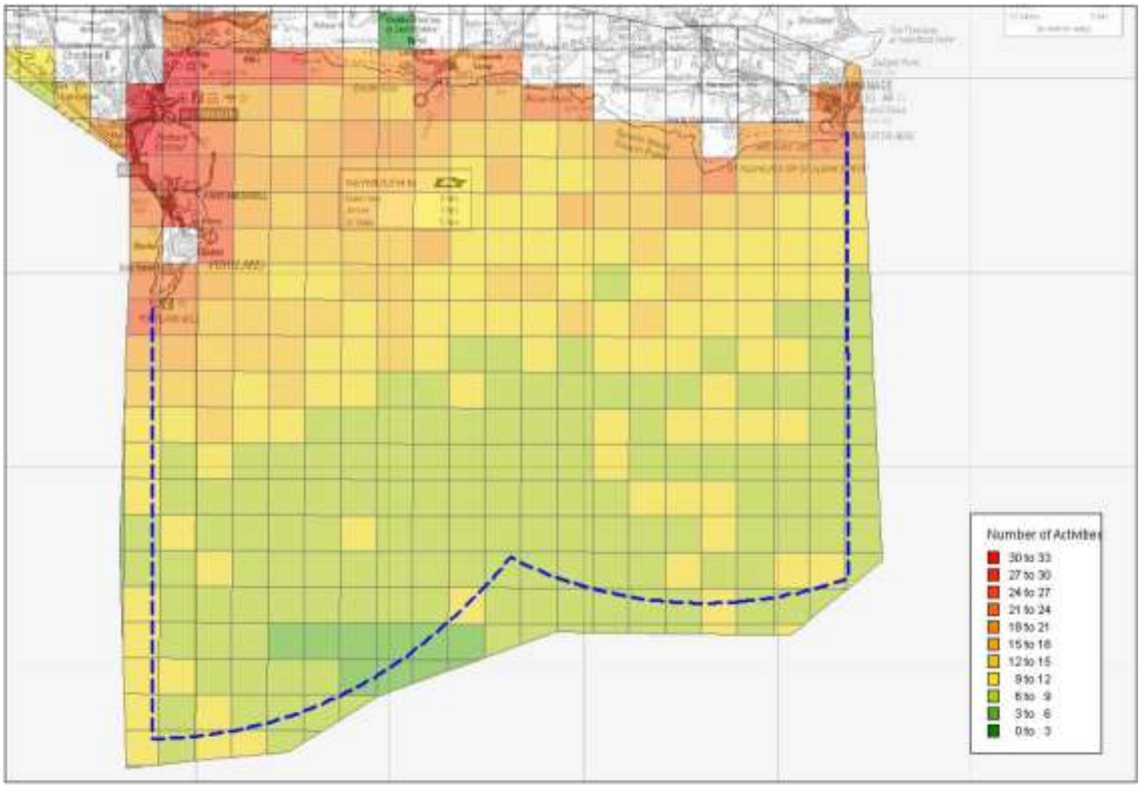


Figure 10: C-Scope Concentration of Human Marine Activity (Smith, 2012).

Building upon what is seen in Figure 10 the initial planning framework was as follows:

1. Using a planning grid (section 3.3), create a GIS database to assess concentration of socioeconomic activities and sites of environmental importance.
2. Include in the database resource information for wind, wave and tide.
3. Issue individual planning unit (PU) penalty scores for the obstruction or destruction to receptors resulting from MRE development.
4. Use Marxan DST to select planning units with an accessible resource and low penalty cost to identify the sites of least constraint to development.
5. Using Arc GIS create output mapping showing planning solutions.

The initial test for the planning process was a section of the Big Russel channel. The resource information used was that for tidal stream energy from the Tidal Resource Report from the Robert Gordon University (Owen, 2010) and constraints were taken from the REA constraints database. For each constraint within the boundaries PUs were issued a penalty score of one, each constraint was evenly weighted with no level of interaction considered.

The target for Marxan was a GWh/year value for which data had been taken from the Robert Gordon University Tidal Report (Owen, 2010).

The test concluded that Marxan could be used effectively to target a specified marine energy resource whilst seeking minimal cost/penalty for impacting socioeconomic and environmental receptors within the planning area. It also highlighted several difficulties in the planning model that are detailed in Appendix 3.

3.2. The Final Planning Process

Figure 11 illustrates the individual steps taken in applying GIS architecture and decision support software to solving an MRE site selection problem, where minimum impact to existing environmental and socio-economic receptors is of key importance. The following sections encompass the steps below and provide a detailed methodology of the planning process for offshore wind development. A similar process could be applied to other MRE technologies as device performance specifications become accessible and resource data improves.

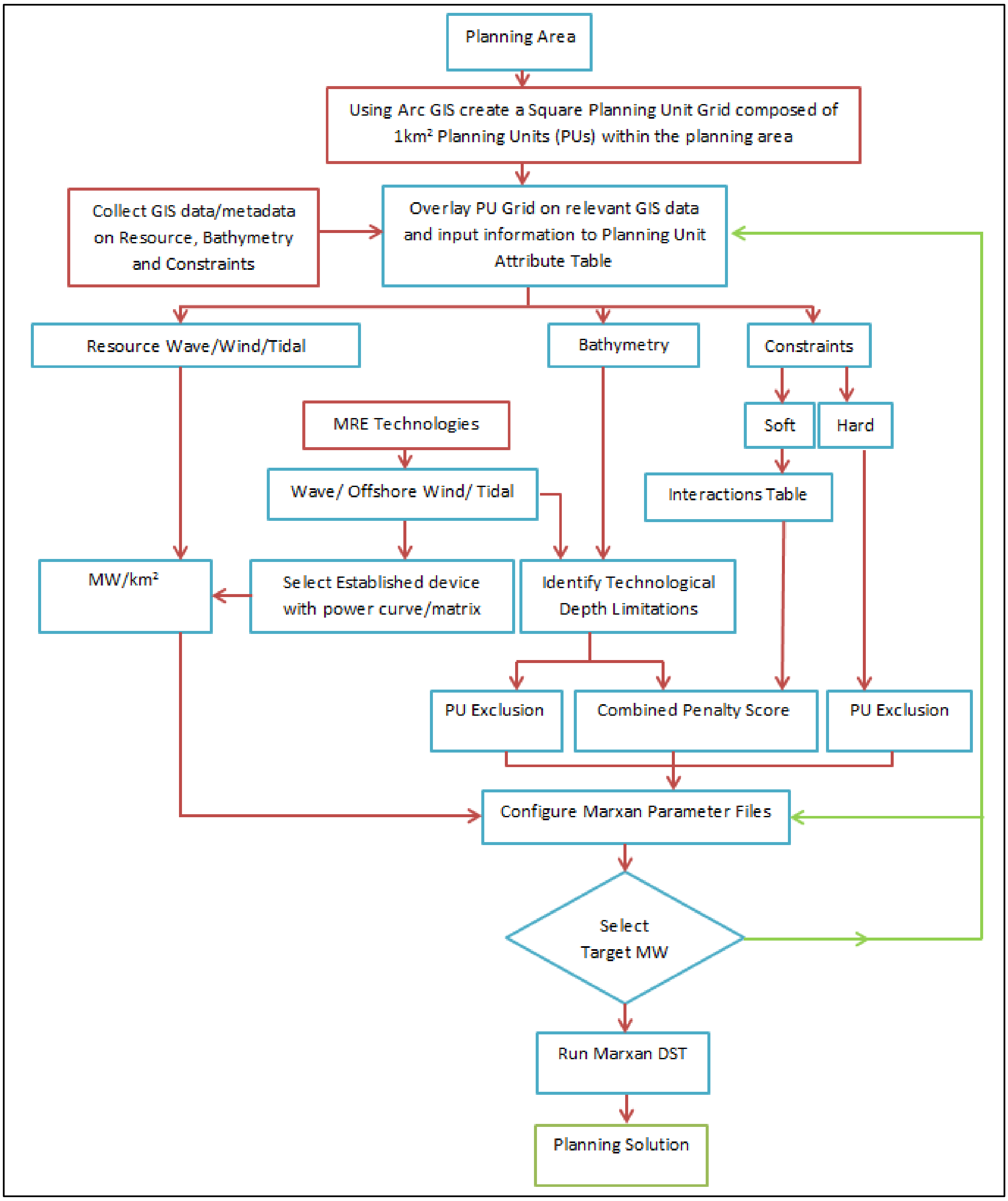


Figure 11: Flow Diagram of Planning Process

3.3. Planning Area

The seabed and waters around Guernsey and Sark belong to the UK Crown, represented by The Queen, as the Duke of Normandy. Throughout the coastal waters of the UK, this is managed through the Crown Estate. However, the Crown Estate does not extend to the Channel Islands, and leasing of the seabed is arranged through Her Majesty's Receiver General (HMRG) in the States of Guernsey. At present, Guernsey and Sark have legal jurisdiction of waters and the seabed to 3nm, with some special areas of legislation (e.g. fisheries) extending to 6 or 12nm (RET, 2011). However, neither Guernsey nor Sark can claim to 'own' this area, and ownership rests with the Crown. Both communities have applied to the UK Crown for a long-term lease of the seabed to 3nm, and this is anticipated to be forthcoming within the timescales required to develop offshore wind or marine renewable projects to deployment (RET, 2011).

Further consideration was given to the States of Guernsey and Sark's pleas to the further extension of legal jurisdiction, and subsequently the right to lease the waters and seabed out to 6 or 12nm (RET, 2011).

For the purposes of this report the waters of Guernsey and Sark will be considered jointly out until the 12nm fishing limit, assuming future extension of legal jurisdiction and leasing of the seabed. The fishing limits do not extend to 12nm where there would exist an overlap with either Alderney, Jersey or France's limits, at these median lines, north, east and south of Guernsey and Sark the fishing jurisdiction extends to the median line between the individual islands and France. The 12nm limit or the limits of a median line represent the outer limits of the area of interest, which, from this point on will be referred to as the 'planning area' (Figure 12).

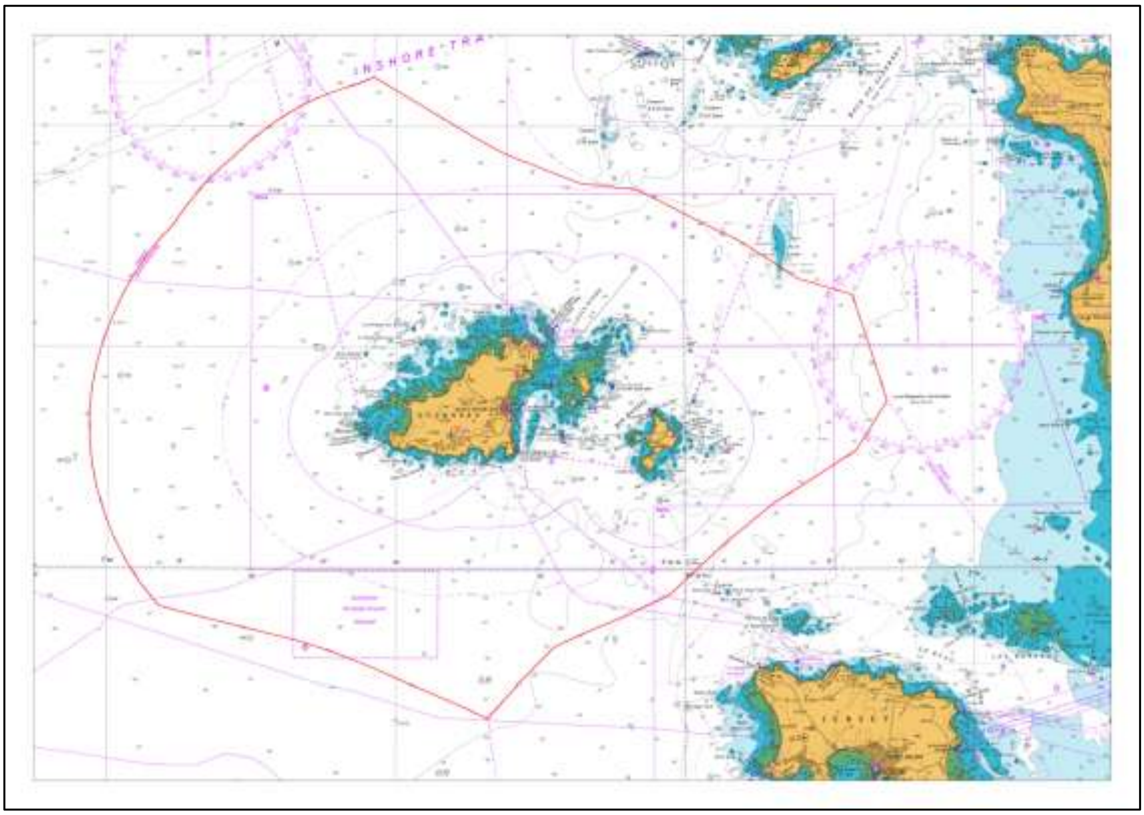


Figure 12: Admiralty Chart Showing Guernsey and Sark's Combined Potential Planning Boundary

3.3.1. The Planning Grid

The MaRS DST uses GIS dataset polygons to form an irregular grid for input and output purposes. However MaRS does not consider strength of resource nor indicate optimal sites for development. Its purpose is to highlight areas of highest constraint which helps narrow down site selection for decision makers. When considering power output for specific technologies a regular grid allows for average power density of energy arrays to be easily calculated and compared.

A square unit planning grid (Figure 13) was created in Arc GIS using the 'Jenness Enterprises Repeating Shapes' tool (Jenness, 2012). Each individual planning unit has an area of 1km^2 totalling 3672 planning units (PUs) which overlap the area of interest (PUs outside the Planning Boundary were excluded from Marxan Solution). A square grid was chosen for its navigational simplicity compared with either hexagonal or triangular grids. Tessellation is important in capturing as much of the planning area as possible.

A typical figure for describing power density in renewable energy is MW/km^2, it is also intended that by using 1km^2 grid units, output mapping will be more understandable to non-experts.

