Site Selection Analysis

For Offshore Combined Resource Projects in Europe

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1 Introduction

This document describes the site selection work carried out under the work package II of the EU FP7 Project, "Offshore Renewable Energy Conversion – Co-ordinated Action" (ORECCA)[1].

The offshore wind, wave and tidal current resource was first assessed using a GIS developed in ORECCA for three defined geographic regions; the North and Baltic Seas, the Atlantic Coast and the Mediterranean and Black Seas. For this GIS data, which was consistent across all of Europe, was collected for each of the resources and for certain site selection parameters such as bathymetry and infrastructure. The results of this analysis give clear indications as to suitable technologies for each region in Europe.

Following on from this analysis, a more detailed assessment was then undertaken such that suitable areas for combined renewable developments could be determined. Existing site selection methodologies were researched and a methodology and weighting/rating system was developed based on the available data collected. Various suitable site locations were then identified in each of the three regions that take account of different combinations of resource (wind/wave and wind/tidal) as well as different foundation technologies (fixed and floating).

2 Site Selection Methodology for combined offshore renewable energy projects

2.1 Introduction

Site selection for offshore renewable energy, a topic being relatively recent, has been following two different approaches. While the studies developed by national authorities have initiated the process by considering broad areas (typically the whole country), technology developers and institutions involved on the site selection for test sites tend to compare a small number of pre-set sites. Both approaches can be addressed using the same type of multi-criteria methodology (preferably quantitative). However, while in the case of broader areas the conclusions tend to reflect what factors are used, in the site specific case the effect of the weight given to each factor has more influence on the overall conclusions (which can increase the biasing).

The methodology presented here is based on work by Nobre A. et al (2009)[2], who proposed a geospatial multi-criteria analysis for wave energy converters. The methodology was used to find the most suitable areas for wave energy deployment by analysing the entire nearshore areas off the coast of Portugal, Spain and France. This work was developed during the SEEWEC project[3]. Two relevant offshore wind site selection studies are also available by RSE using GIS tools for site selection and marine spatial planning [4,5].

The site selection studies and methodologies being developed in recent years all seem to converge into a common vision of the steps to be taken. These include some publically available examples: the study by the Wave Energy Centre on the most suitable locations in the Portuguese coast for the deployment of wave energy converters[6]; a study by EPRI on the site selection for wave energy in the Washington state[7]; the report on the site selection alternatives on the Teesside Offshore Wind farm in the UK[8]; a study for onshore wind using GIS for Thailand[9]; the approach followed by OpenHydro[10].

The geo-spatial multi-criteria analysis method is a very flexible tool to obtain a quantitative response to the problem of choosing the most adequate areas for the deployment of offshore renewable energy technologies. However, this requires a very complete GIS database, which maybe has to be completed with project specific layers. Once the first database for a region is completed, the task becomes much more simplified. As this approach tackles both the exclusion areas and the economic viability side of the projects, it can be considered more stakeholder-friendly than more traditional approaches for the site selection methodologies.

The definition of the site selection steps can be obtained having as a base the method proposed in Nobre et al 2009[2]. For a deeper insight conditioning factors and the methodology detailing, the method can be completed with the guidelines given in the Site Selection Methodology Reports of the European project WavePlam[11, 12]. This method will be presented in the next sections.

2.2 Definition of the region of interest

The first step in site selection process is to define the region of interest. In studies covering a large area (for example national level studies) the region of interest should not exclude areas a priori without a strong motive. The option in the most general case can be to study all the area between the coast and the limit of the territorial waters. The consideration of a region of interest as broad as possible will prevent obtaining results at the end of the analysis that are biased by the initial perceptions, but will also enlarge the workload involved in the study.

2.3 Gathering of data for the analysis and defining the restricted areas

In order to start the analysis of the area of interest, there is the need for gathering data that defines its characteristics as accurately as possible. These sets of data, which in a GIS based have to obviously be geo-referenced, can be divided into two main categories:

a) **Information on the restricted areas within the region of interest** - This includes all the exceptions that occur in the marine area being studied, either natural or human imposed, that restrict the use of a particular region. This includes, but is not restricted to, the following:

- Oil and gas extraction
- Military exercise areas
- Underwater cables
- Harbour entrances and navigation routes
- Areas with environmental restrictions
- Aquaculture
- Sand and gravel extraction
- Marine archaeology sites
- Landscape and seascape as public heritage
- Offshore renewable energy projects already installed

These areas are used to define exclusion areas, and as a consequence are not used in the analysis. Notice that in the GIS model some of these restrictions are represented by area features, but others are line or point features. As a consequence, the line and point features have to be transformed into area features in order to define an exclusion area. As an example, in the underwater cable case, the exclusion area may be defined by '200 meters to each side of the cable'; in marine archaeology sites for example as the '800 hundred meter circle around the archaeological site'. If no specific legislation applies, this process should be rather conservative.

After all the restricted areas are defined and mapped, this mask is applied be applied to the region of interest, defining a new scope for the region to analyse.

b) Information on the relevant characteristics in the region of interest - These are the technical constraints that will allow evaluating the locations regarding its suitability for the deployment of wind and wave energy conversion systems. The constraints can also be used to define restricted areas based on each project specification. Typically, the following technical constraints are considered:

- Available Wave Energy Resource for energy production - The evaluation of the wave energy resource is a critical factor for the evaluation of the suitability of an area for the deployment of wave energy converters. The characterization of the wave climate and its relation with the device performance is a complex issue. There are numerous methods for the Wave resource characterization[13,14,15]. The most typical parameter to define the sites is the average wave power per meter of wave crest, which is expressed in kW/m. Usually this parameter is only used to evaluate the suitability of the site and not used to limit the area of study.
  A note on interpolation and directionality: typically the wave resource is defined at specific locations, and an interpolation is therefore needed in order to obtain the spatial distribution of the parameter. However, this does not consider the wave directionality, i. e. the fact that the wave power comes from a predominant direction and some areas are sheltered. As a consequence this interpolation leads to unrealistic values of the wave power in these shaded areas (namely next to capes and inside estuaries). In the absence of more detailed wave climate data, these shaded areas can be excluded from the analysis. Nobre et al (2009)[2] present an example of this situation, which is solved by estimating the main wave field direction, defining a line starting at a cape with that direction, and excluding the shaded area based on this.

- Wave resource of the site for survivability of the systems - This parameter is applicable to both wind and wave and is used to limit or evaluate the regions of interest for a given project. This parameter can be expressed qualitatively through the maximum significant wave height for a 50 (or 100) year storm. As a consequence, the project maximum significant wave height for a 50 year storm must be defined and the areas that present higher values for this parameter excluded from the analysis. It can also be used as an evaluation parameter, expressing the risk of damage in the systems.

- Wind energy resource - For offshore wind systems this parameter is essential for the evaluation of the sites. However, its spatial variation is not so large in open sea, and as a consequence it ends up being more important to compare sites in different locations than to obtain a spatial evaluation of the sites within a few tens of kilometres. Different sources of information are available, including for example Maratlas[16]. Normally this parameter is expressed in yearly average wind power and is not used for the analysis of wave energy devices.

- Tidal energy resource - For tidal energy systems, the tidal energy resource is the most important factor for the evaluation of the profitability of the project. The tidal resource is usually very concentrated and highly variable in space, which may imply that a finer discretisation of the data may be needed to find the most suitable locations. Strong Tidal currents may also cause higher forces in wave and wind moorings or foundations, but this effect is too site-specific to be considered relevant in the analysis of wave and wind technologies.

- Water depth - The water depth at the site is a very strong technical limitation and site evaluation for both wind and wave projects. In order to characterize this parameter, information on the bathymetry lines must be added to the GIS database. The WavePlam report[11] presents a list of entities by country which can provide this information. New bathymetry lines may have to be interpolated in order to address the specifications of the project. The water depth can be used to limit the region of interest and can also be used to evaluate the site.
  Water depth as a limit for the region of interest: this is dependent on the project specifications. Bottom mounted wind and wave systems usually can only be installed on a very limited range of water depths, as do tidal energy systems. In this case this parameter severely limits the region of interest. In the case of floating systems, usually the admissible range is much broader, and the maximum water depth installation is only limited by the mooring system technical specifications.
  Water depth as a factor for site selection: within the technically admissible range typically the shallower the water depth the most suitable the location, as it usually means reduced construction costs.

- Distance to shore - The distance to shore is measured in straight line, as it is meant to evaluate the cost of the submarine cable that connects to land. This factor is very relevant as the cost of the underwater submarine cable can be one of the most significant parts of the cost of the entire project. The usage of this distance as a selection parameter supposes the connection to the onshore electrical grid is possible close to shore or its cost is negligible compared to the underwater cabling

- Distance to O&M base - This distance can be included in the analysis in order to favour locations that are close to operation and maintenance bases in spite of those which are in more isolated locations. This factor is important not only due to the costs of the device deployment, but also because the number of maintenance operations can be significant, particularly while the technologies are less mature.

- Seabed Geology - The seabed geology is a parameter that can have a large influence on the project costs. One of the reasons is that the underwater cable is a significant part of the projects' costs, and the cable deployment can cost up to one order of magnitude above if the seabed is rock as compared to sand. In the case of monopole offshore wind projects, the seabed geology may also be a significant impact on the total cost or even make the project not valid. In this particular criterion, the analysis of bottom mounted monopole turbine projects is different from other offshore renewable projects.

- Social, Regulatory and Legislative; Examples of conflicting sea uses are waste dumping, existing submarine cables and pipelines, recreational boating, fishing, fish breeding, military restrictions, oil and gas industry prospecting rights, dredging and navigation and shipping lanes.

Planning and environmental considerations (e.g. UK Food and Environment Protection Act 1985 governs deposit of substances and articles below mean water line, crown estates, planning permissions, designated conservation areas or heritage areas)

A potentially strong argument for synergies between offshore renewable energy and fishery is that breeding sanctuaries will be a side-effect of large offshore renewable farms, which typically will be closed to maritime traffic over several square kilometres. The environmental interactions of renewable energy technologies are believed to be limited however environmental impact studies are being carried out on existing offshore wind and ocean energy devices. Noise is likely to be the greatest negative impact in areas with cetaceans however these studies hope to have evidence to support or discount this. Other impacts include the installation and deployment operations which include anchoring and laying cables.

- Archaeology – e.g. wrecks
- Conservation status
- Low environmental sensitivity - Environmental obligations
- Conflicting sea uses
- Interaction between agencies/authorities involved in permitting
- Planning and environmental considerations
- Attitude of local land owners, fishermen and residents
- Designated protected sites
- Planning permission landside

- Safety; It is vital in offshore developments like these that emergency services and search and rescue services are within a safe proximity to the location where the work will be carried out. In general this involves local lifeboat crew and coast guard helicopter stations. Where commercial divers are being used, this will include the nearest de-compression chamber.
    - Decompression chamber access
    - Search and Rescue (SAR) Cover – Lifeboat and Coastguard Helicopter cover
    - Navigation and manoeuvring hazards

- Social issues; Two main aspects can be considered: the social perception and the created jobs. In terms of social perception, landscape effects are a concern; one of the main barriers to wind power plants is visual impact, which is increasingly mitigated as the distance of plants from shore increases. Other kinds of energy conversion plant can bring about very different impacts depending on their source and technology. Many studies report that social acceptance for offshore wind farms can be reached even in coastal areas with high tourism.

At the end of the definition of relevant parameters and its insertion in the GIS database, the relevant area for the study is defined and the data is ready for the multi criteria analysis.

2.4 Choosing the score scale for each criteria

Multi-criteria analysis is a tool designed to allow taking a decision based on decision factors which cannot be expressed in the same units. However, it can be argued that in the multi-criteria analysis presented above, all the criteria could be (at least roughly) expressed in money units: the available resource in revenue per year of electricity sold; the extreme waves as cost associated to the repair of the damage done to the devices or total loss; the distance to coast and seabed geology as cost for the installation of the underwater cable, etc.

Ideally, if this data could be integrated in an economic life-cycle analysis model, the life-cycle costs of a project associated with each location could be determined. The objective function could then be uniquely determined to minimize the life-cycle cost of each location. The weighting factors would in this case be inherently included in the analysis. However, and particularly at the currently very immature stage of the technology development, the estimates of the life-cycle costs and profits still seem as an out of reach perspective. Estimations of the costs and profits associated with each alternative are still useful to help to define common units and the weights of each criterion.

To perform the multi-criteria analysis, all the criteria can be reduced to a common scale (for example from 0 to 100), where 0 is the worst scenario for each criterion and 100 the best. The knowledge of the costs involved will increase the quality of the function. Two examples will be presented next:

EXAMPLE 1: Let's suppose it is considered that the profit from wave energy converter operation is proportional to the average power per meter of wave crest available at the site ($Pavl$). However, when this power exceeds 50kW/m the risks increase linearly. It is known that the maximum for this parameter in Europe is about 80kW/m.

The wave energy resource criterion ($Wres$) would be:

$$Wres = Pavl \times \frac{100}{80}$$

This gives 100 for the maximum existing power (80kW/m), zero on this criterion for zero power and a linear variation in between.

The extreme wave survivability criterion ($Wext$) could be:

$$Wext = 100 \qquad for \quad Pavl < 50$$

$$Wext = \frac{800}{3} - \frac{10}{3} Pavl \quad for \quad 50 < Pavl < 80$$

This gives zero for $Pavl < 50$ and a linear variation between 50 and 80kW/m with a maximum 100 at 80kW/m.

EXAMPLE 2: Consider a floating offshore wind turbine. Imagining the minimum water depth allowed for its deployment is 20 m and the maximum is 80 m above which the mooring start to be significantly higher, and 200 m is the technical maximum limit for the moorings.

The seabed geology preferred is sand, rock is the worst case and silt an intermediate situation.

The criteria for water depth (Dp) excludes water depths (h) under 20 m and over 200 m so these areas should be excluded from the analysis. The criteria for water depth would be

$$Dp = 0 \quad for \quad h < 20$$
$$Dp = 100 \quad for \quad 20 < h < 80$$
$$Dp = 200 - 100\,h \quad for \quad 100 < h < 200$$
$$Dp = 0 \quad for \quad h > 200\,m$$

The criteria for seabed geology (Sg) could be

$$Sg = 100 \quad for \quad geology = "sand"$$
$$Sg = 50 \quad for \quad geology = "silt"$$
$$Sg = 0 \quad for \quad geology = "rock"$$

2.5 Weighting of the criteria

A judicious weighting of the criteria is essential for a solid approach of any multi-criteria analysis. However in many of these type of analysis this choice may seen to include some part of randomness, in the current case it is possible to estimate realistic weights if the criteria are expressed in money units. If one is able to make a rough estimation of the costs/benefits, the suitability differences between locations become more relevant that the weights.

If the criteria have been defined in a scale 0-100, the weights may be chosen so that its sum is 1 and therefore the final classification is also in the scale 0-100.

The following table attempts to summarize the relative importance of the criteria presented before, to be used as a first approach and given for 5 types of offshore renewables projects. Notice water depth is this table corresponds to the scoring of water depth within the admissible range for each technology.

	Floating Offshore Wind	**Bottom-mounted Offshore Wind**	**Offshore floating Wave**	**Bottom-mounted Wave**	**Tidal**
Wave Resource	Not Important	Not Important	+++	+++	Not Important
Extreme Waves	++	++	+	+	+
Wind Resource	+++	+++	Not Important	Not Important	Not Important
Tidal Resource	Not Important	Not Important	Not Important	Not Important	+++
Water Depth	+	+++	+	+++	++
Distance to coast	++	++	++	++	++
Distance to O/M	++	+	++	+	+
Seabed Geology	++	+++	++	++	++

2.6 Analysis and interpretation of results

To obtain the final distributions of the score the region of interest has to be divided into a grid. Depending on the grid size, and the type of technology, this grid size can vary between a few kilometres and one hundred meters. In Nobre et al (2009)[2] the authors have used a square grid with 200 m side. The grid size has to take into account the computational time needed to perform the calculations, but, most of all the spatial detail of the information contained in the GIS database.

The first results of the multi-criteria analysis should be carefully analysed in order to avoid situations where the conclusions are unrealistic. An example is the high score that can result, in the case of wave energy converters, to locations inside bays with ports, when these areas have usually (and by definition) a low energy resource. Therefore, some iteration may be needed in order to obtain realistic results.

The comparison of scores between locations in different countries should also be done with a certain care, as there may be different economic, social acceptance and environmental reasons involved. One of the major factors that may have influence on the differences between countries is the feed-in tariffs (the price paid by utilities for the electricity coming from a certain source). In an international multi criteria analysis scenario however, this can be taken as one of the selection criteria. The social acceptance and the environmental impact assessment issues in different countries can be difficult to be included in the analysis.

2.7 Conclusions on the site selection methodologies

This section has presented the steps needed for the definition of a geo-spatial multi-criteria analysis for the selection of the most suitable deployment sites for offshore renewable energy technologies. The need for the multi-criteria analysis arises for the difficulty in expressing the relative importance of the decisive factors for the economic success of an offshore renewables' project which are not in the same units. The fact that this analysis is geo-spatial arises from the broad territorial areas usually available for the deployment.

An ideal method for the site selection would consist on an economic life-cycle analysis of the project. However, the amount of data needed would increase disproportionately to the effort needed to make the analysis with respect to the precision of the conclusions obtained from the study. As a consequence, the geo-spatial multi-criteria analysis is a method that balances much better the work needed to obtain a significant output.

Multi-criteria analyses are frequently associated with a certain uncertainty involving the fact that the weighting of the criteria is the result of some kind of expertise, and as a consequence, is biased. In the current problem however, a raw estimate of the costs and benefits may lead to weighting factors whose level of biasing tends to be lower than would be expected.

A number of factors to be introduced in the geo-spatial database were presented and its importance was detailed here. These factors are used to define the region of interest and/or as decision factors. In a general case, the ones presented can be considered the most relevant, but the analysis for specific situations can include either a larger number of factors.

On the other hand, the analysis can follow much more minimalistic approach if less data is available. In the second case, the most important decision factors are generally: the water depth (to define the region of interest) and energetic resource and the distance to shore (as decision factors within that range).

3 Existing Site Selection Methodologies

The previous section outlined the factors that influence site selection as well as proposing a geo-spatial multi criteria method of analysis. Such an approach has not generally been adopted up to now as there is no definitive site selection guideline for offshore renewable energy projects. However there are numerous sources of site selection methodologies which share common themes both relating to ocean energy and offshore wind. A number of these, mentioned previously in section 2.1, are further outlined in the following section; many of these have been produced as deliverables of EU funded projects.

3.1 WAVEPLAM D3.2 (2010) – Methodology for Site Selection

The WAVEPLAM Deliverable 3.2 report[11] provides a methodology for wave energy site selection. The report defines two stages which have two levels of detail in the information that is required.

In **stage 1** the planners would gather all the information that could potentially influence the installation of the wave energy park.

The main factors were identified as the following:

Energy resource: several studies have been undertaken in recent years at both European and national level to assess the wave energy resource. As a result, there are documents and software available containing general information about the potential off the European coast, as well as specific national information in some cases. Although the data is not very detailed, they can constitute a reasonably good first approach to the evaluation of the wave resource in a region.

Seabed morphology and Distance to Coast: wave energy devices are designed so that their optimum performance is given at a certain depth. Bathymetry is important because it determines the distance to the coast at which the desired depth is reached, and this distance affects the cost of the installation.

Existing infrastructures: the installation works requires a full support network such as vessels, nearby sizeable ports and a grid to inject the produced energy. Proximity to the grid and to a robust supply industry is very desirable to make the maintenance and the operation of the park as easy and cheap as possible.

Characterisation of the environment: Knowledge of the geographic and atmospheric conditions of the area is essential to select a suitable site for works and to solve problems that may arise during the installation and operation processes.

Environmental information: When planning a wave energy site it is essential to carry out a detailed analysis of all the relevant legislation that is in place in any geographical area. Marine ecosystems can often be under special protection regimes, so regional, national and European legislations should be consulted, as these legislations may affect the siting or functioning of a wave energy park.

Interaction with other human activities: Some activities will prevent the installation, while others will create a conflict with the local socio economy, and both should be considered. This analysis should include how the wave energy site will work and function in harmony with the other activities in the area that have been identified or whether this will be possible.

The document regards the consideration of the above listed information sufficient to indicate whether the previously chosen area is suitable for the installation of wave energy facilities. If it is deemed suitable at this stage, a detailed study to obtain an accurate assessment of the available energy resource is the subsequent step.

In stage 2, a detailed geographical analysis needs to be carried out. As a result of this analysis, the most suitable area or areas would be identified, i.e. those with the most resource, technical advantages and the least constraints. For this purpose, the information is transformed into GIS layers, so that they can be overlapped and the interactions, positive or negative, easily highlighted. The overcrossing of the energy potential and the technical, environmental and socioeconomic limitations permits assessing what part of the energy available in the sea is accessible and technically viable to harness.

The intention of the Waveplam project, in relation to this document, is to provide useful information and guidance to developers that they need to decide where the installation will be located. The authors of the document also underline two facts regarding the consistency of applying this to different countries:

- All the desirable information may not be possible to obtain, or it maybe difficult to do
- The availability and readiness of the information will vary from country to country and so will the relevance of it; interactions with human activities and environmentally protected areas will depend greatly on the national legislation of each country

This methodology was also summarised in a paper presented at the EWTEC 2009 conference in Uppsala, Sweden[17].

3.2 Site Selection of a large Wind Turbine using GIS (2007)

This document[9] outlines a methodology for onshore site selection of a large wind turbine by means of a GIS tool. The onshore site selection in this document is similar to offshore site selection in that it applies layers to each of the parameters under consideration including zones designated for other users. The authors then apply multi-criteria decision making (MCDM) i.e. a weighting scheme, to each of the parameters to produce a potential site. Each layer s given a ranking of 0-5 ranging from 0=exclusion zone to 5=extremely suitable.

The weightings for each of these parameters were dependent on whether it was an urban area, rural area or other.

3.3 Geo-Spatial Multi-criteria Analysis for wave energy conversion system deployment (2009)[2]

Similar to 3.2 above, this paper uses GIS and multi-criteria analysis to select suitable sites for wave energy conversion in Portugal. The zones excluded from the analysis were:

- Military exercise areas;
- Marine protected areas;
- Five hundred-metre areas around underwater cables locations;
- Wave shadow areas;
- Harbour entrances and navigation channels; and
- Areas with water depth below 30 m and higher than 200 m.

Features which were considered as weighted factors were:

- Distance to coastline;
- Distance to ports (the shortest distance, the better);
- Distance to the electric network connection points (the closer the better);

- Type of sea bottom (rock, sand, mud and gravel); and
- Wave climatology (significant height, period and power).

Weightings were applied to the parameters to designate their relative importance to the site selection.

Criteria	Weights (%)
Sea bottom geology	10
Distance to shore	10
Distance to ports	10
Distance to power grid	10
Wave height	20
Wave period	20
Wave power	20

Table 1: Weighting used in Portuguese GIS site selection using multi-criteria analysis

3.4 EMEC - Guidelines for Project Development for Marine Energy Industry (2008)

This document[18] recommends stages of project development for a marine energy project, the initial stage (stage 0) being the project development strategy outlining the main objectives and requirements of the project. The next stage (stage 1) is the site screening where one or more potential sites are identified by means of desk-top studies of existing information.
In this stage it is recommended that the following aspects of the site are researched:

Legislative

- Including Strategic Environmental Assessment (SEA)
- Policies
- Jurisdiction

Technical and Physical

- Available resource: "*The first step in the site screening should be the identification of areas with suitable marine resource. At this stage the resource assessment will be merely based on indicative average resource figures*."
- Electrical Connection: "*A grid connection point in the proximity of the proposed project location with adequate capacity will be required to export the electricity generated*."
- Bathymetry
- Seabed Morphology
- Logistics: i.e. *"…. proximity to suitable harbours for vessel mobilisation for installation and maintenance activities as well as the availability of specialist services*."

Environmental

- Designated Areas: "*designated under European and relevant national nature conservation legislation*"
- Ecology: "*Special attention should be paid to avifauna(resident and migratory) benthic ecology, cetaceans and fish and shellfish resources*"
- Archaeology and Historical Heritage: Location of local wrecks, other identified conservation or archaeological sites, identified unexploded ordnance (e.g. bombs, mines etc)
- Other sea users and infrastructure: Fishing, Commercial navigation, Recreational navigation and other activities (e.g. diving, surfing), MOD activities, Existing sub-sea cables and pipelines, Aggregate mining
- Consultation: "*Key statutory consultees should be identified and approached in order to initiate informal discussions on their views on the proposed project based on their local knowledge and expertise*"

Health and Safety

3.5 Irish Full Scale Wave Energy Test Site – Site Selection (Belmullet)[19]

This document was prepared by the Irish Electricity Supply Board (ESB) and the Marine Institute to select a suitable site for a full scale wave energy test centre on the Irish coast. For the purposes of this a methodology based on weightings of multiple criteria was developed.
The primary requirements were:

- located in an open ocean location off the West coast of Ireland
- A maximum generating capacity of 5-7MW should be accommodated
- A water depth range of between 60m and 100m available
- Appropriate logistical support available locally
- Requirements to upgrade the local electricity network to accommodate power inputs from the site

Each site was given a score from 1 to 5 in terms of how well it meets each specified parameter. Each parameter has a weighting (1 to 4) to differentiate their perceived relative importance. Multiplying each parameter score by the weighting gives a total site score for that parameter.

The primary technical parameters considered were:

- Mean annual theoretical wave energy resource
- Suitability of seabed for cable laying and burial
- Suitability of seabed for plough anchor moorings
- Profile of seabed to seaward of test site
- Absence of overfalls in projected mooring area
- Summary of tidal currents in projected mooring area
- Distance from 90m depth contour to cable landfall
- Distance from 60m depth contour to cable landfall
- Cable landfall exposure
- Cable landfall ground conditions
- Cable landfall road access
- Distance to RIB-suitable pier/slip from 90m contour
- Distance to RIB-suitable pier/slip from 60m contour
- Distance to nearest marine traffic zone
- Distance to nearest deepwater port
- Port Facilities
- Cost of upgrading local electrical network
- Capacity for expansion (network perspective)
- Submarine cable costs (Mobilisation/supply and lay including protection)
- Planning and environmental considerations
- Road access
- Air access
- Marine access
- Distance to nearest meteorological station
- Navigation and manoeuvring hazards
- Existing markers, lights, beacons and their sphere of influence
- Availability of planned or existing wave measurements
- Availability of planned or existing tidal measurements
- Dry dock capacity
- Base availability/vehicle parking/access
- SAR

- Skilled labour availability
- Archaeology
- Conflicting sea uses
- Decompression chamber access

3.6 Offshore Wind Farm EIAs

Offshore wind farm environmental impact assessments generally have information relating to the selection of the site and the alternatives considered. These documents give an insight into the methodology used by developers and the relative importance of certain site parameters. Examples of 2 offshore wind farms are summarised below.

The Environmental Statement for the UK **Teeside Offshore Wind Farm**[20] has a section dedicated to site selection. This offshore wind farm was subject to Crown Estate limitations; i.e. farm area less than 10km^2, less than 30 turbines, greater than 20MW installed capacity and minimum 10km distance between offshore wind farms.

According to this document the primary site selection criteria for the wind farm were as follows:

- Wind speeds and directions
- Shore topography
- Cable connection issues
- Wave heights
- Correlation of wind and wave data
- Tidal data
- Water depths
- Seabed Topography – variation of depth / plan area sizes and shapes
- Seabed Geology
- Adjacent shoreline land use – issues of noise and visual impact / planning considerations
- Marine Biology
- Existing site functions
- Potential site obstructions – cables, pipelines, etc
- Existing shipping movements/functions – commercial shipping routes, lifeboats, offshore berthing, dredging, fishing/trawling, pleasure boating, scientific research, etc.
- Onshore installation issues – land availability, access rights, suitability for grid connections, planning, potential cable routing from offshore, etc.
- Consents and permits,
- Potential interference to provision of guidance to shipping – lighthouse signals, radion and radar, etc.
- Availability/accessibility of suitable onshore construction facilities / resources / expertise – berths, lay-down areas, distance from site
- Availability of suitable offshore construction facilities / resources / expertise – construction platforms, ships, weather related operating restrictions, etc.
- Quality / accuracy of site related data

The Irish **Sceirde Offshore Wind Farm** Environmental Impact Assessment[21] outlines numerous considerations included in the site selection process falling under the headings:

- Human Beings (Flicker, noise, Traffic, aviation, shipping, sub-sea cables/pipelines, health and safety, tourism)
- Physical Environment (geology, bathymetry, seabed material, hydrography, cable route, etc)

- Air and Climate
- Cultural Heritage and Archaeology
- Commercial Fisheries and Aquaculture
- Marine and Terrestrial Ecology
- Birds
- Marine mammals and reptiles
- Living and non-living resources (fossil fuels, mineral deposits, sand and gravel, ocean energy)
- Landscape and Visual Impacts
- Electromagnetic effects

3.7 EQUIMAR – Protocols for wave and tidal resource assessment (2010)

Deliverable 2.7[22] of the EQUIMAR project gives guidance on wave resource characterisation for early stage site assessment. The primary focus of this report is the resource characterisation of the wave or tidal current resource and for early stage site selection this includes "*key statistics*" rather than full spectral data. However it also mentions other important site parameters which may provide "*constraints on exploitation*":

"*A resource assessment shall also consider physical and technical constraints on exploitation of the marine energy resource at a particular site due to device-specific requirements. These shall include:*

Required water depth for deployment and operation

Seabed composition for device installation and cable-laying

Extreme wave predictions

Additional constraints on exploitation will occur due to existing structures and exclusion zones, and co-existing marine activities such as fishing grounds, shipping lanes and military practice areas."

3.8 IEA-OES RAMBOLL - Generic and Site Related Wave energy data (2010)

The RAMBOLL report "Generic and Site related wave energy data"[23] gives a list of appropriate information to be given for a test site. Amongst these it lists;

Site location and Infrastructure

- Distance to large town
- Distance to nearest airport
- Distance from nearest service port to site
- Distance from nearest access harbour to site
- Restrictions, availability & conditions if any

Grid Connection

- On-land
- Off-shore (at what depth)
- Connection voltage and power level

Water Depth and Seabed Conditions

Distance to Shore

- Distance to Shore

- Distance to nearest harbour

Design Wave Data

Design Wind Data

Design Current Data

Design water level variation

Additional information

- Facilities available: Vessels, Cranes, Engineering, Industry
- Equipment available at site:
- Wave measurements (yes/no)
- Wind measurements (yes/no)
- Water level measurements (yes/no)
- Current measurements (yes/no)
- Water/air temperature measurements (yes/no)
- Can additional information be obtained such as, typical wave spectra, directional spectra, tidal current profiles and turbulence?

4 ORECCA Project GIS Tool

4.1 GIS Tool Introduction

Geographical Information Systems (GIS) allow the collecting and processing of geographic data/information with specific elaborations in order to supply easily understandable thematic maps.

The data/information implemented in a GIS project can be stored using different data models (vector, raster, etc), file formats (feature classes, shape files or coverage) and datasets. Through the GIS interface they are visualized as map themes or layers.

The GIS tool populated in the ORECCA project is more comprehensively described in the document "Resource Data and GIS Tool for Offshore Renewable Energy Projects in Europe" of the ORECCA Project[24]. However a brief description of the information collected in the ORECCA Project at European, Regional and National level, which were suitable to be implemented in GIS, are described in the following section.

4.2 European Wide Input Data

The following table lists the sources of data, consistent across Europe, which were used to populate the GIS tool.

Data Type	Data Source
Bathymetry	GEBCO Bathymetry (30 arc-second grid- cell size: 0.008333° corresponding to 750 m x 900 m at Madeira latitude and to 820 m x 1600m at Iceland latitude)[25]
Exclusive Economic Zone (EEZ)	From Encyclopaedia of the Earth[26],[27]
Countries	EU-countries; EFTA countries; other countries from the Economic and Social Research Institute (ESRI) [28]
Population	Cities population from the ESRI [28]
Ports	Location and draft of Ports from ships register[29] and IWES ports database
Offshore Wave and Tidal Energy Converter Locations Database	From IWES Fraunhofer
Marine Protected Areas (MPA)	From Protected Planet website[30] and Natura 2000 sites from European Environment Agency[31]
Wind Speeds	QuikScat annual mean wind speed map @10 m a.s.l. [32],[33] (Source: Risoe-DTU and Norwegian Meteorological Institute[34])
Wave Power	OCEANOR average annual wave power map[35] and Weratlas database[36] (source INETI)
Tidal Current Sites	Tidal current sites from IWES Fraunhofer database and European tidal stream sites from ITPower database

Table 2: European wide data sources used in GIS Tool

4.3 GIS Tool Assembly

For the purposes of the ORECCA project, Europe was considered as 3 target regions which share geographical and resource attributes. These are:

- Region 1: North and Baltic Seas
- Region 2: Atlantic Ocean
- Region 3: Mediterranean and Black Seas

The information/data are in various formats therefore in order to perform quantitative analysis a common reference grid is required to represent the layers involved in the calculation process. Not all of the data collected was query-able and therefore could not be included in the GIS calculations e.g. ports, natura 2000 sites etc. The calculations were performed using:

- wind and wave resource;
- sea depth;
- distance from shore.

The following steps describe how the data/information was prepared:

- WGS84 World Reference system was chosen;
- wind and availability maps: a grid with 0.25°x0.25° cell was built from provided databases with annual mean wind speed and data availability (no information on data availability is present for the Mediterranean and Black Sea Area)
- wind map grid was chosen as reference grid;
- Sea depth map: GEBCO bathymetry was recalculated on the reference grid and classified according 5 depth classes i.e. sea depth: 0-25m, 25-60m, 60-200m, 200-500m, greater than 500m;
- Distance from shore: 4 categories of distances were calculated from shoreline on the reference grid (0-50km, 50-100km, 100-150km, 150-200km)
- Wave map: interpolation was performed on the provided database using the "Natural Neighbour" method on the reference grid (details about the input point database are reported in the images available in the ORECCA document "Resource Data and GIS Tool for Offshore Renewable Energy Projects in Europe"[24]).

4.3.1 Calculation/Analysis mask

Areas suitable for technical installation of offshore multipurpose platforms for energy production have been found by combining information about wind technology sea depths and distance to shore in each geographical region. Water depth less than 500m and distance to shore between 25 and 200 km have been considered. Cells with no data value in the resource maps have also been excluded.

4.3.2 Wind Resource Scenarios

Areas suitable for installation of offshore multipurpose platforms for wind energy were found by combining the calculation mask with wind resource map. Two resource levels have been adopted:

Wind Resource Level	GIS Scenario	Wind Speed Range (m/s)
Level 2	V2	Greater than 8m/s *(at 10m a.s.l.)*
Level 1	V1	6-8m/s *(at 10m a.s.l.)*

Table 3: Annual Average Wind Speed Levels used in GIS

4.3.3 Wave Resource Scenarios

Areas suitable for installation of offshore multipurpose platforms for wind energy were found by combining the calculation mask with the wave resource map. Three levels of annual average wave power have been adopted:

Wave Resource Level	GIS Scenario	Wave Power Range (kW/m)
Level 3	W3	Greater than 25kW/m
Level 2	W2	15-25kW/m
Level 1	W1	5-15kW/m

Table 4: Annual Average Wave Power Levels used in GIS

4.3.4 Combined Resource Scenarios

Areas suitable for installation of offshore multipurpose platforms for energy production from combined wind and wave resource were found by combining the calculation mask with information about both wind and wave resource. For wind and wave information six scenarios have been considered:

Level	GIS Scenario	Wind		Wave	
		Wind Velocity (m/s)	*Wind Resource Level*	*Wave Power (kW/m)*	*Wave Resource Level*
Level 6	Scenario v2-w3	Greater than 8m/s	Level 2	Greater than 25kW/m	Level 3
Level 5	Scenario v2-w2	Greater than 8m/s	Level 2	15-25kW/m	Level 2
Level 4	Scenario v2-w1	Greater than 8m/s	Level 2	5-15kW/m	Level 1
Level 3	Scenario v1-w3	6-8m/s	Level 1	Greater than 25kW/m	Level 3
Level 2	Scenario v1-w2	6-8m/s	Level 1	15-25kW/m	Level 2
Level 1	Scenario v1_w1	6-8m/s	Level 1	5-15kW/m	Level 1

Table 5: Combined Offshore Renewable Resource: GIS Scenarios

Tidal information has been added to the combined wind and wave scenarios. The individual tidal sites are very small relative to the geographical region, therefore in order to make the areas more distinguishable circles have been added around the tidal sites.

4.3.5 List of GIS Output Maps

Maps with the geographical distribution of the resources are available in the ORECCA report "Resource and Site Parameter Database" mentioned previously.

The maps created with the GIS for each region include:

- Defined Region (total area included in the analysis as defined by ORECCA Project)
- Calculation/Analysis Mark Area (i.e. including distance from shore and water depth limitations)
- Sea depth
- Distance from shore
- Ports
- Cities
- MPA (Marine Protected Areas)
- Existing offshore renewable power plants
- Mean annual wind speed
- Average annual wave power
- Wind Resource Levels 1-2, as outlined above
- Wave Resource Levels 1-3, as outlined above
- Combined Wind + Wave Resource Scenarios (Levels 1-6), as outlined above.

The areas with wind & wave combined resources have been calculated for each class of water depth and distance from shore. Calculated areas versus water depth and distance from shore are reported in the Resource ORECCA Report mentioned previously.

For all measurements of areas the WGS84 UTM32 coordinate reference system has been used.

5 Outline of Applied Site Selection Process

Based on the site selection process proposed, in section 2.4 above, as part of the ORECCA project the following section describes the how this process was applied to the GIS analysis results. In order of importance the following parameters were ranked and weighted to provide a site selection score for a given location:

- Combined Resource
- Available Incentives
- Geography (bathymetry and distance from shore)
- Local Infrastructure (distance from deep water port, distance to harbour/pier, available electrical grid)
- Other Users (Shipping)

The headings of the sections below indicate the order of importance of each parameter to the selection process. It is assumed that available resource has the highest priority in site selection, with financial incentives second and site location and logistics subsequent to these.