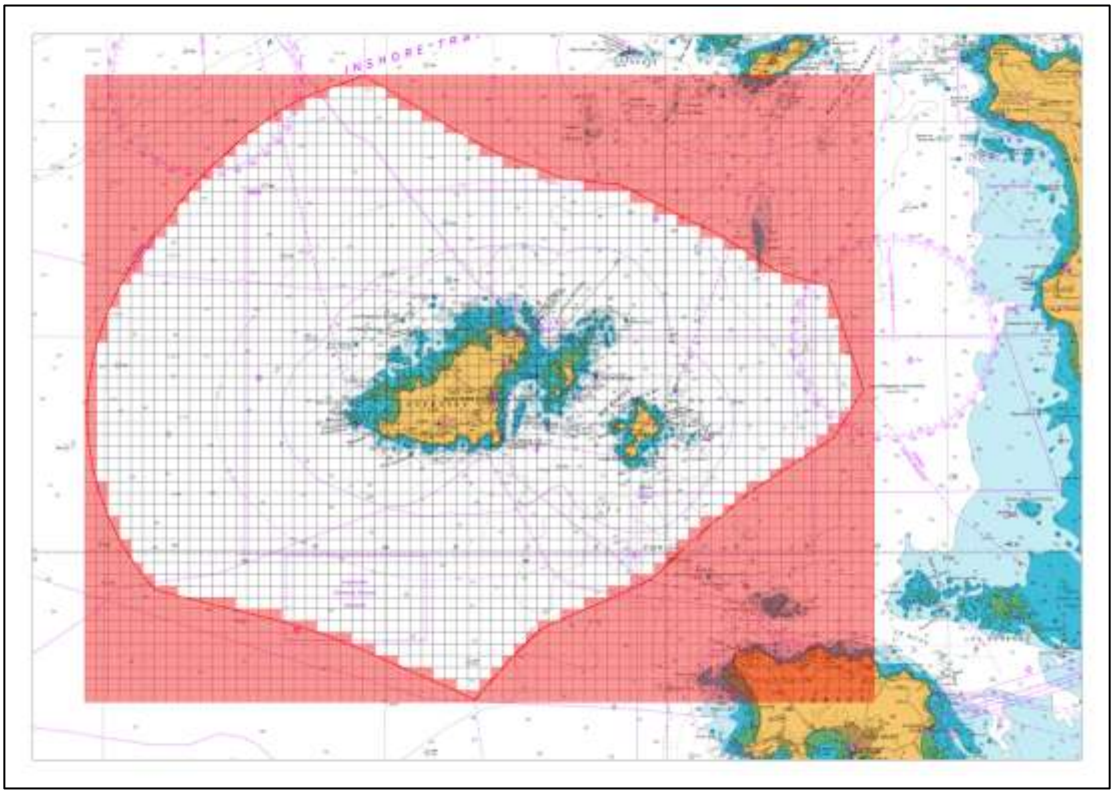


Figure 13: Planning Grid Showing Excluded PUs beyond Planning Limit in Red

3.4. GIS Data/metadata

To build a Marxan dataset Arc GIS was used to ascribe data to individual PUs, this was done using a data overlay process. Using an Admiralty chart with the WGS 1984 co-ordinate system as the base map, the collected data, detailed in the following sections, were independently overlayed in determining resource, bathymetric and constraints factors present within each PU.

3.4.1. Resource Data

This project looks at the development of offshore wind in Guernsey's waters as the technology is well established. However, the planning process is intended to be repeatable for wave and tidal stream technologies as they move to commercial scale and therefore available resource data for these technologies is mentioned in Appendix 5.

Wind

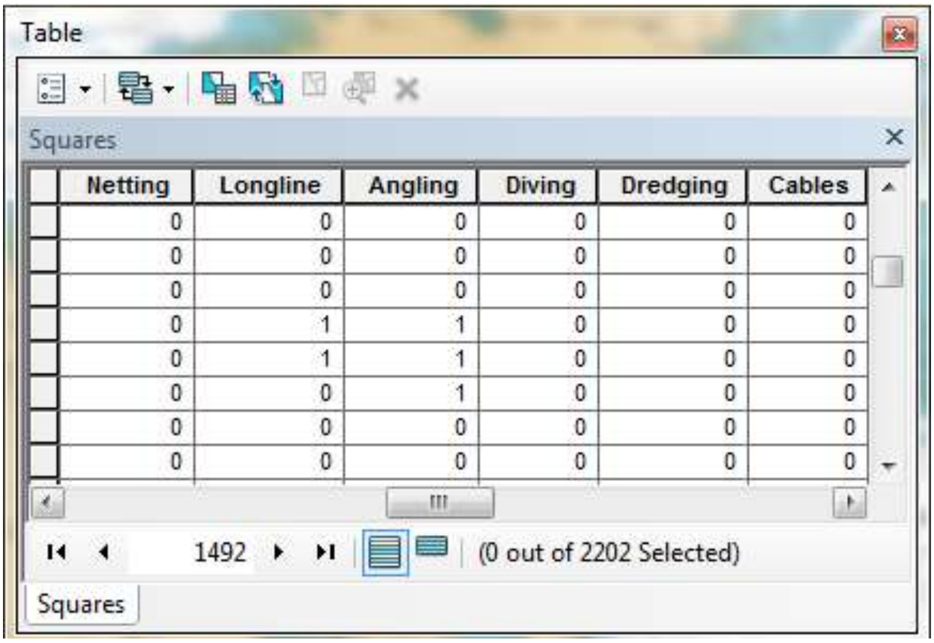
The GIS shape files used in determining average annual wind speeds in each planning unit were downloaded from the ABPMER website, the same shape files were used in the completion of the Renewables Atlas (ABP Marine Environmental Research, 2011). The Renewables Atlas averaged wind speed over 12km^2 grid units, which, in the overlaying process corresponded well with the 1km^2 planning grid. Where the 1km^2 PUs were divided by the boundary of the 12km^2 grid units an average of the two wind speeds was taken, this was only the case for one row of PUs (ABP Marine Environmental Research, 2008).

3.4.2. Constraints

The constraints data is based primarily on GIS shape files provided by Guernsey's RET. Much of the mapping found in the REA is based on the original files created by members of the RET and the Sea Fisheries Department. The REA study area focused on waters within the 3 mile nautical limit but many of the GIS shape files extend beyond this boundary.

The Admiralty Charts were a key source of information on factors that affect the development of MRE. The charts provide information on the whereabouts of subsea cables, explosives dumping ground and military firing practice areas.

In ascribing the presence of constraints within the PUs the 'edit attribute table' function in Arc GIS was used to edit the planning grid shape file. For each particular constraint a 0 indicates no presence in a planning unit and 1 indicates a constraints presence. Figure 14 below shows a screen shot of the planning grid attribute table, it can be seen that long lining and angling are present in a small number of PUs shown, indicated by the value of 1.



Netting	Longline	Angling	Diving	Dredging	Cables
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	1	1	0	0	0
0	1	1	0	0	0
0	0	1	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Figure 14: Screen Shot of the Planning Unit Attribute Table

Any constraints within the boundaries of a PU were marked as present disregarding the proportion of the 1km^2 actually required/utilised by the receptor. For certain receptors such as seal haul out zones, a precautionary buffer zone has been included which indicates receptor presence in all bordering PUs whose nearest corner is within a km of the mapped zone.

3.4.3. Bathymetry

GIS data on bathymetry has been taken from several sources as bathymetry exists in several resolutions, the highest only existing for Guernsey's inshore and shallower waters.

The highest resolution bathymetry, downloaded from Marine Digimap is the Seazone Digital Survey Bathymetry (Digimap, 2012). The scale of the coastal data is based on 1 Arc Second grids (approximately 30m cell size) and offshore, based on 6 Arc Second grids (approximately 180m cell size). The reference level of depth data approximates to LAT. When overlayed, the Seazone Bathymetry corresponds well to depth contours shown on the Admiralty Charts.

The Seazone Bathymetry extends to 50m depth. Beyond 50m the General Bathymetric Chart of the Oceans (GEBCO) has been used. The GEBCO_08 Grid is a continuous terrain model for ocean and land with a spatial resolution of 30 Arc Seconds (GEBCO, 2012). The GEBCO user manual states 'the GEBCO_08 grid is essentially a deep ocean product and does not include detailed bathymetry for shallow shelf waters' (British Oceanographic Data Centre, 2010). When overlayed in Arc GIS the GEBCO 50m contour line does not match up to that of the Admiralty Chart or the Seazone Bathymetry, on the South Coast of Guernsey the 50m contour is almost 2.7km further south than the Seazone Contour. However, the GEBCO bathymetry is the best available for deeper waters in the region and has filled the gaps where Seazone data is unavailable.

Where a PU overlapped a depth contour its category was decided on where the greatest proportion of the square lay. The resulting depth scale used for this planning exercise can be seen in Figure 15.

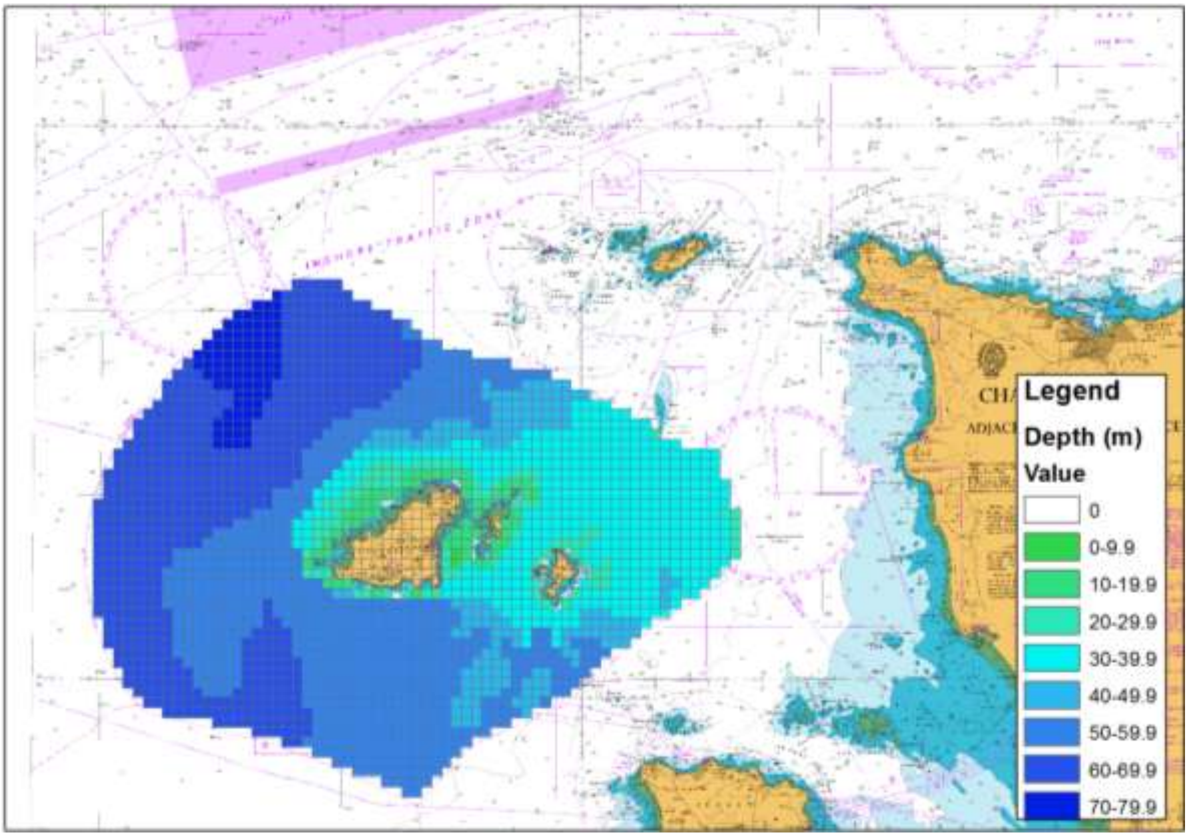


Figure 15: Depth Scale used in Planning Process within Planning Boundary

3.5. Analysis of 'Hard' Spatial Constraints

Hard spatial constraints are those that are likely to prevent an offshore development taking place. This is generally based on pre-existing legislation or strong public opinion.

Guernsey has several hard constraints that could potentially exclude development from certain areas. They are as follows:

3.5.1. Ramsar Sites

The Convention on Wetlands (Ramsar, Iran, 1971), called the "Ramsar Convention", is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the "wise use", or sustainable use, of all of the wetlands in their territories (Ramsar Convention Secretariat, 1971).

There are two Ramsar sites within the planning area, one on the west coast of Guernsey and one on the west coast of Sark. As the only recognised environmental sites of international importance within Guernsey and Sark these areas have been excluded from the planning process.

3.5.2. Explosives Dumping Ground

Roughly 9 ½ km south of Guernsey the Admiralty Charts mark an 'Explosives dumping ground'. Though now disused, there is still a large risk associated with unexploded ordinance that would not permit development in this zone.

3.5.3. Seal Haul Out Zones

The 'Humps' north of Herm are an important haul out area for Grey Seals. The Channel Islands and Brittany form the southernmost limit of the Atlantic Grey Seals range (GREC, 2010). These localised areas and others highlighted in the REA constraints mapping for high number of mammal sightings, have been labelled hard constraints due to the fact that although Guernsey is not subject to EU legislation, seals are listed in Annex 2 and 5 of the EU Habitats Directive which require that Special Areas of Conservation (SACs) be established for their protection (GREC, 2010).

The Grey Seal is also protected under the Convention of Migratory Species (Bonn Convention) that includes unilateral agreements for the conservation and management of such species (GREC, 2010).

Seals have been tracked by the Sea Mammal Research Unit in St. Andrew's, Scotland, travelling down from the west coast of Scotland to the Channel Islands using satellite telemetry (GREC, 2010). They are a highly mobile species and matters influencing their conservation will be of international concern.

Impacts of MRE devices on seals are still being researched. Studies so far in Northern Ireland on the impact of MCT's Seagen tidal stream device on resident seal populations in Strangford Lough have so far reported no measureable impacts on seals, porpoises and seabirds. Environmental monitoring started 4 years prior to device installation in 2008 (Sparling *et al*, 2011).

As the impacts on seals from the installation and operation of MRE devices are not yet confirmed, in the case of this project the precautionary principle will be followed and planning units covering the haul out zones and those within 1km will be excluded from the planning solution.

3.5.4. Military Firing Practice Area

Marked on the Admiralty Charts is a Military Firing Practice area on the north coast of Guernsey that, for this exercise, has been excluded from the planning process.

3.5.5. Landscape Buffer Zone

The SEA for Round 2 wind farm development in the UK recommended a coastal buffer of 8-13km primarily for landscape purposes. In a similar step the RET in their REA have recommended a 1 nautical mile landscape buffer zone in order to help preserve the visual amenity important to residents and tourists alike (PMSS, 2010).

It is important to note that this hard constraint only affects floating or surface piercing renewable energy devices.

3.5.6. Subsea Cables

Referring to the United Nations Convention on the Law of the Sea, it has no provisions requiring coastal States to adopt laws and regulations to protect submarine cables (United Nations, 2012). However, they can establish cable protection zones to limit fishing, dredging and other activities that may pose a threat to submarine cables (Beckman, 2010). For this planning exercise submarine cables have been taken to be hard constraints as installation and decommissioning of devices could pose a high risk of damage.

3.6. Analysis of ‘Soft’ Spatial Constraints

In addition to ‘hard’ spatial constraints there are those that are more flexible in nature that, in this case, will be referred to as ‘soft’ spatial constraints. Soft spatial constraints will further limit the development of MRE but there may be some forms of mitigation measures to lessen the negative impact. In most cases soft constraints will be device and site specific. Full analysis will require stakeholder consultation with individuals or groups representative of those socioeconomic/environmental receptors impacted. For this report the REA has been referred to and soft constraints identified according to its suggested mitigation measures.

3.6.1. Archaeology and Sites of Historic Importance

Guernsey’s REA states that approximately 330 historic wrecks can be located with some degree of certainty. Many more wrecks are recorded but remain un-located.

Historic wreck is protected by The Wreck and Salvage (Bailiwick of Guernsey) Law, 1986. It includes any ‘vessel, aircraft or its cargo that has lain wrecked for 50 years or more’ (GREC, 2010). A licence is required to disturb historic wreck. War graves require a significant exclusion zone at all times (GREC, 2010).

In this planning exercise historic wreck has been considered a soft constraint as with future detailed site survey it should be possible to avoid wreck within a development. However as mentioned wrecks known to be war graves would be a hard constraint to developers and legislation regarding protection radius would have to be observed.

The REA has made some provision for historic landscapes and coastal historic environment which have also been mapped by the RET. Again, these receptors have been considered soft constraints as the REA has identified mitigation methods for negative impact, these are primarily the involvement of archaeologists at an early stage and the avoidance of protected zones (GREC, 2010).

3.6.2. Seasearch Sites

Seasearch is a volunteer dive survey scheme which has the aim of gathering information on seabed habitats and marine wildlife (Wood, 2011).

A total of 13 sites have been surveyed in the planning region, 11 in the coastal waters surrounding Sark. 14 species were identified at the Sark sites that are considered scarce or rare in UK waters.

These sites have been considered soft constraints as individual device siting and cable routes could be planned to avoid damaging key habitats. It is unlikely that these sites would be disturbed by development as other constraints such as Guernsey’s 1 nautical mile coastal buffer will exclude the majority of devices from operating nearby. Guernsey RET have stated their preference of an export cable making landfall at St. Sampson’s which would avoid all Seasearch sites (RET Personal Communication 09/07/12).

3.6.3. Bird Breeding Sites

The REA has identified the important bird breeding areas on the islands of Guernsey, Herm and Sark. They encompass the entire cliffed coastline of Guernsey's south coast the whole of Sark's coastline as well as the south west of Herm, the Humps and Lihou Island Nature Reserve.

The REA lists potential effects as disturbance, effect on feeding areas, collision (above water in the case of wind turbines and below in the case of tidal turbines which would impact diving birds), increased turbidity around devices (considered minor) and pollution and contamination (GREC, 2010).

The REA has analysed the significance of impacts and they range from minor to moderate. Many of the impacts can be mitigated against and the primary concern of disturbance to breeding birds can be avoided through timing the installation (GREC, 2010).

Bird breeding has been regarded as a soft constraint, as impacts are device specific and may be mitigated against through device design. However, due to knowledge gaps and following the precautionary principle a buffer zone has been included in the planning exercise in which a penalty cost applies to all planning units within a 1km range of bird breeding sites.

3.6.4. Benthic Ecology

Guernsey's Ramsar site on the West coast contains a diverse range of benthic habitats and species of global or regional importance. This area has been excluded; however, the REA has mapped sites outside of this site known to support Eunicella verrucosa, commonly known as Pink Sea Fan and Zostera marina eelgrass beds (GREC, 2010).

Zostera marina eelgrass beds are priority habitats known to sustain high marine biodiversity, Guernsey's eelgrass population is considered to be healthy and robust. However these habitats could potentially be affected by physical disturbance through all MRE life cycle stages (GREC, 2010).

The Pink Sea Fan has UK Biodiversity Action Plan (BAP) status as it is classed as a vulnerable species.

Mitigation methods suggested in the REA are to consider geographical avoidance of areas of interest, seasonal avoidance to reduce impeding species reproduction, baseline monitoring strategies and device specific mitigation measures (GREC, 2010).

Benthic Ecology is a soft constraint as there is scope for localised avoidance of key habitats within sites following detailed survey.

3.6.5. Marine Mammals

The REA has included mapping of marine mammal sightings since 2006 however no significance mapping was carried out due to the highly mobile nature of cetacean and pinniped populations (GREC, 2010). The only known and documented region of significance for mammals is the seal haul out zone north of Herm and the Humps, discussed in 'Hard Constraints'.

Apart from the area of importance for seals, other marine mammals have not been considered in this planning process due to the lack of data on populations and key habitats. The REA calls for significant baseline survey and monitoring of marine mammals to be undertaken prior to development (GREC, 2010).

3.6.6. Geology

Geology features in Guernsey's constraints mapping. Under this topic the REA considers among others, subsurface geology, seabed morphology, sediment distribution and sediment dynamics.

There are concerns for the region identified as sensitive over impact on seabed scour, bedrock, coastal sediment systems, bio-sedimentary processes and impacts on biotopes as a result of interrelationships (GREC, 2010).

For all of the identified impacts, significance of impact was thought to be of local effect and of low magnitude. It is thought that engineering solutions could help mitigate negative impact to geological receptors.

As a geologically sensitive zone has been identified by the REA in the constraints mapping, there is an associated penalty for those PUs whose areas overlap.

3.6.7. Navigation

In the UK, the post consultation report for the SEA of Offshore Wind stated: "developments should not impinge on major commercial navigation routes, significantly increase collision risk or cause appreciably longer transit times"

Guernsey's REA constraints mapping highlights the channels of the Little Russel, Big Russel and waters to the east of Sark as well as the main routes north and south of the islands as the zones most important to navigation. The constraints mapping encompasses the 'pinch points' the REA identified on the Admiralty Charts which are associated with the approaches to the various ports on the islands.

The following tables detail the possible operational and safety impacts MRE devices may have on navigation.

Table 2: Potential Safety Effects on Navigation (GREC, 2010)

Safety Effect	Vessels/receptors	Result
Collision	All	Damage/pollution/ sinking of vessels
Counter Pollution	Commercial vessels	Impede anti pollution operations
Search and Rescue (SAR)	All	Impede SAR operations or training
Reduced visibility	All	Obstruct navigational marks or lights
Electronic/magnetic interference	All	Interference with radar, communications and magnetic compass and navigation aids
Changes to tidal streams, heights and times	All	Increased tidal stream and changes to tidal heights and times are a risk to navigation

Table 3: Potential Operational Effects on Navigation (GREC, 2010)

Operational Effect	Vessels/receptors	Result
Increased Journey times and distances	All	Delayed schedules and increased costs to shipping
Displacement of shipping	All	Increased densities of vessels
Reduced Trade Opportunities	Commercial vessels	Disruption of trade
Reduced fishing Opportunities	Fishing vessels	Disruption of fishing commercial and leisure
Leisure vessels by-pass the area	Leisure vessels	Loss of marine tourists and income to marine traders

In the planning process any planning units that contain within their boundary, areas identified by the REA as important to navigation, have been ascribed a penalty score based on the extent of interaction between devices and receptor.

3.6.8. Fisheries

The potential effects MRE could have on fisheries were identified by Guernsey's REA study as:

Ecological impacts

Noise

The noise associated with installation operations and cable laying could affect the distribution and movement habits of commercial species (GREC, 2010). The operative noise of the devices may also be an issue.

Direct Mortality

Installation operations may lead to the direct mortality of commercially important shellfish species either through direct destruction of the benthos where the devices are connected to the seabed or through smothering caused by settling sediment/debris ejected into the water column by installation methods.

Electromagnetic Fields

It has been shown that certain species of fish, especially elasmobranchs (rays and sharks) are sensitive to electromagnetic fields.

Temporary displacement from traditional fishing grounds

Construction, installation and decommissioning of devices could result in fishing vessels being temporarily displaced onto different fishing grounds, increasing competition and reducing economic returns.

Collision/Entanglement

The main collision/entanglement risks identified are:

- Mobile gear too close to structures/cables.
- Pots, nets or longlines too close to structures.
- Divers colliding with structures.
- Potting vessels creeping for lost gear which involves dragging grapnels.

Permanent displacement from fishing grounds

In considering impact to fisheries, some sectors may be completely excluded from development areas due to the likelihood of damage or entanglement with substructure. This will lead to direct loss of fishing or potting grounds which will increase pressure on alternative fishing grounds and potentially cause long term reduction in fishing fleets (GREC, 2010). There is, however, the argument that exclusion zones will benefit fish and crustacean stocks within the area, consequently benefiting fishing/potting in bordering waters as species overspill. In this planning process solely the negative impact of obstruction/exclusion of commercial and recreational fishing is considered.

Fisheries Sectors

Guernsey has 195 registered commercial fishing vessels in its fleet, primarily operating out of St Peter Port and St Sampson (GREC, 2010).

The RET, working with Guernsey's Sea Fisheries Department and for use in the REA, created GIS layers of the different branches of commercial and recreational fishery within their Territorial Sea. The study focuses on the area within the 3 nautical mile limit which is exclusively fished by Guernsey's fleet but does provide some information on activities out to the 6 nautical mile limit. These GIS layers have provided the basis for ascribing a penalty score to planning units in which MRE development would negatively impact fisheries activities.

Each branch of commercial and recreational fishing/potting has been treated as an independent receptor and therefore scored separately. No weighting has been given in terms of the overall percentage value of individual fisheries. Different fisheries sectors can be divided into the two broad categories of 'static' and 'towed gear' (Table 4). For detailed information on the individual types of fishing see the REA (GREC, 2010).

Table 4: Broad Categories for Guernsey's Fishing Sectors

Static Gear	Towed Gear	Other
Potting	Demersal Trawling	Diving (Scallops)
Set Netting	Pelagic Trawling	
Long Lining	Sand Eel Trawling	
Mariculture	Scallop Dredging	
Angling and Hand Lining	Beam Trawling	
Recreational Fishing		

The extent of interaction between MRE developments and individual fisheries sectors is analysed in section 3.8. based on information from the REA.

3.7. MRE Technologies

3.7.1. Offshore Wind

The device chosen for constraints analysis in this scenario is the Vestas V112-3.0MW offshore wind turbine. Vestas are one of two leading manufacturers of offshore wind turbines and the V112 is the predecessor to the V90-3.0MW which has proven success in over 4GW of on and offshore projects worldwide (Vestas, 2012). The V112 has a lower rated wind speed of 12.5m/s than the V90 which is better suited to Guernsey's average offshore wind speeds based on data from the ABPMER Renewables Atlas (Vestas, 2012).

Wind turbines require a separation distance so as not to be detrimental to one another's performance. The air flow in the lee of a turbine becomes turbulent. Turbulent flow results in varied pressures and can be damaging to turbines downstream. A turbulent flow will return to laminar flow given enough recovery distance. A device separation distance of 6.4 x Blade Diameter, as used in the Kentish Flats offshore development comprised of 140 turbines of 90m diameter (MacKay, 2009), was used to calculate the device density for the V112 turbine. The conclusion was, that based on 6.4 x Blade Diameter separation, there is a device density for the Vestas V-112 of 1.95 turbines per km^2. For simplicity, this figure has been rounded to 2 turbines per km^2.

Using the average annual wind speeds taken from the Renewables Atlas (ABP Marine Environmental Research, 2011), the published power curve for the Vestas V112 turbine (Figure 16) and the calculated device density, the MW/km^2 output was calculated for each PU providing a MW target (see section 3.9.4) for the Marxan target parameter.

Technological Limitations

Wind turbines are currently restricted to depths within 50m. This is due to the technical challenge of installation. The installation vessels, specifically the largest 'Jack Up Barges' necessary to lay the piled foundations are restricted to use within this depth.

In the selection of optimal sites PUs exceeding 50m at LAT depth have been excluded from the Marxan planning area.

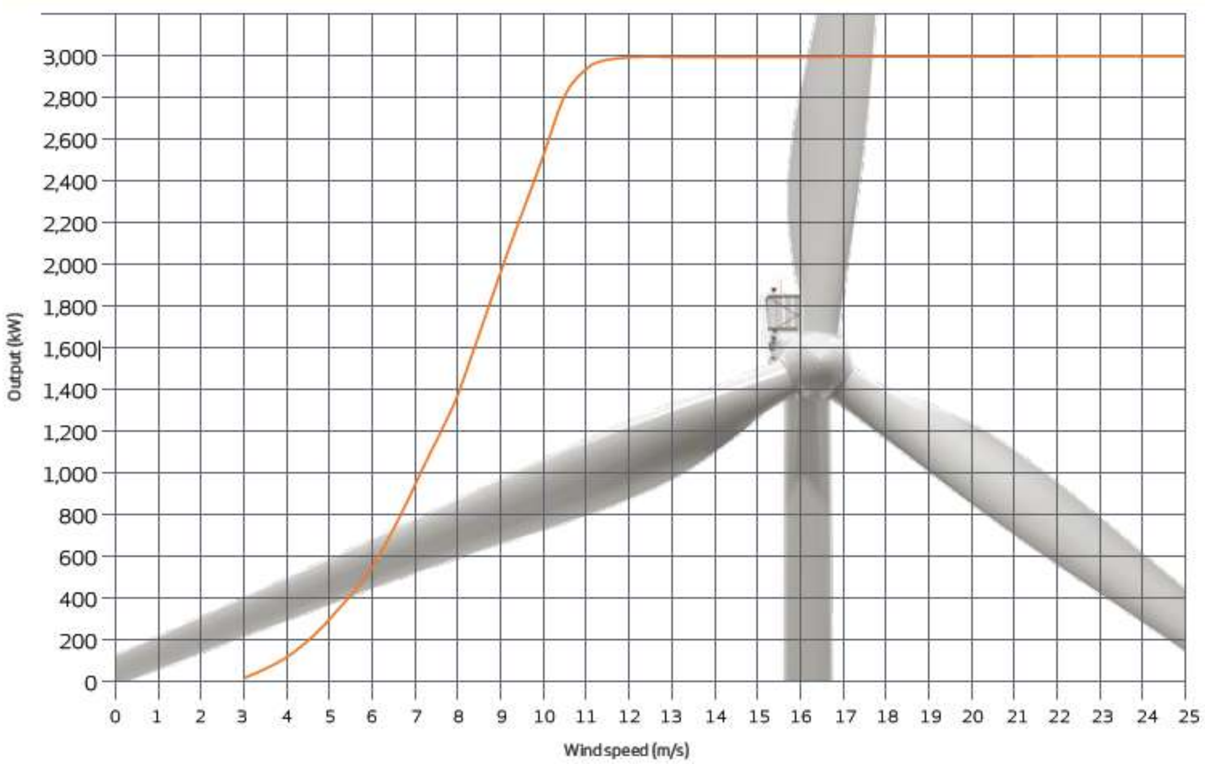


Figure 16: Power Curve for Vestas V112-3.0MW Offshore (Vestas, 2012)

3.8. Device and Receptor Interaction

When ascribing a penalty score for MRE developments' impact on the various receptors discussed it's necessary to consider the extent of negative interaction between the renewable energy devices and each individual receptor.