While the methodology outlined previously (Section 2.4) proposes the use of economic costs as indicators of importance of a parameter to the site selection, in reality these are very difficult to acquire particularly in terms of the economic costs or benefits of combined offshore renewable projects such as offshore wind and wave energy. As such, the following methodology proposes ranking the parameters in terms of a logical preference which may also be indicative of costs e.g. it is assumed the greater the distance from shore, the greater the costs incurred and the lower the points it will receive as a potential site.

Inherently the figures used for ranking and weighting parameters are subjective and so it is intended that this methodology could be adopted by a user and the rankings and weighting adapted to suit their primary criteria however the figures used in this methodology are expected to be representative of a generic site selection. It is possible that once cost figures become available the weighting system could be adapted to reflect these and give a more accurate economic comparison.

It should be noted that due to the resolution of the resource data in the GIS the 25km from shore zone has not been considered. Current offshore wind farms are typically installed in this zone and it is likely that the majority of this region is in the fixed technology range in the north of Europe and may include almost all of the fixed water depth range available in the south of Europe where the bathymetry drops off close to shore.

5.1 Resource

The available resource at a site essentially decides whether a project will be economically feasible. The GIS data analysed in ORECCA simply gives average wind speed at 10m above sea level and average wave power per metre wave crest. In reality, there are many more factors involved to determine the suitability of a site to a given technology however these values provide a general indication of the resource in an area which is of acceptable detail for this level of site selection.

The wind speeds are categorised into 2 groups of average annual wind speeds; those in the range 6-8m/s at 10m a.s.l. (V1) and those greater than 8m/s (V2). The wave power levels are categorised into 3 levels of average annual wave power per metre wave crest; 5-15kW/m (W1), 15-25kW/m (W2) and greater than 25kW/m (W3). Typically the industry rule of thumb is to look for a resource of greater than 20-25kW/m however there are some research groups and development occurring in areas with wave power levels less than this.

With regards average wind speeds, these values are at 10m above sea level and it is very likely that the wind speeds at hub height will be significantly greater than this. Therefore the "lower" resource level of 6-8m/s is likely to be deemed a viable wind speed at height.

Therefore, the following is a list of the combined resource levels in order of preference:

Order of Preference	GIS Combined Resource Level		Average Wind Speed Range	Average Wave Power Range	Site Selection Ranking
1	**Level 6**	**V2_W3**	Greater than 8m/s	Greater then 25kW/m	10
2	**Level 3**	**V1_W3**	6-8m/s	Greater then 25kW/m	9
3	**Level 5**	**V2_W2**	Greater than 8m/s	15-25kW/m	6
4	**Level 2**	**V1_W2**	6-8m/s	15-25kW/m	5
5	**Level 4**	**V2_W1**	Greater than 8m/s	5-15kW/m	3
6	**Level 1**	**V1_W1**	6-8m/s	5-15kW/m	2

Table 6: Wind and Wave: Combined Resource Levels used in GIS Tool and Site Selection Ranking

Order of Preference	Combined Resource Level	Average Wind Speed Range	Minimum Ave. Tidal Current	Site Selection Ranking
1	**Higher Wind + Tidal**	Greater than 8m/s	Greater then 1.75m/s	10
2	**Lower Wind + Tidal**	6-8m/s	Greater then 1.75m/s	8

Table 7: Wind and Tidal: Resource Levels and Ranking used in Site Selection

5.2 Incentives, in order of preference

Although there are numerous types of funding incentives available for renewable energy generation, for the purposes of this selection process only feed-in tariffs are considered for ease of assessment. Other available incentives are described and analysed in the ORECCA Report "*Investment and Grant Opportunities for Offshore Renewable Energy Projects in Europe*"[37].

The following table outlines the feed-in tariffs available for offshore wind and ocean energy in some coastal countries in Europe as gathered by the ORECCA finance report.

The EU aims to develop a central European Electricity market; as yet this has not occurred however there is some evidence of convergence[38] according to the EU SESSA Project[39]. For the purposes of this assessment a pan-European electricity price was deemed sufficient as the task of collecting average wholesale electricity prices on a country basis would be too extensive for this project. The following table has been compiled assuming a Pan-European Wholesale Electricity Price of €0.07/kWh.

As wholesale electricity prices typically are not the same in all countries and fluctuate due to a number of different factors, these figures should not be taken as the expected wholesale electricity price to be received in Europe. In order to rank the incentivised electricity prices the highest was given a value of 10 and the lowest a value of 1, i.e. the pan-European wholesale price, and middle values were attained by interpolation.

For offshore wind: 0.19 = 10 and 0.07 = 1 and a linear relationship is assumed between the 2 values. Similarly, for ocean energy: 0.34 = 10 and 0.07 = 1. Therefore in order to calculate any ranking value simple interpolation is used where, y is the Price received and x is the ranking value.

Offshore Wind: $\frac{0.19-0.07}{10-1}=\frac{0.19-y}{10-x}$; Ocean Energy: $\frac{0.34-0.07}{10-1}=\frac{0.34-y}{10-x}$

€/kWh	Wind			Ocean			Combined Site Selection Ranking
	FiT	Price Received	Ranking	FiT	Price Received	Ranking	
Belgium	0.11	0.11	**4.00**	0.00	0.07	**1.00**	**2.5**
Denmark	0.04	0.11	**4.00**	0.05	0.12	**2.67**	**3.3**
Germany	0.15	0.15	**7.00**	0.00	0.07	**1.00**	**4.0**
Ireland	0.14	0.14	**6.25**	0.22	0.22	**6.00**	**6.1**
Greece	0.00	0.00	**1.00**	0.00	0.07	**1.00**	**1.0**
Spain	0.03	0.10	**3.25**	0.00	0.07	**1.00**	**2.1**
France	0.13	0.13	**5.50**	0.15	0.15	**3.67**	**4.6**
Italy	0.18	0.18	**9.25**	0.34	0.34	**10.00**	**9.6**
Netherlands	0.19	0.19	**10.00**	0.00	0.07	**1.00**	**5.5**
Portugal	0.07	0.07	**1.00**	0.26	0.26	**7.33**	**4.2**
UK	0.07	0.14	**6.50**	0.11	0.18	**4.67**	**5.6**
Norway	0.00	0.07	**1.00**	0.00	0.07	**1.00**	**1.0**
Scotland*	0.07	0.14	**6.50**	0.28	0.28	**8.00**	**7.25**

**The ocean energy FiT for Scotland is based on 5ROCs for Wave Energy with August 2011 ROC prices of €0.45/kWh[40] however in reality tidal energy projects receive 3ROCs or approx €0.135/kWh*

Table 8: Country Specific National Production Incentives and Site Selection Ranking

5.3 Geography

5.3.1 Water depth

Water depths are indicative of a likely suitable technology for a site especially in the case of offshore wind. For example, based on current technology trends, water depths of 0-60m typically indicate a fixed offshore structure and water depths of 60-500m would require floating structures. It can also be assumed that with water depth the costs increase due to mooring, anchoring and cabling costs in deeper waters. Based on existing offshore wind structures and for the purposes of this site selection process, 60m is the maximum preferred depth for fixed combined structures and 60-200m is the preferred for floating structures however the GIS tool has analysed the available resource in 5 depth ranges based on offshore wind technology.
It is assumed, for the purposes of this site selection methodology, that the shallower the water, the higher the ranking. The ranking figures given to each water depth range are listed in Table 9 below.

Order of Preference	Water Depth Range	Typical Wind Turbine Structure	Site Selection Ranking
1	0-25m	Monopile/Gravity Base/Suction Base	10
2	25-60m	Tripod/Jacket	9
3	60-200m	Floating	8
4	200-500m	Floating	5
5	Greater than 500m	Possibly future floating technology	1

Table 9: Wind and Wave: GIS Water Depth Ranges and Site Selection Ranking

Order of Preference	Water Depth Range	Site Selection Ranking
1	25-60	10
2	60-200	9
3	Greater than 200 or less than 25m	1

Table 10: Wind and Tidal: Water Depth Ranges and Site Selection Ranking

5.3.2 Distance from Shore

Distance from shore will determine cabling and O&M costs among others and so for the purposes of this site selection, the requirement is for a minimal distance from shore up to a maximum of 200km which represents the current limits of existing offshore wind farm proposals. Visibility from shore can often be a planning constraint and for that purpose a minimum distance from shore of 20km has been chosen as indicative of current planning preferences. The UK DECC Report suggests a minimum of 22km buffer zone

for future generation sites to reflect coastal sensitivity[41]. Unfortunately, for combined wind and tidal current combinations this may hinder projects as the majority of tidal current sites are within this range (see ORECCA Report "Resource Data and GIS Tool for Offshore Renewable Energy Projects in Europe" www.orecca.eu). For tidal current technology alone it is unlikely to cause an issue as the devices are largely submerged, however combined with a wind turbine the visibility may become a hindrance.
The ranking figures given to each water depth range are listed in Table 11 and Table 12 below.

Order of Preference	Distance from Shore	Site Selection Ranking
1	20-50km	10
2	50-100km	8
3	100-150km	6
4	150-200km	4
5	Greater than 200km or Less than 20km	1

Table 11: Wind and Wave: Distance from Shore Ranges and Site Selection Ranking

Order of Preference	Distance from Shore	Site Selection Ranking
1	20-50km	10
2	Less than 20km	1

Table 12: Wind and Tidal: Distance from Shore Ranges and Site Selection Ranking

5.3.3 *Geology and Seabed Material*

As outlined in the previous sections, seabed material is a very important parameter in site selection for determining foundation, mooring, anchoring and cabling costs. The aim of this study was to consider the information that is available consistently across Europe and as yet, seabed material is not available Europe-wide. A recent EU funded project, GEOSEAS[42], aims to collate this information into one central location.
Therefore in this methodology, the seabed material is considered in those countries/regions which have a seabed study available however for consistency in comparison, this was not included in the final site selection ranking.

5.4 *Infrastructure*

5.4.1 *Ports*

At the 2nd ORECCA Workshop in Milan, 7-8th June 2011, a minimum required port draft for installation of offshore renewable energy projects was identified to be 10-15m by the infrastructure discussion group. Therefore only ports with a suitable draft are included in the "Ports" aspect of the site selection. However a second ranking has been included in order to accommodate smaller ports and harbours which can provide refuge in extreme weather or a base for smaller craft and maintenance vessels. The ideal distance from a small pier was taken as the shortest category for distance from shore i.e. less than 50km.

It should be noted that the distances considered are simply radial distances from the site rather than travel distances by sea.

Order of Preference	Distance from Deep Water Port	Site Selection Ranking	Distance from Safe Haven/Pier	Site Selection Ranking
1	Less than 100km	10	Less than 50km	10
2	100-150km	9	50-60km	9
3	150-200km	8	60-70km	8
4	200-250km	7	70-80km	7
5	250-300km	6	80-90km	6
6	300-350km	5	90-100km	5
7	350-400km	4	100-110km	4
8	400-450km	3	110-120km	3
9	450-500km	2	120-130km	2
10	Greater than 500km	1	Greater than 130km	1

Table 13: Distance from Port or Safe Haven and Site Selection Ranking

5.4.2 Grid

Costs for connection and upgrading of the local electrical grid can be the developer's responsibility in many cases and so close proximity to a high voltage strong grid is preferable. The highest available local line capacity is used as an indicator to assess this for site selection.

Order of Preference	Voltage Capacity of Closest Available Grid	Site Selection Ranking
1	Greater than 500kV	10
2	380-500kV	8
3	220-380kV	6
4	Less than 220	4
5	Distribution Grid	2

Table 14: Available High Voltage Line Category and Site Selection Ranking

5.5 Other Uses

5.5.1 Shipping and Navigation

Primary shipping lanes can increase the complexity of the planning process and so based on visual assessment of satellite detection of shipping routes, the density of shipping is categorised and ranked as follows:

Order of Preference	Shipping Density	Site Selection Ranking
1	Low	10
2	Medium	6
3	High	1

Table 15: Available High Voltage Line Category and Site Selection Ranking

5.6 Parameter Weighting

The following weightings were given to each of the site parameters under consideration. For a given site, the rankings for each parameter will be multiplied by the weighting and summed to give the final figure for that site; the higher the number the better the site. Different sites can then be compared for their value and the site with the highest ranking is deemed the most suitable, pending further studies.
It should be noted that the "Location" parameter in Table 16 includes the average of the "Distance to shore", "Distance to Port" and "Available Grid" parameters.

Parameter	Weighting Values	Comment
Resource	0.3	Without a good resource a project will not be viable, therefore it is given the highest weighting
Incentives	0.2	The price received for a unit of electricity produced will determine the economic viability of the project
Water Depth	0.2	A suitable water depth is important for technology
Location	0.2	Distance from shore and available infrastructure will affect the viability of a project in terms of costs and time dedicated to installation and maintenance
Other Uses	0.1	While other users of the sea may exist in an area the shared use may be negotiable
Total	1	

Table 16: Site Selection Parameter Weightings

6 Site Selection Application to: North and Baltic Seas Region

The North Sea area, as outlined by Figure 1 below, has strong offshore wind and oil and gas industries in addition to a strong maritime and fishing culture.

The following section will analyse the region using the previously defined site selection process, with the objective of identifying viable sites for combined wind-wave or wind-tidal current sites based on both GIS results compiled in the ORECCA project and available national data.

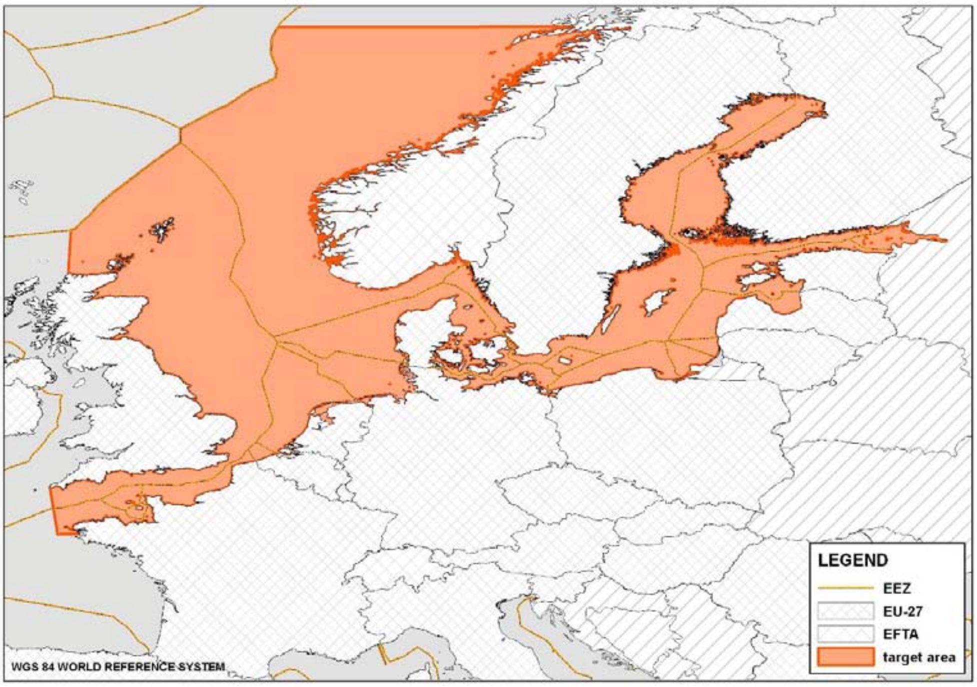


Figure 1: North and Baltic Seas: Region as defined by the EU FP7 ORECCA Project

6.1 Resource

6.1.1 Wind & Wave Combination

Based on the combined resource maps created by the GIS tool, the west coast of Norway and the North-East of Scotland have the best combined wind and wave resource in this region with a minimum wind speed of 8m/s at 10m a.s.l. and minimum wave power of 25kW/m (indicated by the red colour, level 6).

As you move further south, the wave resource reduces significantly while the wind resource stays at the higher level in much of the east of the North Sea. The second most promising area for combined wind and wave generation, appears to be a small area in the Danish EEZ which has the higher wind level (>8m/s) and the medium wave resource level (15-25kW/m) indicated by the orange colour (level 5).

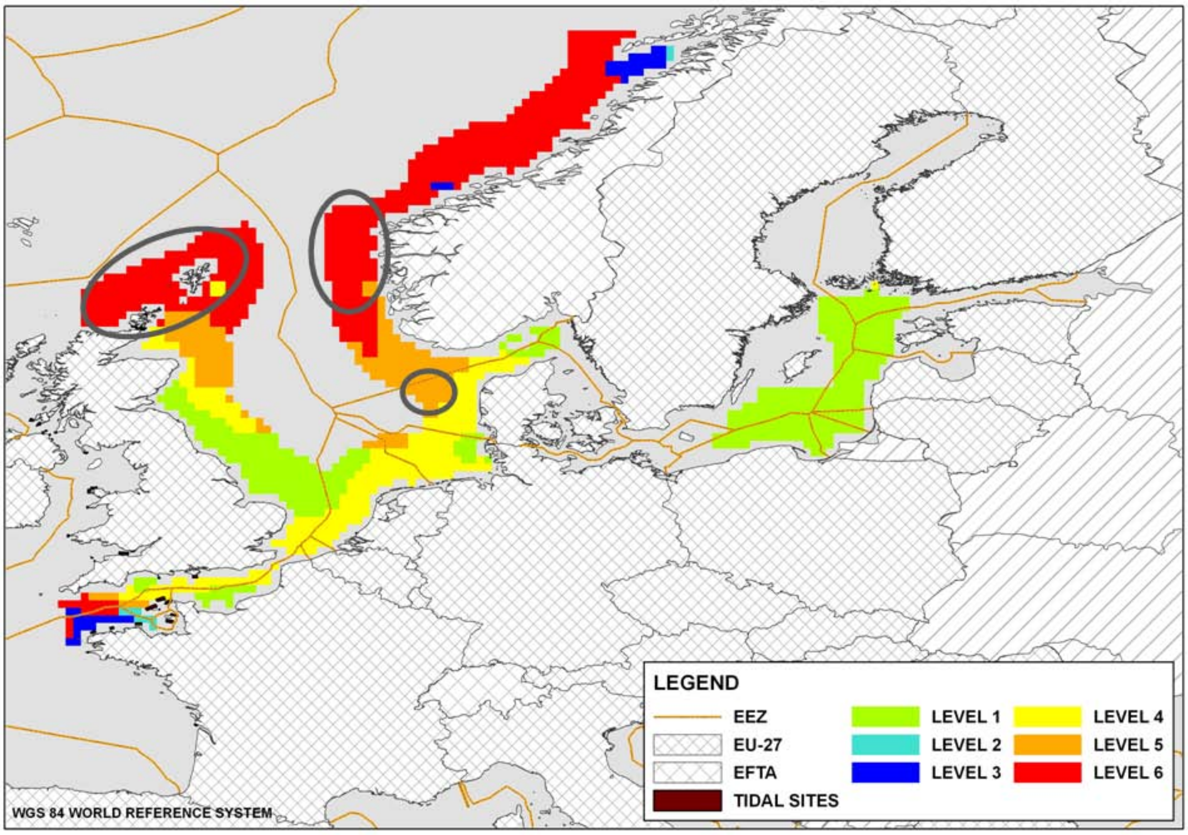


Figure 2: North and Baltic Seas: Combined Resource Levels with identified potential sites

This combined map was compiled using OCEANOR wave data and Quikscat wind data and looking at these individually, Figure 3 and Figure 4 below, can give more specific information.

The location off the west coast of Denmark appears to have a wave resource of 15-25kW/m in that area according to OCEANOR and an average wind speed of 8-9m/s according to Quikscat.

The OCEANOR map below gives average annual wave power per unit wave crest of approximately 30-60kW/m in the areas off Norway and Scotland. The Norwegian location has average wind speeds of 8-9m/s according to Quikscat data however Scotland has a slightly greater available wind speed of 9-10m/s. It is therefore difficult to distinguish the most promising location for a combined renewable energy project based on these resource maps alone.

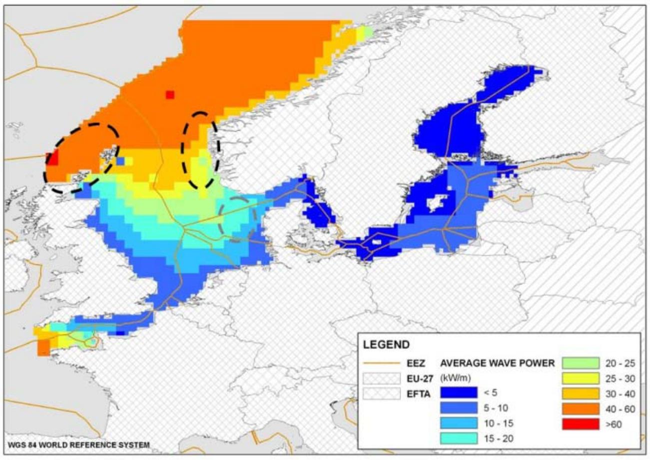


Figure 3: North and Baltic Seas: Average Wave Power Levels according to OCEANOR

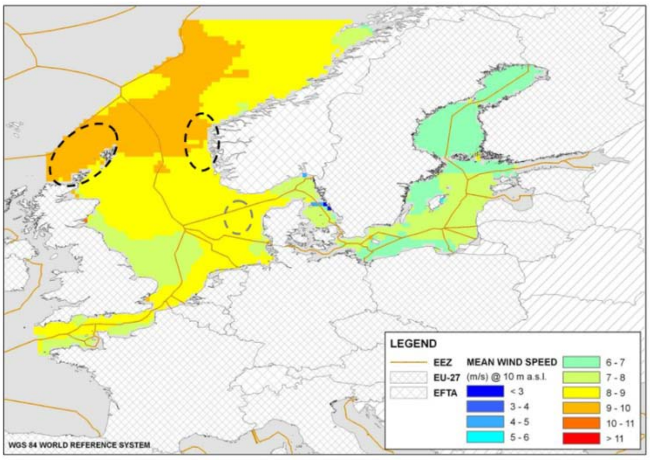


Figure 4: North and Baltic Seas: Average Wind Speeds according to Quikscat

National resource atlases can give much greater insight into the resource available at a given location. Using these, we can further evaluate the resource in these 3 identified areas.

Figure 5 shows that there is an available wave power resource of 30-50kW/m on the northern tip of Scotland and an average wind speed of 10-11.5m/s in the same location at a height of 100m. This height is more consistent with what would be expected at the hub height of an average offshore wind turbine.

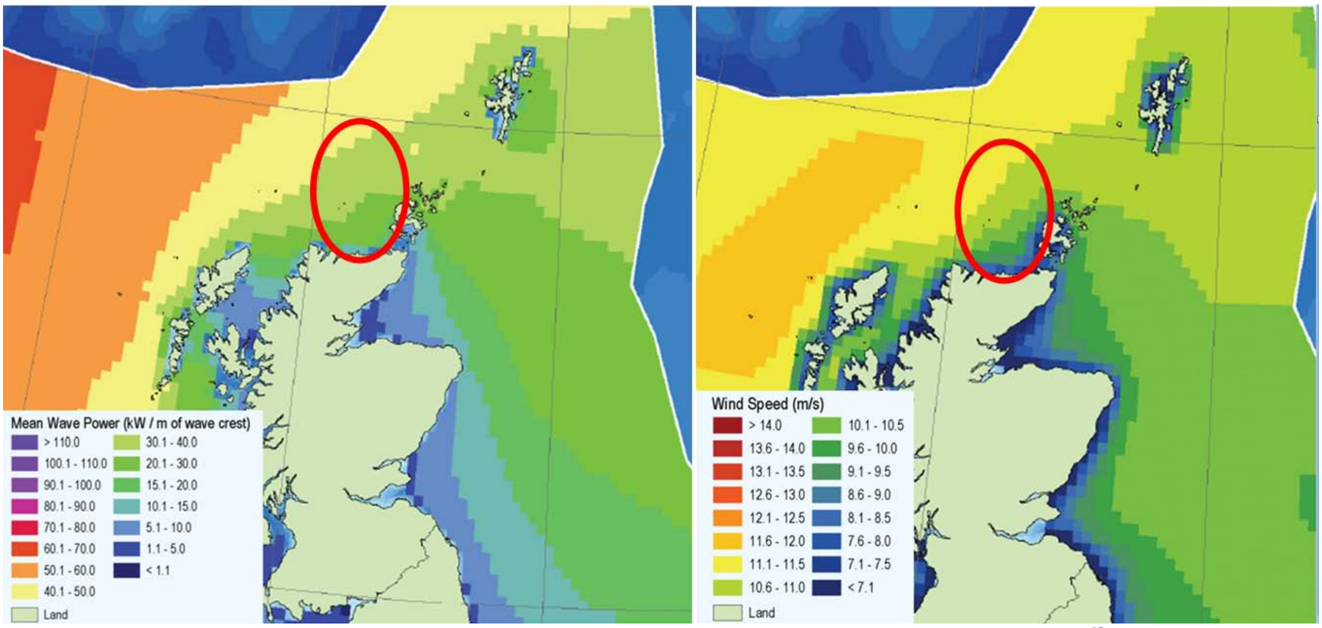


Figure 5: Scottish Mean Annual Wave Power (LEFT) and Mean Annual Wind Speeds (RIGHT)[43]

There is no known wave atlas available for Norway however a paper[44] analysing the buoy data collected in the North Sea gives average wave power levels of 23-33kW/m along the Norwegian coast. Unfortunately these buoys are further south (in the orange zone of Figure 2 above) than the region being considered here however it is assumed that the average resource at the location being considered would likely be in agreement with the OCEANOR data.

The Norwegian wind atlas gives average wind speeds at 100m height. As shown in Figure 6 below, the average wind speeds are 9.5-10.5 m/s in the area being considered.

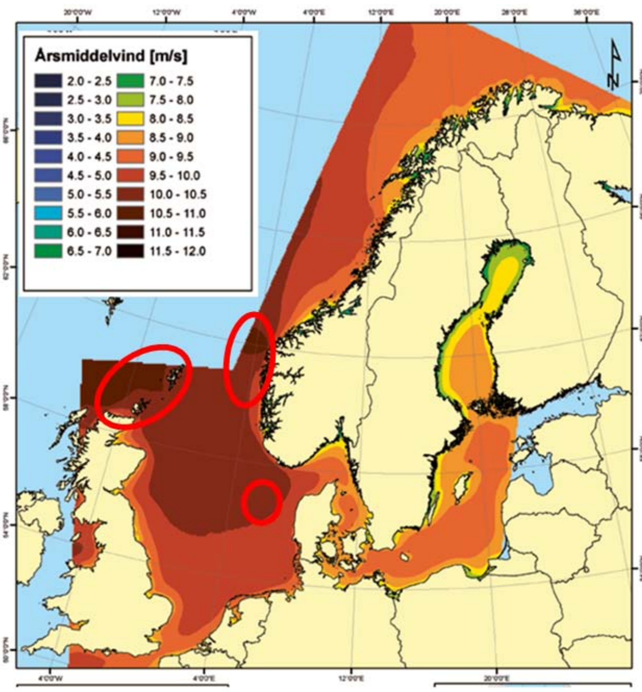


Figure 6: Offshore Wind Resource Norway - Annual Mean Wind Speeds

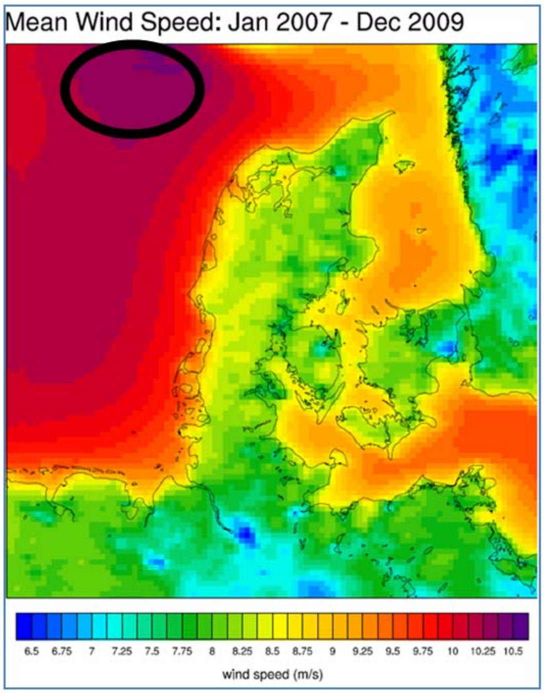


Figure 7: Danish Annual Mean Wind Speeds at 100m a.s.l.[45]

A specific Danish Offshore Wind Resource Atlas was not found during the course of this project however the Danish offshore wind speeds can also be determined from the Norwegian resource atlas, giving average wind speeds of 9.5-10.5 in the area concerned and also from the Risø Atlas of the Southern Baltic Sea which gives a value of 10-10.5m/s at 100m a.s.l. in Figure 7 above.

6.1.2 <u>*Wind & Tidal Current Combination*</u>

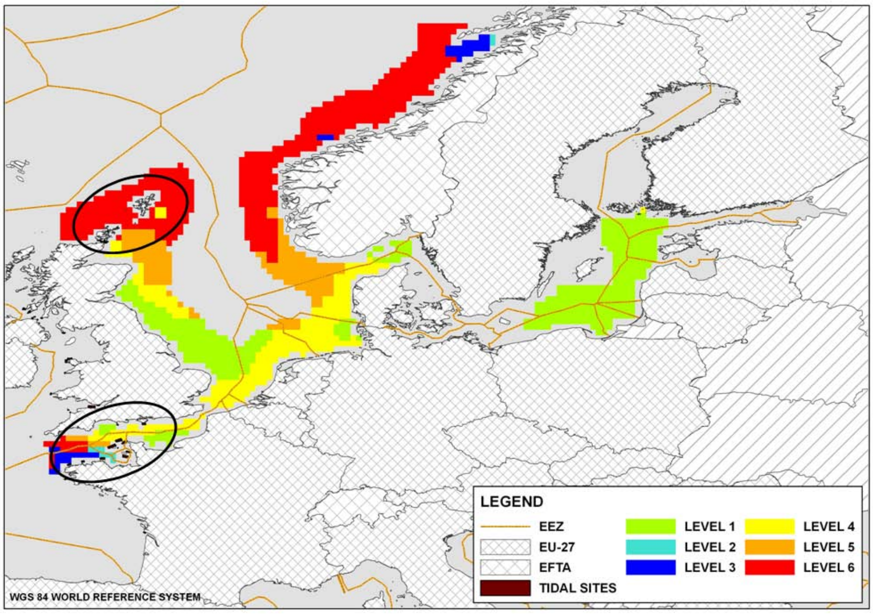


Figure 8: North and Baltic Sea: Combined Resource - wind + wave + tidal current (circled)

Figure 8 above illustrates the areas with combined wind and wave resource and highlights the regions which also have a number of tidal current sites illustrated by the circles. These tidal current sites are very small in relation to the scale of the map and so are not clearly identifiable without this aid. Figure 9 below identifies the known tidal current sites in the region.

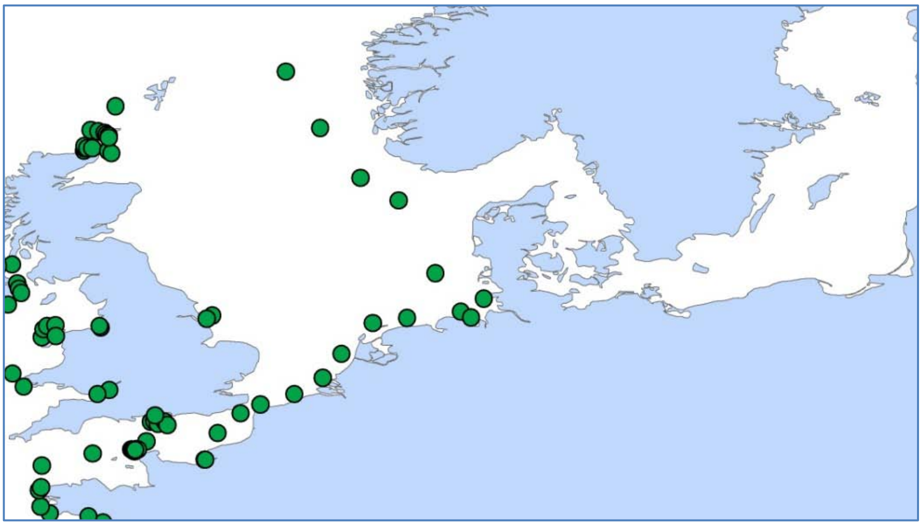


Figure 9: North and Baltic Seas: Tidal Current Sites

The north-east coast of Scotland has a number of suitable known tidal current sites with currents greater than 4m/s in some areas around the Orkney Islands, as evident in Figure 10 below. The region also has an average wind speed of greater than 8m/s. Therefore the approximate location identified in Scotland for wind and wave combinations is also suitable for wind and tidal combinations. The other region highlighted in Figure 8 has a lower average wind speed (identified by the blue-green colour scheme).

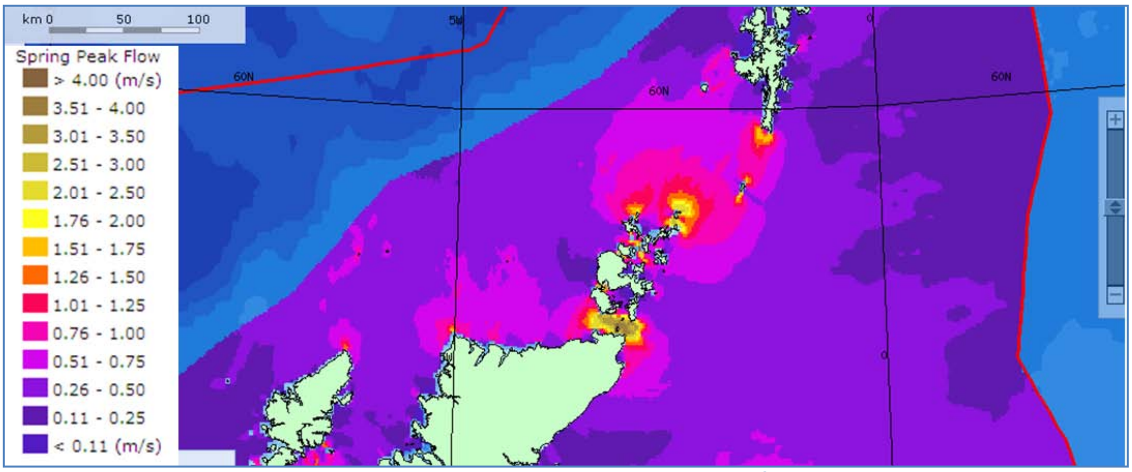


Figure 10: Scottish Spring Tidal Currents[46]

6.1.3 Application of Site Selection Methodology

Therefore applying these resource figures to the site selection methodology, the following are the points given to each site:

Country	Resource Level	Site Selection Points
WIND & WAVE		
Northern Scotland	Level 6	**10**
Western Norway	Level 6	**10**
North West Denmark	Level 5	**6**
WIND & TIDAL		
Northern Scotland	Level 1	**10**
Western France	Level 2	**6**

Table 17: North and Baltic Sea: Wind & Wave Resource Site Selection Points

6.2 Incentives and RE Targets

The ORECCA Project provided research into incentives and grant opportunities available for offshore renewable energy technologies in a number of countries around Europe. It must be noted that incentives and government policies can change dramatically over very short time frames however, assuming a pan European Price Index of €0.07/kWh, Table 18 shows the potential prices seen by a developer in each country and their relevant points in terms of the site selection methodology.

€/kWh	Wind			Ocean			Site Selection Points
	FiT	Price Received	Points	FiT	Price Received	Points	
Belgium	0.11	0.11	4.00	0.00	0.07	1.00	2.5
Denmark	0.04	0.11	4.00	0.05	0.12	2.67	3.3
Germany	0.15	0.15	7.00	0.00	0.07	1.00	4.0
France	0.13	0.13	5.50	0.15	0.15	3.67	4.6
Netherlands	0.19	0.19	10.00	0.00	0.07	1.00	5.5
UK	0.07	0.14	6.50	0.11	0.18	4.67	5.6
Norway	0.00	0.07	1.00	0.00	0.07	1.00	1.0
Scotland	0.07	0.14	6.50	0.28	0.28	8.00	7.25

Table 18: North and Baltic Sea: National Production Incentives and Wholesale Electricity Prices

Scotland provides €0.28/kWh for marine energy generation and €0.14/kWh for offshore wind energy. Conversely there are no dedicated incentives in Norway for offshore renewable energy.

Denmark, as the third most favourable location in the North and Baltic Sea region, has the lowest available production incentives in the region for offshore wind and marine energy with €0.04/kWh and €0.05/kWh above the wholesale electricity price respectively.

Another indicator of political will in a country for offshore renewable energy is the existing percentage of electricity produced from renewable energy and the countries intended NREAP targets for 2020. According to the Eurostats for 2009, (Figure 11 below) the gross electricity consumption coming from renewable sources in the UK is in the range of 4.3-8.6% while Denmark and Norway are in the ranges of 16.6-28.7% and 28.7-109.4% respectively. According to the latest EEA report on projected NREAP targets[47] the UK intends on 1300MW of ocean energy capacity and 12,990MW of offshore wind by 2020. Denmark has set targets of 0MW of ocean energy and 1,339MW of offshore wind capacity.

According to an interview by EurActiv[48] with the Norwegian State Secretary for Petroleum and Energy[49], almost 99% of Norway's electricity comes from renewable sources, with the overall share in the energy mix at 60%. According to the article, Norway intends to increase this by 2030 with an emphasis on offshore wind energy. It is therefore possible that incentives will be introduced in the coming years to attract the offshore wind energy industry.