Destruction or displacement of a receptor, though it may be deemed acceptable for the development of MRE is considered more costly in terms of negative impact in this planning process.

Table 5 shows the extent of interaction between the Vestas V-112 and each receptor considered in this process. Certain receptors may co-exist with devices with minimal impact where as others may be permanently displaced. Table 5 considers long-term co-existence and not the short term impacts during installation. For full interactions analysis including wave and surface piercing, submerged tidal devices and cables see Appendix 4.

Table 5: Interactions Table for Offshore Wind

Key	
[green]	Co-existing with minimal impact
[amber]	Co-existing but a degree of negative impact to receptor
[red]	Exclusion to MRE devices or Receptor

Receptor	**Vestas V-112**	***Justification of interaction rating***
Archaeological Wreck	[amber]	Avoidance necessary
Ramsar Sites	[red]	MRE Excluded
Sea Search	[amber]	Care in avoiding key habitat sites
Bird Breeding Sites	[red]	Vestas excluded from near proximity due to collision risk.
Eunicella	[amber]	Care must be taken in avoiding key habitats
Zostera	[amber]	Care must be taken in avoiding key habitats
Demersal Trawling	[red]	High risk of damage to substructure or entanglement.
Sand Eel Trawling	[red]	High risk of damage to substructure or entanglement.
Potting	[green]	Wind turbines can be easily avoided.
Pelagic Trawling	[red]	High risk of damage to substructure or entanglement.
Beam Trawling	[red]	High risk of damage to substructure or entanglement.
Netting	[green]	Low risk among wind turbines
Longlining	[green]	Low risk among wind turbines
Angling	[green]	Low risk among wind turbines,
Diving	[green]	Low risk among wind turbines.
Scallop Dredging	[red]	High risk of damage to substructure or entanglement.
Cables	[red]	Risk of damage to existing cables with installation. MRE excluded
Explosives Dumping Ground	[red]	Unexploded ordinance. MRE excluded
Military Firing Range	[red]	Military use, risk of damage to devices. MRE excluded.
Geology	[amber]	Localised impact of low magnitude.
Landscape Buffer Zone	[red]	Surface piercing devices excluded.
Navigation	[amber]	Surface piercing devices can be avoided by implementing navigation routing.
Seal Haul Out Area	[red]	Environmentally sensitive, the seal haul out zones and a surrounding 1km buffer zone are excluded to MRE development.
Historic Importance	[amber]	Sites of significance may be avoided following further survey.

3.9. Configuring Marxan Parameter Files

Marxan requires several parameter files to function, as mentioned the software is designed to provide conservation planning solutions and has been adapted for this function. The key parameters required for Marxan to function are species, target, PU cost and PU boundary length. These parameters are described in more detail in the following sections.

3.9.1. Input File

The Input File is used to set values for all the main parameters that control the way Marxan works. The 'Marxan Manual' (Game & Grantham, 2008) and the 'Marxan Good Practices Handbook' (Ardron *et al* 2010) were used as a guide to setting the input variables. In most cases the recommended or default values were adhered to. The main variables are described below.

Repeat Runs

Variable: NUMREPS

This variable is effectively the number of solutions Marxan will generate, from which the best solution will be selected. In this case there is only one species (MRE device) being considered at any one time, which simplifies the planning problem. The recommended minimal value of 100 runs was not sufficient in generating an effective solution for lower targets (see section 3.11) showing a high degree of variation in identical runs and often missing the known better areas. On 1000 runs Marxan still shows a slight variation with each run but 'best solution' results are within close proximity to each other. Marxan runs of 1000 repetitions will be used for the final planning outputs. It should be noted that in testing a new set of variables and for time saving, a small number of runs were selected to check Marxan was performing as desired.

Boundary Length Modifier

Variable: BLM

The BLM determines how much emphasis should be placed on minimising the overall reserve system boundary length. Minimising this length will produce a more compact reserve system which may be a more costly solution. For this planning exercise one compact site was considered preferable to cheaper fragmented areas for the reason that cabling costs represent a high percentage of project development costs. Minimising cabling costs would be favourable for a developer and minimising cabling distance results in less impact to socioeconomic and environmental receptors.

Zonae Cogito is a user interface designed for Marxan, the software allows calibration of the BLM, as there exists a certain value beyond which there is little reduction in boundary length for increase in cost. A BLM value of 0.2 was selected based on the calibration values seen in Figure 17. It can be seen that there is a sharp decrease in boundary length between a BLM of 0 and 0.2, after which there is little change for a large increase in cost.

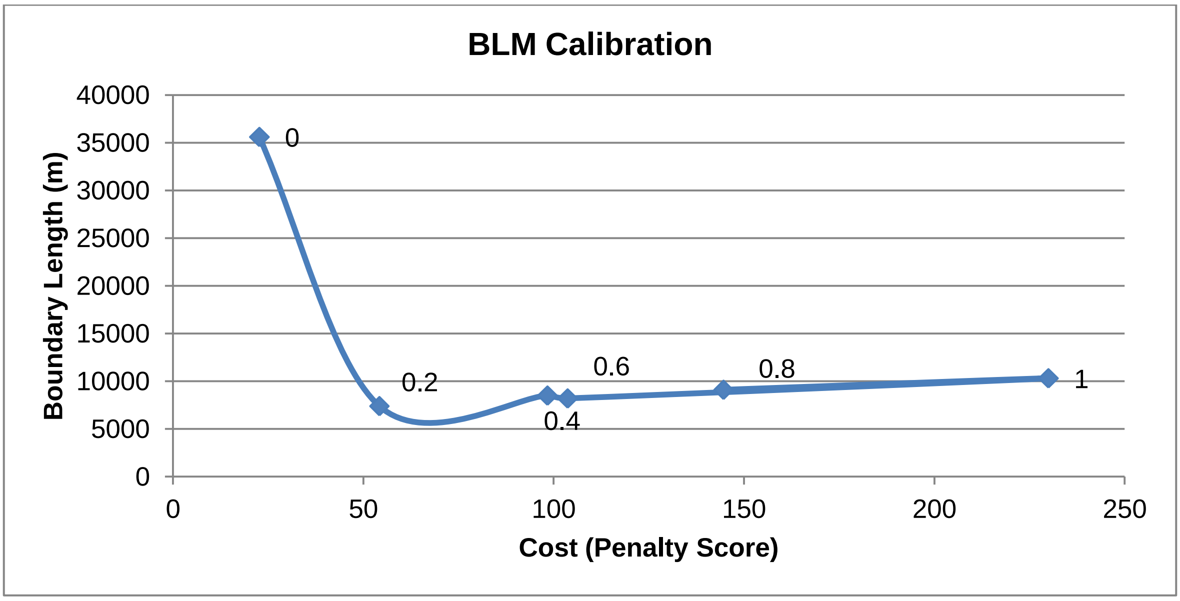


Figure 17: Boundary Length Modifier Calibration Graph

Run Options

Variable: RUNMODE

This is an essential variable that defines the method Marxan will use to locate good reserve solutions (Game & Grantham, 2008). The strength of Marxan lies in its use of Simulated Annealing to find solutions to the reserve selection problem. The Marxan manual states that of various combinations of methods to locate the 'best solution', the most useful is Simulated Annealing followed only by Iterative Improvement as Simulated Annealing searches the solution space effectively, and the Iterative Improvement then ensures that the solution represents the best option in the immediate area of the decision space (known as a 'local minimum').

3.9.2. The Planning Unit File

The Planning Unit File contains information about the planning units themselves, such as ID number, cost and status. A screen shot of the PU file for offshore wind can be seen below.

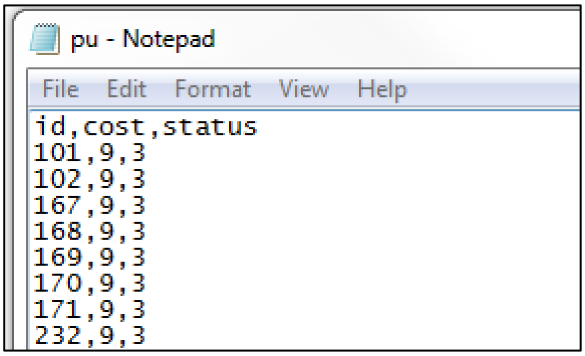


Figure 18: Screenshot of Planning Unit File

'id': the individual PU identification number

'cost': Section 3.10

'status': Table 6

For this planning process a status of either 1 or 3 (Table 6) has been used to include/exclude PUs from the planning solution based on constraints or the technical limitations of the technologies. Figure 19 shows the exclusion zone for offshore wind within the planning area. A similar output was prepared for the Pelamis wave device (see Appendix 6).

Table 6: PU Status Explanation Table (taken from Marxan Manual, ignore section number)

Status	Meaning
0	The PU is not guaranteed to be in the initial (or seed) reserve system, however, it still may be. Its chance of being included in the initial reserve system is determined by the 'starting proportion' specified in the **Input Parameter File** (see Section 3.2.1).
1	The PU will be included in the initial reserve system but may or may not be in the final solution.
2	The PU is fixed in the reserve system ("locked in"). It starts in the initial reserve system and cannot be removed.
3	The PU is fixed outside the reserve system ("locked out"). It is not included in the initial reserve system and cannot be added.

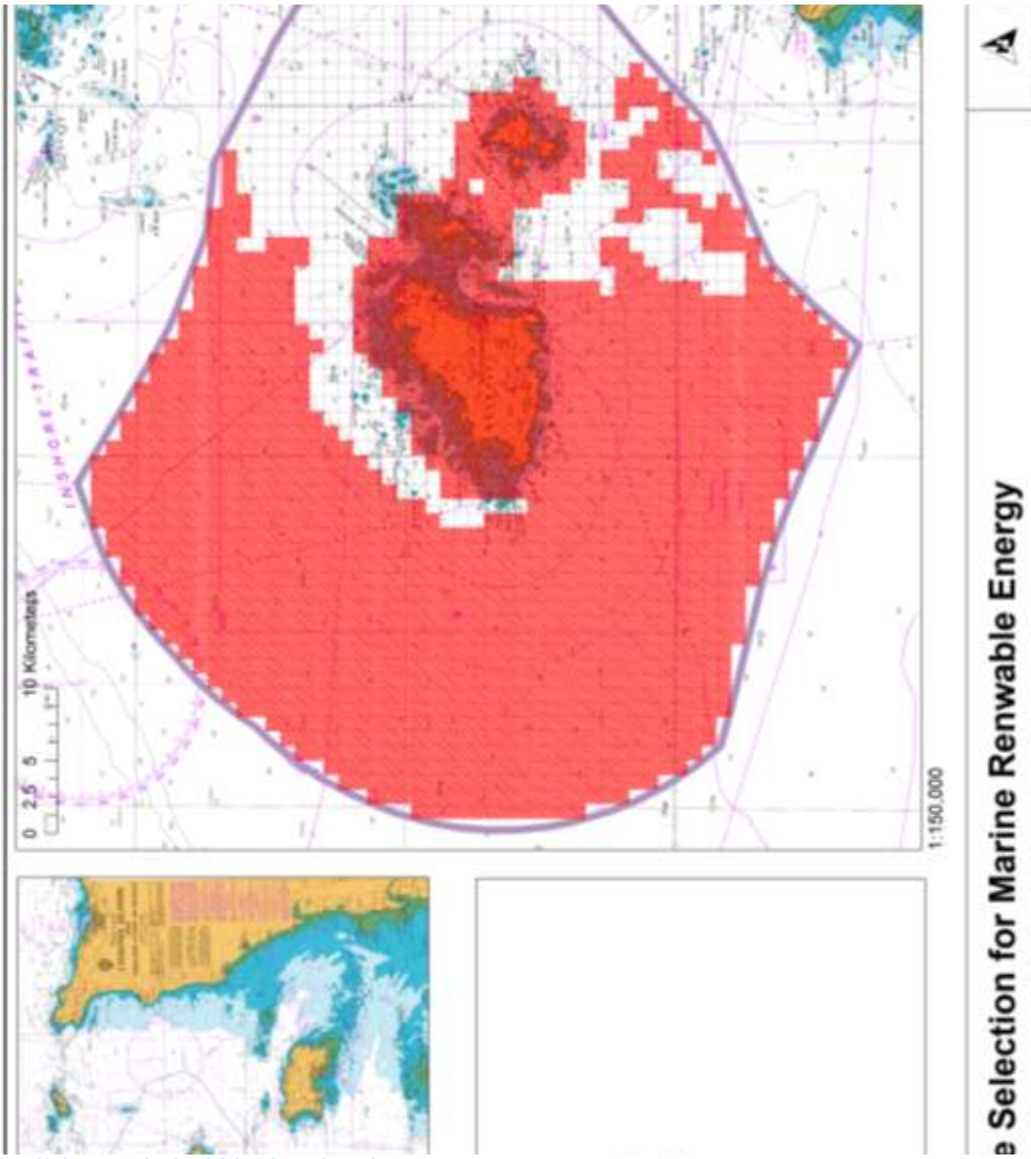


Figure 19: Exclusion Zone for Offshore Wind within the Planning Area

3.9.3. The Planning Unit versus Conservation Feature File

The Planning Unit versus Conservation Feature File contains information on the distribution of conservation features in each of the planning units.

puvspr - Notepad

File Edit Format View Help

```
species,pu,amount
1,101,4.28
1,102,4.28
1,167,4.28
1,168,4.28
1,169,4.28
1,170,4.28
1,171,4.28
1,232,4.28
1,233,4.28
1,234,4.28
```

Figure 20: Screenshot of Planning Unit vs. Conservation File

'species': In this scenario 1 represents the Vestas wind turbine

'pu': The planning unit id number

'amount': In this scenario, represents the potential MW output of devices located in each PU.