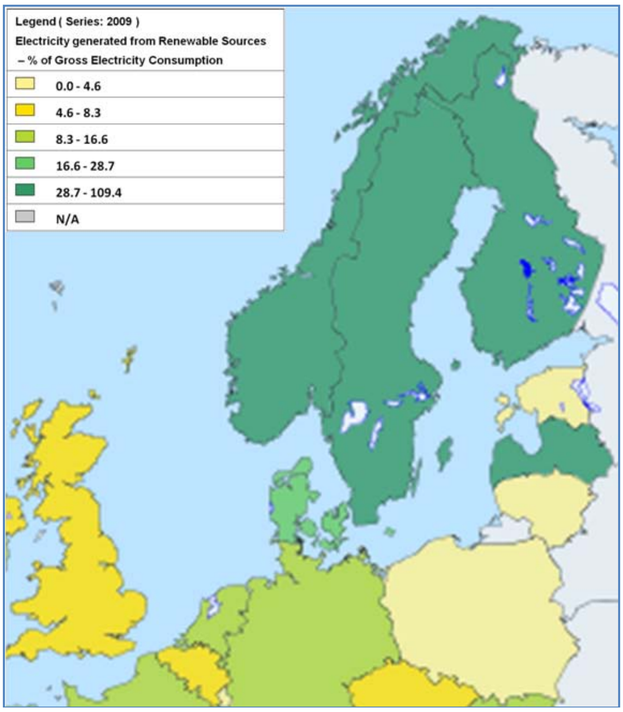


Figure 11: North and Baltic Seas: Country Specific - Electricity Generated from Renewable Sources (% gross electricity consumption) [50]

6.3 Geography

6.3.1 Water Depth

As evident from the image below, the waters off Norway are much deeper than those off Scotland with a very small area near the coast with depths less than 200m. Scotland benefits from the plateau which surrounds Ireland and the UK and as such has large areas of sea with water depths between 60-200m.
Neither country has significant available areas with water depths suitable for fixed structures (i.e. less than 60m) with the exception of small areas off the east coast of Scotland in low wave resource areas (v2_w1).
The region being considered in the Danish EEZ however is in water depths of 25-60m which is considered suitable for transition depth fixed offshore structures.

Tidal current sites tend to be close to shore (i.e. within 25km) and therefore in shallower water depths than that of other technologies. This map may not provide sufficient detail to identify those locations specifically.

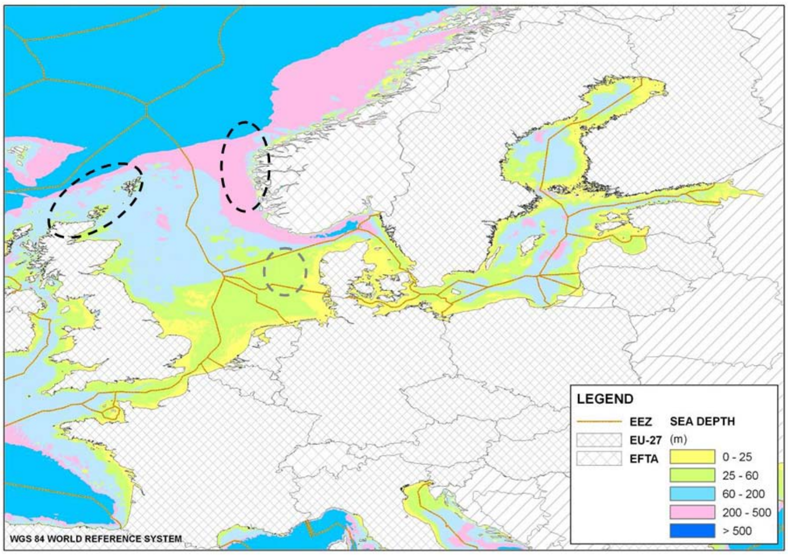


Figure 12: North and Baltic Sea: Bathymetry

The water depth points for the suitable sites are given in the table below.

Country	Water Depth Range	Typical Wind Turbine Structure	Site Selection Points
	WIND & WAVE		
Scotland	60-200m	Floating	8
Norway	60-200m	Floating	8
Denmark	25-60m	Tripod/Jacket	9
	WIND & TIDAL		
Scotland	**25-60**	Fixed	10
France	**25-60**	Fixed	10

Table 19: North and Baltic Seas: Water Depth Site Selection Points

6.3.2 Distance from Shore

The location of interest with a high wind and wave resource in the North of Scotland is within the 50km or 100km distance from shore boundary making this a viable location.

The site located in the Danish EEZ however is within the 150-200km zone and potentially beyond. It is likely that this site would need to provide significant energy production in order to make this a viable location for combined deployment and counteract the costs for the large distance from shore.

It is likely that any suitable tidal site will be close to shore where land constricts the tidal current flow.

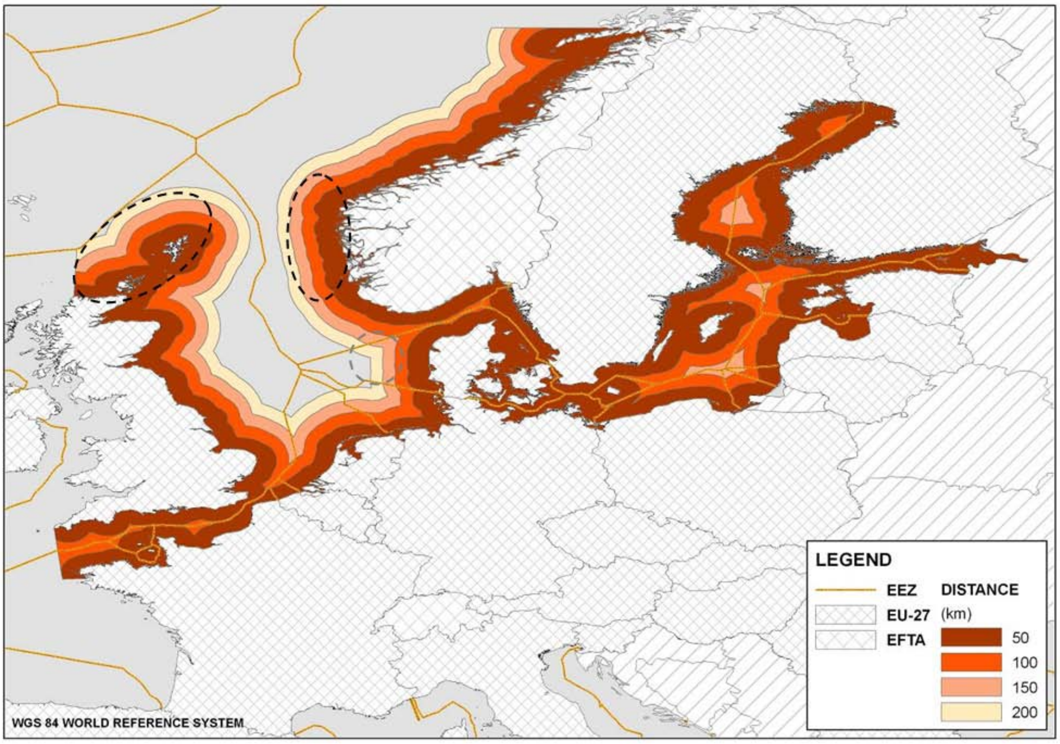


Figure 13: North and Baltic Seas: Distance from shore boundaries

Country	Distance from Shore	Site Selection Points
WIND & WAVE		
Scotland	50-100km	**8**
Norway	50-100km	**8**
Denmark	150-200km	**4**
WIND & TIDAL		
Scotland	0-20km	**1**

Table 20: North and Baltic Seas: Distance from Shore Site Selection Points

6.4 Infrastructure

6.4.1 Ports

Figure 14 below identifies all available ports in the region with 10-15m draft or greater. Each of the 3 locations identified have suitably sized ports in their locality.

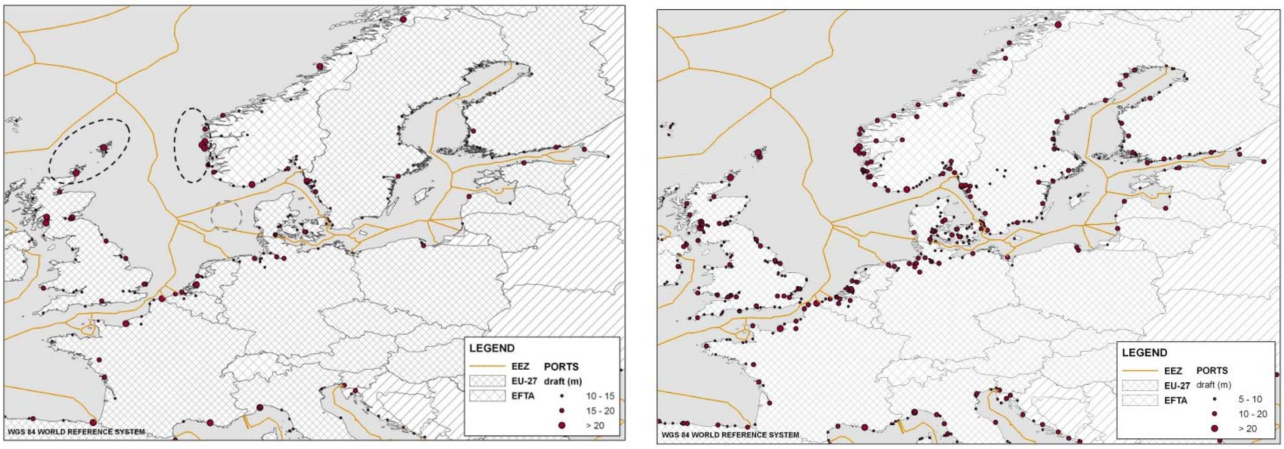


Figure 14: North and Baltic Seas: Location of Ports (LEFT: minimum 10-15m draft, RIGHT: All ports)

Country	Distance from Deep Water Port	Distance to Port - Site Selection Points	Distance from Shallow Port	Distance to Pier - Site Selection Points	Total Site Selection Points
	WIND & WAVE				
Scotland	100-150km	9	80-90km	6	**7.5**
Norway	Less than 100km	10	50-60km	9	**9.5**
Denmark	200-250km	7	200-250km	1	**4**
	WIND & TIDAL				
Scotland	Less than 100km	10	Less than 50km	10	**10**

Table 21: North and Baltic Seas: Distance from Port Site Selection Points

6.4.2 Electrical Grid

All 3 locations identified have high voltage transmission lines in the area with sub-sea interconnectors for distribution to continental Europe. The availability and strength on these grids would need to be determined in more detailed site selection studies.

There are a number of offshore cables in UK waters as evidenced in Figure 16Figure 52 below however there are none in the northern Scotland area under consideration. There appear to be numerous sub-sea cables in Danish waters in the location being considered.

Country	Local Grid kV Capacity	Site Selection Points
WIND & WAVE		
Scotland	220-380kV	6
Norway	Less than 220kV	4
Denmark	380-500kV	8
WIND & TIDAL		
Scotland	220-380kV	6

Table 22: North and Baltic Seas: Local Grid Site Selection Points

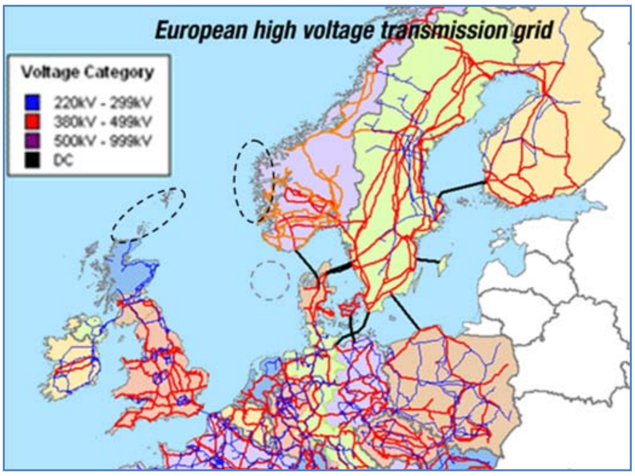


Figure 15: North and Baltic Seas: Electrical Grid Infrastructure

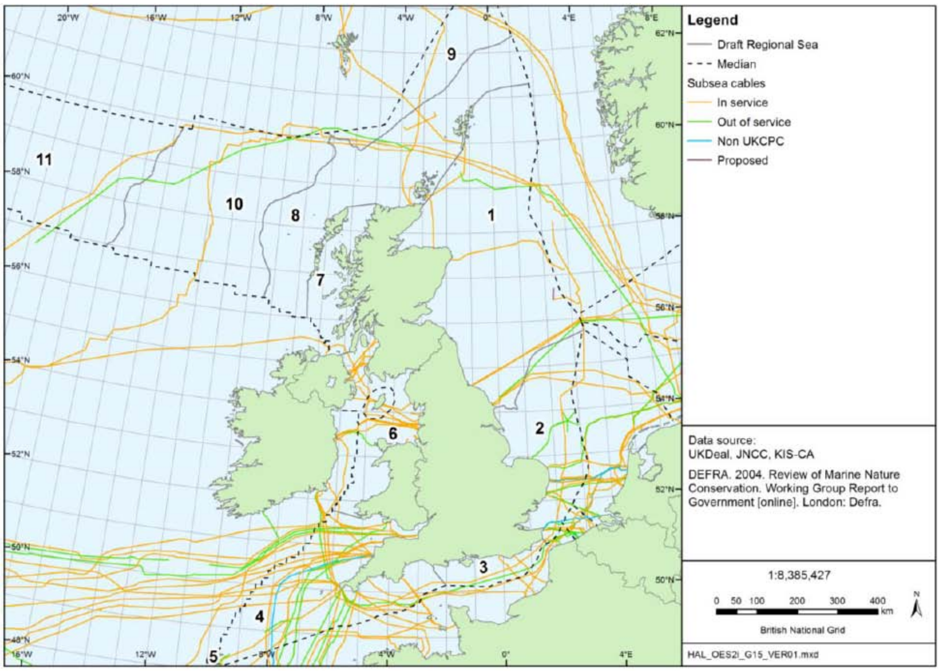


Figure 16: Location of Submarine Cables in UK Waters[51]

6.4.3 Population/Demand Centres

Of the 3 sites under consideration, the coast of Norway appears to have the lowest population/demand in its vicinity, however it should be noted that the sub-sea cables to continental Europe void this concern. Therefore based on Figure 17 below, all 3 locations have demand centres to supply to.

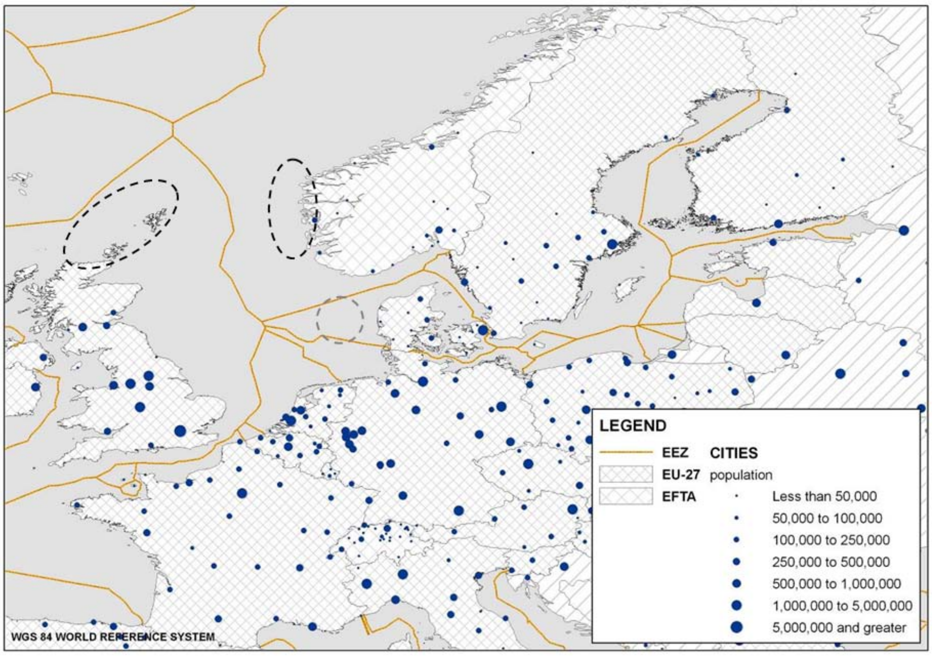


Figure 17: North and Baltic Seas: Population/Demand Centres

6.5 Other Uses

6.5.1 Designated Environmental Protected Areas

European designated Marine Protected Areas (MPA), illustrated in Figure 18 below, do not appear to pose a threat to the 3 locations under consideration in this region however locally/nationally designated sites would need to be further investigated.

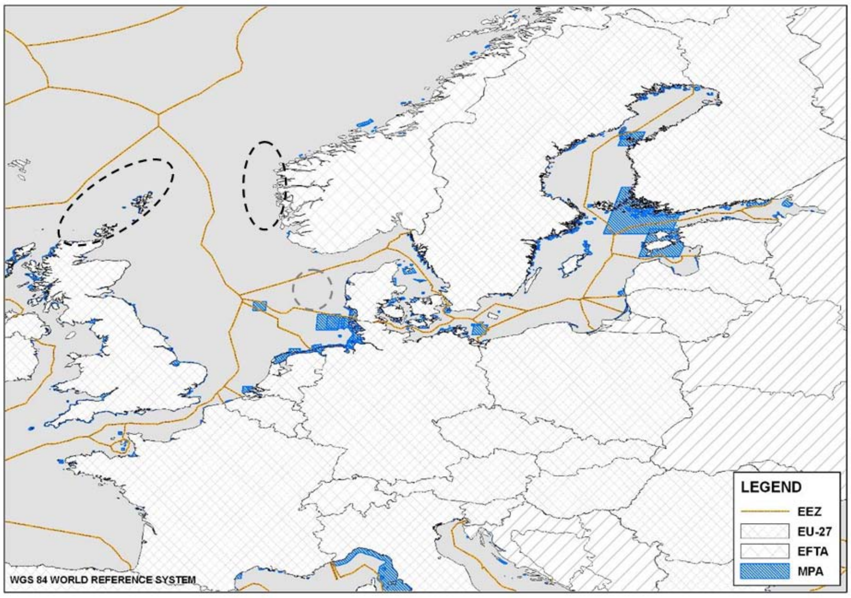


Figure 18: North and Baltic Seas: Designated Marine Protected Areas

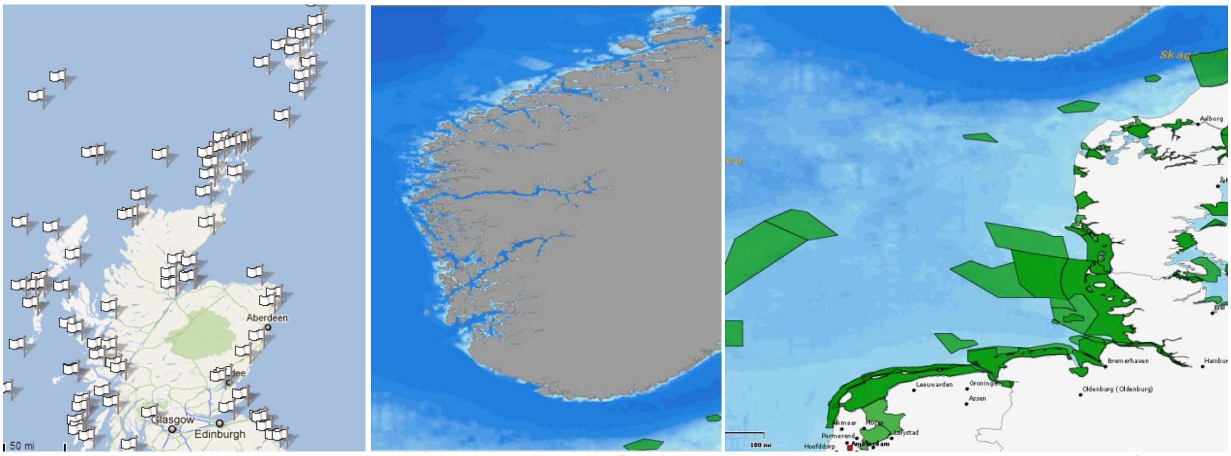


Figure 19: Marine Protected Areas for Scotland[52] and NATURA 2000 sites for Norway and Denmark[53]

6.5.2 Navigation & Shipping Lanes

The North Sea has high volumes of sea traffic as evidenced by the blue markings in Figure 20 below. The locations, identified off Norway and Denmark, have particularly high sea traffic and therefore a combined offshore renewable project may conflict with these other uses of the sea. In comparison, the area in Scottish waters has much lower volumes of traffic.

The density of shipping traffic along the main shipping route close to the Danish coast would be designated "high" while the area being considered further west is being designated "medium" as is the coast of Norway.

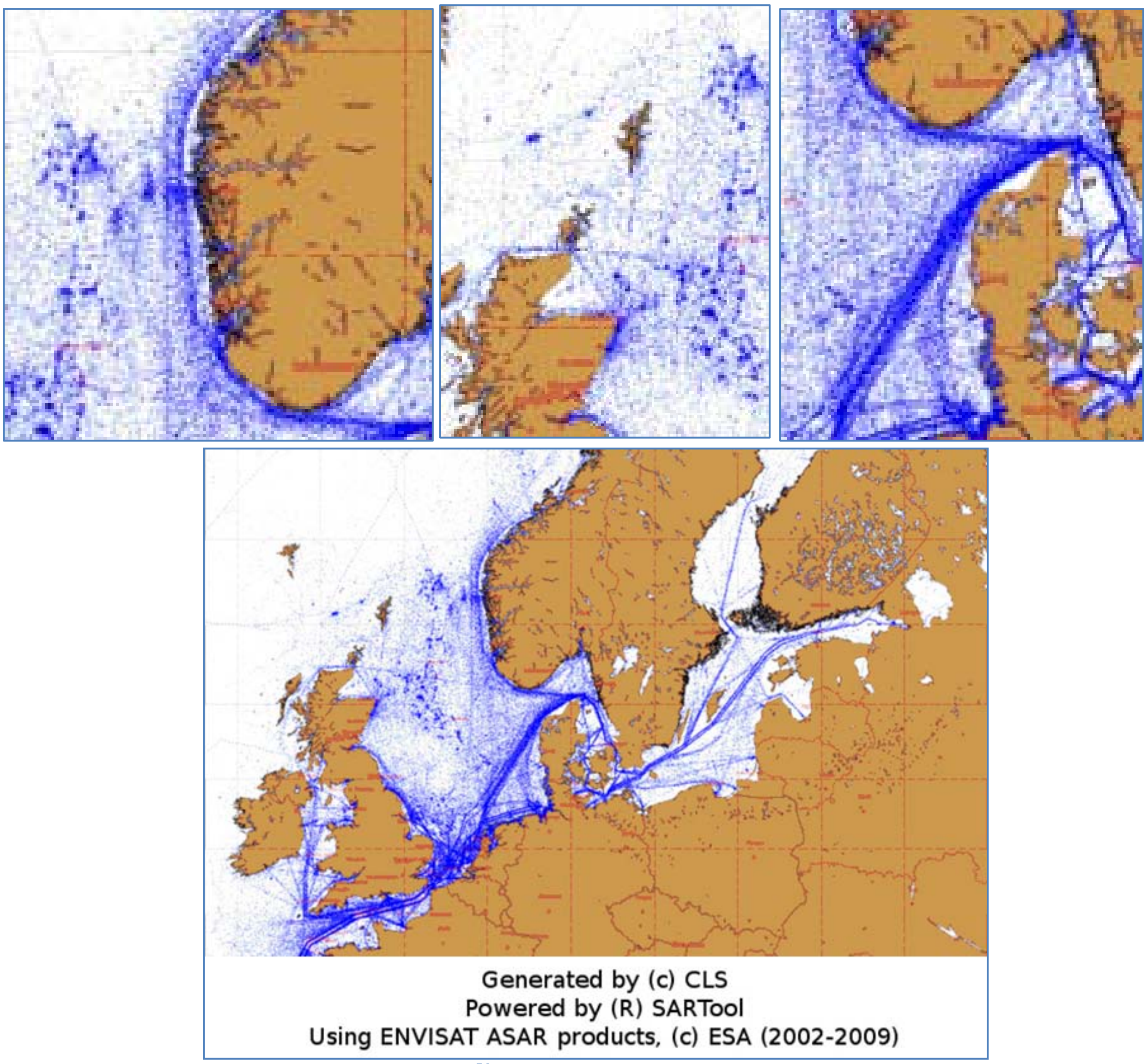


Figure 20: North and Baltic Seas: Shipping Routes[54] for coast of Norway (TOP: LEFT), Scotland (TOP: CENTRE), Denmark (TOP: RIGHT) and All of Region (BOTTOM)

Country	Shipping Density	Site Selection Points
WIND & WAVE		

Scotland	**Low**	**10**
Norway	**Medium**	**6**
Denmark	**Medium**	**6**
WIND & TIDAL		
Scotland	**Low**	**10**

Table 23: North and Baltic Seas: Shipping Density Site Selection Points

The Norwegian Wind Atlas includes detailed maps of shipping traffic (figure x below) which can give further insight into site selection.

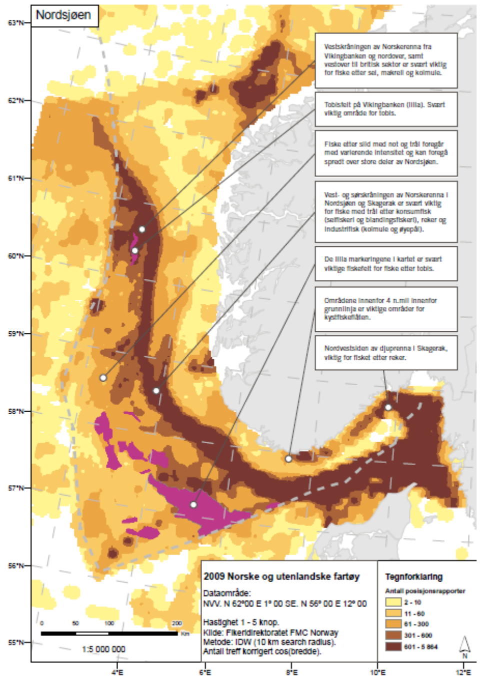


Figure 21: Norwegian Atlas Shipping Density Image

6.5.3 ***Military Exercise Areas***

As there is no existing European wide map of military exercise areas or coastal zone uses, it is necessary to look on a national level for this information. The Scottish Marine Atlas provides detailed information on other uses of the sea and Figure 22 below shows that there may be some conflict with military exercise areas, however there remains a significantly large area suitable for offshore renewable energy deployment.

Unfortunately much of the maritime zone management in Norway is on a regional and local level and as yet no national document exists and a map of military uses could not be found.

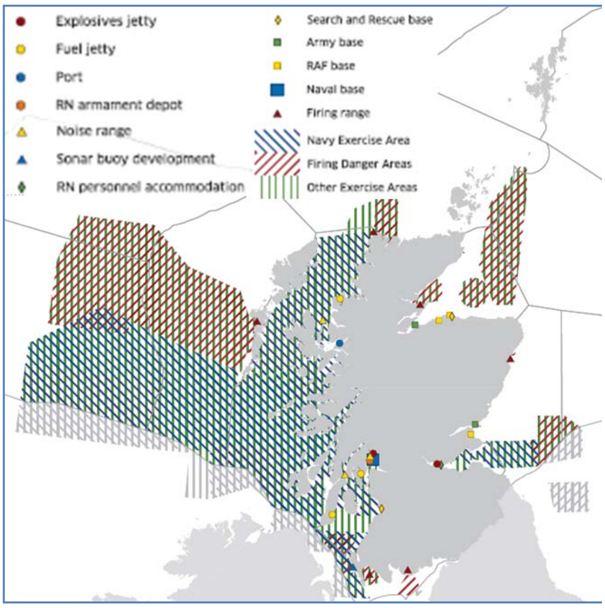


Figure 22: Scottish Military Exercise Areas[55]

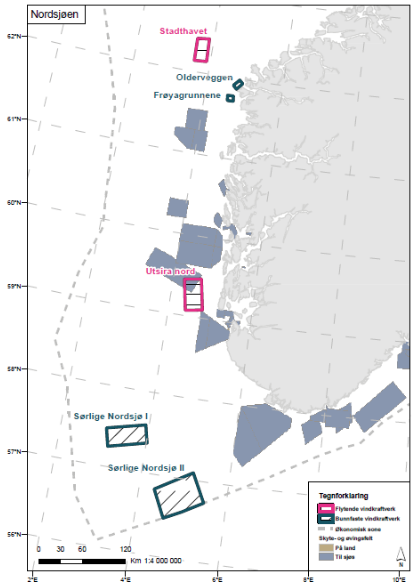


Figure 23: Norwegian Military Exercise Areas

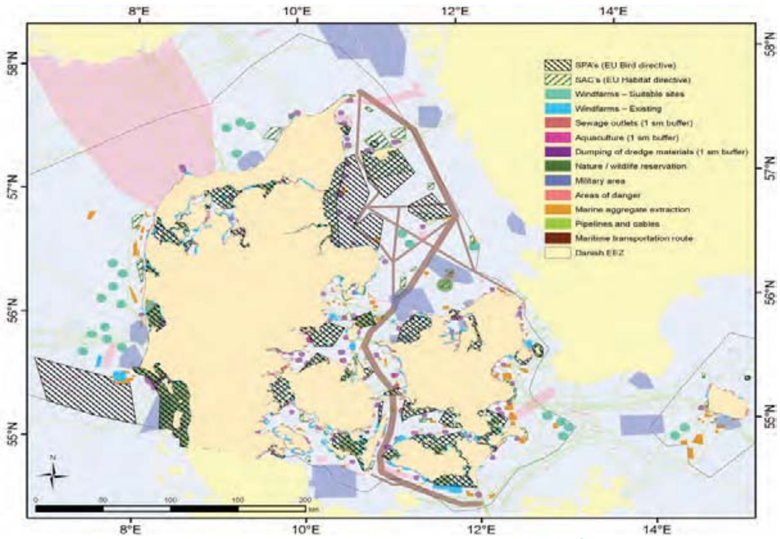


Figure 24: Danish Uses of the Sea Map[56]

The Danish map, Figure 24 above, illustrates the military (light blue colour) and other users of the sea around the Danish coast. The majority of the activity depicted in this image is located close to shore; it is unlikely that the location chosen in this site selection will coincide with any military exercise areas however there may be some other uses which will become clear with a Danish Marine Spatial Plan.

The Norwegian Wind Atlas gives maps of military areas shown in Figure 23 above.

6.5.4 Oil and Gas Fields

Of particular importance in the North Sea region are oil and gas fields as other users of the sea. Figure 25 gives an overview of the primary fields in this region however the Norwegian Wind Atlas gives maps of oil and gas areas, Figure 26 as does the UK OESEA, Figure 28 below. In conjunction with the field area, there also are major oil and gas pipelines in the region to contend with, Figure 27 below.

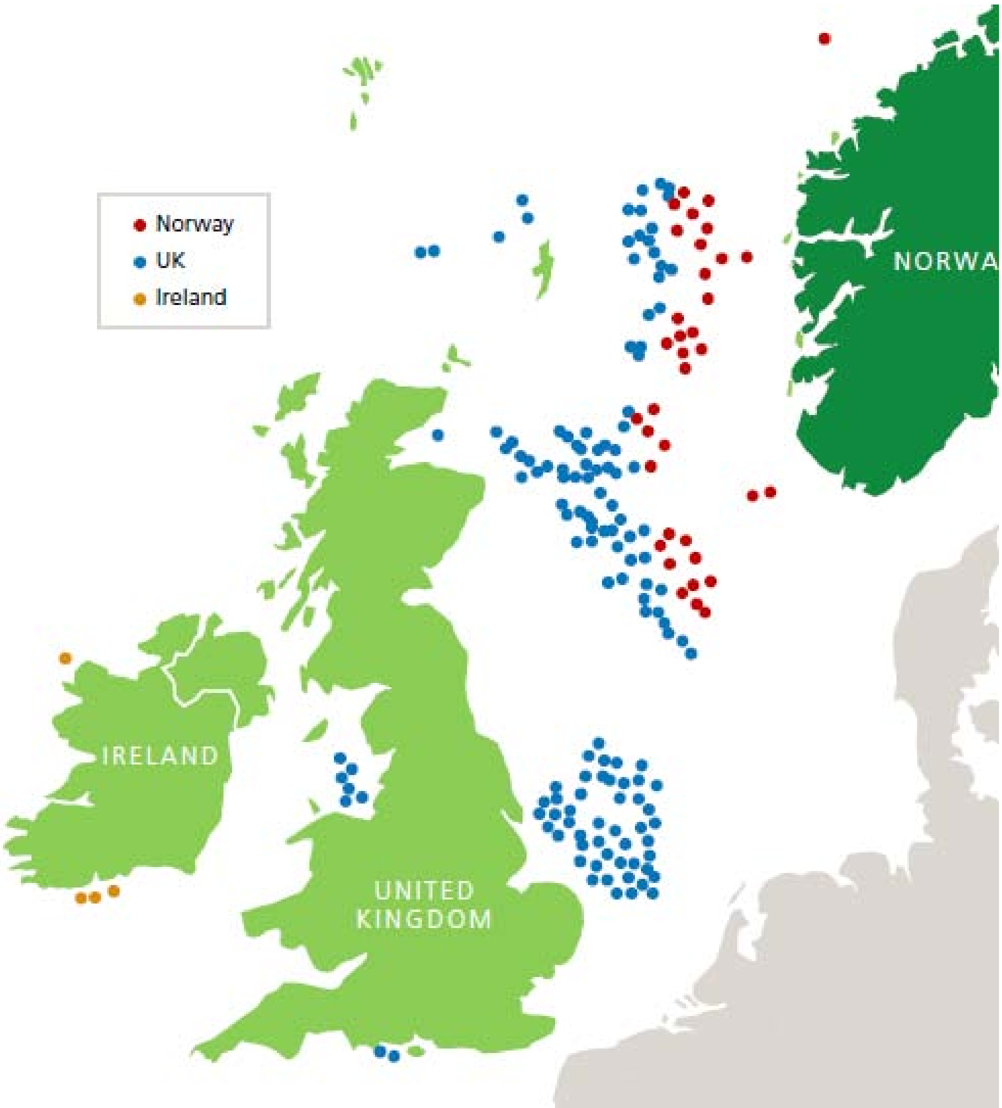


Figure 25: North Sea Oil and Gas Fields[57]

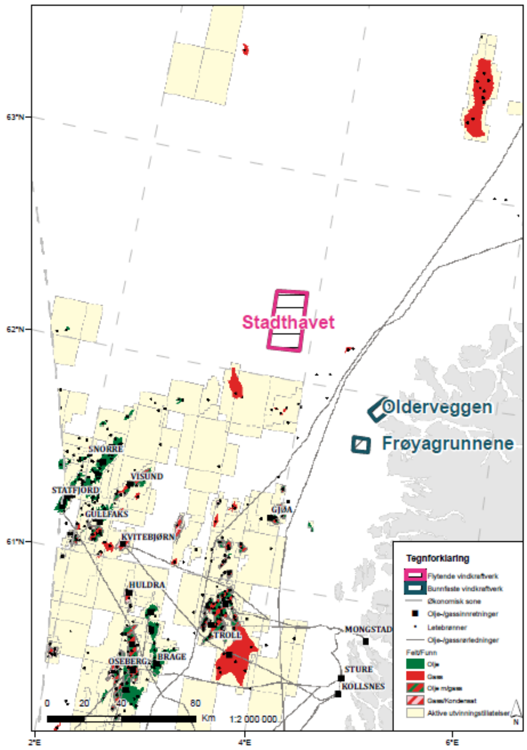


Figure 26: Norwegian Oil and Gas Fields

Figure 27: North Sea Oil Pipelines[58]

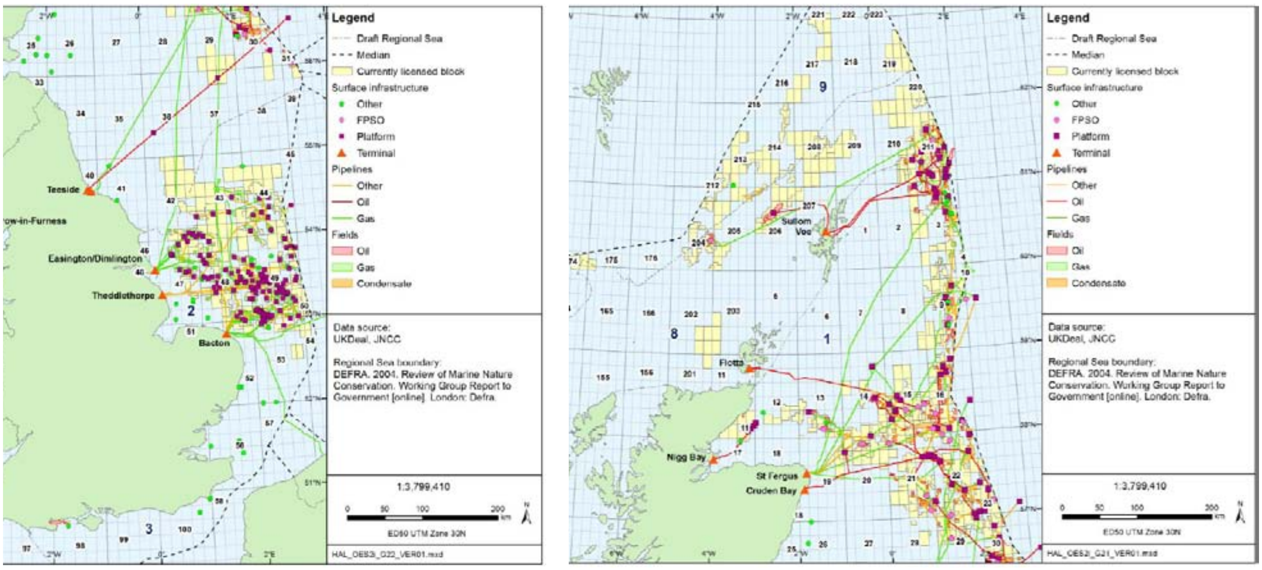


Figure 28: UK Oil and Gas Fields[59]

6.5.5 Fishing Zones

The European Atlas of the Seas[60] provides information on fisheries for each maritime region in Europe. Fishing regions in general are given by Sea, e.g. North Sea is one fishing region. However there is data on a country specific and coastal region basis as to the distribution of the European fishing fleet illustrated by Figure 29 below. Unfortunately this information is for EU countries only and so Norway is not included in this data. It can be seen however that Danish and Scottish regions have a very active role in the fishing industry in Europe with between 500-1000 vessels on average in the regions. This image also shows the smaller ports which are used for fishing and may not have a suitable draft for installation vessels of offshore renewable plants but could potentially be used for smaller craft for maintenance and servicing.