3.9.4. The Species File

The Species File contains information about each of the conservation features (MRE technologies in this case), being considered, such as their name, targets and representation requirements, and the penalty that should be applied if these representation requirements are not met.

A screenshot of the Wind Conservation file can be seen below (Figure 21) and the variables are explained.

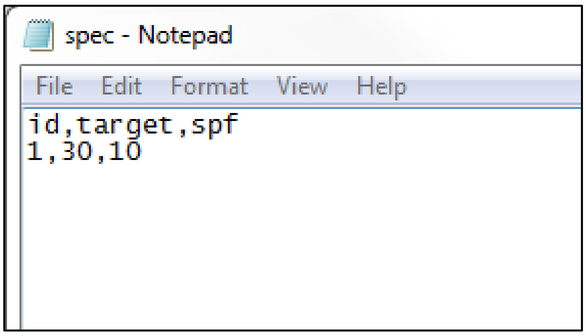


Figure 21: Screenshot of Species File

'id': 1, in this scenario is the label given to the Vestas wind device

'target': in this scenario is 30MW

'spf'= penalty for not achieving target (a high value guarantees target is met or exceeded)

3.9.5. The Boundary Length File

The Boundary Length File contains information about the length or 'effective length' of shared boundaries between planning units. This file is necessary in order to use the Boundary Length Modifier to improve the compactness of reserve solutions. Using a square PU grid means that every PU interface is the same distance (Figure 22).

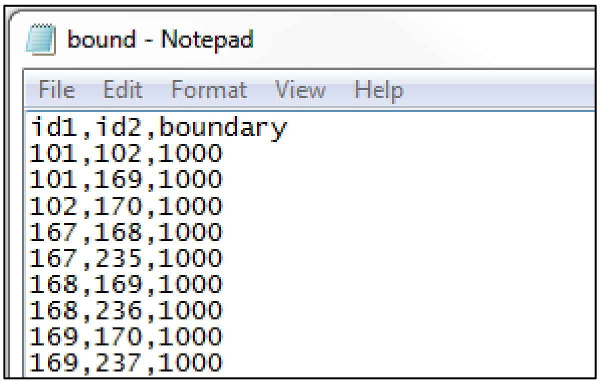


Figure 22: Screenshot of Boundary File

3.10. Marxan Cost Parameter

Marxan solves the previously described ‘minimum set problem’ where the objective is to minimise cost subject to achieving user defined targets.

Each Marxan PU is assigned a score based on the following function:

Score = Cost + Penalty + Boundary Length

The penalty in the function relates to the Marxan solution not meeting the target, however, by setting a high value for the ‘species penalty factor’ (SPF) Marxan will place more weighting on meeting the target than reducing cost.

3.10.1. Cost

In this scenario:

Cost = Depth Penalty + Constraints Penalty

3.10.2. Depth Penalty

Table 7 shows how the depth penalty has been applied to the depth banding used in the planning process.

Table 7: Table of Depth Penalties

Metres below sea level (LAT)	Depth Penalty
0 - 9.9	1
10 - 19.9	2
20 - 29.9	3
30 - 39.9	4
40 - 49.9	5
50 - 59.9	6
60 - 69.9	7
70 - 70.9	8

3.10.3. Constraints Penalty

Initially each PU was issued a penalty score of 1 for every constraint within its boundaries. This method produced initial results on wind farm placement but did not consider the varying levels of interaction and potential co-existence of MRE devices and receptors.

Based on the interaction table (Table 5) a scaled penalty score was applied dependant on the level of interaction (Table 8). The penalty score could be taken further to include weighting and priority scores like the MaRS model, however stakeholder consultation would be required to establish priority of receptors.

Table 8: Table of Constraints Penalties

Level of Interaction	Constraints Penalty Score
Co-existing with minimal impact	1
Co-existing but a degree of negative impact to receptor	5
Exclusion/Destruction Receptor	10

Figure 23 shows the penalty concentration for offshore wind over the planning area. As one would expect level of constraint increases nearer to the coastline. A similar output was prepared for the Pelamis wave energy converter as comparison (see Appendix. 7).

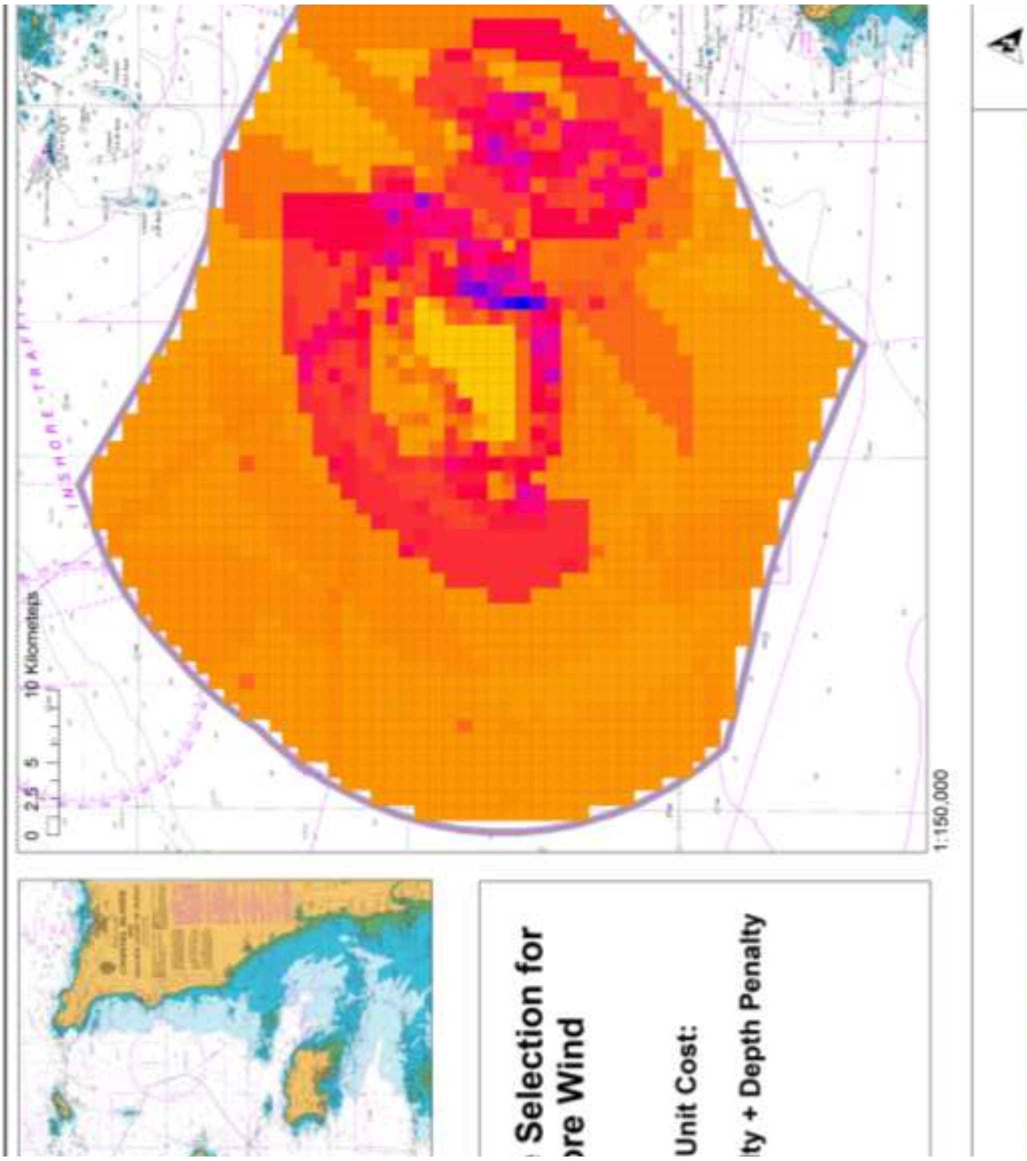


Figure 23: PU Penalty Concentration for Offshore Wind within the Planning Area

3.11. Independent Check on Marxan Solutions

Prior to running the Marxan parameters detailed in the previous sections it was necessary to verify that Marxan finds the best solution within the planning grid.

To test Marxan a separate set of simplified test parameters were created. In this scenario all PUs had an equal target amount of 5MW. Each PU had a cost value of 2 apart from four bordering PUs randomly selected as test units (Figure 24).

The objective was to verify that Marxan would choose the test units in determining the best planning solution for targets of 10 and 50MW

It was found that on a run of 100 Marxan could miss the best solution for a target of 10MW (2 PUs). When the NUMREP was increased to 1000 Marxan located a best solution comprised of two of the test PUs immediately (Figure 24).

Marxan located the test PUs for the 50MW target on a NUMREP of 100 (Figure 24). Due to the larger number of PUs necessary to meet the target Marxan has a higher chance of selecting a test PU and with iterative improvement (see Variable: RUNMODE, section 3.9.1) identifying those remaining.

The test confirmed, that a NUMREP of 1000 be used in the final solutions, to safely increase the chance that Marxan locates the 'best solution' for all targets.

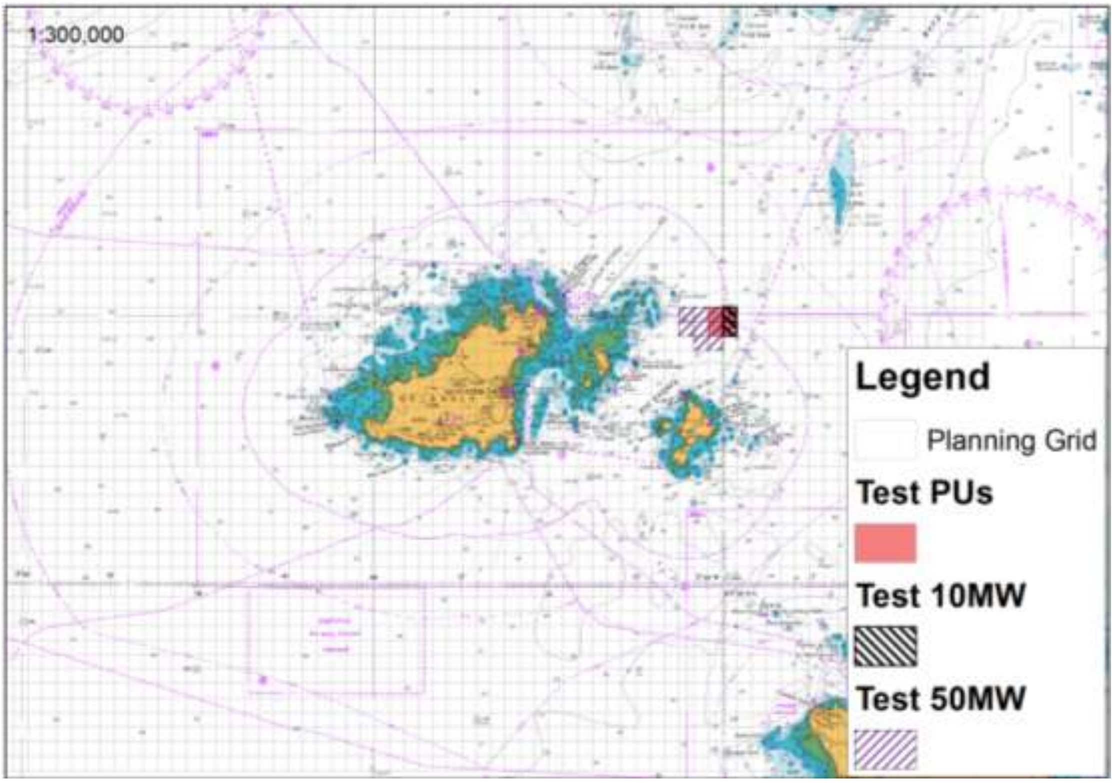


Figure 24: Test Outputs Showing Lower Cost Test PUs

3.12. Cable Route

With solutions for various MW wind arrays it was then intended to apply a cost surface to Arc GIS to optimise cable routes between sites and identified grid connection points. In meetings with Guernsey's RET their preference for a cable landing point was into St Sampson's where the Vale Power Station is located. Many rocky inlets on the West Coast have been considered for a substation connection for sites based off the west of Guernsey which could be required for other MRE technologies.

Using the British Geological Survey (BGS) offshore data there are 3 predominant superficial layers within the planning region. They are rock, gravel and sandy gravel (Figure 25).

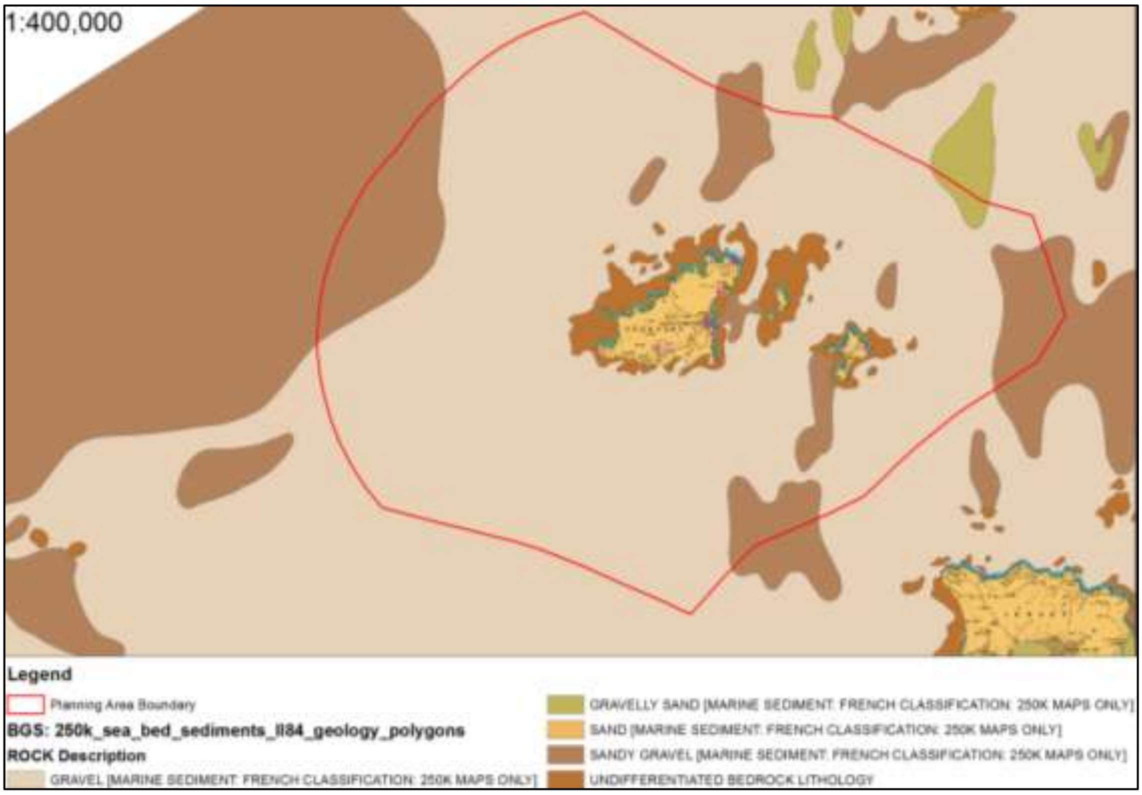


Figure 25: BGS Data Showing Seabed Sediments (British Geological Survey, 2011)

3.12.1. Factors Influencing Cable Route

With the level of marine use over all sectors within Guernsey's waters it can be assumed that some sort of cable protection measure will be used for the export and inter array cables.

Stuart Wilson, route engineering manager at Global Marine Systems states: 'the most economical and effective cable protection is through cable burial' (Personal Communication 06/08/12). The most common and economical method is ploughing, in which a subsea plough is towed by the cabling vessel along the sea bed cutting and lifting a wedge of sediment and feeding the cable into the hole which is then buried (BERR, 2008). This method can be used through gravel and has been implemented successfully at Barrow Wind Farm in the UK (BERR, 2008).

Guernsey's strong tidal currents are the reason for the absence of finer sediments, there is also the risk that the surface sediment layer is thin. Global Marine Systems have installed telecom cables in Guernsey's waters, Wilson suggests: 'it will be possible to get some plough and burial in the gravel regions but rougher ground should be anticipated, where some additional protection methods, such as rock placement or mattresses will certainly be required' (Personal Communication 06/08/12).

In the absence of detailed geotechnical survey work this report seeks solely to recommend a cable route based on BGS data and receptor interactions.

4. Results

4.1. Results Tables for Offshore Wind Planning Solutions

The following tables (Table 9-Table 12) present the Marxan planning solutions for 4, 10, 30 and 50MW targets, the target representing the average output of the Vestas devices at the average annual wind speed at 100m height (see 3.7.1.) These targets represent an example spread of potential developments. Marxan was set to 1000 repetitions with the parameters discussed in sections 3.9 and 3.10.

Note that MRE Arrays are often classed by their capacity rating which is the power rating for the array if devices were operating at full capacity. This is never the realistic case as devices are limited in their performance by several factors such as the Betz limit and conversion efficiency among others.

The results tables show the array capacity rating as well as the average power output and estimated annual energy production based on average output.

For mapping of the solutions see Figure 26.

Table 9: Potential Planning Solution for a 4MW Average Output wind Array

PU	Av. Wind Speed (m/s)	Interactions Penalty	Depth (m)	Depth Penalty	Total Penalty Cost	Power Output per Turbine (kW)	Output-2 Turbines (MW)
2635	9.45	0	30-39.9	4	4	2240	4.48
Total Area							1 km^2
Total Number of Vestas V-112-3.0MW Turbines							2
Array Capacity Rating							6 MW
Average Power Output							4.48 MW
Annual Energy Production							39.24 GWh

Table 10: Potential Planning Solution for a 10MW Average Output wind Array

PU	Av. Wind Speed (m/s)	Interactions Penalty	Depth (m)	Depth Penalty	Total Penalty Cost	Power Output per Turbine (kW)	Output-2 Turbines (MW)
1901	8.96	0	30-30.9	4	4	1990	3.98
1902	8.96	0	20-29.9	3	3	1990	3.98
1970	8.96	0	20-29.9	3	3	1990	3.98
Total Area							3 km^2
Total Number of Vestas V-112-3.0MW Turbines							6
Array Capacity Rating							18 MW
Average Power Output							11.94 MW
Annual Energy Production							104.59 GWh

Table 11: Potential Planning Solution for a 30MW Average Output wind Array

PU	Av. Wind Speed (m/s)	Interactions Penalty	Depth (m)	Depth Penalty	Total Penalty Cost	Power Output per Turbine (kW)	Output-2 Turbines (MW)
1833	8.96	0	30-39.9	4	4	1990	3.98
1834	8.96	0	20-29.9	3	3	1990	3.98
1901	8.96	0	30-39.9	4	4	1990	3.98
1902	8.96	0	20-29.9	3	3	1990	3.98
1969	8.96	0	30-39.9	4	4	1990	3.98
1970	8.96	0	20-29.9	3	3	1990	3.98
2037	8.96	0	20-29.9	3	3	1990	3.98
2038	8.96	0	20-29.9	3	3	1990	3.98
Total Area							8 km^2
Total Number of Vestas V-112-3.0MW Turbines							16
Array Capacity Rating							48 MW
Average Power Output							31.84 MW
Annual Energy Production							278.92 GWh

Table 12: Potential Planning Solution for a 50MW Average Output wind Array

PU	Av. Wind Speed (m/s)	Interactions Penalty	Depth (m)	Depth Penalty	Total Penalty Cost	Power Output per Turbine (kW)	Output-2 Turbines(MW)
2634	9.2	0	30-39.9	4	4	2140	4.28
2635	9.45	0	30-39.9	4	4	2240	4.48

2636	9.45	0	30-39.9	4	4	2240	4.48
2637	9.45	0	30-39.9	4	4	2240	4.48
2702	9.2	0	30-39.9	4	4	2140	4.28
2703	9.45	0	30-39.9	4	4	2240	4.48
2704	9.45	0	30-39.9	4	4	2240	4.48
2705	9.45	0	30-39.9	4	4	2240	4.48
2770	9.2	0	30-39.9	4	4	2140	4.28
2771	9.45	0	30-39.9	4	4	2240	4.48
2772	9.45	0	30-39.9	4	4	2240	4.48
2773	9.45	0	30-39.9	4	4	2240	4.48
Total Area							12 km^2
Total Number of Vestas V-112-3.0MW Turbines							24
Array Capacity Rating							72 MW
Average Power Output							53.16 MW
Annual Energy Production							465.68 GWh

4.2. Mapping Output for Wind Planning Solutions

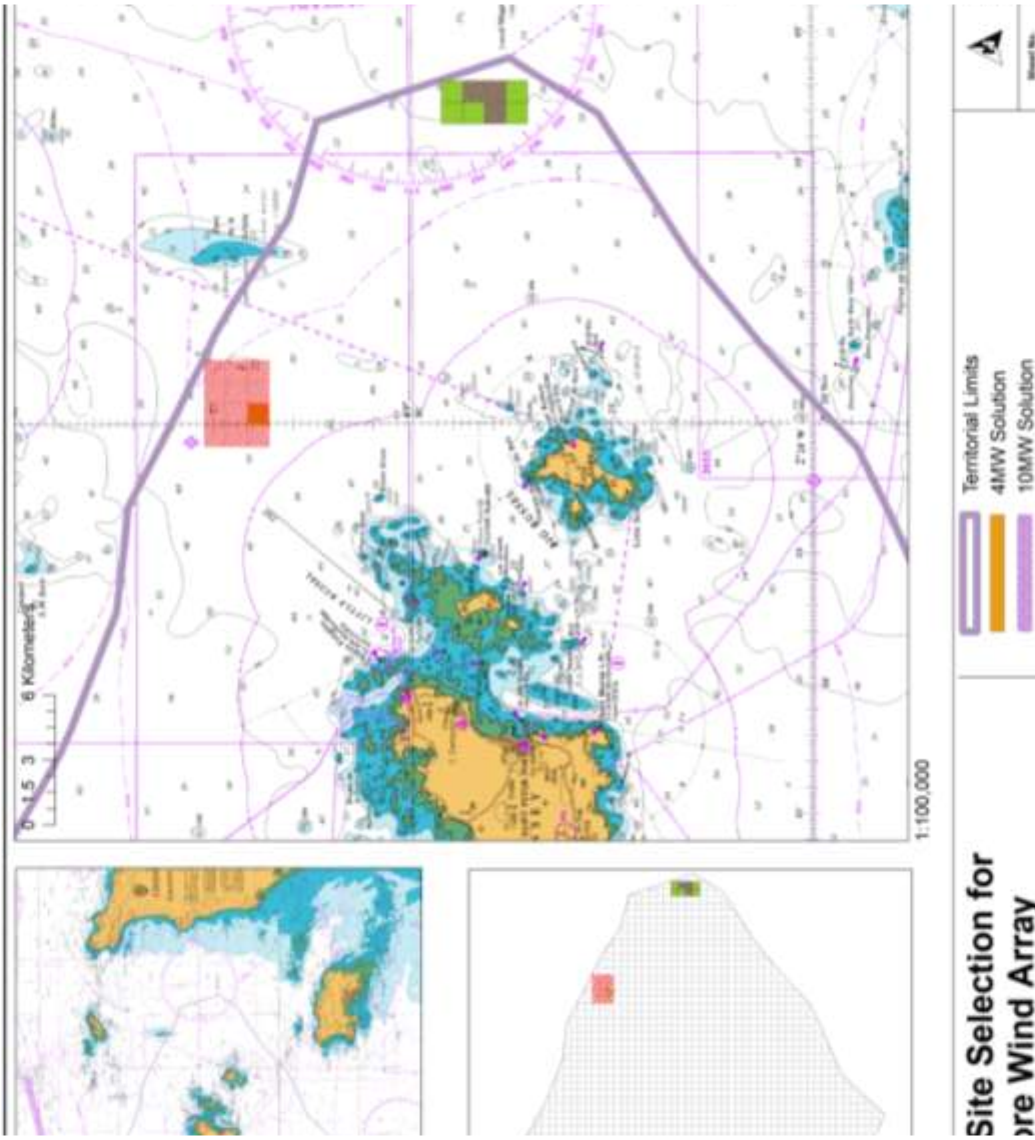


Figure 26: Mapping Output for Marxan Planning Solutions for Offshore Wind

4.3. Potential Export Cable Routes for Planning Solutions

Based on BGS offhore data for marine sediments and bedrock (British Geological Survey, 2011), Figure 27 shows two potential export cable routes for the planning solutions assuming that the most direct route over sandy gravel and gravel would be preferable to cable laying over bedrock. Cable exclusion areas are based on the interactions table found in Appendix 5.

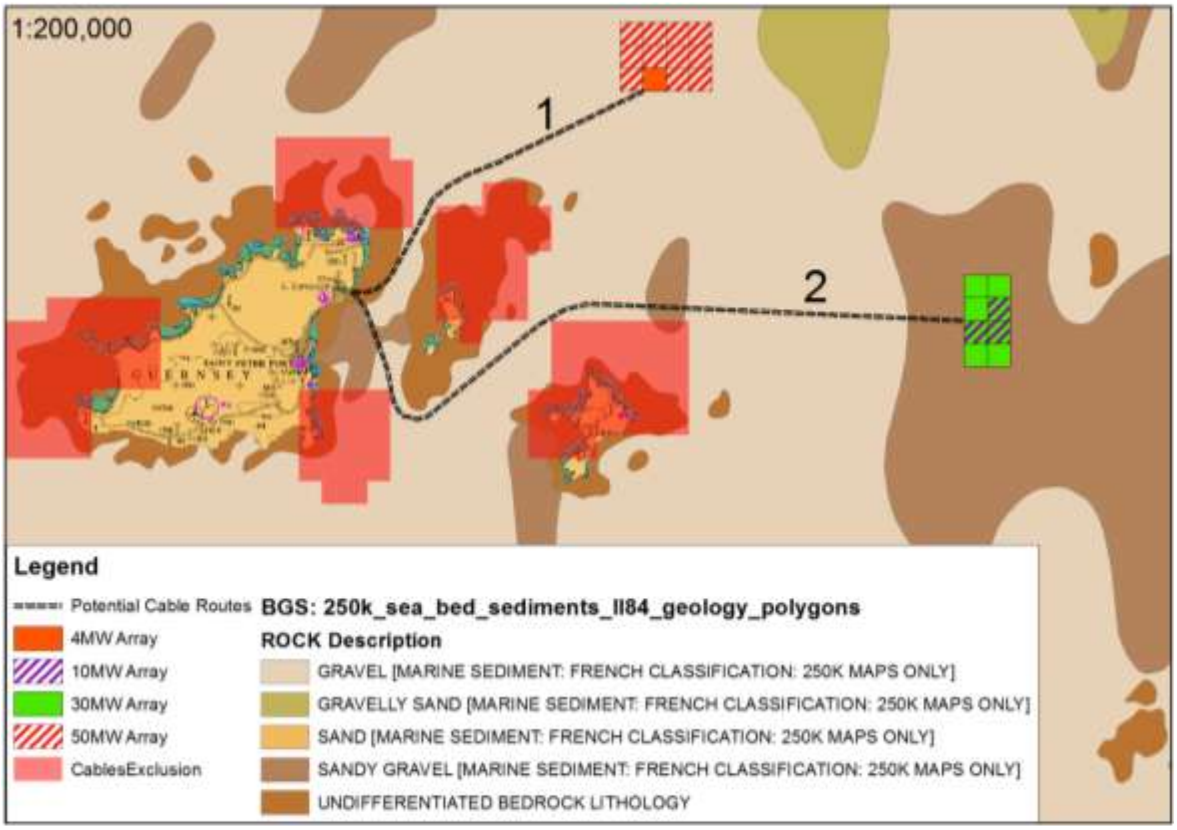


Figure 27: Potential Export Cable Routes for Offshore Wind Planning Solutions

Cable Route 1 = 16.1km

Cable Route 2 = 31.1km

5. Discussion

As expected the planning solutions for offshore wind are all beyond the 3nm limit as interactions and competition for space are much higher within the 3nm zone. The following sections consider the advantages and disadvantages of each solution presented.

5.1. Planning Solution for 4MW Average Output

By running a 4MW target in Marxan it was expected to identify an overall best individual PU boasting highest resource and minimal constraint.

The highest average annual wind speed at 100m height is 9.45m/s within the available planning area. This solution has successfully selected a site with the highest resource and no recorded constraints. However, on further analysis there are 11 other PUs with the same attributes. Marxan has selected the individual PU on the basis of selection frequency i.e. out of 1000 runs Marxan has selected this PU a greater number of times than the others. An advantage of this PU as opposed to others of equal attribute is that it is the closest to St Sampson lessening export cable costs. Its position bordering PUs of equal attribute shows a clear opportunity for expansion of this potential development outwards towards the 6nm boundary.

Advantages:

- Within 6nm limit.
- Captures the highest wind resource of 9.45m/s (100m height) within available planning area.
- Avoids all identified constraints.
- In between main navigation routes.
- Potential for a direct export cable route through the Little Russel.