All 3 countries have a large number of these smaller ports.

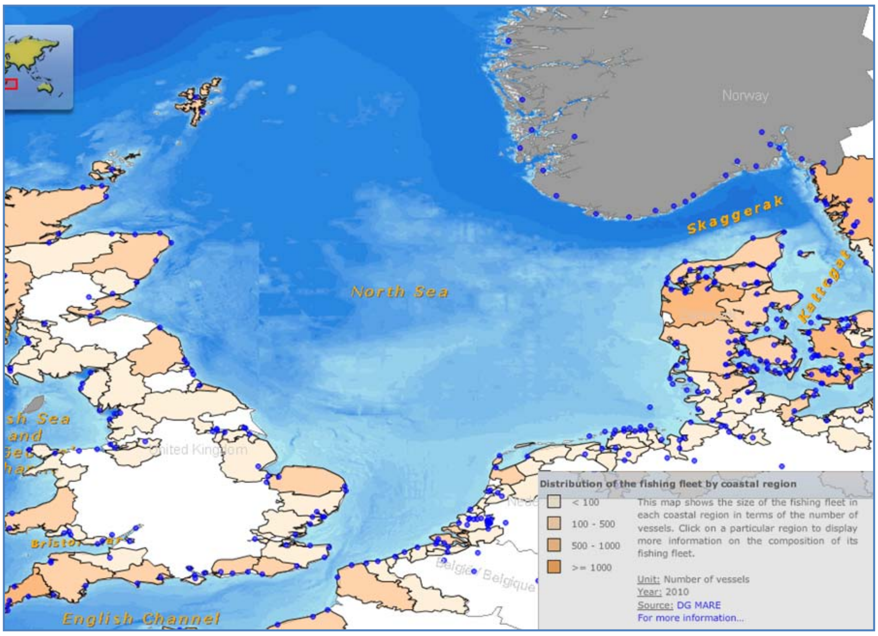
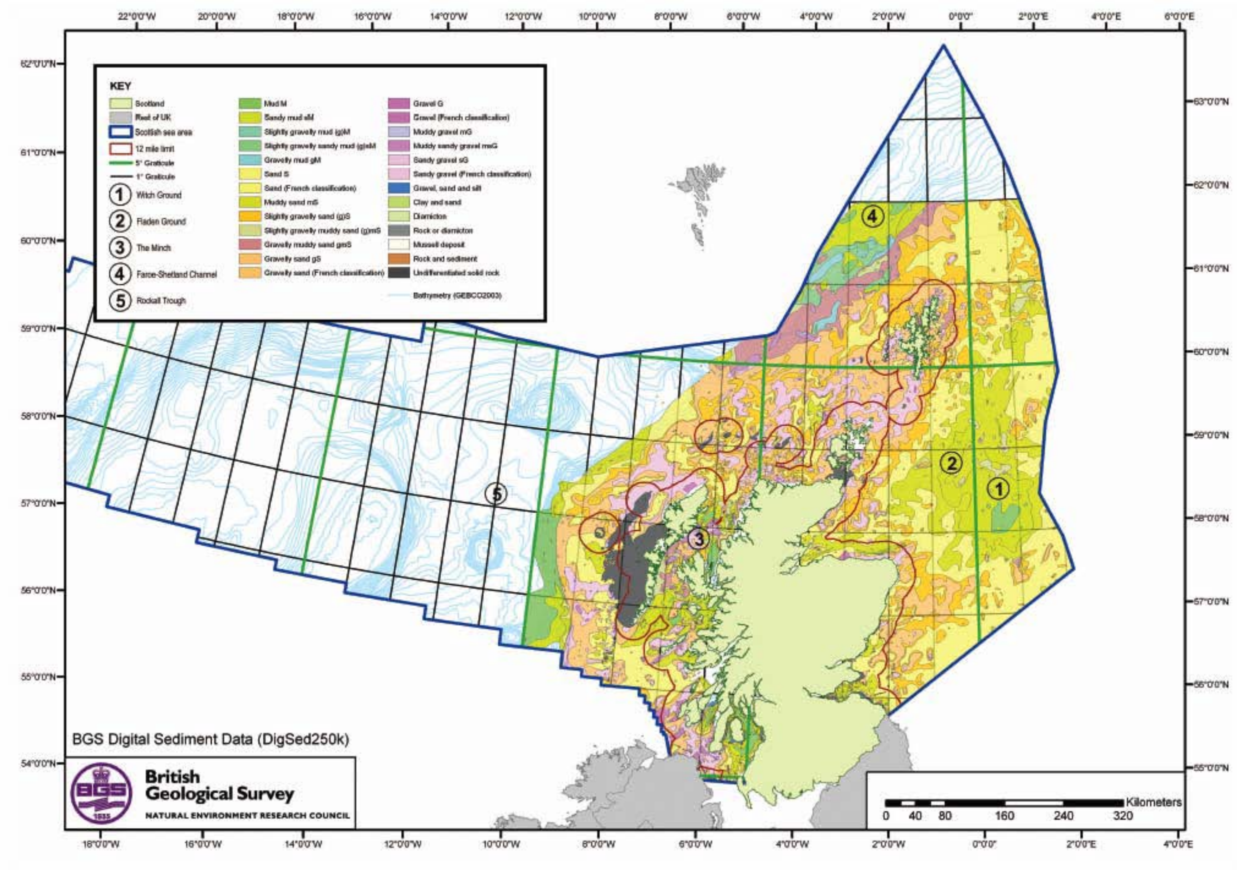


Figure 29: North and Baltic Seas: Distribution of fishing fleet by coastal region and location of fishing ports

6.6 Physical characteristics of the Site

6.6.1 Seabed Type

At present there is no central catalogue of existing geotechnical information for seabeds in Europe.



6.7 Final Site Selection

The following table is based on the points scheme used throughout the site assessment process to categorise the site parameters. According to this assessment methodology, the best combined wind and wave site in the North and Baltic Sea area is the location in the North of Scotland.

This is primarily due to the weighting given to incentives.

Parameter	Weighting	Scotland		Norway		Denmark	
		Points	Weighted	Points	Weighted	Points	Weighted
Resource	0.3	10	3	10	3	6	1.8
Incentives	0.2	8.3	1.66	1	0.2	3.3	0.66
Water Depth	0.2	8.0	1.6	8	1.6	9	1.8
Location	0.2	7.17	1.43	7.17	1.43	5.3	1.07
Other Uses	0.1	10	1	6	0.6	6	0.6
Total	1		**8.69**		**6.83**		**5.93**

Table 24: North and Baltic Seas: Site Selection

6.7.1 Site 1 – Floating, high resource area

For a site with the highest available wind and wave resource, the northern coast of Scotland is the most likely location due to the proximity to ports, population centres and grid infrastructure however the primary driver is the available production incentives in the form of feed-in tariffs for both offshore wind and marine energy.

The Norwegian coastline also has potential and if sufficient incentives are provided for offshore renewable energy projects to overcome costs of deploying in 200-500m water depths, Norway could become an important location for offshore renewable energy projects. Development and testing of a floating offshore wind energy device is already in progress in the country, illustrating the potential of the region due to resource alone.

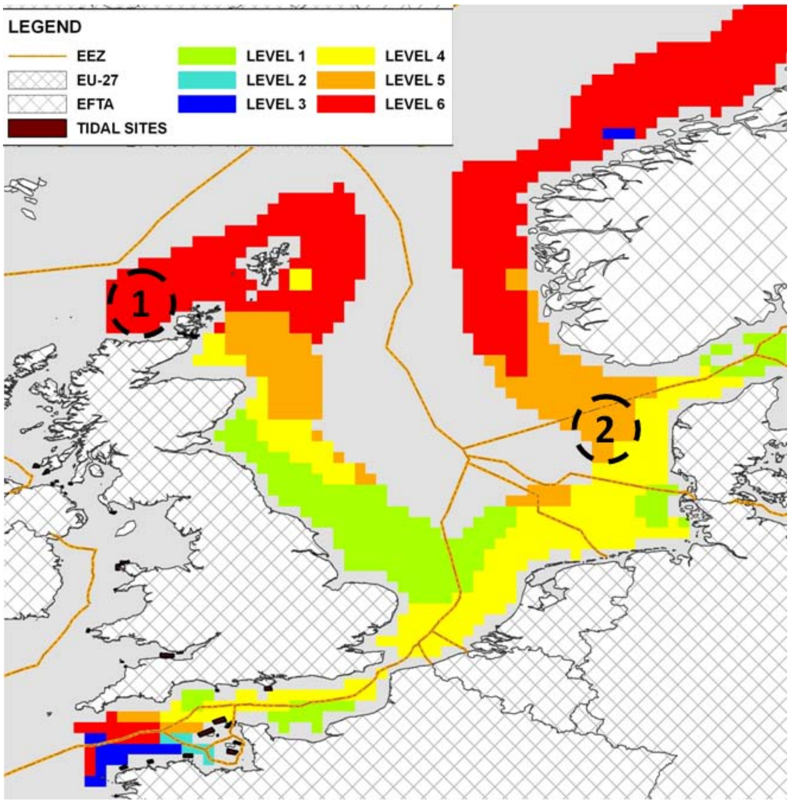


Figure 30: North and Baltic Seas: Promising Combined Renewable Energy Sites

6.7.2 Site 2 – Fixed, high wind/medium wave resource area

The south of the North Sea has the highest concentration of offshore wind farms in the world due to the wind resource, the suitable water depths and proximity to population centres and infrastructure. It is therefore likely that the first combined wind and wave projects will be in this region. The area identified in the Danish EEZ provides high wind resource (greater than 8m/s) and a medium wave resource (15-25kW/m). It is promising that, in this region, there are numerous offshore wind farms in the concept stage and an existing wind-wave platform prototype in the more sheltered eastern coast of Denmark[61].

Figure 31: Screenshot image of planned offshore wind farms in the Danish EEZ[62]

6.7.3 Site 3 – High wind/tidal current resource area

Locations with tidal current sites combined with high wind resource are limited in this region. Therefore the location in the Orkney Islands in the North-East of Scotland provides the best balance of all site parameters.

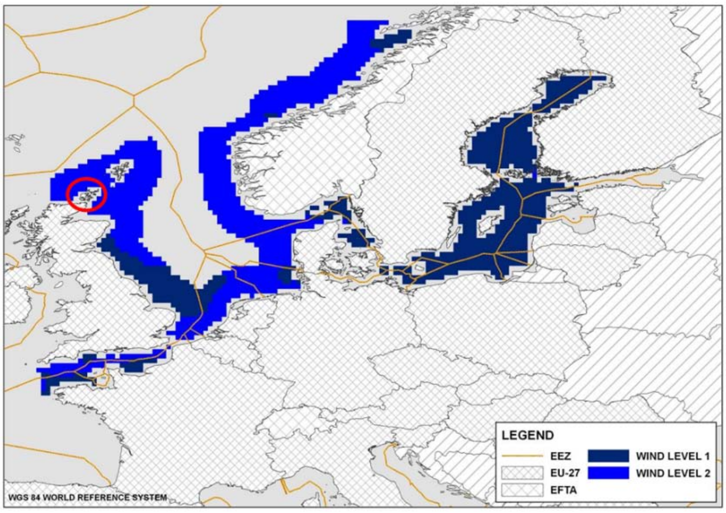


Figure 32: North and Baltic Seas: Combined Wind and Tidal Site

7 Site Selection Application to: Atlantic Region

The Atlantic Ocean region, defined in Figure 33 below, has an inherent maritime and fishing culture and some of the most extreme weather in Europe. The region has the highest wind and wave resource in Europe due to the large fetch of the Atlantic Ocean.

The following section will analyse the region using the previously defined site selection process, with the objective of identifying viable sites for combined wind-wave or wind-tidal current sites based on both GIS results compiled in the ORECCA project and available national data.

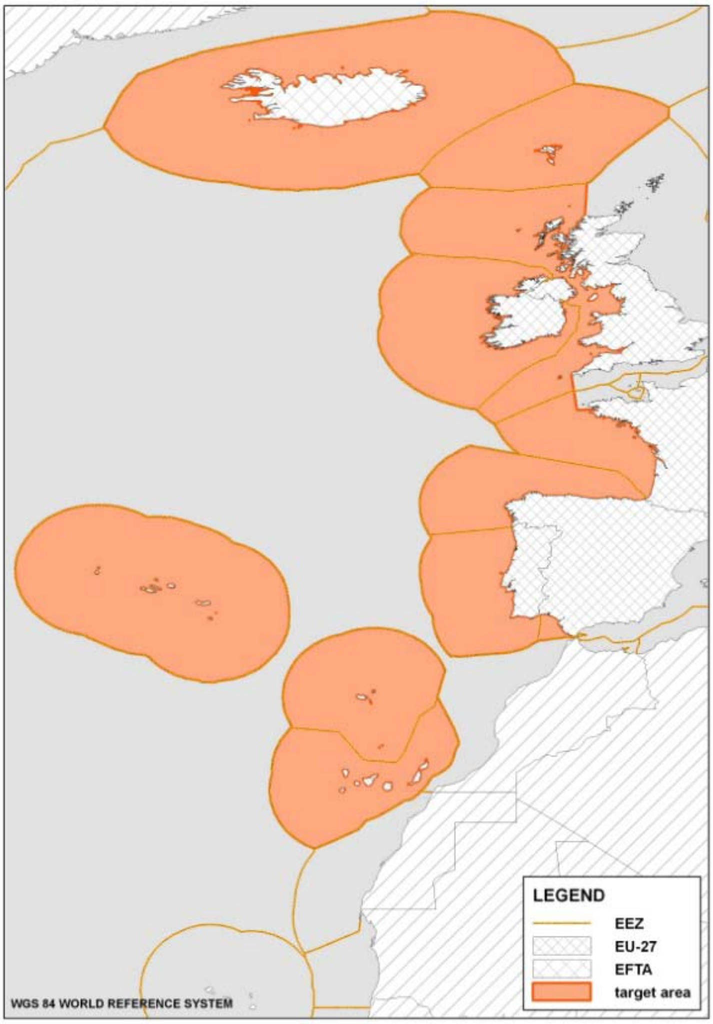


Figure 33: Atlantic Ocean: Region as defined by the EU FP7 ORECCA Project

7.1 Resource

7.1.1 Wind & Wave Combination

Figure 34 below shows the results of the GIS tool which designates the resource into 6 resource levels. The wave resource all along the Atlantic coast is in the higher designated resource level (greater than 25kW/m illustrated by Level 6 and Level 3) with the higher wind speeds (Levels 4-6) in the north of the coastline and the lower wind speed level (Levels 1-3) in the southern half i.e. coast of France, Spain and Portugal.

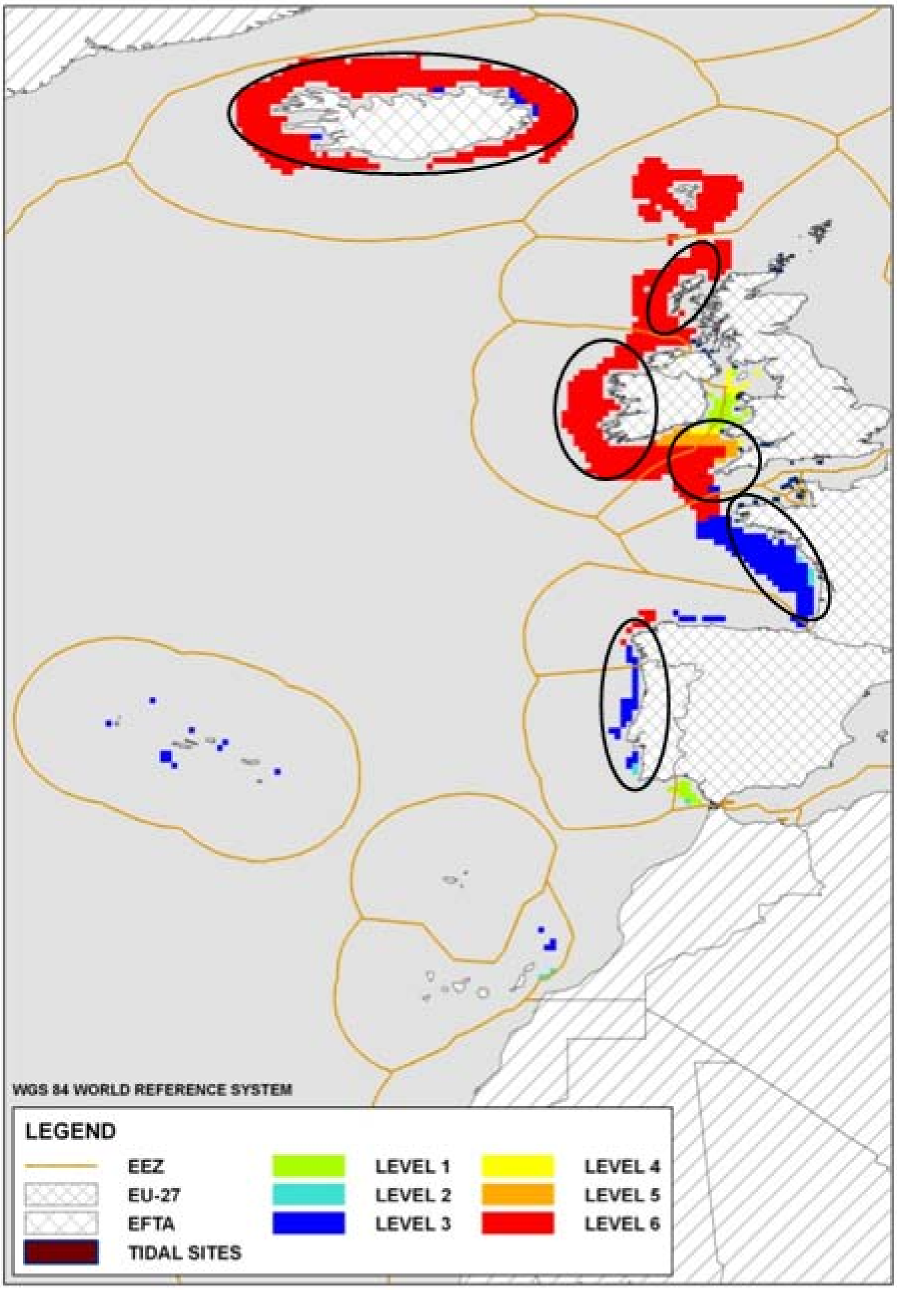


Figure 34: Atlantic Ocean: Combined Resource Levels with identified potential sites

Looking at the OCEANOR and Quikscat data separately, it can be seen that Ireland, Scotland and Iceland have average annual wave power levels greater than 60kW/m with southern England, Northern France, Northern Spain and Portugal having 40-60kW/m. Quikscat gives average annual wind speed values of 9-10m/s in north-west Ireland, Scotland and Iceland, 8-9m/s in southern Ireland, England and Northern Spain and 7-8m/s in Northern France and Portugal.

It is evident from this data that the western coast of Ireland, Scotland and Iceland have the highest resource in the region for both wind and wave with 9-10m/s and greater than 60kW/m averages respectively.

The southern half of the continent has average wind speed levels of 6-8m/s with a peak of 8-9m/s off the northern tip of Spain and average wave power levels of 30-40 and 40-60kW/m in northern Spain.

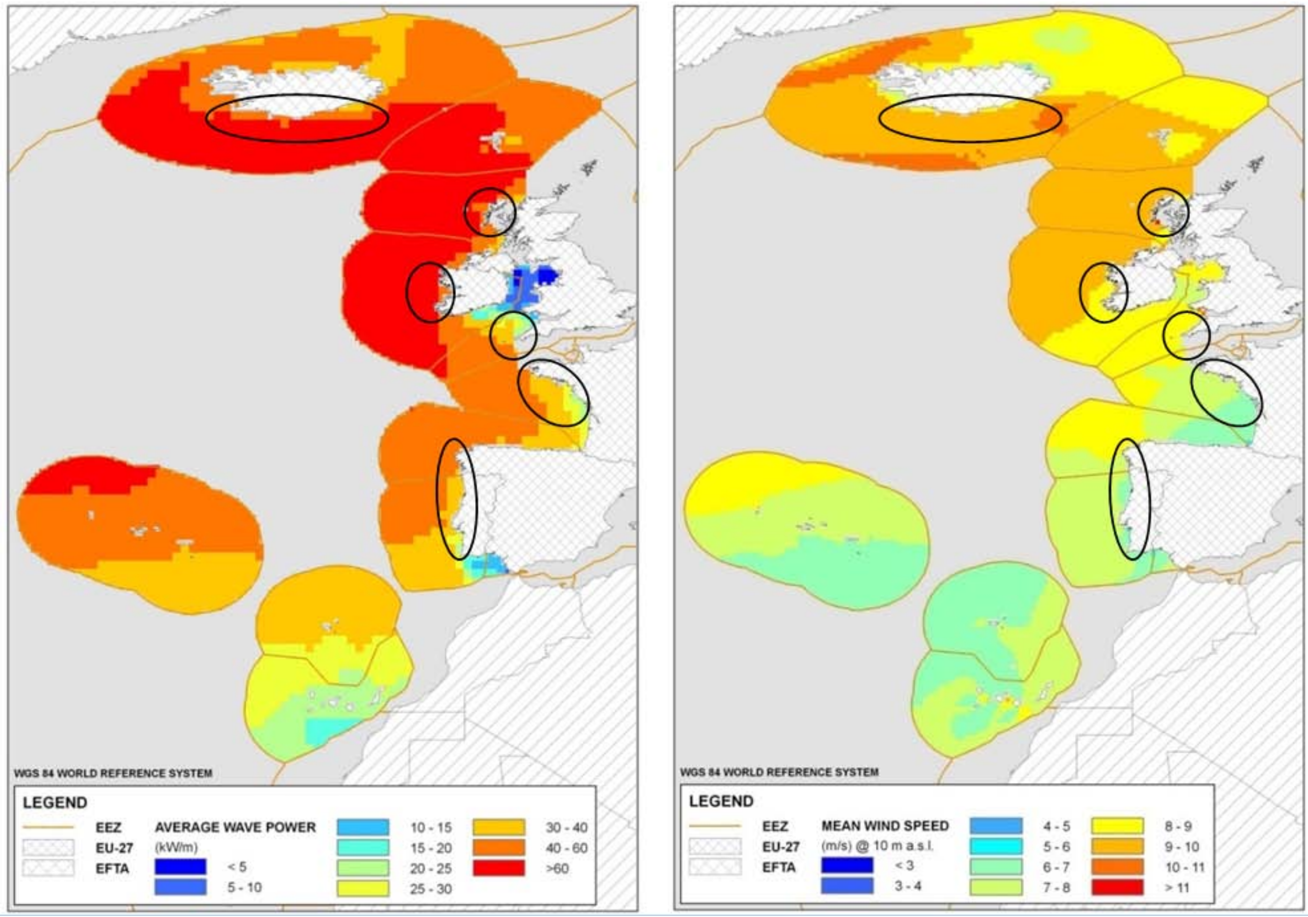


Figure 35: Atlantic Ocean: Average Wave Power Levels according to OCEANOR (LEFT) and Average Wind Speeds according to Quikscat (RIGHT)

Due to the isolated nature of the island of Iceland, the Azores and the Canary islands from mainland Europe and due to the lack of local data and information for these, the focus of this site selection will be on continental Europe, Ireland and the UK.

The UK Marine Renewable Resource Atlas, Figure 36 below, gives average annual wave power levels of 40-50kW/m in the West of Scotland and 20-40kW/m off the southern tip of England. Likewise the average annual offshore wind speeds are 11-11.5m/s in western Scotland and 9.5-10.5m/s in southern England.

According to the national resource atlases for Ireland, the annual average wave power level available on the west coast of Ireland is 125-175kW/m and average annual wind speeds are 9-10.5m/s.

There are no known offshore renewable energy resource atlases for France however the PreviMer website provides free current and wave height forecasting online[63] and Meteo France provides 2 weeks data plots online also[64].

A paper illustrating the wave energy resource in France according to the ANEMOC database (Figure 38) gives 30-40kW/m along the west coast of France with up to 60kW/m off the North-Western tip which is greater than those values given by the OCEANOR database (Figure 35 above) . A document prepared by Matthies and Garrad (1995) for EC Joule 1 programme, gives nearshore wind speeds for the Atlantic French Coast, Figure 39 below, of 8-10m/s at 60m a.s.l. in the North-West coast of France.

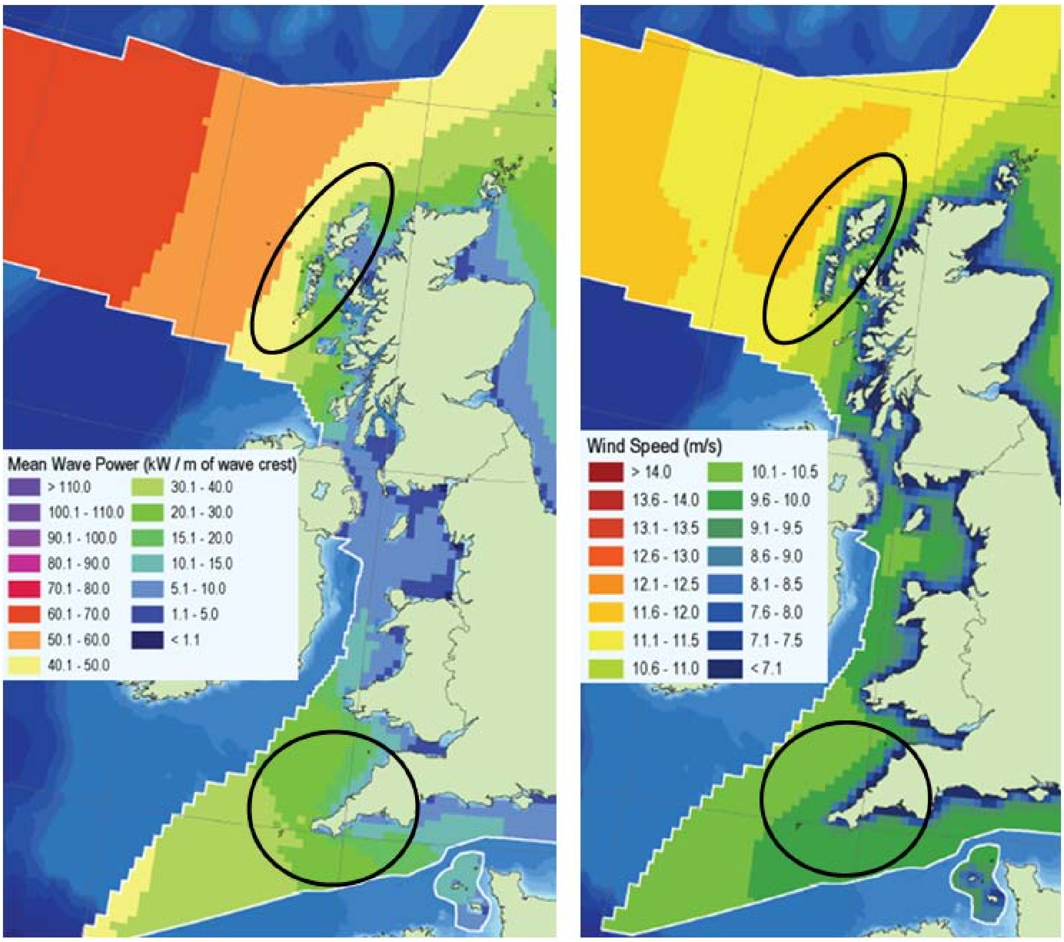


Figure 36: UK Mean Annual Wave Power (LEFT) and Mean Annual Wind Speeds at 100m a.s.l. (RIGHT)[65]

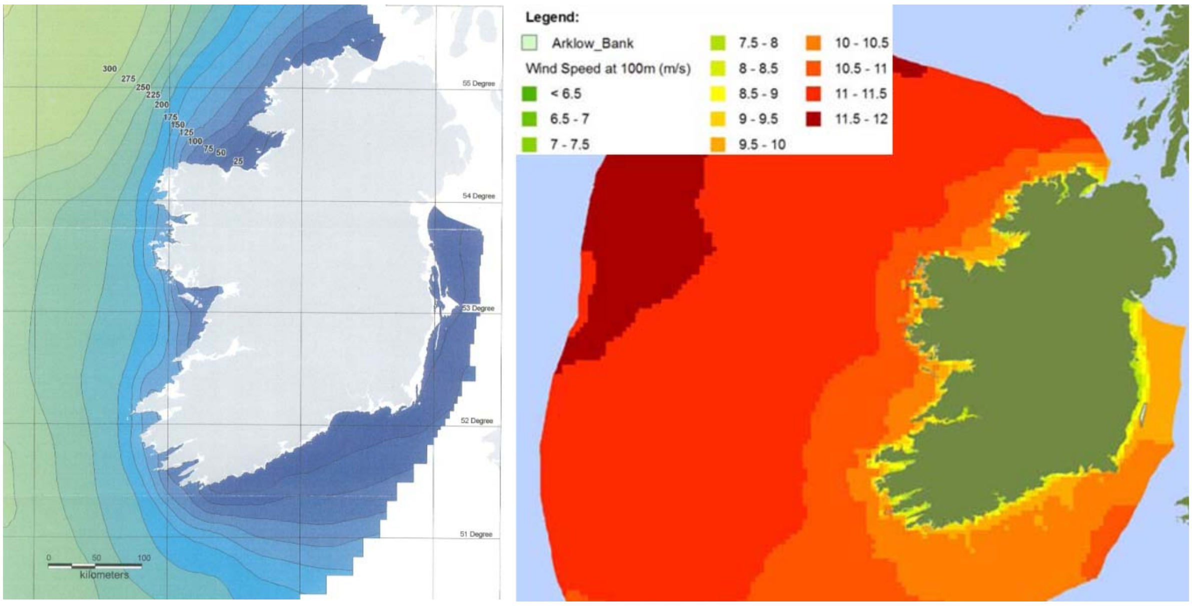


Figure 37: Ireland's Average Annual Wave Power[66] (LEFT) and Average Annual Wind Speeds at 100m a.s.l.[67] (RIGHT)

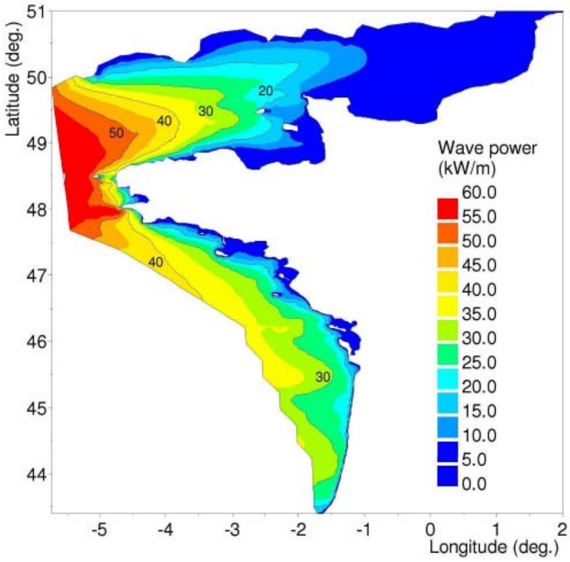


Figure 38: North West France: Average Annual Wave Power Levels[68]

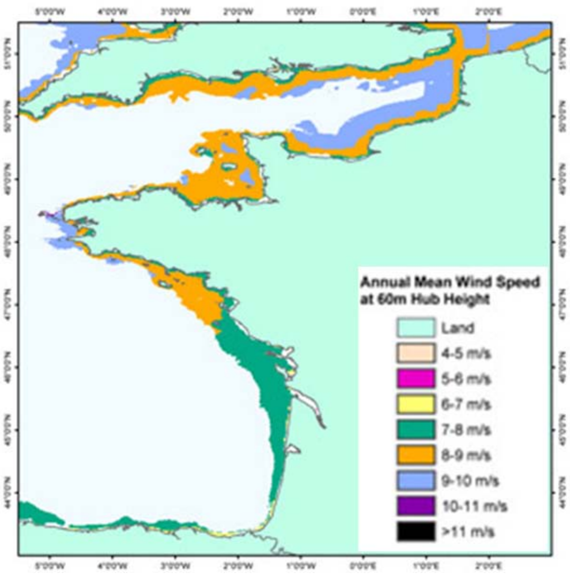


Figure 39: French Atlantic Coast: Offshore Wind Resource[69]

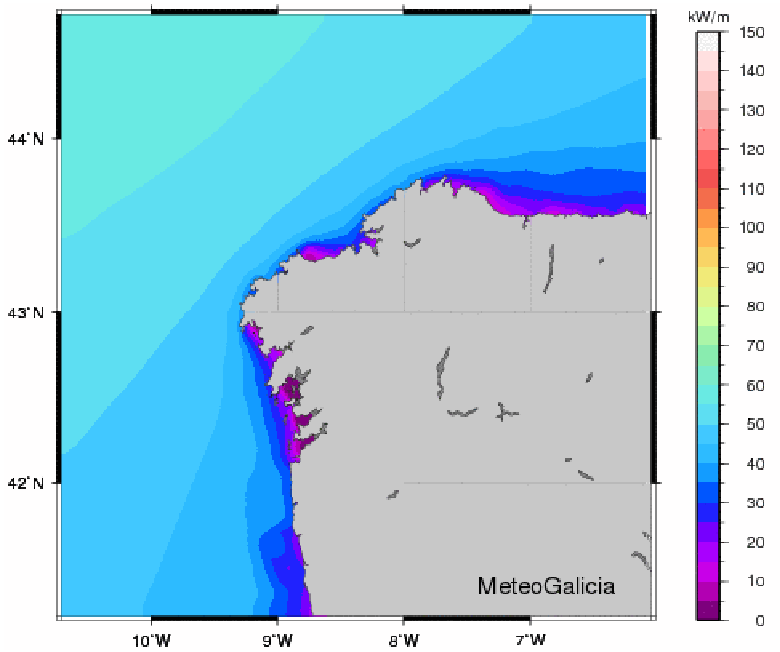


Figure 40: Galician Annual Average Wave Power Atlas[70]

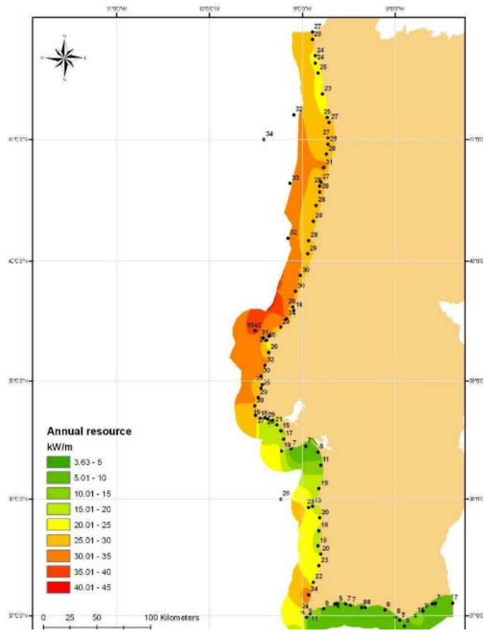


Figure 41: Portuguese Near Shore Wave Atlas (ONDATLAS)[71]

The wave resource atlas for Galicia (Figure 40) gives approximately 40kW/m average annual wave power for the area under consideration in the north-west coast of Spain. Figure 41 depicts the nearshore wave atlas for Portugal, known as ONDATLAS giving approximately 30kW/m nearshore in the western tip of Portugal. There is also a more recent Portuguese GIS tool known as PEMAP which assesses other uses of the sea, geomorphology, infrastructure, bathymetry etc.

7.1.2 Wind & Tidal Current Combination

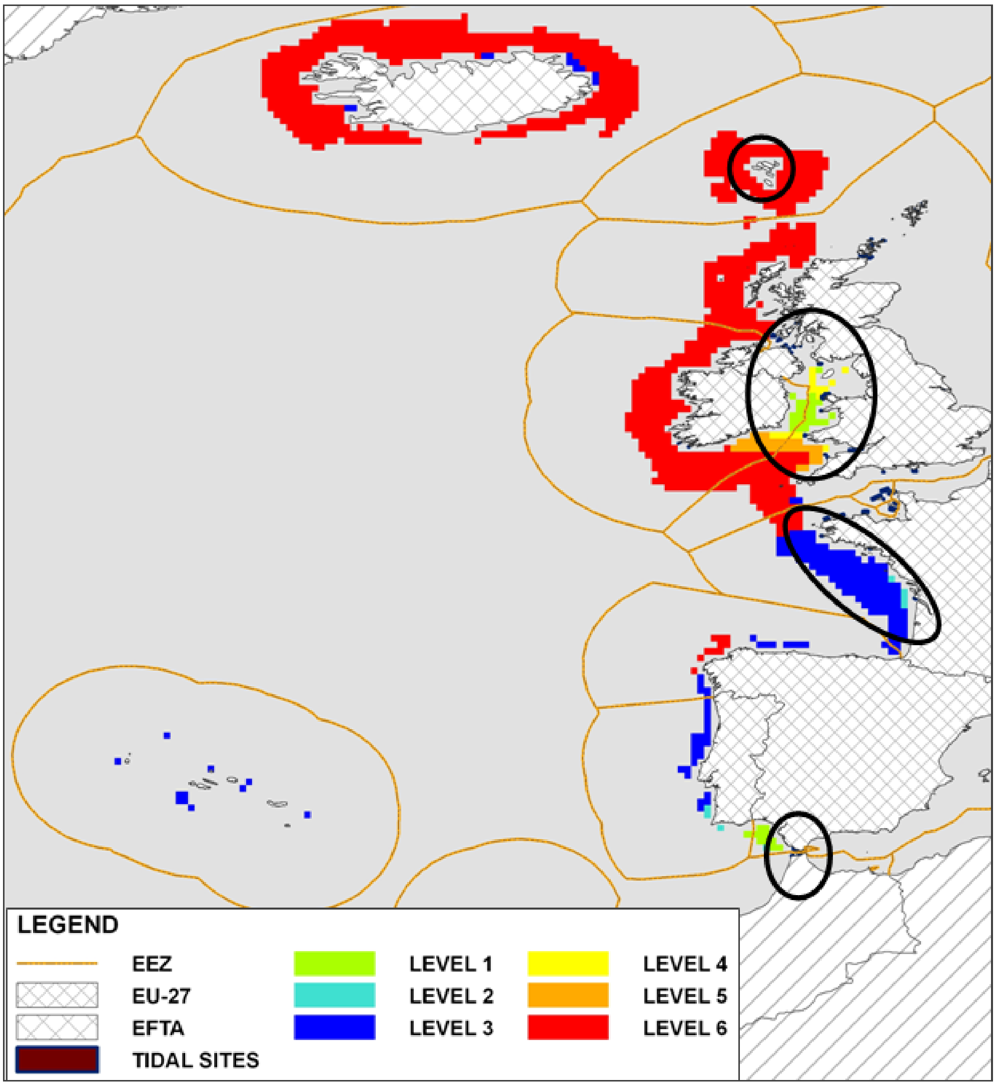


Figure 42: Combined Resource in Atlantic, wind + wave + tidal current (circled)

The majority of the tidal current sites in the region exist in the Irish Sea and the English Channel with the best tidal current resource sites in the region found specifically off the Island of Islay, Carmel Head, Milford Haven and the Bristol Channel as depicted by Figure 43 and Figure 44 below. The average wind speeds in the Irish Sea are 8-9m/s.