Disadvantages:

- Within the 30-39.9m depth range at LAT, nearing technological limits for installation.
- 15.8km from St Sampson.

Table 13 shows Guernsey's total electricity consumption for the tax years 2010-11 and 2009-10. The planning solution would contribute nearly 10% of Guernsey's electricity requirements based on 2010-11 figures.

Table 13: Guernsey's Imported/Generated Electricity (Guernsey Electricity Ltd, 2011)

	2010-2011	**2009-2010**
Electricity Imported (GWh)	308.6	152.24
Electricity Generated (GWh)	84.6	239.33
Total (GWh)	393.2	391.57

5.2. Planning Solution for 10MW Average Output Array

With an estimated MW output for each PU, it was known that for a 10MW solution Marxan would require a minimum of three PUs to meet the target. In solving the minimum set problem Marxan has reduced cost by selecting PUs with shallower depths on the east of the planning area, however by doing so has forfeited the higher wind resource in the north of the planning area.

Advantages:

- Rests along the 30m depth contour with two PUs within the 20-29.9m depth band and the remaining one within the 30-39.9m depth band. Shallower than both the 4 and 50MW solutions.
- Avoids all identified constraints.
- Borders proposed French development region, opportunity for joint development.

Disadvantages:

- Roughly 27km from St Sampson.
- Would require a meandering export cable to avoid Herm and Sark if cable were to land in St Sampson.
- Beyond the 6nm limit.
- Slightly lesser wind resource of 8.96m/s at 100m height.

With an 18MW capacity rating and an 11.94MW average output, the planning solution would contribute 26.6% of Guernsey's required electricity based on 2010-11 figures (Table 13).

5.3. Planning Solution for 30MW Average Output Array

This solution could have been solved with 7 PUs at a penalty cost of 28 in the north of the planning area, utilising the highest wind resource. However, in this instance Marxan has selected 8 PUs in the East of the planning area with lesser wind resource but shallower water depths resulting in reduced penalty cost of 27. Arguably this is may not be the best solution for offshore wind development of this scale (see section 5.5).

Advantages:

- At shallower depth compared to 4 and 50MW solutions, rests along the 30m depth contour, with five PUs within the 20-29.9m depth band and the remaining three within the 30-39.9m depth band.
- Avoids all identified constraints.
- Borders proposed French development region, opportunity for joint development.

Disadvantages:

- Roughly 27km from St Sampson.
- Would require a meandering cable to avoid Herm and Sark if cable were to land in St Sampson.
- Beyond the 6nm limit.
- Slightly lesser wind resource of 8.96m/s at 100m height.

An array of 48MW capacity rating with average output of 31.84MW, this potential development could contribute nearly 71% of Guernsey's electricity requirements.

5.4. Planning Solution for 50MW Average Output Array

This example solution addresses the RET's considerations on exporting electricity. A 50MW average output development surpasses Guernsey's own electricity requirements and the surplus could potentially be exported to other Channel Islands or France.

Advantages:

- The majority of development is within the 6nm limit.
- Makes use of higher wind resource in this region of the planning area.
- Avoids all identified constraints.
- Between main navigation routes.
- Potential for a direct export cable route through the Little Russel.
- Nearest corner of array 15km from St Sampson. The closest of all solutions to the preferred connection point at Vale Power Station.
- Surplus generation could result in exportation of electricity.

Disadvantages:

- All PUs within the 30-39.9m depth range at LAT, nearing technological limits for installation.

With a capacity rating of 72MW and an estimated average output of 53.16MW the development could potentially supply 118% of Guernsey's electricity requirements.

5.5. Use of Marxan in Identifying Sites of Minimal Impact for MRE Development

The solutions discussed are those Marxan considers the 'best solution' for the 'minimum set problem' of achieving the target at minimal penalty cost. They have been selected as the best solutions from runs of 1000 potential solutions. It was found, however, that Marxan when running identical runs of 1000 repetitions with the same limitations and parameters would output a slight variation of the best solution each time. Solutions tend to vary in position (though are generally overlapping) and orientation.

It can be seen from the example solutions that there two general sites for consideration, one in the north of the available planning area and one in the east, that avoid all other receptors identified in this study. In this respect Marxan has performed well as a planning tool as all solutions avoid negative impact to the receptors discussed.

The 30MW solution shows that Marxan will target a larger area at slightly less cost than a smaller area with better resource/km^2 where both achieve the target. Table 14 shows a comparison of the 30MW solution and a choice of 7 PUs selected from within the 50MW site.

Table 14: Comparison of the 30MW Solution and a 30MW Site within the Northern Area

	30MW Solution (Eastern)	Northern site solution for 30MW
Area	8 km^2	7 km^2
Number of PUs	8	7
Av. Output (MW)	31.84	31.36
Number of Turbines	16	14
Total Penalty Cost	27	28

From an offshore wind developers' perspective, without considering depth and distance from shore, the northern site may seem more desirable for the fact that two additional turbines in the comparison make very little difference to the output and though the northern site is more costly in terms of penalty, the cost of devices and developing an extra 1km^2 could weigh the decision towards the northern site.

The numerous questions that arise from the solutions require policy and engineering experts to decide on their feasibility, which leads this discussion in the direction of general areas for minimal impact development for offshore wind. As well as a 'best' solution output, Marxan also creates a summed solution output which can be linked to Arc GIS to show selection frequency. Figure 28 shows the PU selection frequency for the 30MW planning solution and the 4 areas of highest PU selection (Potential development areas 1-4). Area 5 contains the 'best' solution sites for 10 and 30MW average output arrays.

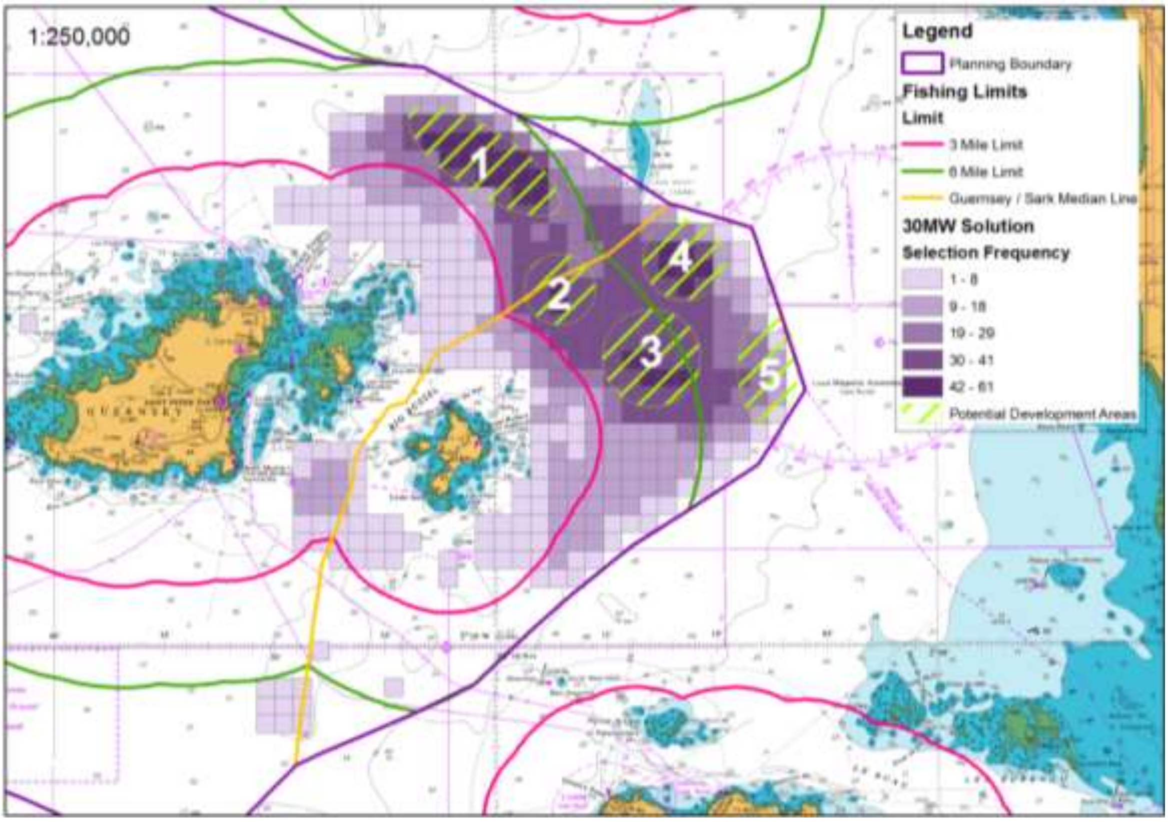


Figure 28: 30MW Solution Selection Frequency Showing Potential Development Areas.

Area 1 in Figure 28 has highest number of high frequency PU selections which corresponds to the 4 and 50MW 'best' solutions. This area has the highest wind resource in the available planning area. The western edge of this area is on the 50m depth contour line, resulting in a higher depth penalty cost and explaining the 4 and 50MW solutions being sited in the east of this area in water depths of 30-39.9m.

Areas 2-4 don't contain any 'best' solutions as that they are largely constrained by navigation. In minimising boundary length whilst maximising area Marxan will tend to create regular shaped sites. This is more difficult to achieve where there exists higher constraint. Area 2 corresponds well to the Exeter Study's site selection for a 300MW rated capacity wind array (BSc Renewable Energy Final Year Students, 2012). Navigation in both Exeter's Study and this report is considered a 'soft' constraint as exclusion zones could be implemented to guide larger vessels around wind arrays.

A large advantage of sites 1-3 is that they lie, or their majority lies, within the 6nm limit. If the States of Guernsey are successful in their plea for jurisdiction to 6nm there are a range of potential development areas for offshore wind without necessarily requiring jurisdiction to 12nm. However, jurisdiction to 12nm does present a larger opportunity for the development of other MRE technologies.

Area 5 is where the ‘best’ solutions for 10 and 30MW average output arrays are located. In this eastern most area of the planning area shallower depths and no interactions penalties have reduced penalty costs. This area has a slightly lower wind resource of 8.96 m/s at 100m but as mentioned another advantage of this site is that it borders the proposed French wind farm and could present an opportunity for joint development.

6. Conclusions

The planning process undertaken has been successful in identifying minimal impact sites for offshore wind. The potential solutions presented for the various scales of offshore wind array development have not previously been considered by earlier studies and present less constraint than those that have. However further site specific studies must be undertaken before the true viability of any proposed site is known.

The planning process used is complex and time consuming and when a single development scenario is being discussed, likely to be unnecessary, as areas of least constraint can be identified by a competent user of GIS. However, once a GIS database exists for resource and constraints information it is relatively straightforward to adapt this process to different MRE technologies. In Guernsey and Sark's case, the range of MRE options considered feasible in the near surroundings justify user knowledge of such a planning process, as it can be applied to individual MRE devices.

Planning outputs should not be taken as definitive development solutions as there are many factors that are not considered in this planning method. Actual estimations of monetary cost of development must be applied to each development solution and stakeholder engagement is recommended from the outset of decision making.

The strength of the planning model lies in identifying general areas for minimal impact sites through a range of 'best' solution outputs in combination with the summed solution frequency selection of PUs. This presents options for stakeholders and decision makers that can be built upon with knowledge from policy and engineering experts.

Cabling distance and depth are likely to be large influencing factors on final site selection. Although the Beatrice Demonstrator site has proven installation and operation in water depths of 45m, maximum spring tidal range at the site is 3.34m. Guernsey has a spring range of approximately 8.9m which must be taken into account when looking at planning solutions in a depth band of 30-39.9m LAT.

Recommendations

Detailed site survey is required going forward. High resolution bathymetry would be useful in further studies. Surveys of particular use to aid site analysis would include geophysical survey with multi-beam sonar. Areas of known steep incline unsuitable for wind farm development could then be excluded from the planning process. Site specific bore holes in characterising seabed sediments and depth would aid understanding of foundations required and level of cable protection necessary.

There is limited constraints knowledge beyond the 6nm boundary. Guernsey's Sea Fisheries Department can input their knowledge on the level of commercial fishing within identified potential development areas. Site specific impacts to navigation, especially re-routing of larger vessels should be considered.

Communication with France is recommended in regard to the feasibility of joint or co-operative development as this may considerably drive down costs of development.

When compared to The Crown Estate's MaRS DST this model is inferior in terms of the available datasets. Depth was the sole technical dataset used in constraints analysis however the MaRS technical dataset should be referred to for an example on including seabed slope and sediment type (see Appendix 2) when considering constraint to development. The valuation of the individual fishing activities in Guernsey's waters would be beneficial in applying weighting as seen in the MaRS dataset (see Appendix 2).

The planning database should continue to be added to as resource information becomes higher resolution and as more constraints become known. There is scope for high resolution planning grids if detailed geophysical survey data becomes available however it's recommended that high resolution grids remain site specific as the process becomes labour intensive.

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8. Appendices

Appendix 1: MaRS Exclusions and Restrictions Datasets for Offshore Transmission Model

The second iteration of the Round 3 map excluded areas constrained by the following features:

- Live Cables (telecoms and electricity)
- Live Pipelines
- Live Interconnectors
- Outside of UK Continental Shelf
- Round 1 Wind Farms
- Round 2 Wind Farms
- Wind Farm Cables
- Round 2 SEA Regions
- Wind farm Anemometers
- Protected Wrecks
- Deep Mining Minerals
- Oil and Gas Surface Installations
- Oil and Gas Subsurface Installations
- Oil and Gas Safety Zones
- Live Wells
- Dredging Licence Areas
- Dredging Option Areas
- Dredging Application Areas
- Dredging Prospecting Areas
- Aquaculture and Foreshore Leases
- Tunnels
- Seascape Buffer (13 km) (upper end of range from Round 2 SEA conclusions)
- Bathymetry <5m and >60m

Restrictions were weighted and scored to identify areas that may offer suitable development opportunities. The specific layer weightings and scores were based upon knowledge and expertise within The Crown Estate, consultees and stakeholders.