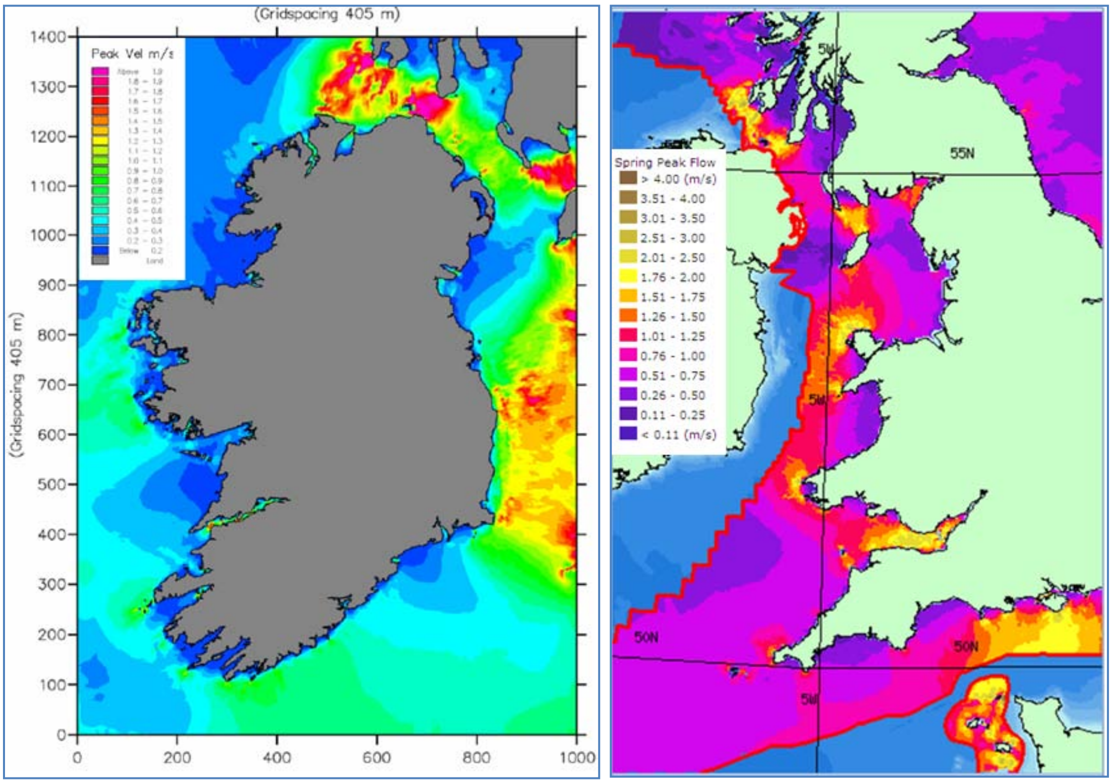


Figure 43: Spring Tidal Currents in UK[72] and Irish waters[73] of the Irish Sea

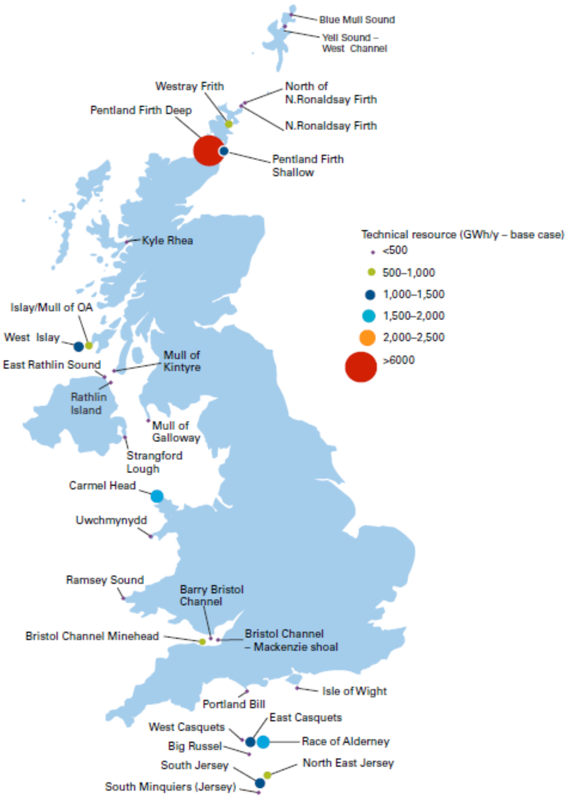


Figure 44: Tidal Resource Sites in UK[74]

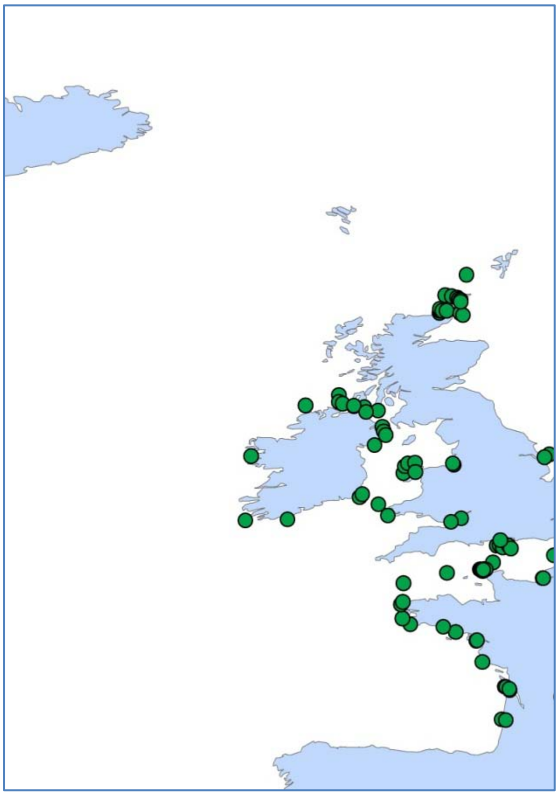


Figure 45: Atlantic Ocean: Location of known tidal current sites

7.1.3 Application of Site Selection Methodology

Therefore applying these resource figures to the site selection methodology, the following are the site selection points given to each site:

Country	Resource Level	Site Selection Points
WIND & WAVE		
Scotland	Level 6	**10**
Ireland	Level 6	**10**
England	Level 6	**10**
Spain	Level 6	**10**
France	Level 3	**9**
Portugal	Level 3	**9**
WIND & TIDAL		
Scotland	Level 1	**10**
Wales	Level 2	**6**
England	Level 1	**10**

Table 25: Atlantic Ocean: Wind & Wave Resource Site Selection Points

7.2 Incentives and RE Targets

Scotland, Portugal and Ireland have the highest production incentives available for ocean energy with €0.28, €0.26 and €0.22/kWh respectively however Scotland also has the highest available incentives for offshore wind with €0.17/kWh.

€/kWh	Wind			Ocean			Combined Site Selection Points
	FiT	Price Received	Points	FiT	Price Received	Points	
Ireland	0.14	0.14	**6.25**	0.22	0.22	**6.00**	**6.1**
Spain	0.03	0.10	**3.25**	0.00	0.07	**1.00**	**2.1**
France	0.13	0.13	**5.50**	0.15	0.15	**3.67**	**4.6**
Portugal	0.07	0.07	**1.00**	0.26	0.26	**7.33**	**4.2**
UK (England)	0.07	0.14	**6.50**	0.11	0.18	**4.67**	**5.6**
Scotland	0.07	0.14	**6.50**	0.28	0.28	**8.00**	**7.25**

Table 26: Atlantic Ocean: National Production Incentives and Wholesale Electricity Prices

The existence of production incentives illustrates the economic feasibility of a project in a given country but also the political will of that country for offshore renewable energy. Another indicator is the existing percentage of electricity from renewable sources and the intended NREAP targets. A low renewable energy percentage of gross electricity consumption could be interpreted as an indication of impending investment by government to meet carbon reduction and NREAP targets. For example the UK which has one of the lowest percentages has the greatest NREAP targets for Offshore Wind and Ocean Energy

The following table summarises the figures available in Eurostats and the NREAP summary document from the European Environment Agency.

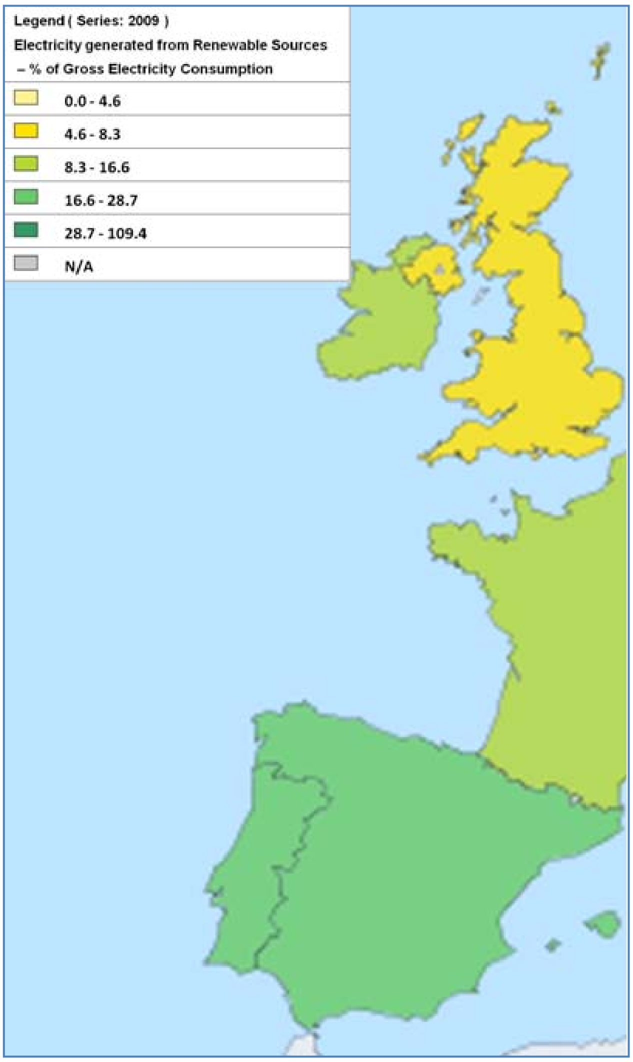


Figure 46: Atlantic Ocean: Country Specific - Electricity Generated from Renewable Sources (% gross electricity consumption)[75]

Country	% Gross Electricity Consumption from RE sources (2009)	NREAP Targets by 2020 (MW)[76]	
		Offshore Wind	**Ocean**
Ireland	8.3-16.6	555	75
UK (including Scotland)	4.6-8.3	12,990	1,300
France	8.3-16.6	6,000	380
Spain	16.6-28.7	3,000	100
Portugal	16.6-28.7	75	250

Table 27: Atlantic Ocean: Country Specific NREAP Targets and RE % of Gross Electricity Consumption

7.3 Geography

7.3.1 <u>Water Depth</u>

The primary locations with water depths suitable for fixed technologies are the Irish Sea and the west coast of France; the remainder of the region is in the floating water depth range.

Based on the combined resource map (Figure 34) the western Scottish islands, the Outer Hebrides; the southern tip of England at Cornwall; and the western coast of France are the primary locations for fixed structure, combined wind and wave projects based on resource and bathymetry classifications.
Including the available incentives in consideration, the Scottish islands are the most promising, followed by England second and France third.

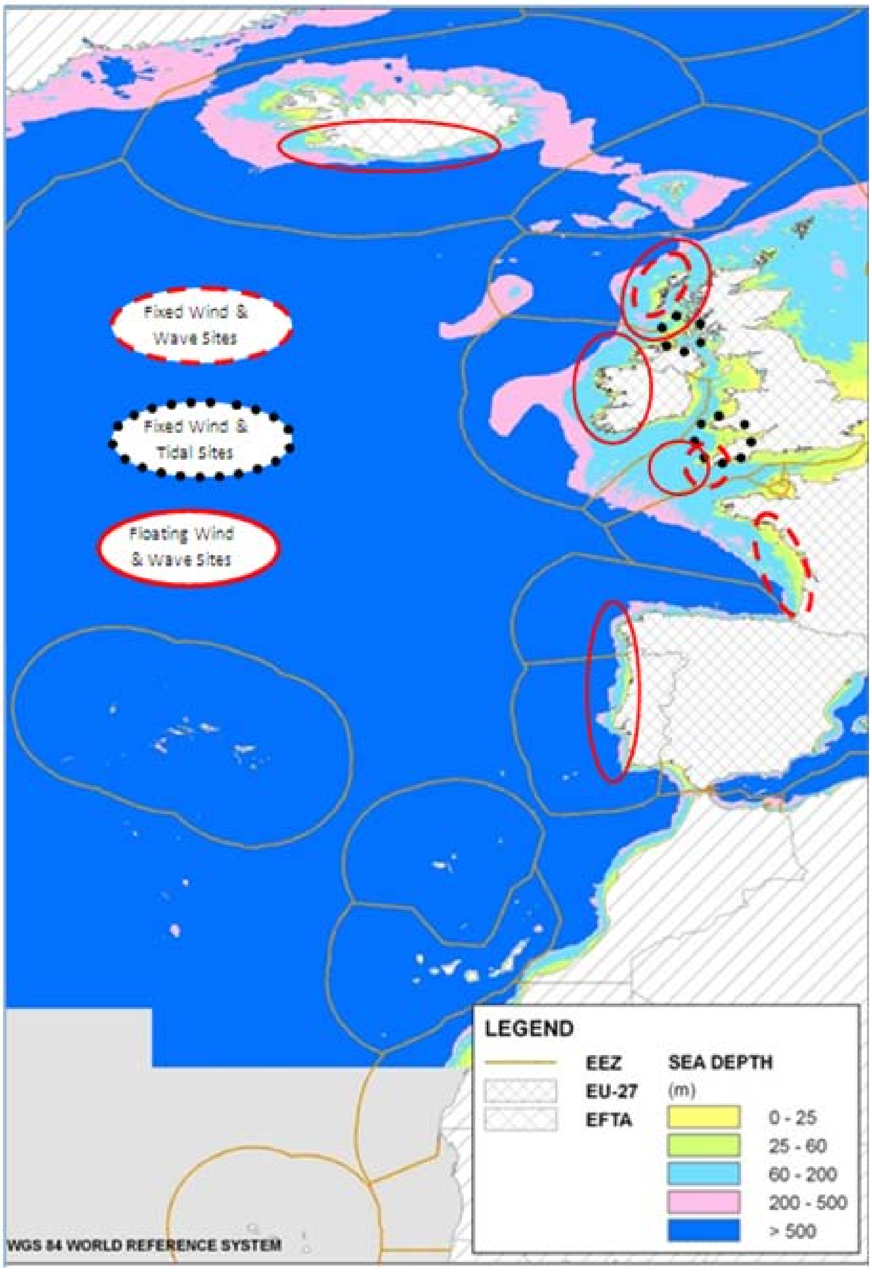


Figure 47: Atlantic Ocean: Bathymetry

For floating combined wind and wave projects the west coast of Ireland, Scotland, Portugal, South-West England and the North-western point of Spain are the most suitable with regards resource and bathymetry. These countries also have the highest incentives available in the region.

Based on bathymetry, the most suitable combined wind and tidal sites include the Bristol Channel and the island of Islay. Including available production incentives in the consideration and the island of Islay becomes the preferred location.

Country	Water Depth Range	Typical Wind Turbine Structure	Site Selection Points
	WIND & WAVE		
Ireland	60-200	Floating	**8**
Scotland	0-25	Fixed – Monopile/GB…	**10**
	60-200	Floating	**8**
England	25-60	Fixed - Tripod/Jacket	**9**
	60-200	Floating	
France	25-60	Fixed - Tripod/Jacket	**9**
Spain	200-500	Floating	**5**
Portugal	60-200	Floating	**8**
	WIND & TIDAL		
Scotland	25-60	Fixed	**10**
Wales	25-60	Fixed	**10**
England	25-60	Fixed	**10**

Table 28: Atlantic Ocean: Water Depth Site Selection Points

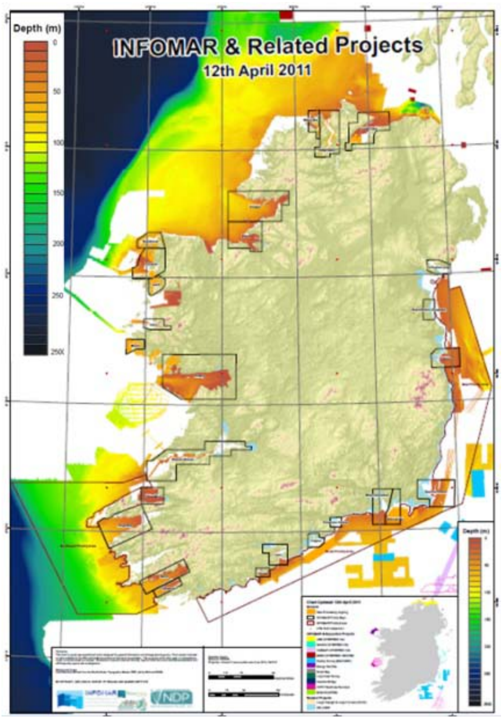


Figure 48: Irish Bathymetry Map from INFOMAR[77]

7.3.2 Distance from Shore

All of the locations being considered for both wave and tidal and fixed and floating technologies are within 100km from shore as illustrated in Figure 49 below.

Country	Distance from Shore	Site Selection Points
WIND & WAVE		
Ireland	0-50km	10
Scotland	50-100km	8
	0-50km	10
England	0-50km	10
	50-100km	8
France	0-50km	10
Spain	0-50km	10
Portugal	0-50km	10
WIND & TIDAL		
Scotland	0-20km	1
Wales	0-20km	1
England	0-20km	1

Table 29: Atlantic Ocean: Distance from Shore Site Selection Points

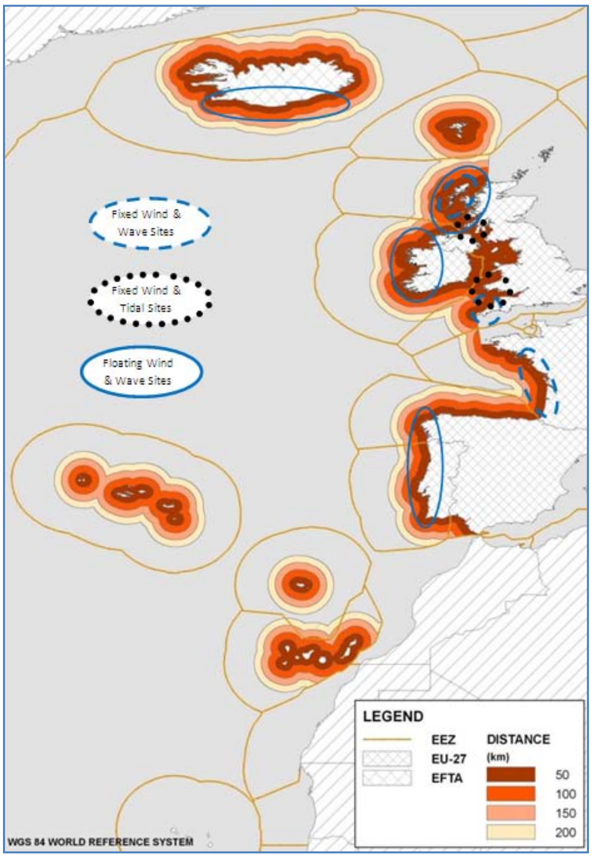


Figure 49: Atlantic Ocean: Distance from shore boundaries

7.4 Infrastructure

7.4.1 Ports

Generally there are significant numbers of ports in the Atlantic region and as such each of the sites have achieved high values in the site selection points system. The locations off the west coast of Ireland are limited to the West and South-West coasts where the larger and deeper water ports are available.

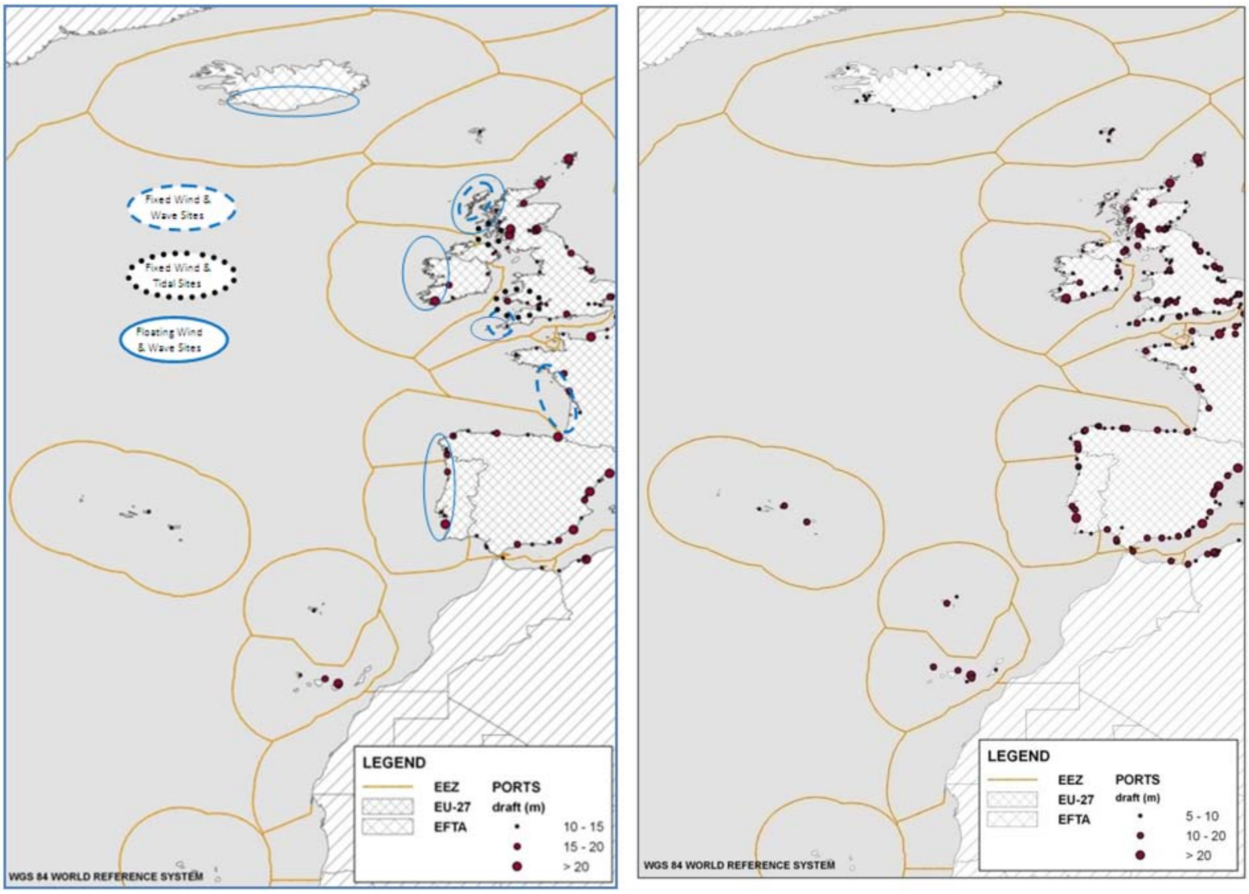


Figure 50: Atlantic Ocean: Location of Ports (LEFT: Minimum 10-15m draft, RIGHT: All Ports)

Country	Distance from Deep Water Port	Distance to Port - Site Selection Points	Distance from Shallow Port	Distance to Pier - Site Selection Points	Total Site Selection Points
		WIND & WAVE			
Ireland	150-200km	8	50-60km	9	8.5
Scotland	150-200km	8	Less than 50km	10	9.0
England	Less than 100km	10	Less than 50km	10	10
	Less than 100km	10	50-60km	9	9.5
France	Less than 100km	10	50-60km	9	9.5
Spain	Less than 100km	10	50-60km	9	9.5
Portugal	Less than 100km	10	50-60km	9	9.5
		WIND & TIDAL			
Scotland	Less than 100km	10	50-60km	9	9.5
Wales	Less than 100km	10	50-60km	9	9.5
England	150-200km	8	50-60km	9	8.5

Table 30: Atlantic Ocean: Distance from Port Site Selection Points

7.4.2 Electrical Grid

The Irish Grid is known to be low in the West of the country where the greatest resource exists. The primary connection point to higher voltage is at Galway and thus this will likely dictate the location of any offshore renewable installation.

Likewise there is very little grid infrastructure in the west of Scotland around the locations chosen. England, France and Spain all have numerous high voltage grid lines along the coastline.

As can be seen in Figure 52 below, there are numerous sub-sea cables located in southern England and Wales however there are no sub-sea cables in the locations under consideration in Scotland or Ireland.

Country	Local Grid kV Capacity	Site Selection Points
WIND & WAVE		
Ireland	380-500kV	8
Scotland	220-380kV	6
England	380-500kV	8
France	380-500kV	8
Spain	380-500kV	8
Portugal	380-500kV	8
WIND & TIDAL		
Scotland	Less than 220	4
Wales	380-500kV	8
England	380-500kV	8

Table 31: Atlantic Ocean: Local Grid Site Selection Points

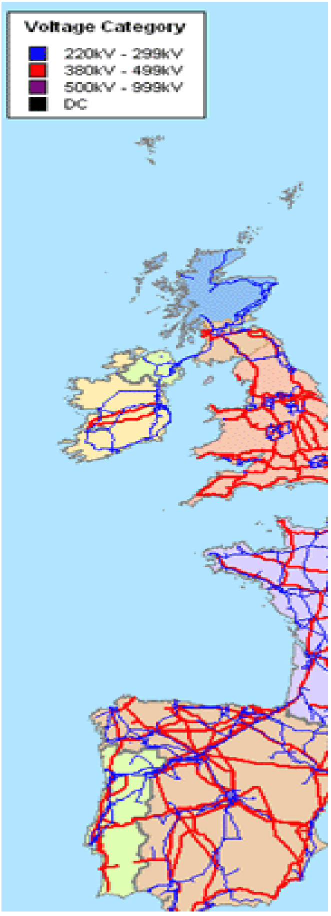


Figure 51: Atlantic Ocean: Electrical Grid Infrastructure

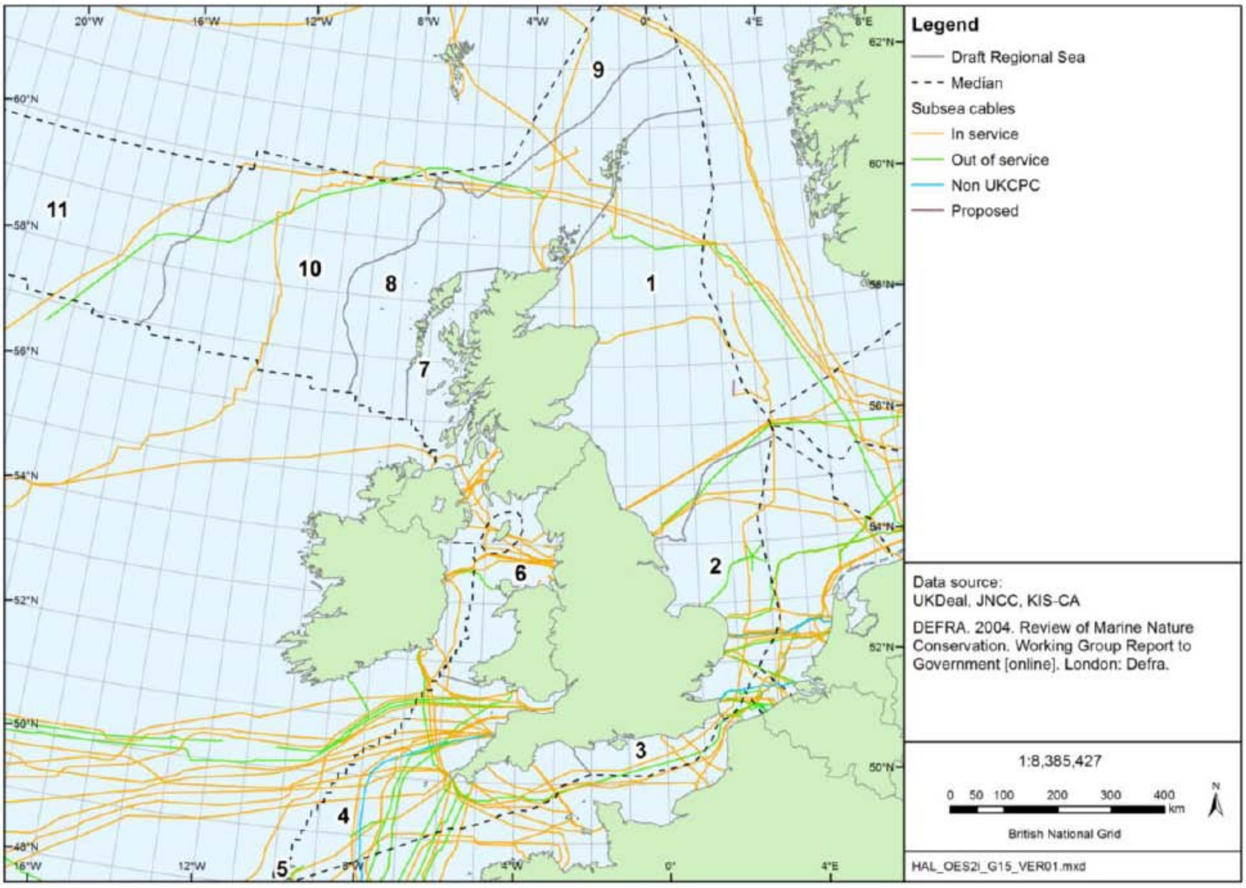


Figure 52: Location of Submarine Cables in UK Waters[78]

7.4.3 Population/Demand Centres

The primary cities in the region are marked in Figure 53 below and it is evident that there are few large population centres (greater than 50,000) in the west coast of Ireland, north-west Scotland and southern England however all have the capability to transport the electricity to a larger demand centre elsewhere in the country or region via high voltage electricity lines and interconnectors.

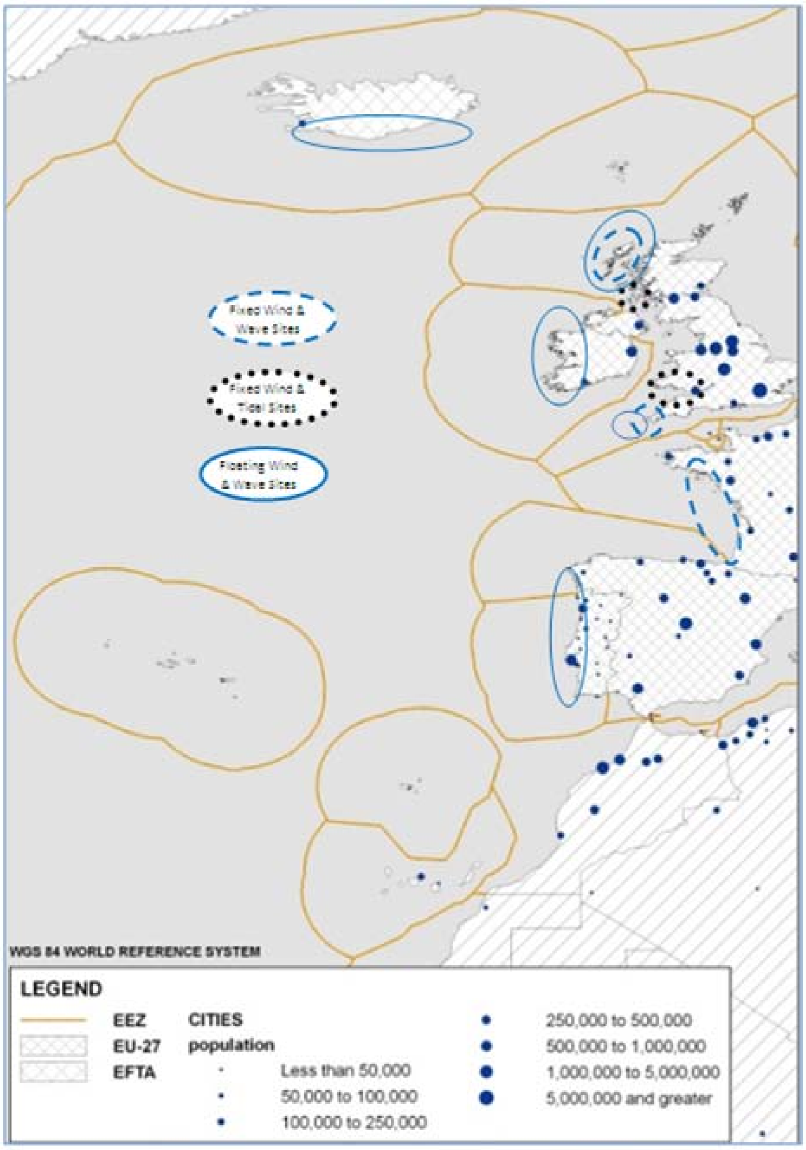


Figure 53: Atlantic Ocean: Population/Demand Centres

7.5 Other Uses

7.5.1 Designated Protected Areas

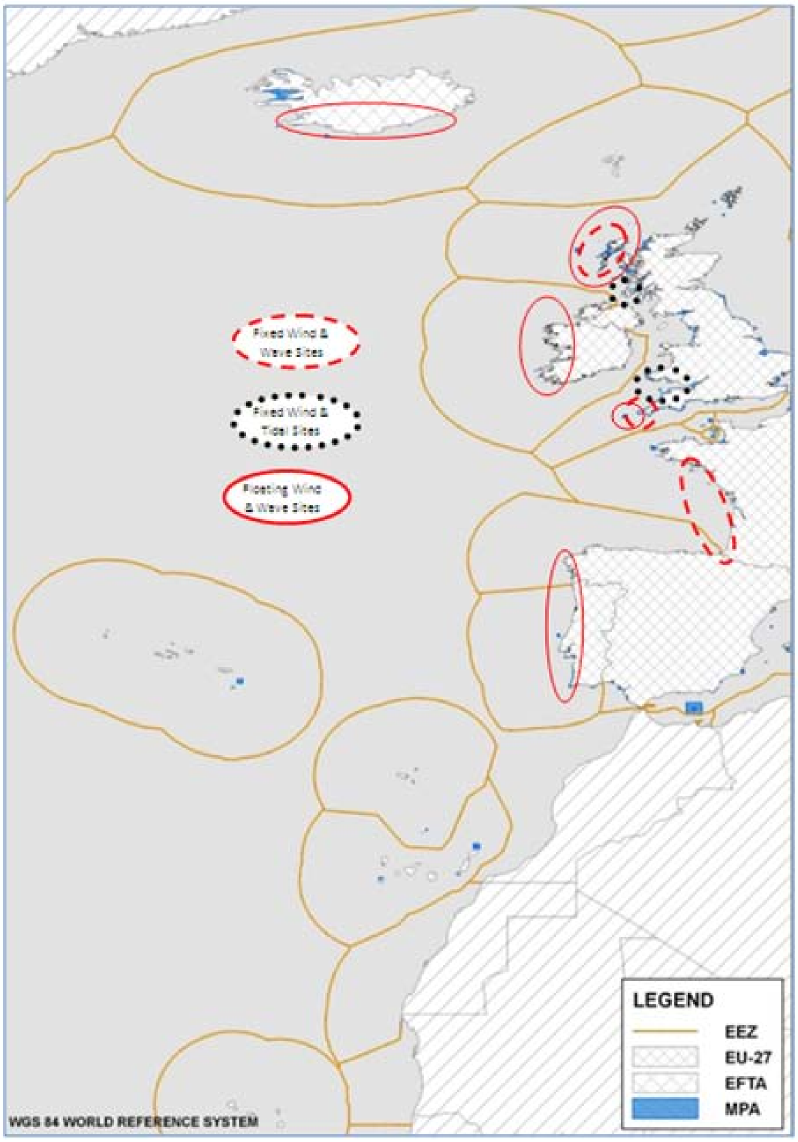
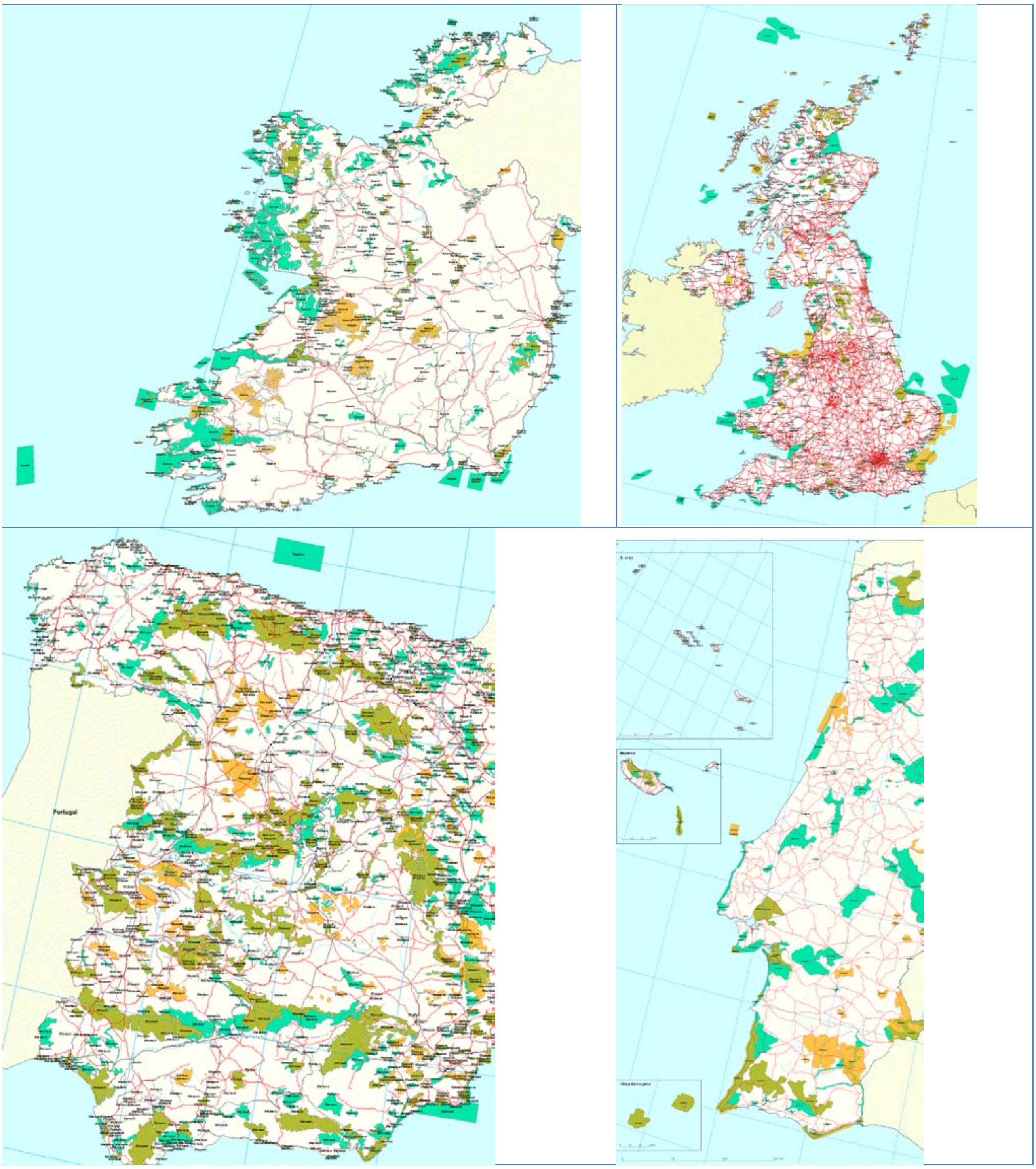


Figure 54: Atlantic Ocean: Designated Marine Protected Areas

A 3 year EU Project known as MAIA (Marine Protected Areas in the Atlantic Arc) began in 2010 to encourage collaboration and experience sharing amongst Atlantic coast countries and to encourage stakeholder participation in MPA designation[79].

The OSPAR Project[80] aims to provide a catalogue of MPAs in the North-East Atlantic (including the North Sea) however this project has only just begun and national information is not available as yet.

Natura2000 sites are EU designated protected areas both on-shore and off-shore. The two types of MPAs that are included in the Natura2000 network are the Special Areas of Conservation (SAC) and the Special Protection Areas (SPA) which are designated under the Habitats Directive and the Birds Directive.


Portugal

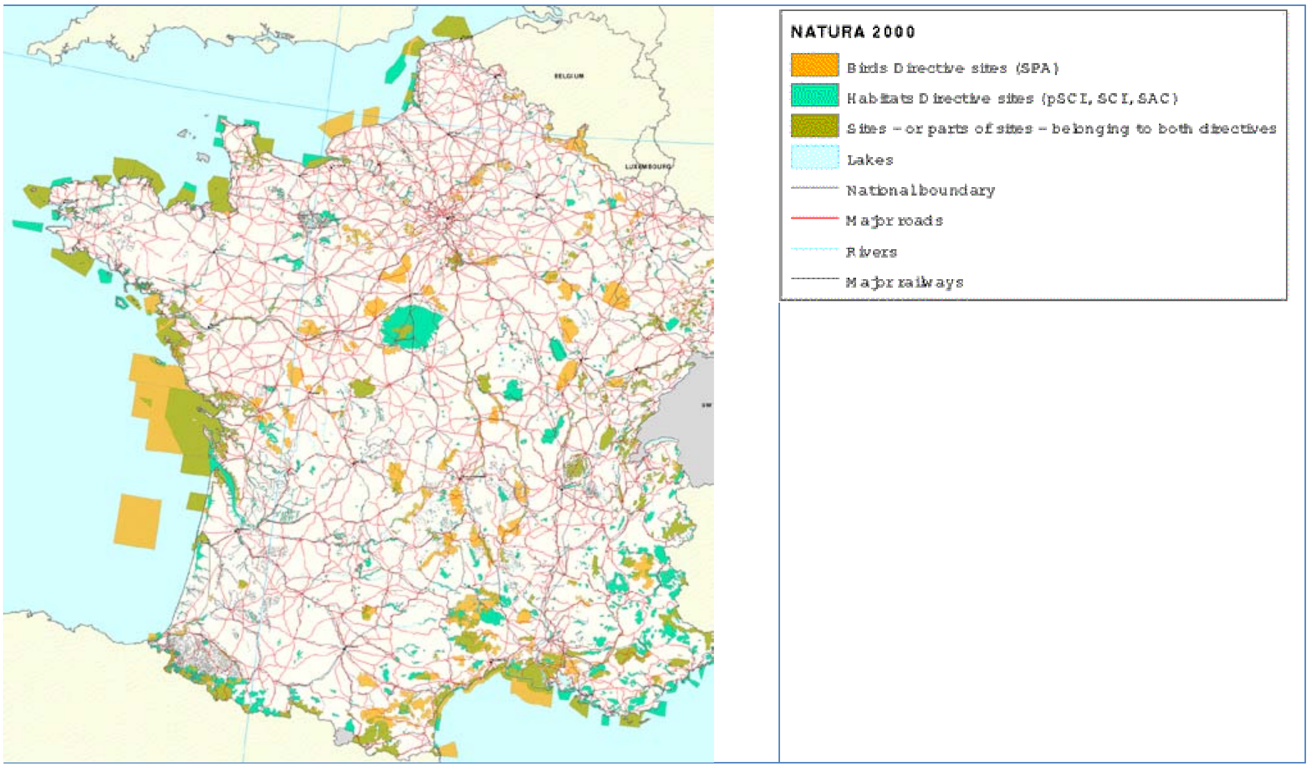


Figure 55: National Natura 2000 Maps; Ireland (Top LEFT), UK (TOP RIGHT), Spain (CENTRE LEFT), Portugal (CENTRE LEFT) and France (BOTTOM LEFT) and NATURA2000 Legend (BOTTOM RIGHT)[81]

Nationally however countries can have other marine protected areas that are designated under national law. The EU provides a database of the Natura2000 sites however the national sites may be more difficult to identify without local knowledge of the appropriate governing body.

For example the UK has a number of designations such as the Sites of Special Scientific Interest (SSSI/ASSI), Ramsar Sites, Marine Nature Reserves (MNR), Scottish Marine Protected Areas (MPA) and the latest Marine Conservation Zones (MCZ)[82]. These UK MPAs are available on interactive maps available on the JNCC website or the UK MPA Centre website[83]. It can be seen from Figure 56 below that there are a number of small protected areas in the identified locations in the west coast of Scotland and also in Wales and Southern England. However the majority of these areas are coastal sites in that they are very close to shore and are unlikely to affect the siting of combined wind and wave devices however they may have an impact on the siting of combined wind and tidal technologies as visibility from shore may be more important near these locations if the protected area is for example protected for its beauty.

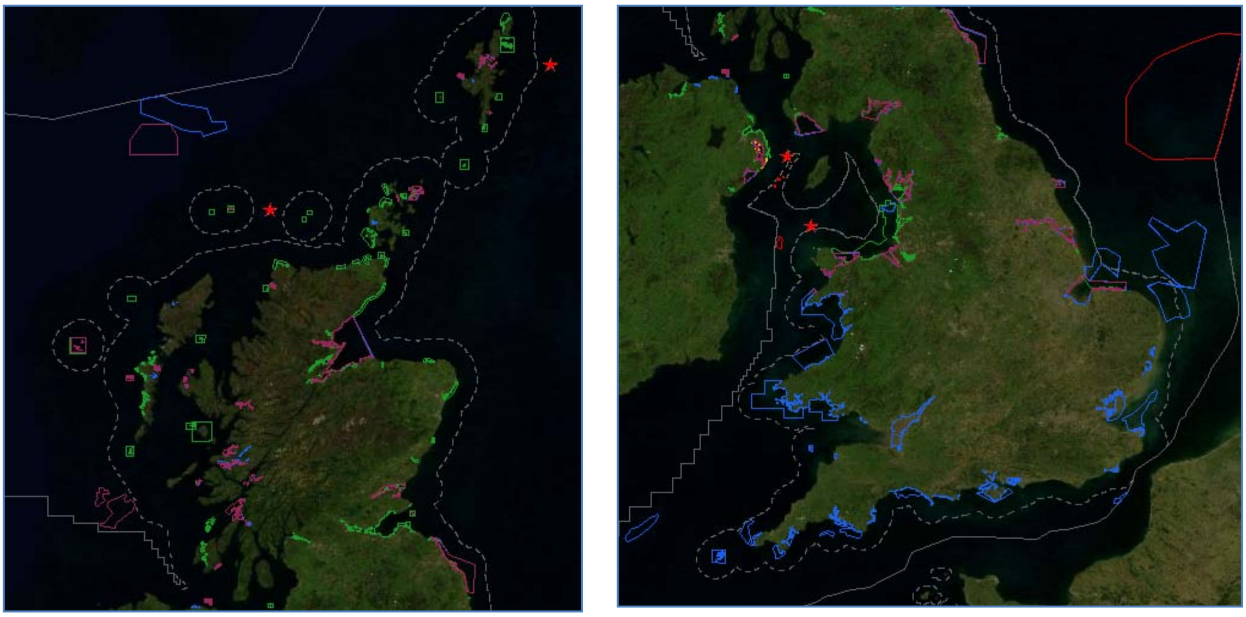


Figure 56: UK MPAs; Scotland (LEFT) and England and Wales (RIGHT)[84]

Ireland likewise has a number of nationally designated sites, the GIS datasets and maps for which are downloadable from the Irish National Parks and Wildlife Service website[85]. The majority of these sites also appear to be in the near-shore or coastal region and as such, should not impact on the siting of a combined wind and wave project.

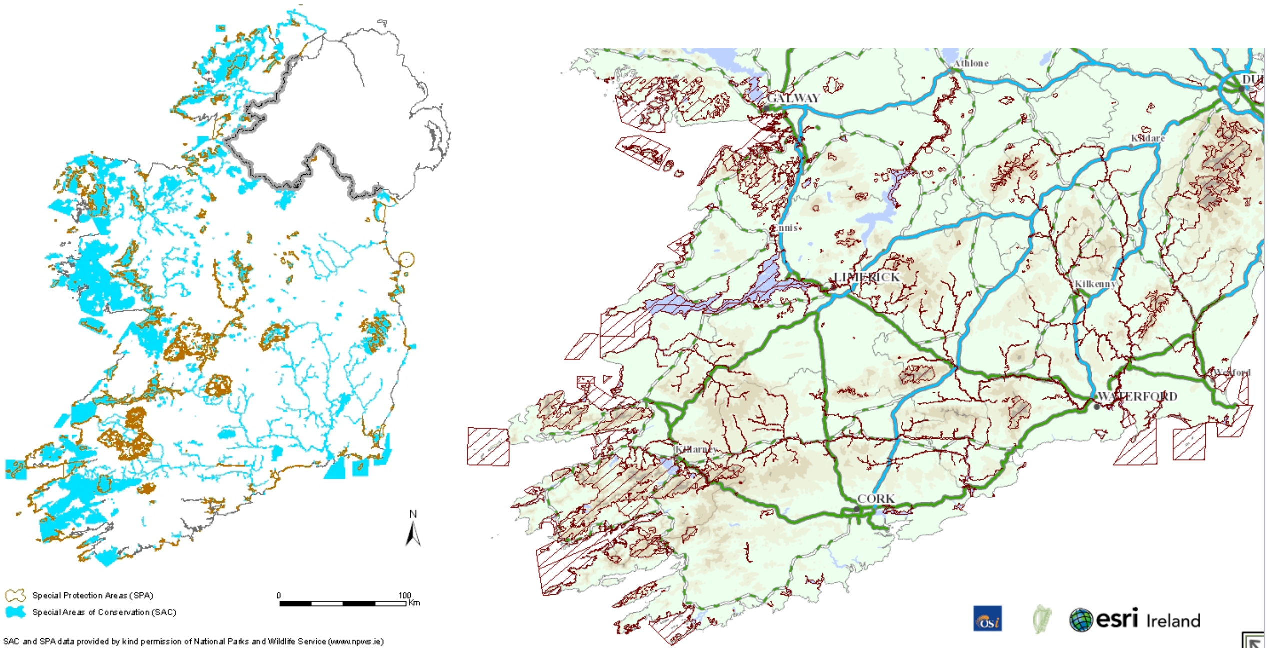


Figure 57: Irish MPA Maps from the Irish Environmental Protection Agency[86] **and the National Parks and Wildlife Services**[87]

Figure 58 below illustrates the national and European marine protected areas in France. It is evident that there is a large MPA in the north-west tip of France where the wind and wave resource is at its greatest. This will likely affect the siting of a wind-wave combined project or the cable layout.

Unfortunately no national information could be found for Spain and Portugal on Atlantic MPAs.

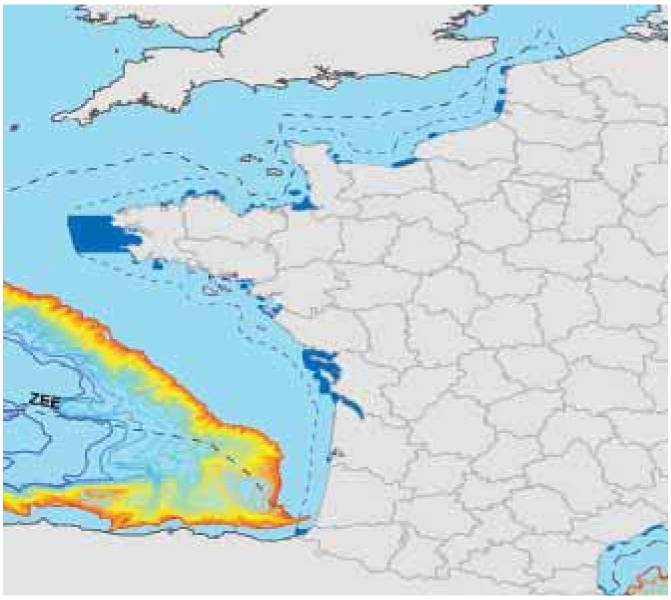


Figure 58: French Marine protected areas (Natura 2000 sites, French and Corsican nature reserves marine nature park, national park, etc.)[88]

7.5.2 Navigation & Shipping Lanes

One of the primary European shipping routes runs from the south coast of England, along the Atlantic coast of France and Portugal to the tip of Gibraltar. From this primary route, tributary routes connect to the relevant ports. Therefore there is a high density of traffic along the north-western tip of France and Spain and the coast of Portugal. The French Atlantic coast, the west coast of England and Wales and the North coast of Spain have a lower traffic density. The west coast of Ireland and Scotland has little to no shipping traffic.

It is possible that any projects located off Portugal or North-west Spain and France will have conflicting use with shipping traffic however this may be rectifiable with sufficient lighting and navigational aids.

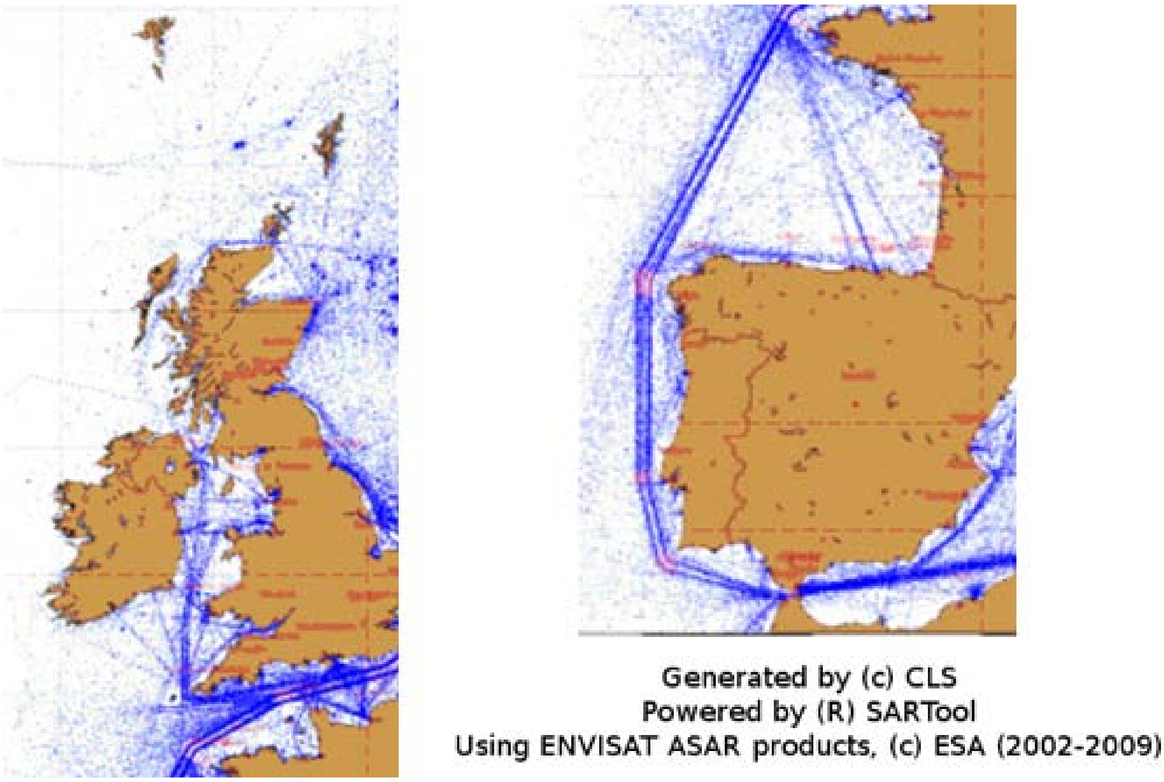


Figure 59: Atlantic Ocean: Shipping Routes for North Atlantic (LEFT) and South Atlantic (RIGHT)[89]

Country	Shipping Density	Site Selection Points
	WIND & WAVE	
Ireland	Low	**10**
Scotland	Low	**10**
England	High	**1**
	Medium	**6**
France	Medium	**6**
Spain	Medium	**6**
Portugal	High	**1**
	WIND & TIDAL	
Scotland	Low	**10**
Wales	Medium	**6**
England	High	**1**

Table 32: Atlantic Ocean: Shipping Density Site Selection Points

7.5.3 Military Exercise Areas

National military exercise maps are difficult to acquire without national knowledge and therefore military exercise maps of France, Spain and Portugal could not be found however a detailed map for Scotland can be found in the Scottish Marine Atlas, Figure 60 below and for the UK in the UK Offshore Energy Strategic Environmental Assessment Document. It can be seen that there is significant military activity in the 2 areas identified for combined offshore renewable projects. Fortunately the “Firing Danger Areas”, outlined in red hatch, are limited to the southern Hebrides.

The UK Map of Military Areas, Figure 61, has designated army danger areas off the coast of Wales and Airforce and Navy areas off the south west coast of England. It is possible that some understanding could be reached for an offshore renewable project however this would need to be taken up with the relevant authority in a more in-depth site selection.

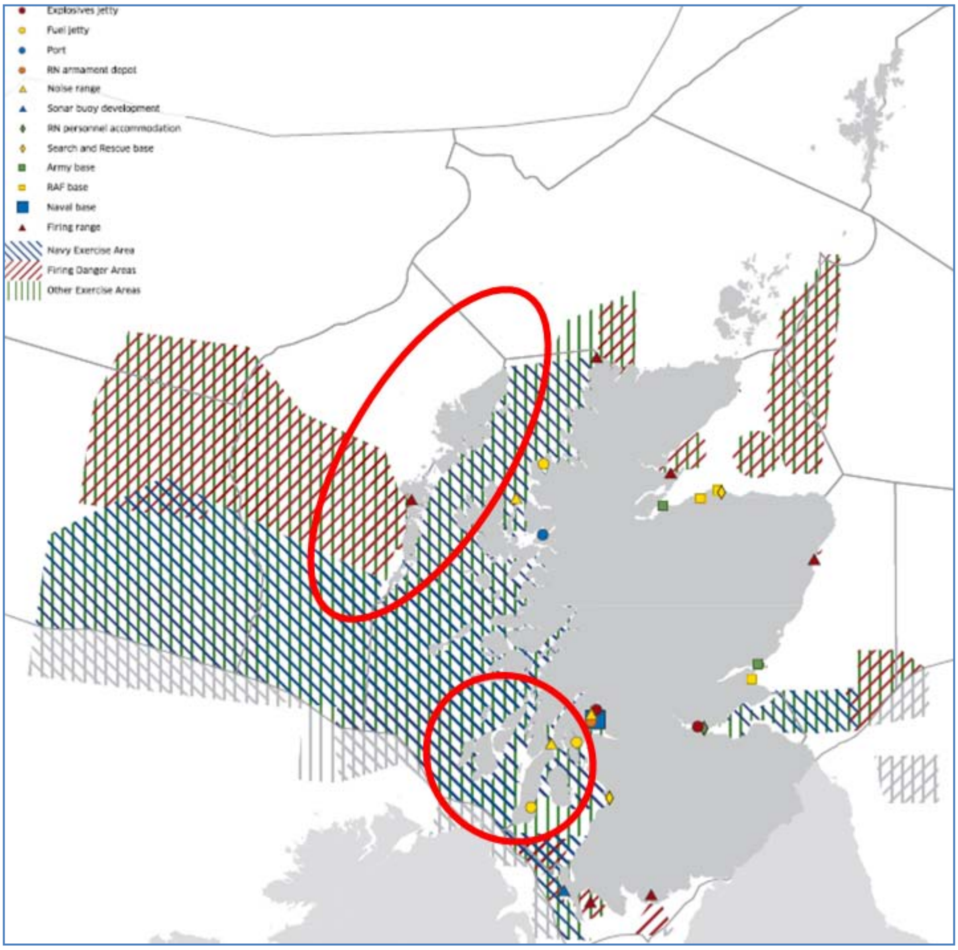


Figure 60: Scottish Military Exercise Areas [90]

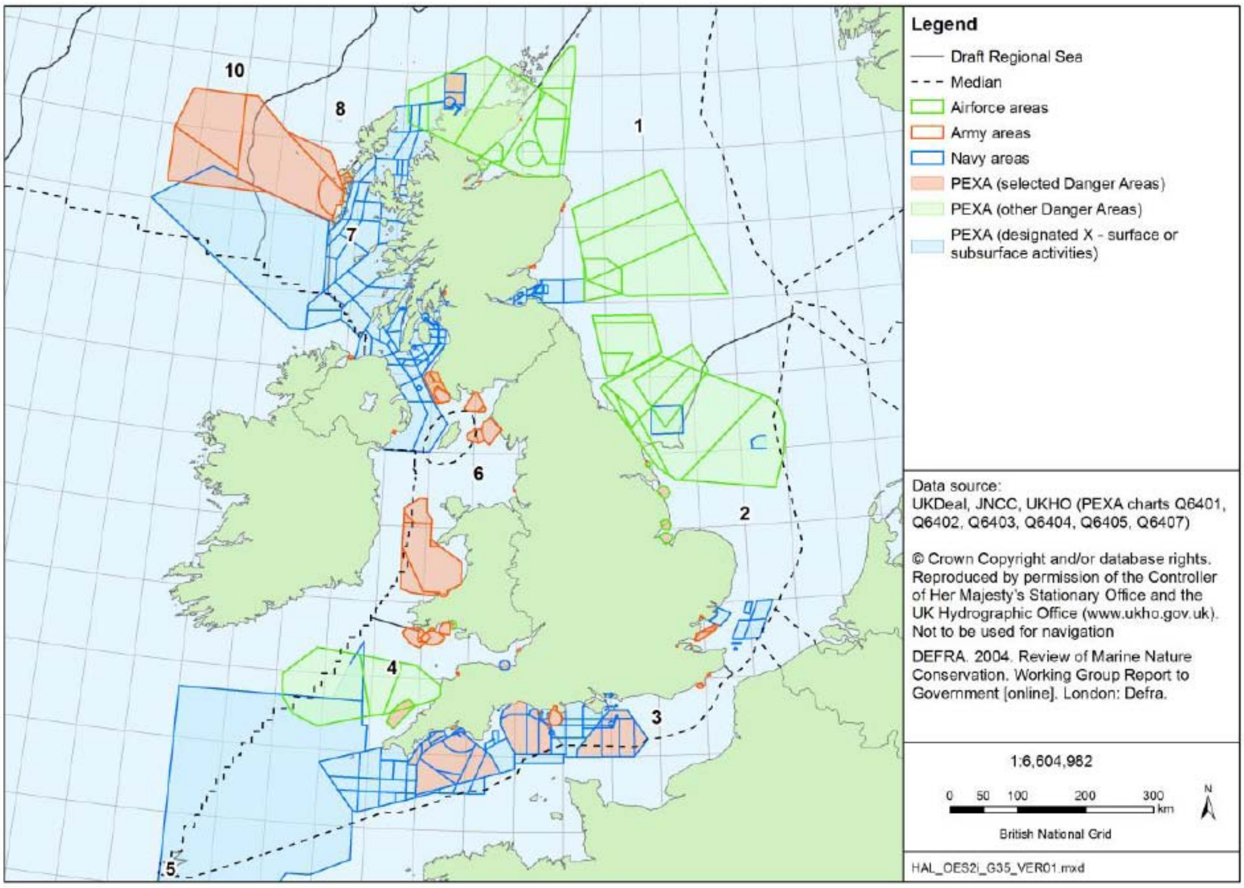


Figure 61: UK Military Exercise Areas[91]

7.5.4 Oil and Gas Fields

Oil and gas exploration is not as prolific in the Atlantic as in the North Sea region however there do exist a number of fields, for example in the Irish Sea shown in Figure 64 below.

Figure 62: Oil and Gas Pipelines in Irish Sea[92]

Figure 63: Oil and Gas Fields in Northern Europe[92]

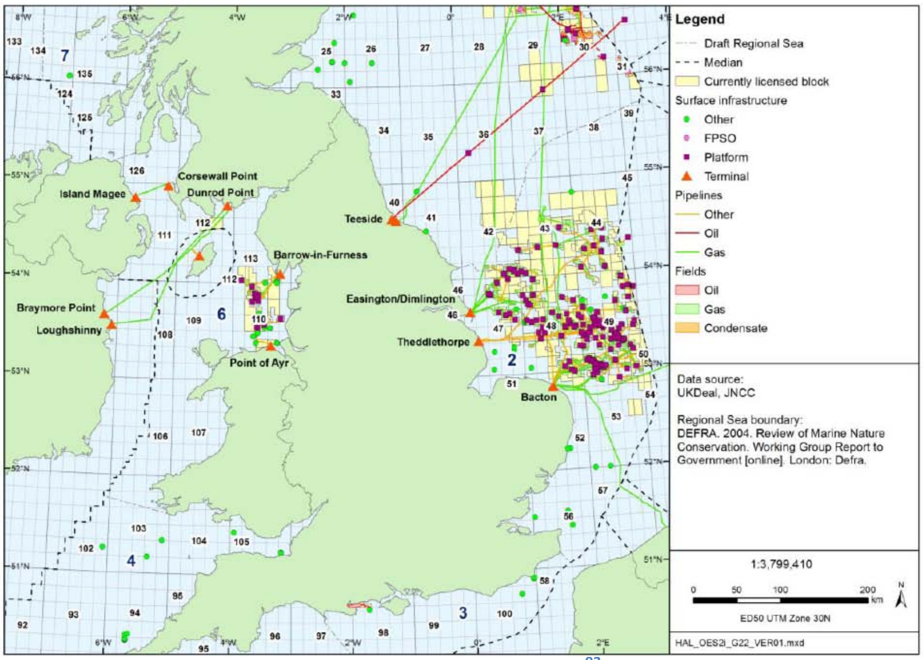


Figure 64: UK Oil and Gas Fields[93]

7.5.5 Fishing Zones

The European Atlas of the Seas divides the ORECCA Atlantic Ocean region into 2 seas; the Celtic Seas and the Bay of Biscay and Atlantic Iberian Coast. Figure 65 shows the distribution of the fishing fleet by coastal region in these 2 sea regions. It is evident that, particularly in the north of the Atlantic, there is a large number of fishing ports with greater than 1000 vessels in many of the coastal regions (west Ireland, south-west England, north-west France, north-west Spain and south-west Portugal) in proximity to the locations identified in this section for combined offshore renewable projects.

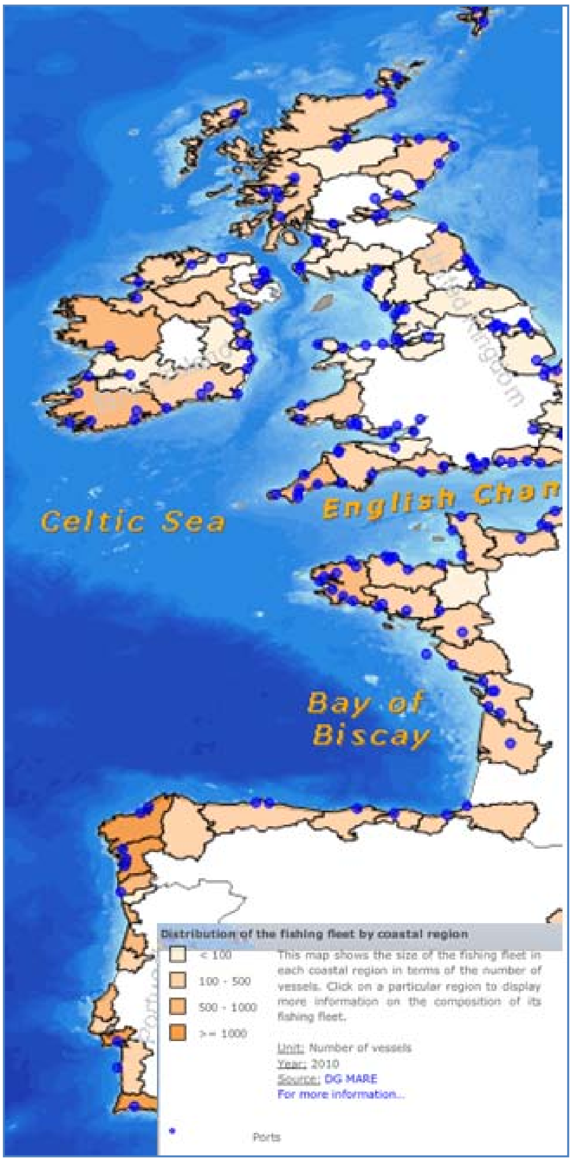


Figure 65: Atlantic Ocean: Distribution of fishing fleet by coastal region and location of fishing ports[94]

7.6 Physical characteristics of the Site

7.6.1 Seabed Type

The seabed surface and materials and given depths is important information for a developer as it will determine the viability of an installation, the foundation or mooring technology required and the cost of installing cabling. The Irish seabed landscape is currently being mapped by the INFOMAR Project seen in Figure 66 below. The Irish Sea and UK waters are modelled by a UK project by the Joint Nature Conservation Committee Figure 67, Figure 68 and Figure 69 below. An EU INTERREG project known as MESH[95] is providing a central forum for researchers working in gathering seabed and habitat data for various European countries.

The GEOSEAS[96] Project is an EU FP7 Infrastructures Project aiming to catalogue all available seabed mapping and geotechnical data from studies carried out in European waters.

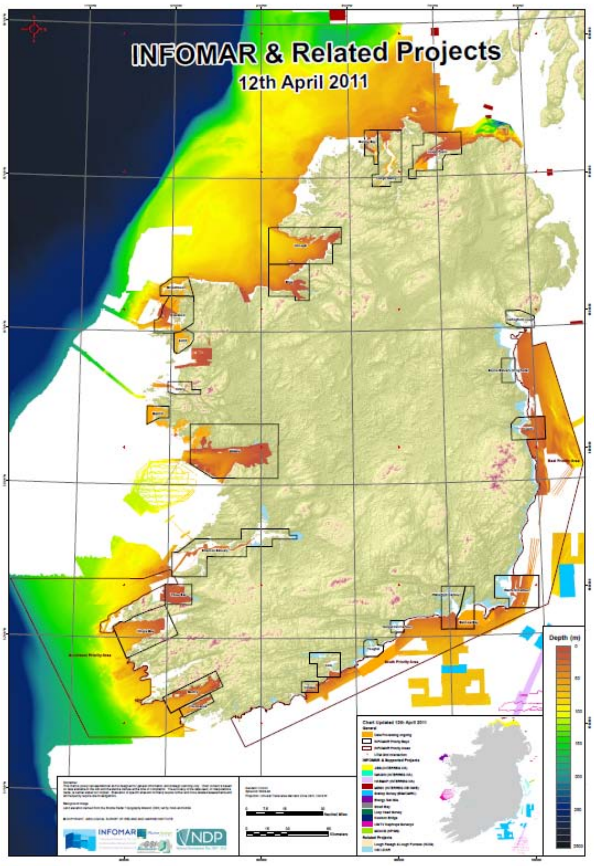


Figure 66: INFOMAR Irish Seabed Mapping Project Map[97]

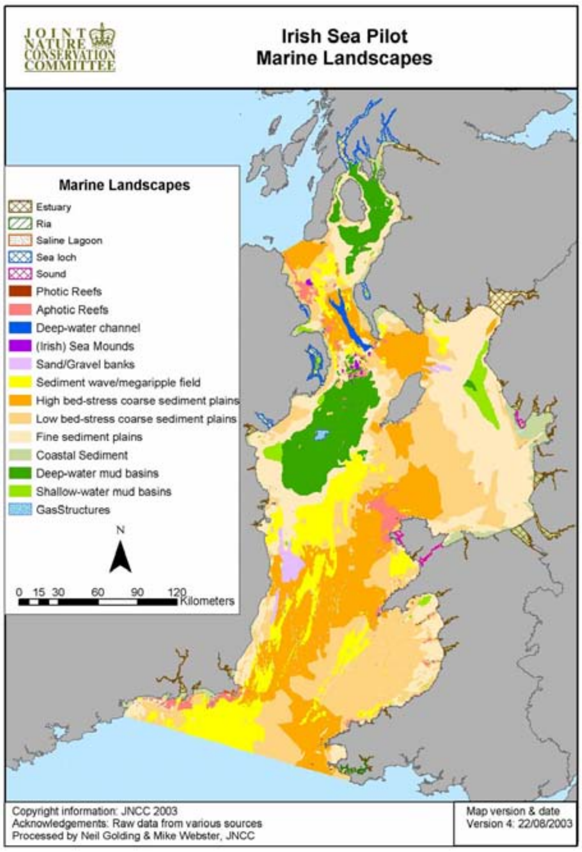


Figure 67: Irish Sea: Marine Landscape[98]

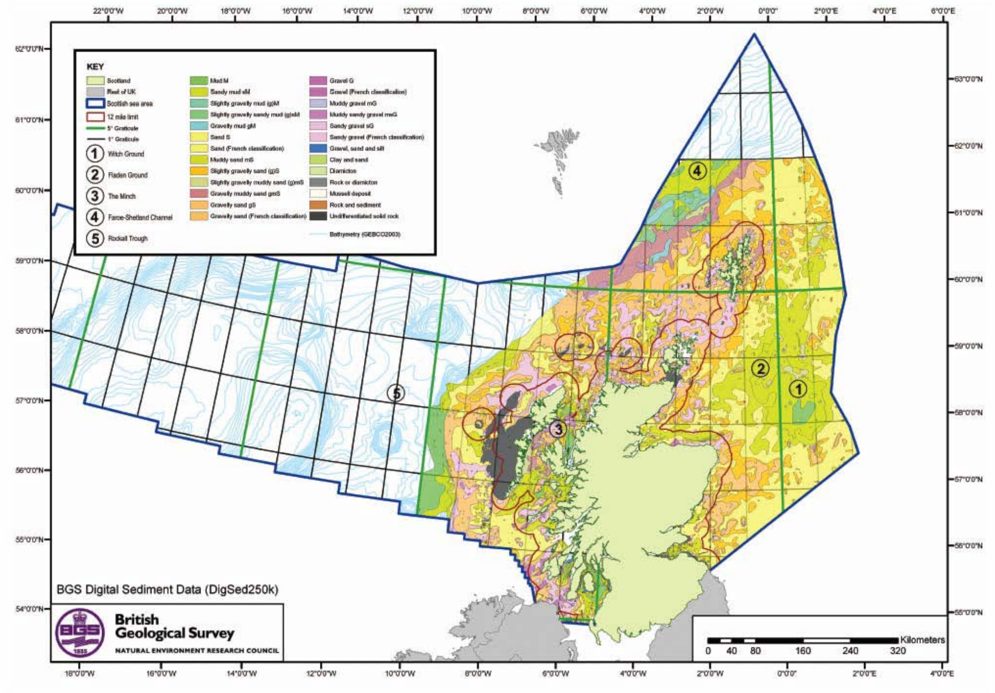


Figure 68: Scottish Seabed Type[99]

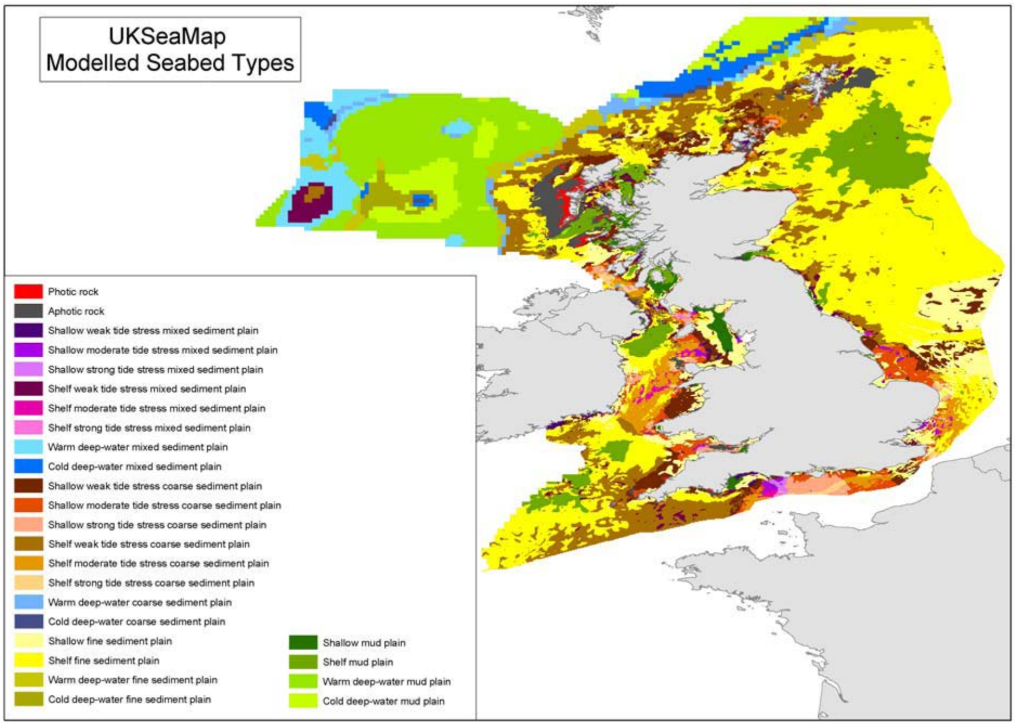


Figure 69: UK SeaMap Seabed Sediments[98]

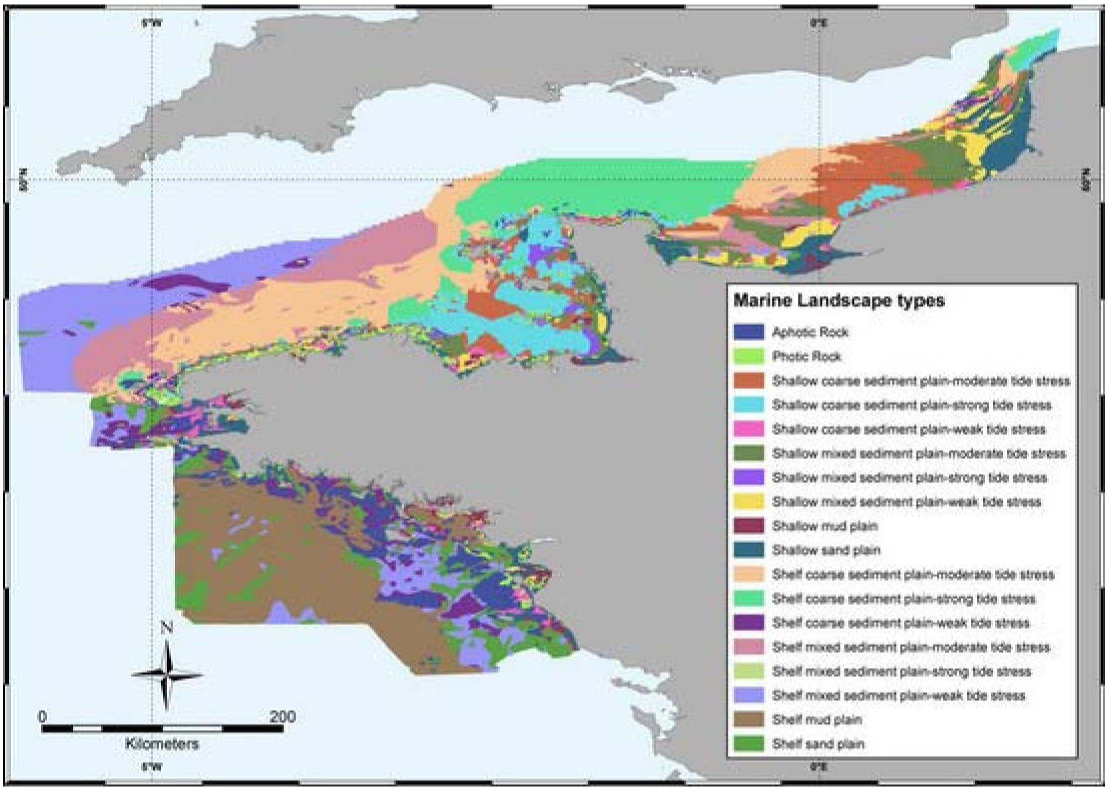


Figure 70: French Seabed Map[100]

7.7 Final Selection

The following table calculates the final site selection figure for each of the locations considered, which were ranked for each parameter in the preceding sections. Based on these weighting and point allocation assumptions, the North-West of Scotland near the Hebrides is the best fixed combined wind and wave site with a score of 9 out of a possible 10. In reality it may be found that the isolated nature of the islands and the subsequent distance to an available high voltage electrical grid may be economically prohibitive.