Restrictions

- Bathymetry (scored by depth)
- Wind resources (scored by annual mean wind speed at 100m)
- Military PEXA + Munitions Dumps
- Decommissioned Oil & Gas Wells
- Aggregate Future Interest Areas
- Sites of Special Scientific Interest (SSSI)
- Special Areas of Conservation (SAC)
- Potential Offshore SAC
- Special Protected Area (SPA)
- National Nature Reserve (NNR)
- Local Nature Reserve (LNR)
- Marine Nature Reserve (MNR)
- Ramsar Sites
- World Heritage Sites
- Out of Service Cables
- Out of Service Pipelines
- Shipping Density
- Port Navigation Channels
- Active Dumping Grounds
- Gas Storage Areas
- R1 Wind Farm Exclusion Zones
- Anchorage Areas and Buoys (navigation and metocean)
- Disused Dumping Rounds (not closed)
- Recreational Craft Routes and Areas
- Charted Navigation
- Potential Gas Storage Areas

Appendix 2: MaRS Technical and Other Uses and Obstacles Datasets for Offshore Transmission Model

Dataset Name	Buffer (m)	Weight	Score	W*S
Technical				
Slope (%)				
< 2.7	n/a	100	3	300
2.7 - 5.5	n/a	100	3	300
5.5- 8.2	n/a	100	3	300
8.2 - 11.0	n/a	100	5	500
11.09 - 13.7	n/a	100	5	500
13.7 - 16.5	n/a	100	9	900
16.5 - 19.2	n/a	100	12	1200
19.2 - 22.0	n/a	100	16	1600
22.0 - 24.7	n/a	100	20	2000
24.7 - 28.5	n/a	100	24	2400
Sea-bed Sediment of UK Waters				
Mud	n/a	700	19	13300
Muddy sand [marine sediment]	n/a	700	32	22400
Sandy mud [marine sediment]	n/a	700	32	22400
Slightly gravelly mud [marine sediment]	n/a	700	32	22400
Slightly gravelly sandy mud [marine sediment]	n/a	700	32	22400
Sand [marine sediment]	n/a	700	43	30100
Slightly gravelly muddy sand [marine sediment]	n/a	700	43	30100
Slightly gravelly sand [marine sediment]	n/a	700	43	30100
Gravelly mud [marine sediment]	n/a	700	43	30100
Muddy gravel [marine sediment]	n/a	700	53	37100
Clay and sand	n/a	700	53	37100
Gravel, muddy, sandy [marine sediment]	n/a	700	53	37100
Gravel, sand and silt	n/a	700	53	37100
Gravelly muddy sand [marine sediment]	n/a	700	53	37100
Gravelly sand [marine sediment]	n/a	700	53	37100
Sandy gravel [marine sediment]	n/a	700	63	44100
Bathymetry (m)				
0 to -25	n/a	400	7	2800
-25 to -50	n/a	400	15	6000
-50 to -75	n/a	400	22	8800
-75 to -100	n/a	400	29	11600
-100 to -125	n/a	400	36	14400
-125 to -150	n/a	400	44	17600
-150 to -175	n/a	400	51	20400
-175 to -200	n/a	400	58	23200
-200 to -225	n/a	400	65	26000
-225 to -250	n/a	400	73	29200

Other uses and obstacles				
Round 26 Conditional Award Blocks	n/a	500	50	25000
Obstructions to Navigation	100	1000	100	100000
Inactive UK Offshore Wells	100	1000	100	100000
Munitions Dumps	n/a	1000	100	100000
Disused Disposal Sites	n/a	300	30	9000
Closed Disposal Sites	n/a	300	30	9000
Open, Not in Use Disposal Sites	n/a	700	70	49000
Open Disposal Sites	n/a	900	90	81000
Fish Value for Trawls - VMS (average £/yr)				
< £916	n/a	800	15	12000
£916 - £1,833	n/a	800	29	23200
£1,833 - £2,749	n/a	800	44	35200
£2,749 - £4,583	n/a	800	58	46400
£4,583 - £6,416	n/a	800	73	58400
£6,416 - £10,082	n/a	800	87	69600
£10,082 - £14,665	n/a	800	102	81600
£14,665 - £21,082	n/a	800	116	92800
£21,082 - £32,998	n/a	800	131	104800
£32,998 - £23,4655	n/a	800	145	116000

Appendix 3: Problems Experienced in Initial Marxan Trials

1. **Overlay in Arc GIS**

   Although the Tidal Report produced a modelled grid of 1km^2 units, the same scale selected for the planning grid, the data was taken from a TIFF image geo-referenced to an Admiralty Chart base map. Geo-referencing warped the tidal data layer creating difficulties in alignment and subsequently difficulties issuing individual values to PUs.

2. **Irregular Shape Files**

   Constraints data presents spatial information in irregular GIS layers. Whilst a PU may in one scenario completely overlap a constraints zone the constraints layer may also only occupy a small percentage of a 1km^2 PU. It was decided that any constraint within a PU contribute to the PU penalty no matter what percentage of the PU is occupied.

3. **File Management**

   Initially a database containing all relevant data can be created in Arc GIS by editing the planning grid's attribute table. By exporting the completed table as a .CSV file it can then be opened in Microsoft Excel where power output equations and SUM calculations for constraints can be applied to create the parameter files for Marxan. Each parameter file was created on a separate Excel spread sheet and then saved as .CSV files. Note that to function in Marxan the parameter files were opened in notepad and re-saved as .DAT files. The full Excel Database should be saved as backup.

   The Marxan folder must be organised as seen in Figure 29 for Marxan to function correctly and very close attention must be paid to the user manual when naming the parameter files (see section 3.9) located in the input folder. The ZCP file and the pufile folder (containing a copy of the planning grid shapefile) are only for use with the Zonae Cogito Marxan Interface. The Inedit application is used to create the input.dat file and the user manual should be followed in setting the various Marxan controls.

Name	Date modified	Type	Size
input	30/07/2012 15:53	File folder	
output	30/07/2012 17:25	File folder	
pufile	30/07/2012 16:07	File folder	
Inedit	21/03/2002 08:55	Application	1,805 KB
input	09/08/2012 08:57	DAT File	1 KB
Marxan_x64	05/07/2012 11:10	Application	293 KB
project1	08/08/2012 17:36	ZCP File	1 KB

Figure 29: Recommended Elements in the Marxan Folder

If changing the target resource in Marxan any previous output file will be overwritten, therefore it is necessary to copy and paste each set of output files to a separate folder.

Marxan can be set to create a ‘best solution’ and ‘summed solution’ .CSV output files formatted to open in Arc GIS, this should be linked to a planning grid shape file using the ‘join’ function in Arc GIS. Again it should be noted that the output file is overwritten each time Marxan is run. It was found that the most efficient way of storing and managing each individual ‘best solution’ mapping output was to create a Personal Geodatabase in Arc Catalog and import each solution attribute as a feature class before starting the next Marxan run.

4. **Representative Target for MRE**

The Tidal Study used for resource data provides GWh/year over 1km^2 grid squares. Using this resource as a target is deceptive in a planning sense as it would be impossible to convert all of the tidal energy available within a PU to electricity. It was decided that the next step would be to estimate actual power output (MW) based on the average resource using device specific power curves/matrices (4.7).

Appendix 4: Interactions Table Including Wind, Wave & Tidal Stream Technologies and Subsea Cables

MCT Seagen S	Submerged Tidal	Pelamis	Export Cables	Key	
				Green	Co-existing with minima
				Amber	Co-existing but a degre receptor
				Red	Exclusion to MRE devic
				Justification of interaction rating	
Amber	Amber	Amber	Amber	Avoidance necessary in placing of substructure	
Red	Red	Red	Red	MRE Excluded	
Amber	Amber	Amber	Red	Care in avoiding key habitat sites	
Amber	Amber	Amber	Green	Vestas excluded from near proximity due to collision risk. Small likelihood of submerged structures. Cable installation could cause disturbance but could b season.	
Amber	Amber	Amber	Amber	Care must be taken in avoiding key habitats. Cable installation could cause s proximity.	
Amber	Amber	Amber	Amber	Care must be taken in avoiding key habitats. Cable installation could cause s proximity.	
Red	Red	Red	Red	High risk of damage to substructure and cables or entanglement as gear is to	
Red	Red	Red	Red	High risk of damage to substructure or entanglement.	
Amber	Red	Red	Green	Wind turbines can be easily avoided. Seagen is surface piercing but has high lost gear. Submerged tidal turbines cannot be seen therefore there exists a h entanglement. The mooring lines and exposed export cabling for Pelamis rep risk.	
Red	Red	Red	Green	High risk of damage to substructure or entanglement. Cables should not pose be at risk of damage as gear is not towed on bottom.	
Red	Red	Red	Red	High risk of damage to substructure or entanglement.	
Red	Red	Red	Green	Low risk among wind turbines though high risk of entanglement among tidal s mooring lines/export cables. Export cables once buried or rock armoured sho risk.	

	Low risk among wind turbines, Seagen is visible therefore avoid entanglement with submerged turbines and at close proximity to buried or rock armoured should not be at risk or pose a risk
	Low risk among wind turbines. High risk to divers in strong curre Necessary care to be taken at close proximity to wave devices. armoured should not be at risk or pose a risk
	High risk of damage to substructure or entanglement. High risk
	Risk of damage to existing cables with installation. MRE exclude cross, care must be taken to avoid damage to either existing or
	Unexploded ordinance. MRE excluded, cables excluded.
	Military use, risk of damage to devices. MRE excluded.
	Localised impact of low magnitude.
	Surface piercing devices excluded. Cables must come ashore.
	Surface piercing devices can be avoided, submerged devices sl of vessels above. Larger vessels may be excluded. Cables at ris necessary.
	Environmentally sensitive, the seal haul out zones and a surrou MRE development and cabling.
	Sites of significance may be avoided following further survey.

Appendix 5: Data Sources for Wave and Tidal Stream Development Planning.

Wave

Wave data is also available from ABPMER as GIS shape files, the data primarily provided by the Met Office UK and based on the UK Waters Wave Model which has a spatial resolution of 12km (ABP Marine Environmental Research, 2008).

For higher resolution modelled wave data in Guernsey's area of interest, Cael Joshi' s MSc project for the University of Plymouth, also in collaboration with Guernsey's RET provides a resolution of 1.1km. The model is based on two years of Met Office UK Wave Watch III data and will be available for future use (Joshi, 2012).

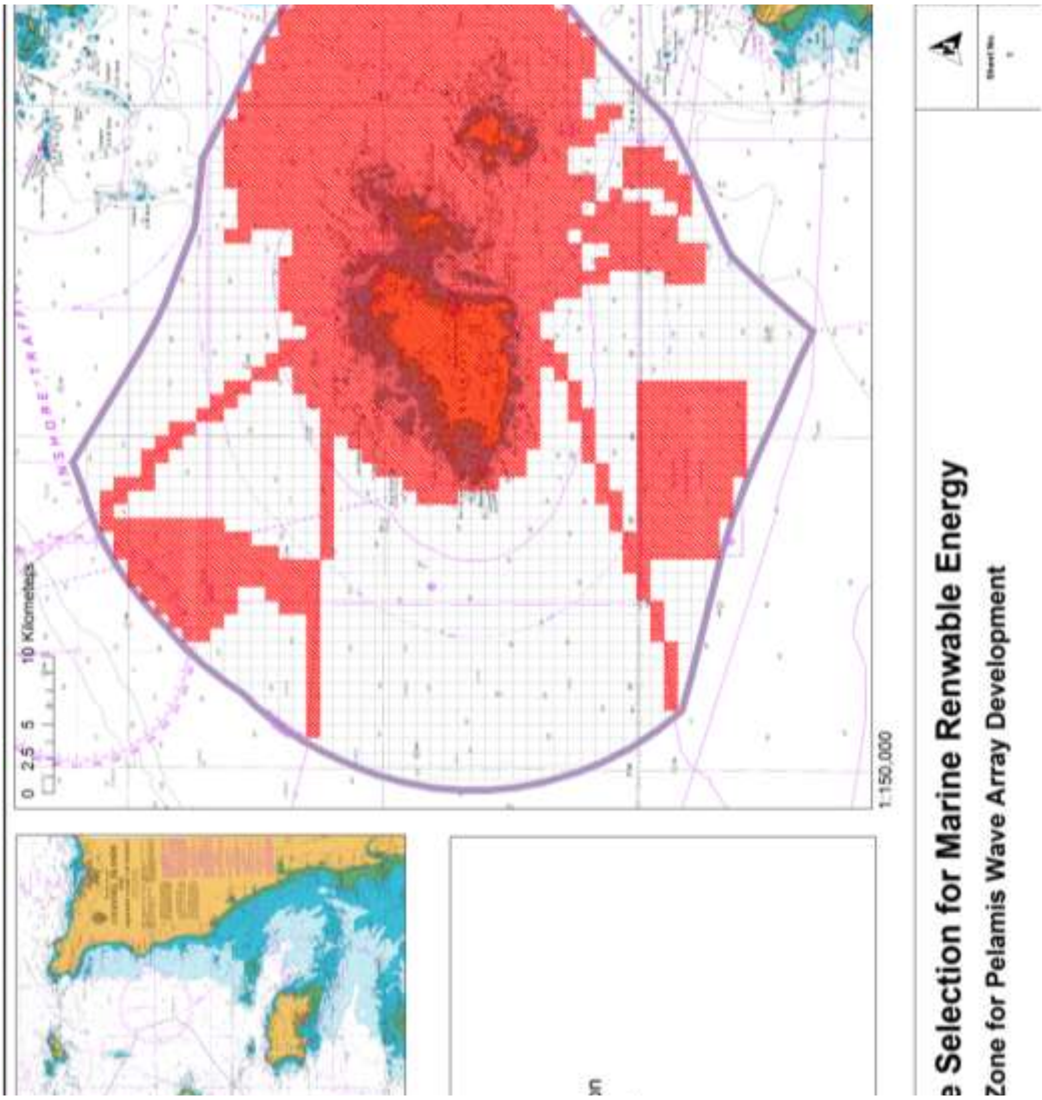
Tidal Stream

Modelled tidal stream data is again available from ABPMER as a GIS shape file (ABP Marine Environmental Research, 2011). The POL HRCS model was used to derive the tidal parameters for the Renewables Atlas. The model has a resolution of approximately 1nm which when overlayed on a km^2 planning grid makes the data difficult to interpret and transfer (ABP Marine Environmental Research, 2008). Although wind and wave data covered the whole of the UK waters surrounding Guernsey, there are gaps in the tidal stream coverage and data for the northern half of the area of the planning area is unavailable.

The Tidal Mapping by the Robert Gordon University that will be finalised this year will also provide useful data for future planning of tidal stream development (Owen, 2010).

Sarah Beddingham's MSc project (Plymouth University) also working in collaboration with Guernsey's RET, involves modelling the tidal flow around Guernsey. The model uses a two year dataset derived from the Met Office UK and has a 500m resolution (Beddingham, 2012). This report should also benefit future planning for tidal stream development.

Appendix 6: Exclusion Zone for Pelamis Wave Device based on technical specifications from product brochure (Pelamis, 2007) and Company website (Pelamis, 2012).



Appendix 7: Penalty Concentration for Pelamis Wave Device