The second most viable site is a floating wind and wave project off the west coast of Ireland with 8.6 site selection points followed by the floating site off south-west England with 8 points.

Both the south-west coast of England fixed site and the north-west coast of France have received equal points of 7.9 each. If the MPAs were included in the points system, it is possible that France would receive slightly less points than England due to the large Natura 2000 site surrounding the high resource area of the North-West coast (Figure 55 above).

Parameter		Scotland (Fixed)		Ireland (Floating)		England (Fixed)		England (Floating)		Spain (Floating)		France (Fixed)		Portugal (Floating)	
	Weighting	Points	Weighted	Points	Weighted	Points	Weighted	Points	Weighted	Points	Weighted	Points	Weighted	Points	Weighted
Resource	0.3	10	3	10	3	10	3	10	3	10	3	9	2.7	9	2.7
Incentives	0.2	7.3	1.5	6.1	1.2	5.6	1.1	5.6	1.1	2.1	0.42	4.6	0.92	4.2	0.84
Water Depth	0.2	10	2	8	1.6	9	1.8	8	1.6	5	1	9	1.8	8	1.6
Location	0.2	7.7	1.5	8.8	1.8	9.3	1.9	8.5	1.7	9.17	1.8	9.17	1.8	9.2	1.83
Other Uses	0.1	10	1	10	1	1	0.1	6	0.6	6	0.6	6	0.6	1	0.1
Total	1		**9.0**		**8.6**		**7.9**		**8**		**6.9**		**7.9**		**7.1**

Table 33: Atlantic Ocean: Combined Wind and Wave Site Selection

7.7.1 <u>Site 1 – Fixed, high resource area</u>

The Scottish location west of the Hebrides Islands received the highest points in all of the considered site parameters with the exception of "location" for which it received the lowest score. Figure 72 below illustrates the primary ports in the region by draft; the closest deep water port (greater than 20m) is Glasgow with 2 shallower ports available closer to the islands.

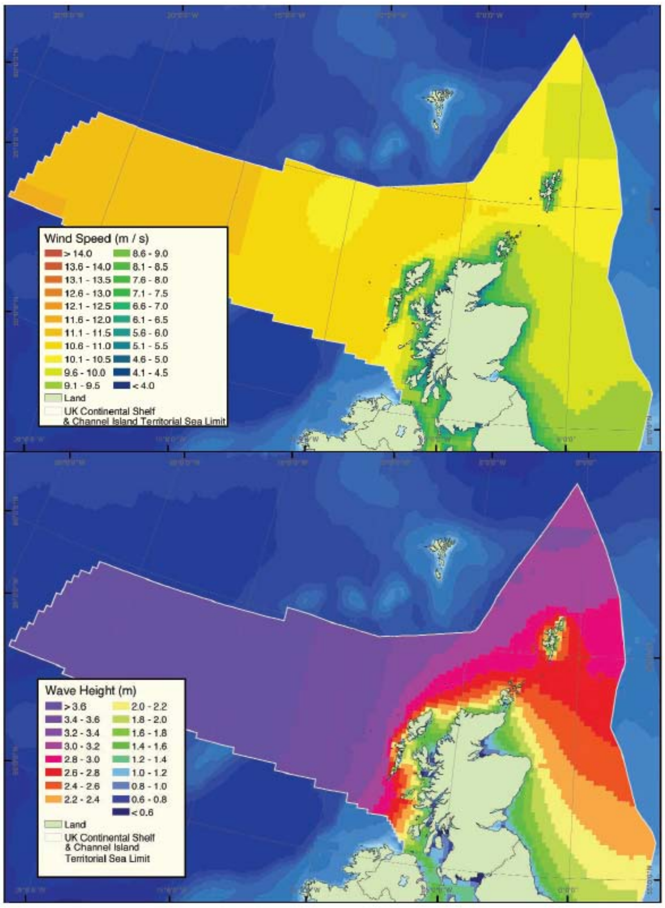


Figure 71: Scottish Offshore Wind and Wave Resource[99]

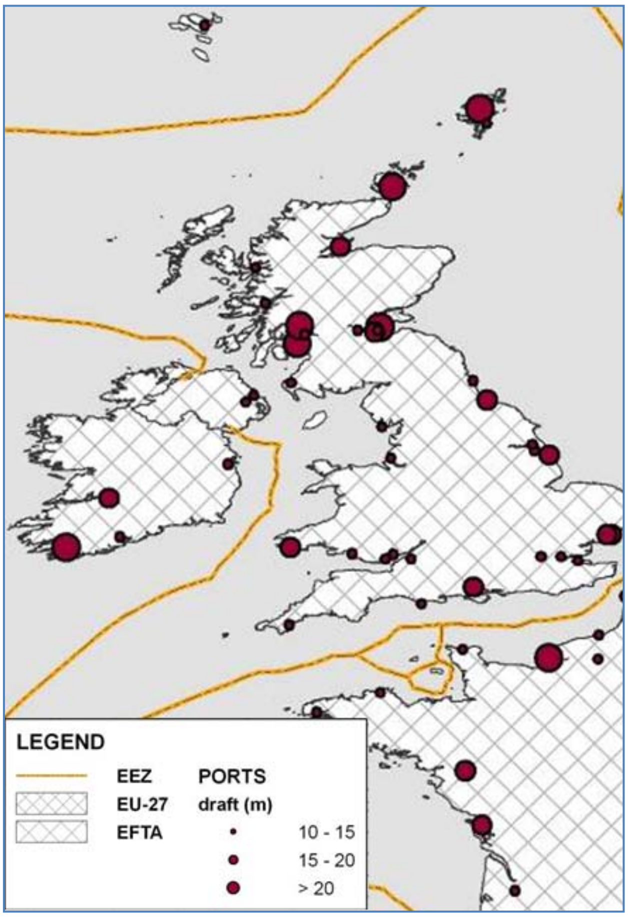


Figure 72: Scotland Ports

7.7.2 Site 2 – Floating, high resource area

The west coast of Ireland provides the best location for floating combined wind and wave energy projects according to the site selection methodology. Due to the location of ports and grid infrastructure this document is specifically referring to a location west of Connacht.

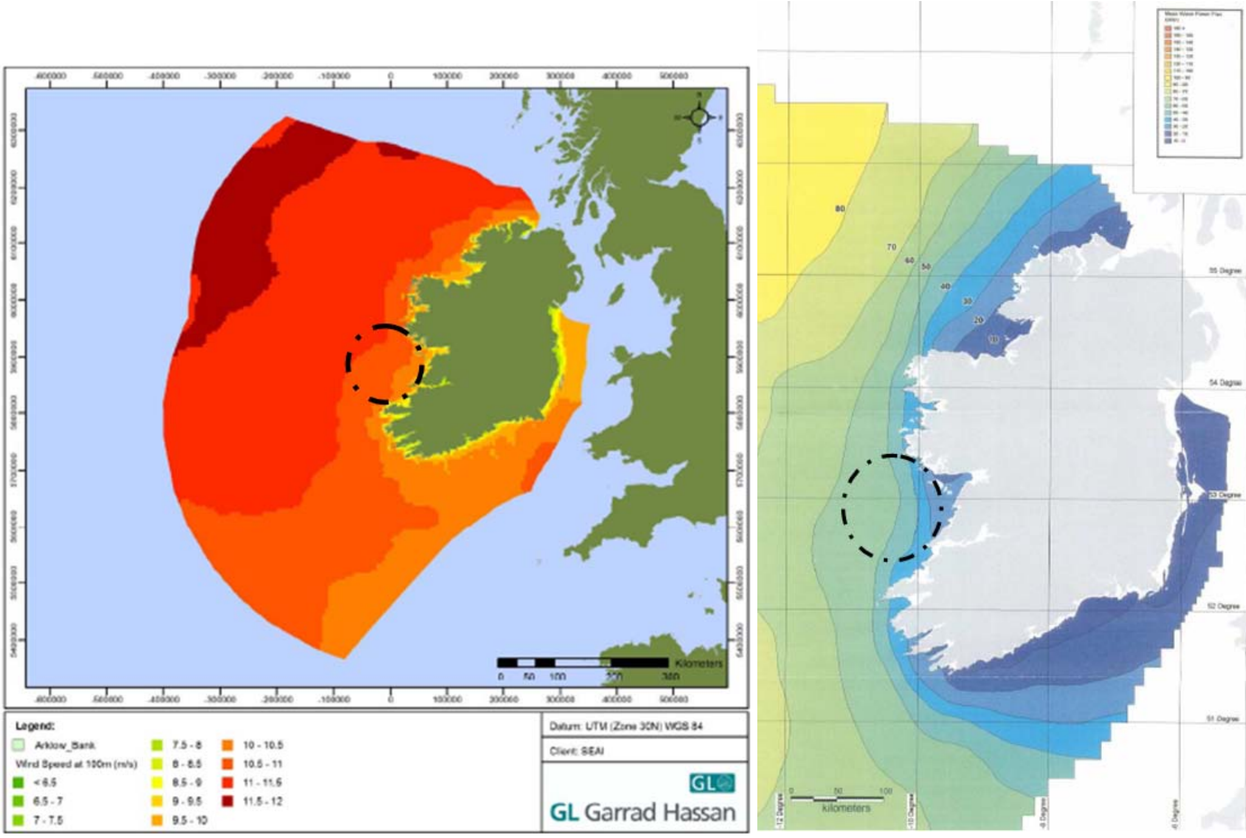


Figure 73: Irish Site Selection Location for combined wind and wave floating

The location has received high points for resource and incentives and for other users as there is little shipping, military or oil and gas activity. However it should be noted that there is significant activity in fishing and aquaculture in the area and any potential conflicts with this industry will need to be addressed in more specific site assessment.

7.7.3 Site 3 –High wind and tidal current resource area

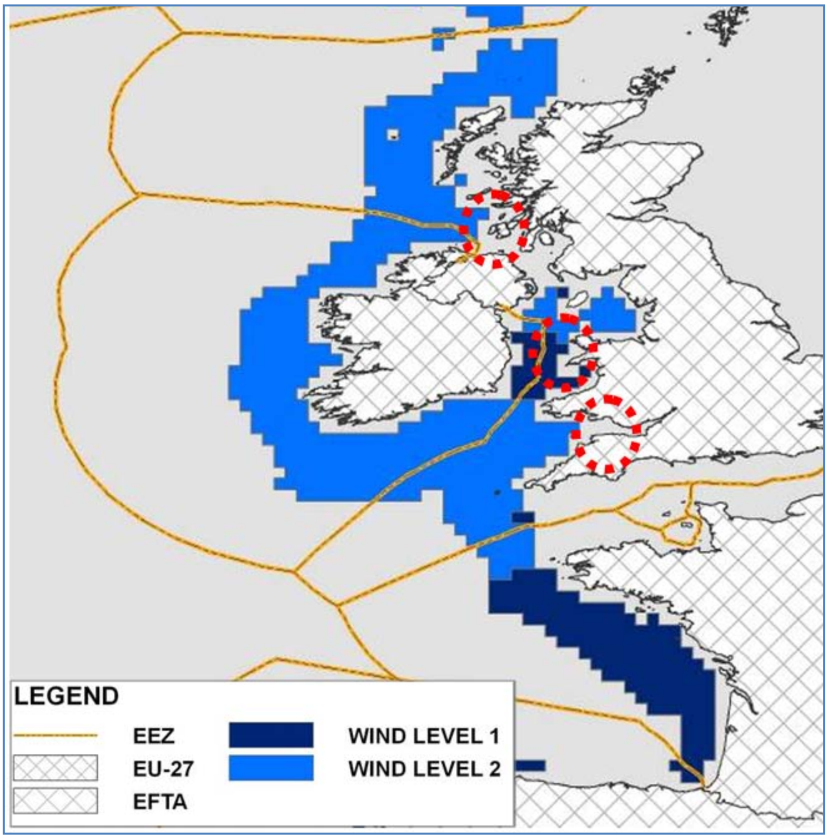


Figure 74: Atlantic Ocean: Combined Wind and Tidal Locations

Based on the site selection methodology outlined in this document, the 3 primary combined wind and tidal sites are located off the island of Islay in Scotland, Carmel Head in Wales and the Bristol Channel in England. It should be noted that this assessment methodology does not take into account the tidal velocities available in the three sites and considers them as sites with a resource greater than 1.75m/s. Therefore although the Scottish site achieves the highest value in the assessment, further research needs to be carried out to determine the actual potential energy output of the 3 sites.

Parameter	Weighting	Scotland		Wales		England	
		Points	Weighted	Points	Weighted	Points	Weighted
Resource	0.3	10	3	6	1.8	10	3
Incentives	0.2	7.25	1.45	5.6	1.12	4.6	0.92
Water Depth	0.2	10	2	10	2	10	2
Location	0.2	4.8	0.97	6.17	1.23	5.83	1.17
Other Uses	0.1	10	1	10	1	1	0.1
Total	1		8.42		7.15		7.19

Table 34: Atlantic Ocean: Combined Wind and Tidal Site Selection

8 Site Selection Application to: Mediterranean and Black Seas Region

The area considered under the Mediterranean and Black Sea region is shown in Figure 33 below. It is an intersection of 3 continents and countries at different stages of development. There is a strong historical link to early navigation and early western civilisation and the region is well known for its mild climate; there is high coastal tourism, fishery and navigation in the region.

The preceding site selection methodology outlined in section 5, will be applied to the region in the following section, with the objective of identifying viable sites for combined wind-wave or wind-tidal current sites based on both GIS results compiled in the ORECCA project and available national data.

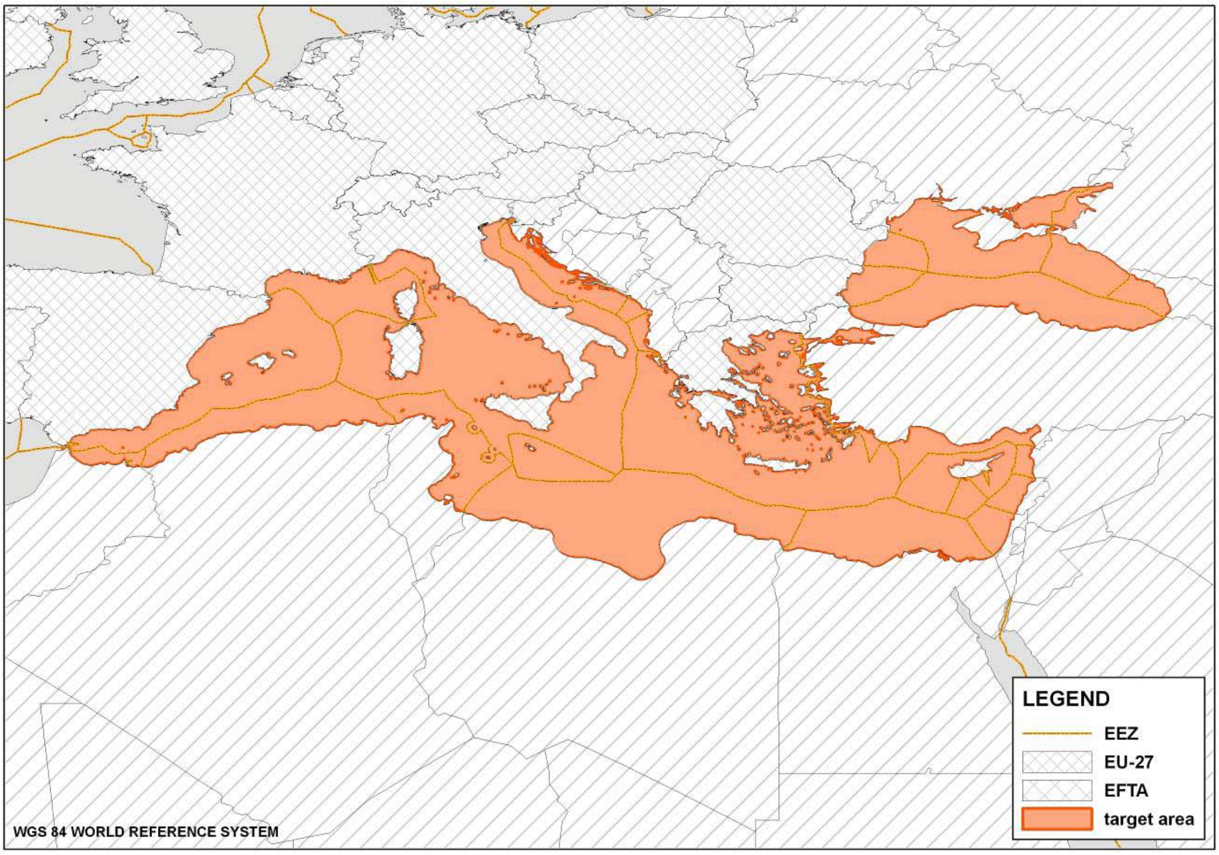


Figure 75: Mediterranean and Black Seas: Region as defined by the EU FP7 ORECCA Project

8.1 Resource

8.1.1 Wind & Wave Combination

The results of the GIS tool are shown in Figure 34 below. This divides the resource into 6 resource levels, 3 wave resource levels (5-15kW/m, 15-25kW/m and greater than 25kW/m) for 2 different wind resource levels (6-8m/s and greater than 8m/s at 10m a.s.l). The wave resource is the lowest level (i.e. 5-15kW/m) for all relevant areas in the Mediterranean and Black Sea region with the lower wind level predominant (level 1, 6-8m/s at 10ma.s.l.) and 2 locations with the higher wind level, indicated by level 4 (greater than 8m/s at 10m a.s.l.).

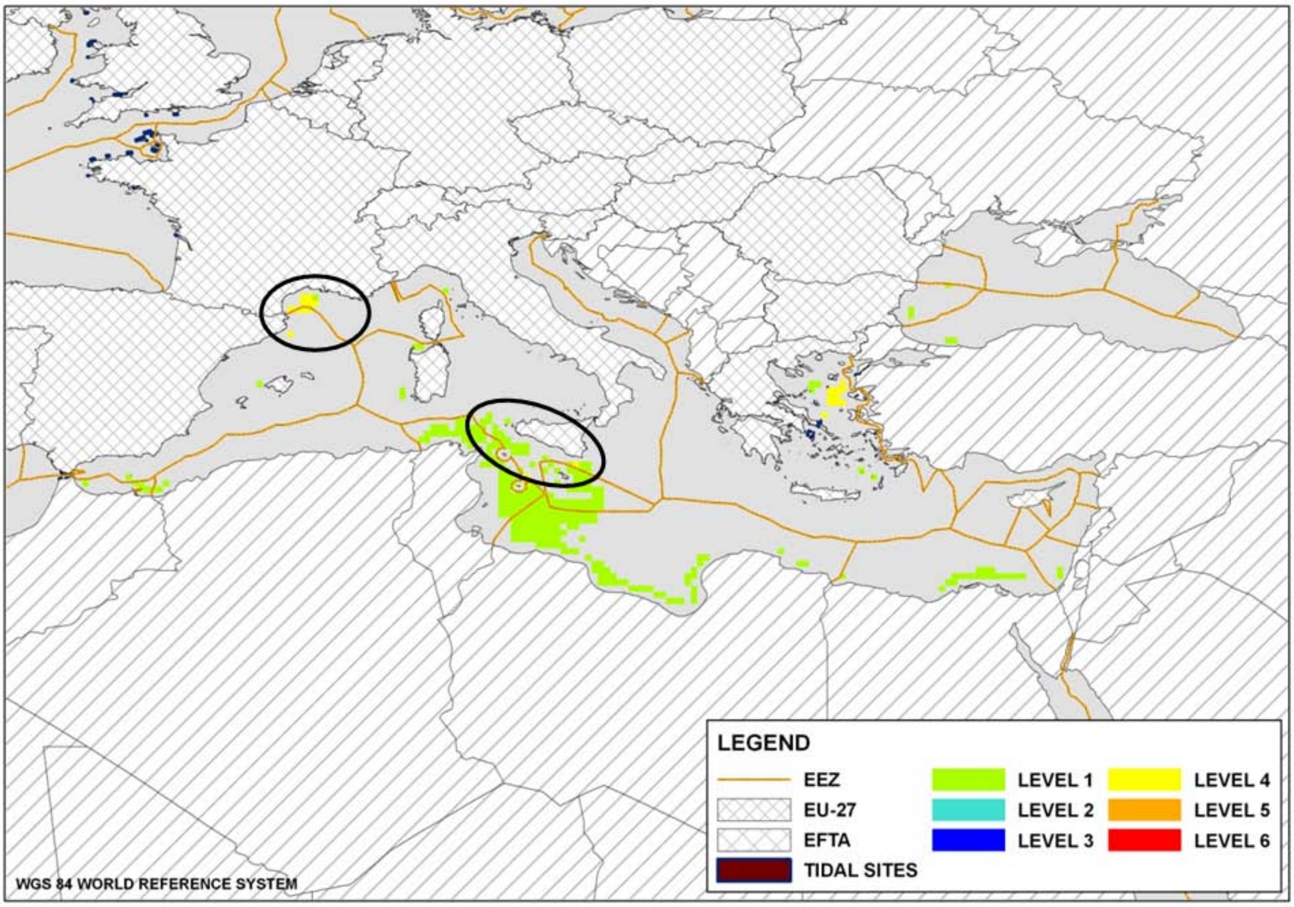


Figure 76: Mediterranean and Black Seas: Combined Resource Levels with identified potential sites

Looking at the OCEANOR and Quikscat data individually, it can be seen that the majority of the area of both seas has an average wave power level of 5-10kW/m with a greater power available off the south coast of France and Spain with 15-20kW/m.

A good wind resource exists across both seas with large areas showing average wind speeds of 6-7 and 7-8m/s at 10m a.s.l. and an area off the south coast of France with wind speeds of 8-10m/s.

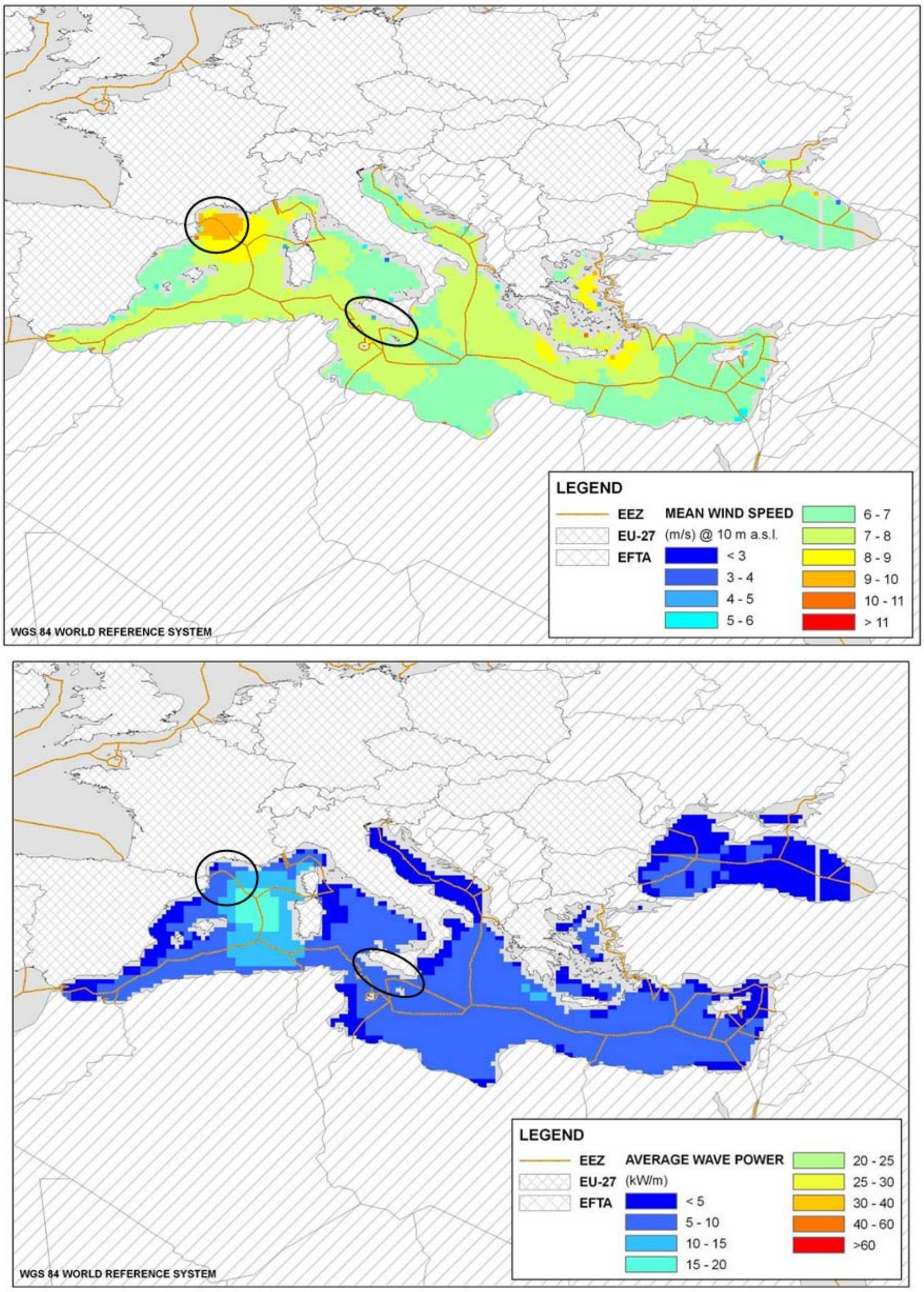


Figure 77: Mediterranean and Black Seas: Average Wave Power Levels according to OCEANOR (BOTTOM) and Average Wind Speeds according to Quikscat (TOP)

The Italian Wind Atlas shows average annual wind speeds of 6-7m/s at 75m a.s.l. in the north-west of the country and the south-east with wind speeds of 7-8 and 8-9m/s available in the islands of Sicily and Sardinia and in some locations along the Adriatic coast.

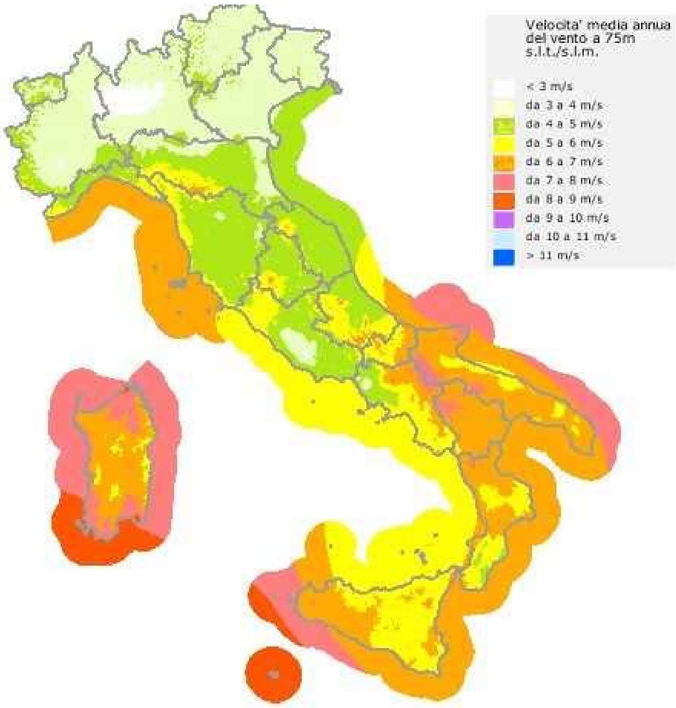


Figure 78: Italian Offshore Wind Atlas[101,102]

The French offshore wind map only shows wind speeds very close to shore, however these are shown to be 7-8m/s at 60m a.s.l. along the coastline and 8-9m/s slightly further out.

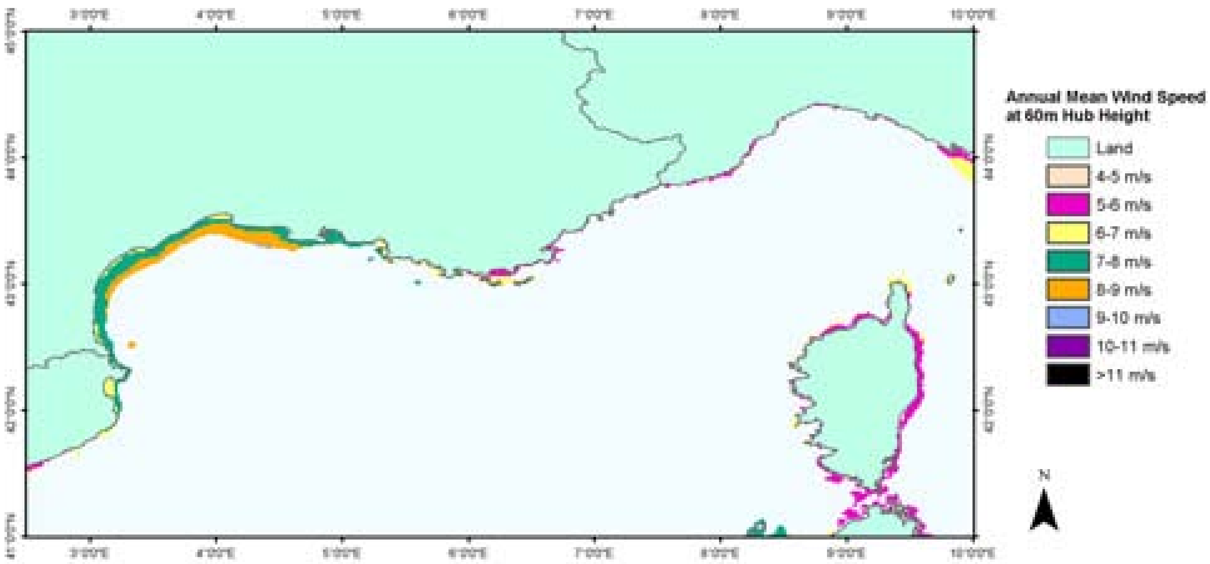


Figure 79: French Offshore Wind Resource: South coast[103]

As there are very few areas suitable to wave energy extraction in the region, there likewise are few national wave energy atlases. A wind and wave energy atlas of the Mediterranean is available for purchase as a result of the MedAtlas project and was produced by the Western European Armaments Organisation

Research Cell (WEAO)[104]. Likewise a wind and wave atlas of the Hellenic seas is available for purchase[105] on request.

Based on the available wind and wave resource data, there are no prominent sites that would be suitable for combined wind and wave projects. The south coast of France may provide the greatest combined wind and wave resource in the region with 10-15kW/m.

The other potential location is the south-west coast of Sicily based on the resource.

8.1.2 Wind & Tidal Current Combination

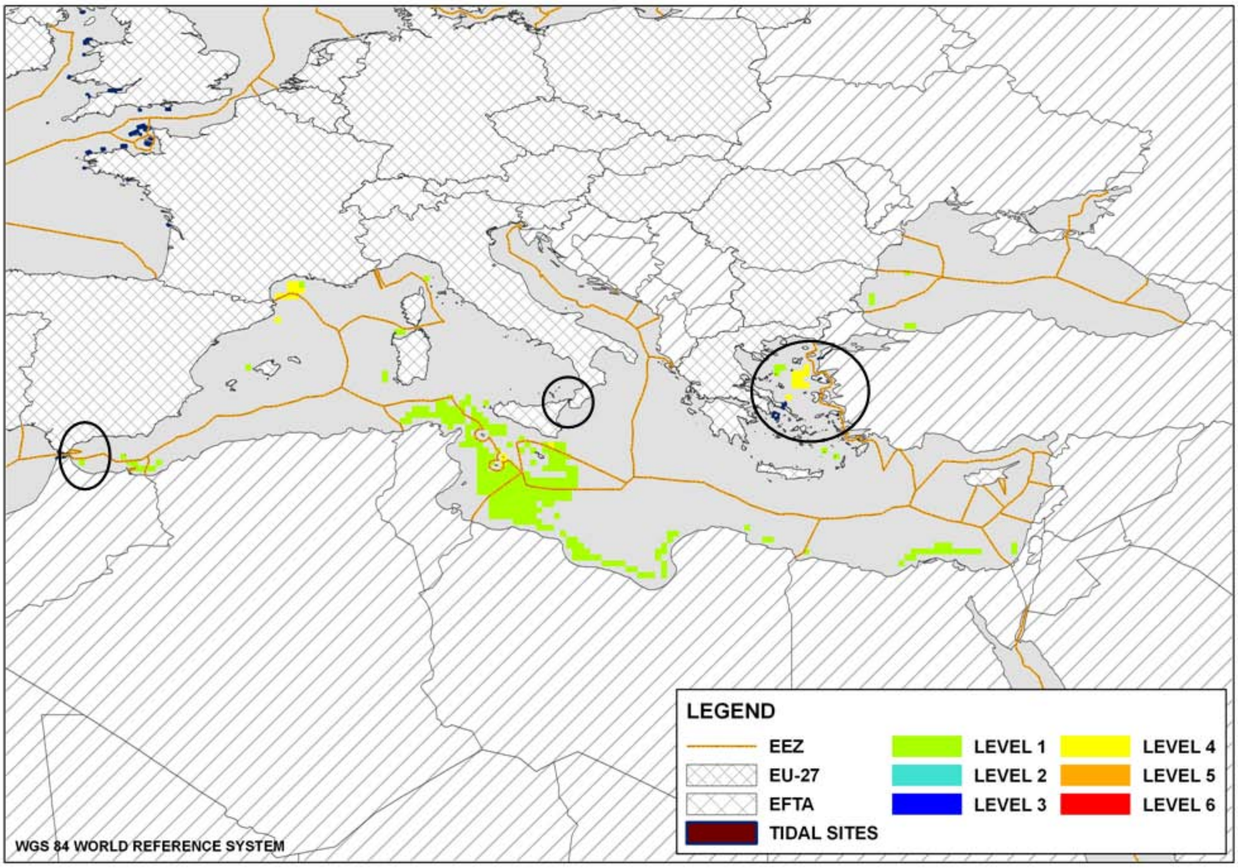
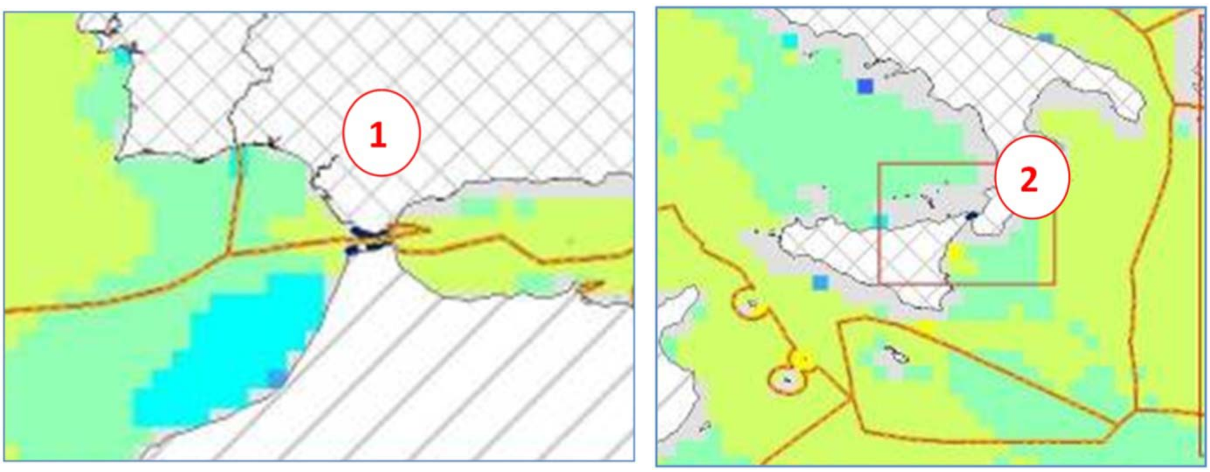


Figure 80: Combined Resource in Mediterranean and Black Sea: wind + wave + tidal current (circled)

There are 3 primary locations for ocean and tidal currents in the Mediterranean and Black Sea region; the Straits of Gibraltar, Straits of Messina and the Bosporus Straits and Aegean Sea. These 3 locations are clearly identified in Figure 80 above and more specifically marked in navy in Figure 43 below and overlayed on the Quikscat wind speed map.



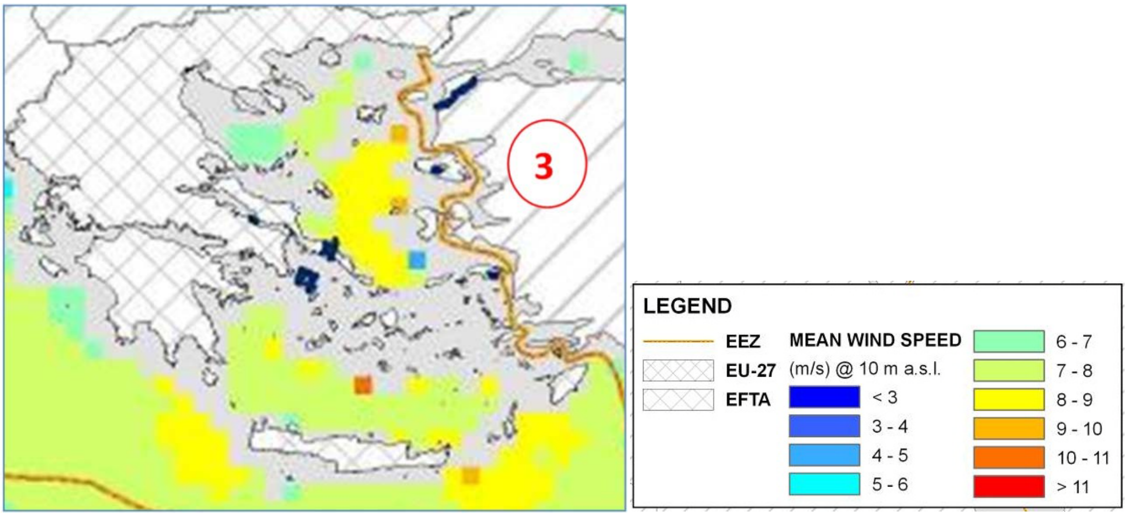


Figure 81: Primary Locations of Ocean Currents in the Mediterranean and Black Sea based on GIS datasets; Straits of Gibraltar (TOP LEFT), Straits of Messina (TOP RIGHT) and Aegean Sea and Bosporus Straits (BOTTOM)

8.1.3 Application of Site Selection Methodology

Therefore applying these resource figures to the site selection methodology, the following are the rankings given to each site:

Country	Resource Level	Site Selection Points
WIND & WAVE		
France	Level 4	**3**
Italy	Level 1	**2**
WIND & TIDAL		
Gibraltar	Level 2	**8**
Sicily	Level 2	**8**
Aegean	Level 1	**10**

Table 35: Atlantic Ocean: Wind & Wave Resource Site Selection Ranking

8.2 Incentives and RE Targets

Italy provides the best production incentives in the region by far with €0.18/kWh for offshore wind and the greatest available feed-in tariff in Europe for ocean energy with €0.34/kWh giving a site selection score of 9.6. In comparison the country with the second highest available incentives is France with €0.13/kWh for offshore wind and €0.15/kWh for ocean energy giving a total site selection score of 4.6.

€/kWh	Wind			Ocean			Combined Site Selection Points
	FiT	Price Received	Points	FiT	Price Received	Points	
Greece	0.00	0.00	**1.00**	0.00	0.07	**1.00**	**1.0**
Spain	0.03	0.10	**3.25**	0.00	0.07	**1.00**	**2.1**
France	0.13	0.13	**5.50**	0.15	0.15	**3.67**	**4.6**
Italy	0.18	0.18	**9.25**	0.34	0.34	**10.00**	**9.6**

Table 36: Mediterranean and Black Seas: National Production Incentives and Wholesale Electricity Prices

Production incentives enhance the economic feasibility of a project in a given country and give some indication of the political interest of that country in offshore renewable energy. The existing percentage of electricity from renewable sources and the countries NREAP targets for 2020 are also indicative of intent.

Figure 82: Mediterranean and Black Seas: Country Specific - Electricity Generated from Renewable Sources (% gross electricity consumption)[106]

Table 37 below summarises the figures available in Eurostats and the NREAP summary document from the European Environment Agency.

France has one of the lower current percentages of gross electricity consumption coming from renewable energy however they have the highest NREAP targets for offshore wind and ocean energy in the region. Greece, conversely, has the lowest percentage of electricity from renewables but also has the lowest

NREAP targets for offshore energy and may be investing in alternative renewable energies such as solar which would be suitable for their climate.

Italy has a low percentage of gross electricity consumption and low NREAP targets for offshore energy however it has the highest feed-in tariff for ocean energy in Europe.

Country	% Gross Electricity Consumption from RE sources (2009)	NREAP Targets by 2020 (MW)[107]	
		Offshore Wind	Ocean
Spain	16.6-28.7	3,000	100
Italy	8.3-16.6	680	3
France	8.3-16.6	6,000	380
Greece	4.6-8.3	300	0

Table 37: Mediterranean and Black Seas: Country Specific NREAP Targets and RE % of Gross Electricity Consumption

8.3 Geography

8.3.1 Water Depth

The bathymetry of the Mediterranean and Black Sea is very deep (greater than 500m) close to shore as can be seen in Figure 84. Areas with a water depth of less than 500m are limited to the north of the Adriatic Sea, parts of the Aegean Sea and between the coasts of Sicily and Tunisia.

Unfortunately if the area available to the GIS query is considered once a depth limit of 500m has been applied, the majority of the high wind and wave regions are removed from the assessment. This depth limit is due to the current restrictions of the latest floating offshore renewable technologies.

Fortunately there appear to be shallower waters available in the locations identified by resource (highlighted in Figure 83 below).

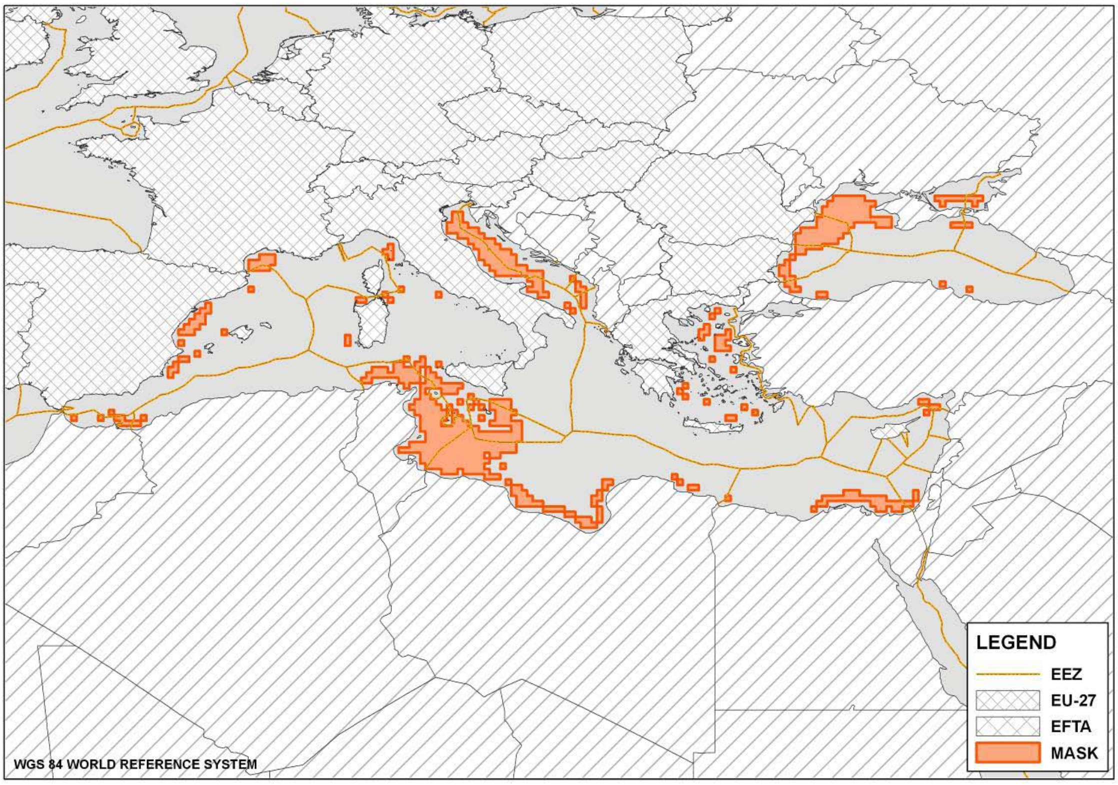


Figure 83: Mediterranean and Black Seas: Available area with depth and distance from shore limits applied

Even in the more shallow areas for combined wind and wave, the water depth is in the floating range of 60-200m minimum. The 3 tidal locations appear to also be in the 60-200m water depth range which may pose a problem for existing tidal technologies if it is the higher end of this range however more detailed studies would need to be carried out to determine if there are suitable locations for fixed foundations or if a suitable floating tidal technology could be installed at these locations. For the sake of this investigation, we will assume that there are sites of suitable water depth (i.e. approximately 60m) at the three tidal locations.

In Figure 84 below the orange circles designate the combined wind and wave locations being considered (i.e. southern France and western Sicily) while the red circles show the combined wind and tidal locations (i.e. Straits of Gibraltar, Straits of Messina and Bosporus Straits).

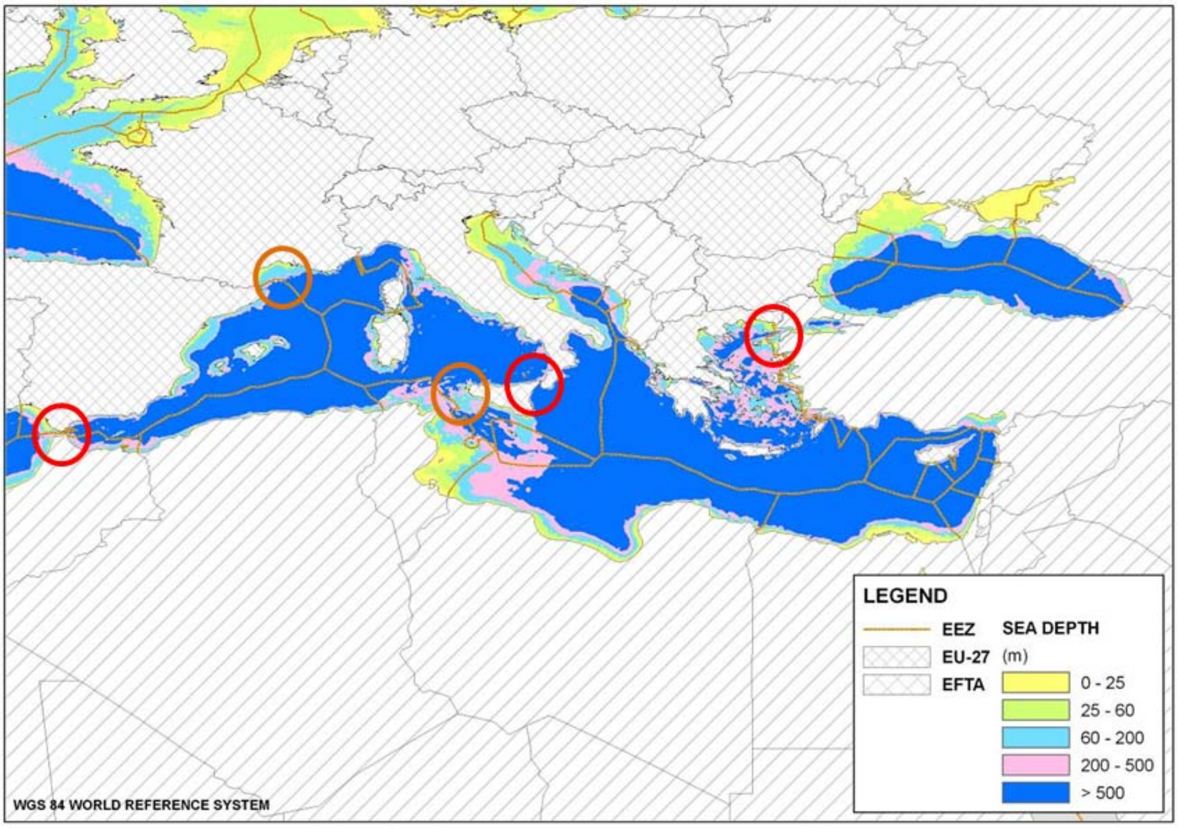


Figure 84: Mediterranean and Black Seas: Bathymetry (Orange Circles designate combined wind+wave sites, Red Circles represent wind+tidal sites)

The following table outlines the scoring given to each location based on its bathymetry (assumed to be within the fixed range for tidal).

Country	Water Depth Range	Typical Wind Turbine Structure	Site Selection Points
	WIND & WAVE		
France	60-200	Floating	**8**
Italy	60-200	Floating	**8**
	WIND & TIDAL		
Spain	60-200	Fixed	**9**
Italy	60-200	Fixed	**9**
Greece	60-200	Fixed	**9**

Table 38: Atlantic Ocean: Water Depth Site Selection Ranking

8.3.2 Distance from Shore

Both combined wind and wave locations are within 100km from shore while all tidal sites are likely to be within 20km from shore based on statistics from the GIS tool and Figure 49 below.

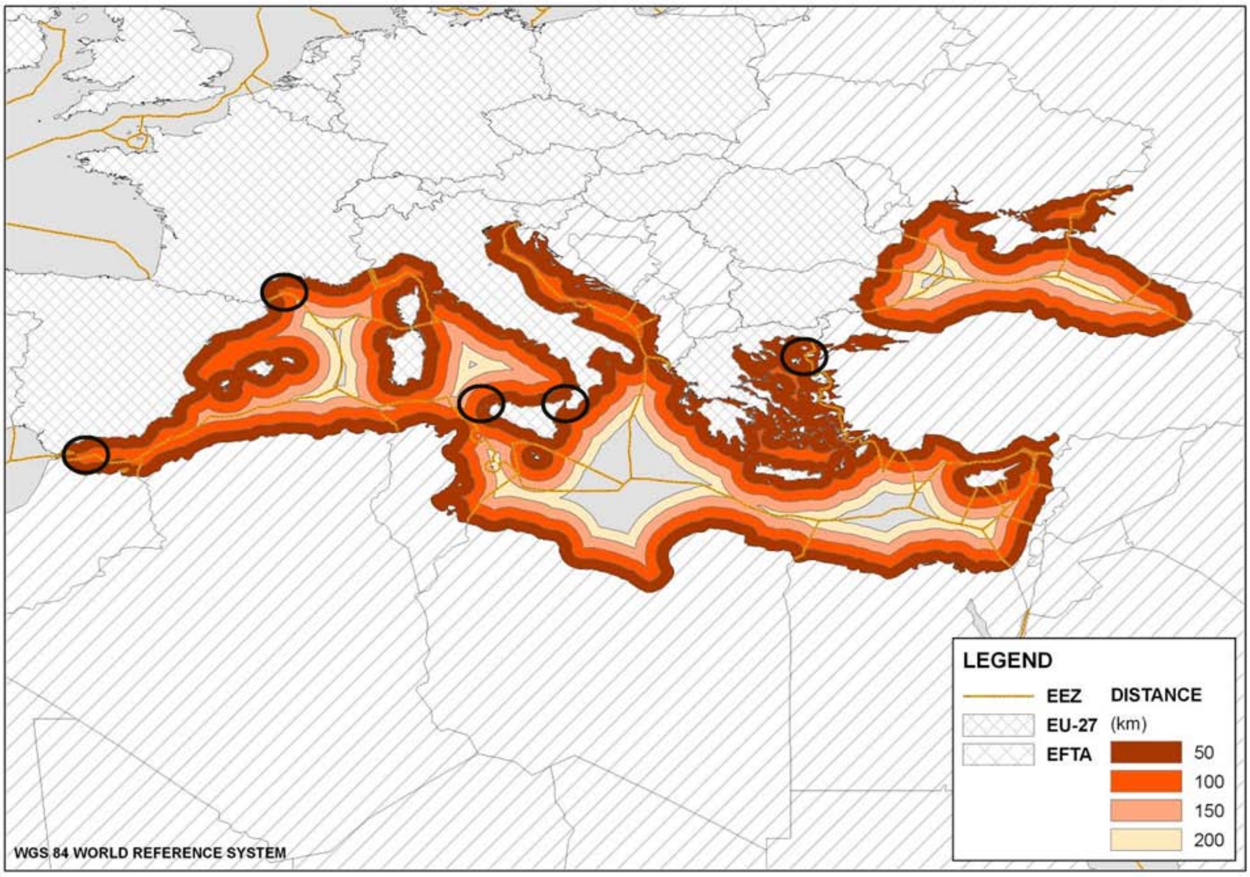


Figure 85: Mediterranean and Black Seas: Distance from shore boundaries

Country	Distance from Shore	Site Selection Points
WIND & WAVE		
France	50-100km	8
Italy	50-100km	8
WIND & TIDAL		
Spain	0-20km	1
Italy	0-20km	1
Greece	0-20km	1

Table 39: Mediterranean and Black Seas: Distance from Shore Site Selection Ranking

8.4 Infrastructure

8.4.1 Ports

There is a proliferation of ports in both the Mediterranean and Black Sea with numerous deep and shallow ports available in each of the locations being considered.

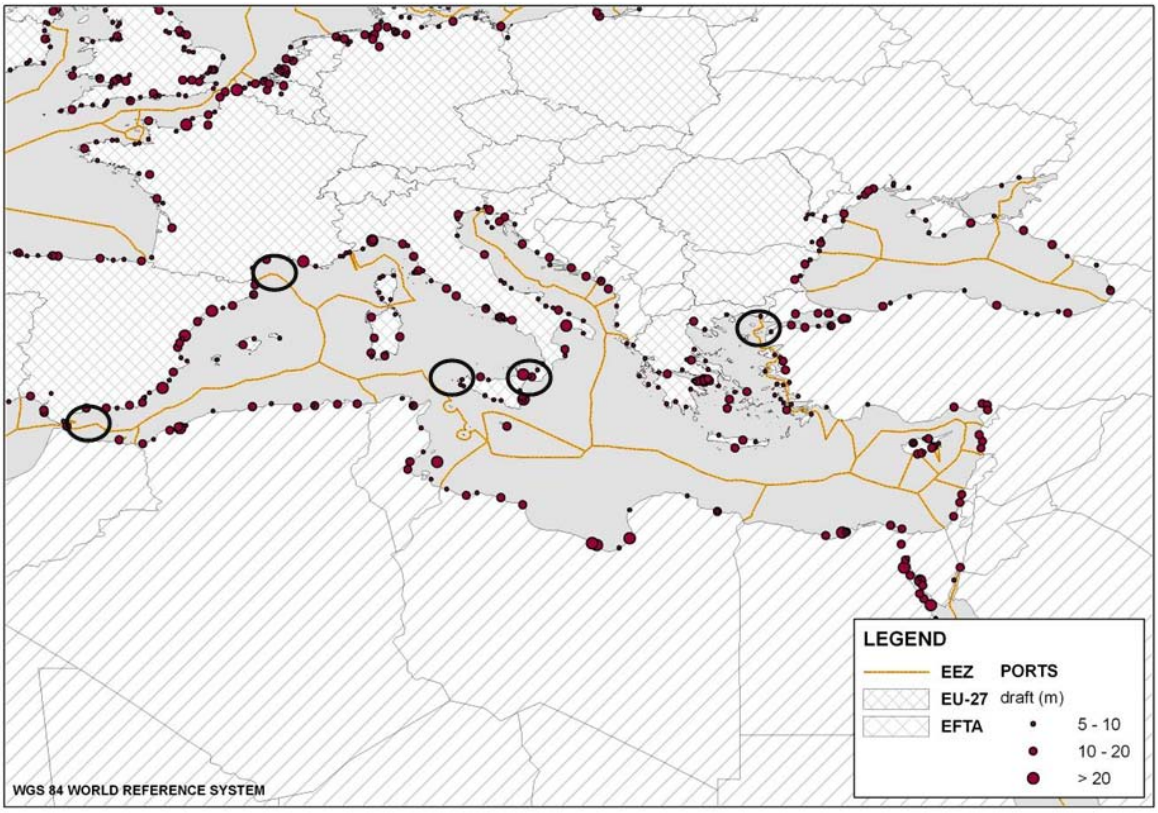


Figure 86: Mediterranean and Black Seas: Location of Ports (LEFT: Minimum 10-15m draft, RIGHT: All Ports)

Country	Distance from Deep Water Port	Distance to Port - Site Selection Points	Distance from Shallow Port	Distance to Pier - Site Selection Points	Total Site Selection Points
		WIND & WAVE			
France	Less than 100km	**10**	70-80km	**7**	8.5
Italy	Less than 100km	**10**	70-80km	**7**	8.5
		WIND & TIDAL			
Spain	Less than 100km	**10**	Less than 50km	**10**	10
Italy	Less than 100km	**10**	Less than 50km	**10**	10
Greece	Less than 100km	**10**	Less than 50km	**10**	10

Table 40: Mediterranean and Black Seas: Distance from Port Site Selection Points

8.4.2 Electrical Grid

The electrical grid infrastructure in the region is much denser than that of its Northern European counterparts, Ireland, Scotland and Norway. All locations selected in this section are within close proximity to multiple high voltage 380-500kV lines in each country with the exception of the wave and wind location off the coast of Sicily.

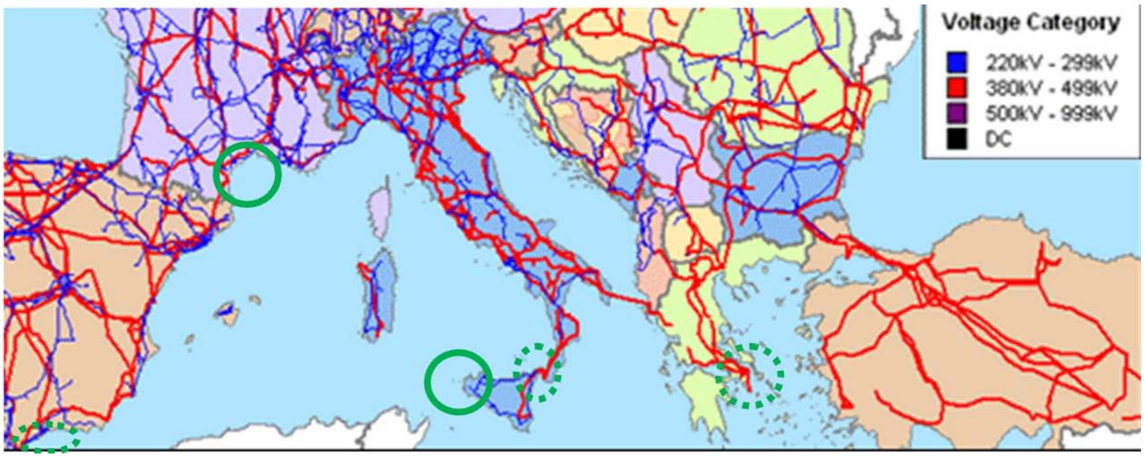


Figure 87: Mediterranean and Black Seas: Electrical Grid Infrastructure (Solid Circles: Wind + Wave Sites, Dotted Circles: Wind + Tidal Sites)

Country	Local Grid kV Capacity	Site Selection Points
WIND & WAVE		
France	380-500kV	8
Italy	380-500kV	8
WIND & TIDAL		
Spain	380-500kV	8
Italy	220-380kV	6
Greece	380-500kV	8

Table 41: Mediterranean and Black Seas: Local Grid Site Selection Points

Figure 88 below outlines the intended grid infrastructure projects for 2020 which includes a number of sub-sea cable interconnectors in the Mediterranean and Black Seas. For example the wind-wave identified site west of Sicily will be located in the region of an interconnector to Africa and the grid is due to be upgraded on the island of Sicily which would increase the site selection points for this site.

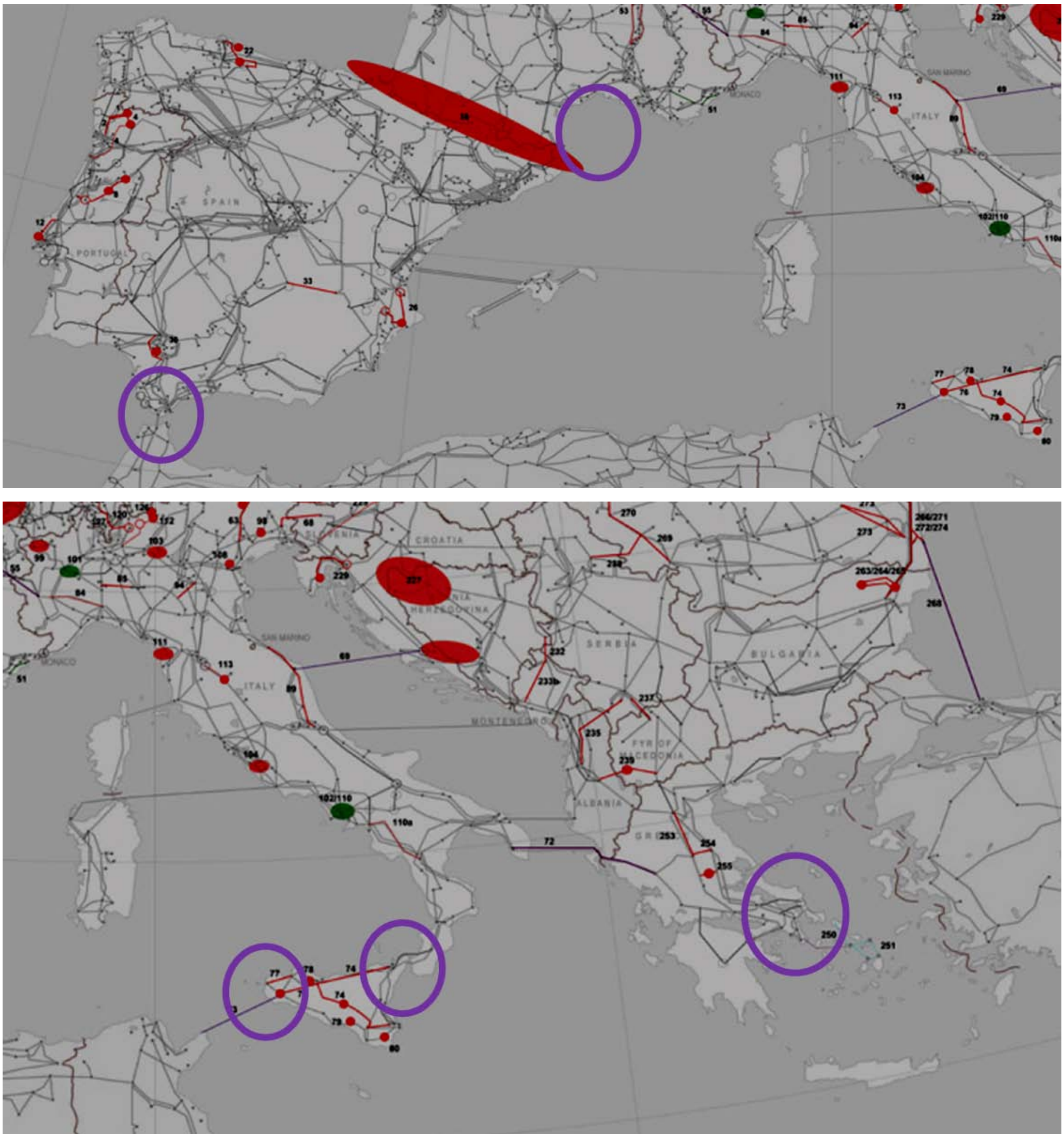


Figure 88: Mediterranean and Black Seas: Location of Submarine Cables 2020 for identified sites (circled in purple) - TOP: Spain and France, BOTTOM: Italy and Greece[108]

8.4.3 Population/Demand Centres

The primary cities in the region are marked in Figure 53 below. There are a number of large (greater than 250,000) population centres in the region on both sides of the seas with the least density of cities on the south coast of Spain and France however the Mediterranean is an area of high tourism and so the demand along the coast is likely to increase significantly in the summer months.

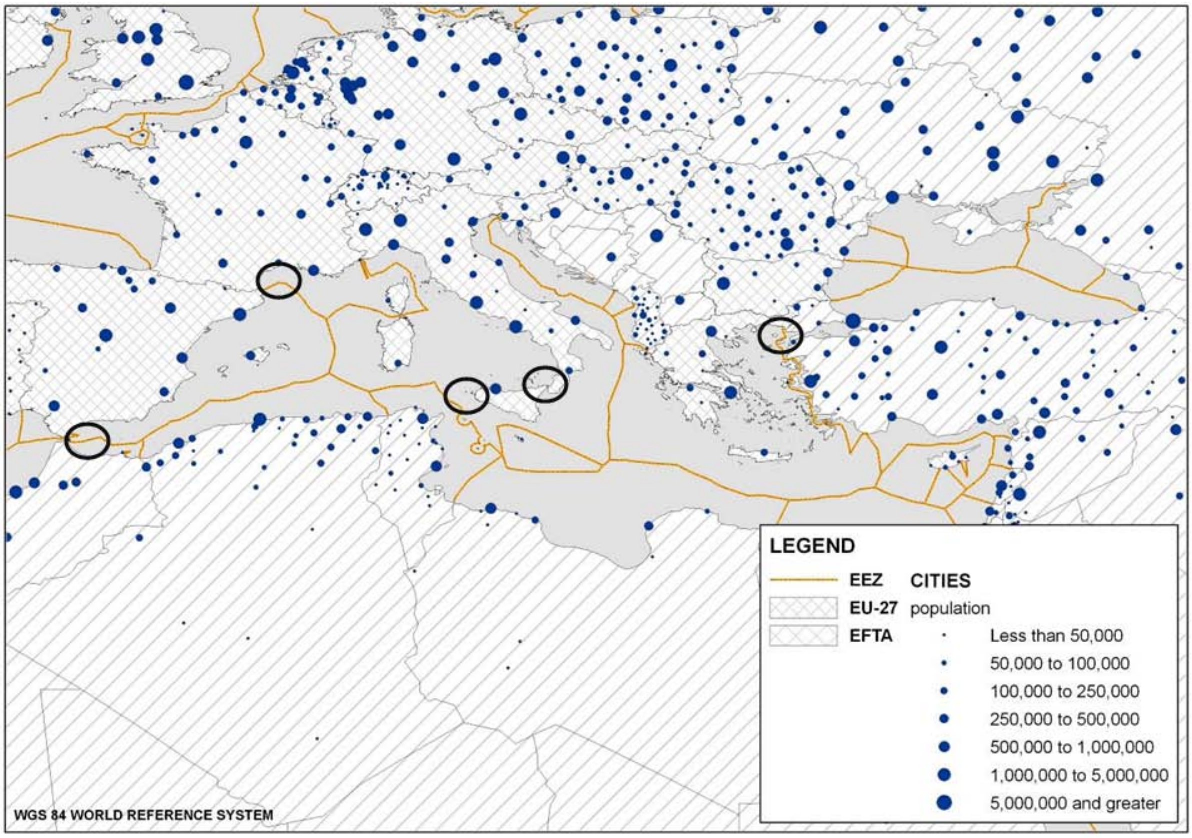


Figure 89: Mediterranean and Black Seas: Population/Demand Centres

8.5 Other Uses

8.5.1 Designated Protected Areas

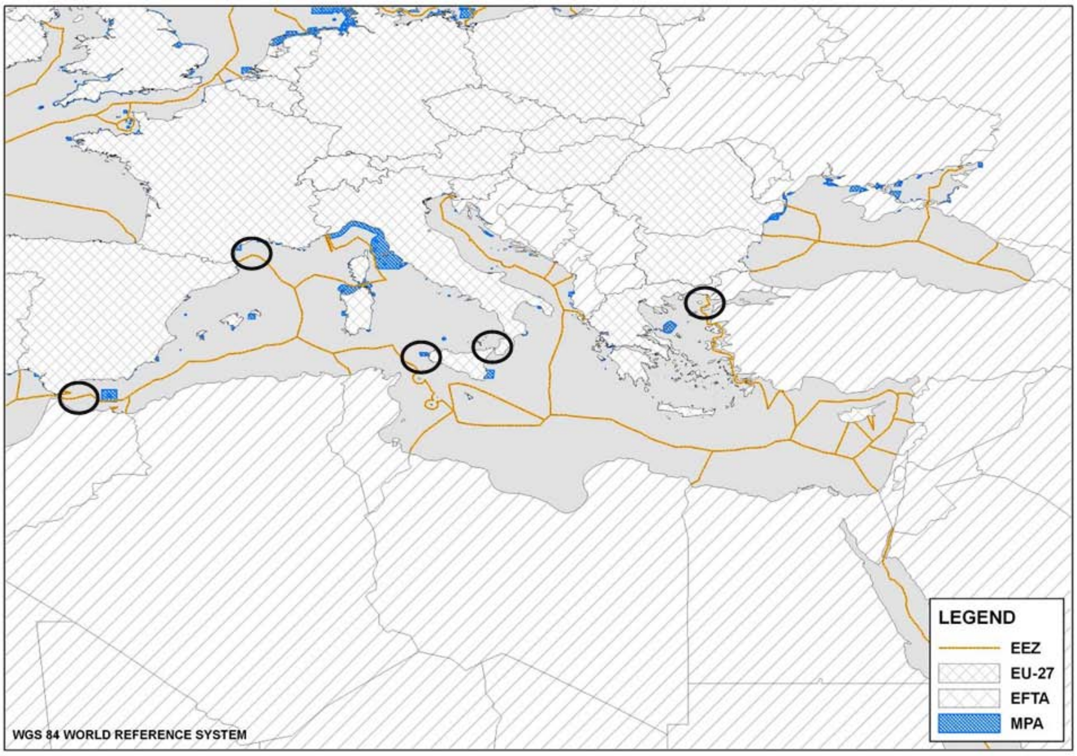


Figure 90: Mediterranean and Black Seas: Designated Marine Protected Areas

Natura2000 sites are EU designated protected areas both on-shore and off-shore. The two types of MPAs that are included in the Natura2000 network are the Special Areas of Conservation (SAC) and the Special Protection Areas (SPA) which are designated under the Habitats Directive and the Birds Directive.

A European INTERREG Project exists in this region known as MedPAN which is a network of Managers of Marine Protected Areas in the Mediterranean[109]. A sister network also exists in the Adriatic Sea, known as AdriaPAN[110].

Figure 91 to Figure 94 below show the MPAs as defined nationally in the MedPAN network and as defined under the EEA Natura 2000 network for each country identified in the preceding sections for combined offshore renewable projects. The MedPAN website gives links and contact information for the relevant MPA governing body in each country in the network and a list of relevant legislation.

Spain has a number of MPAs on its Mediterranean coast including a location at the top of Gibraltar. This would need to be considered in a more detailed site selection.

It is evident that France does not have many MPAs however the existing few are situated along the coast of the identified combined resource area. A project 50km from shore should not have any interaction with these however contact would need to be made with the relevant local authority to ensure this.

Italy has numerous protected areas, which includes a site off the west coast of Sicily in the identified region for combined wind and wave projects. Greece also has numerous protected areas however the majority of these appear to be on the various islands and very few are marine protected areas.

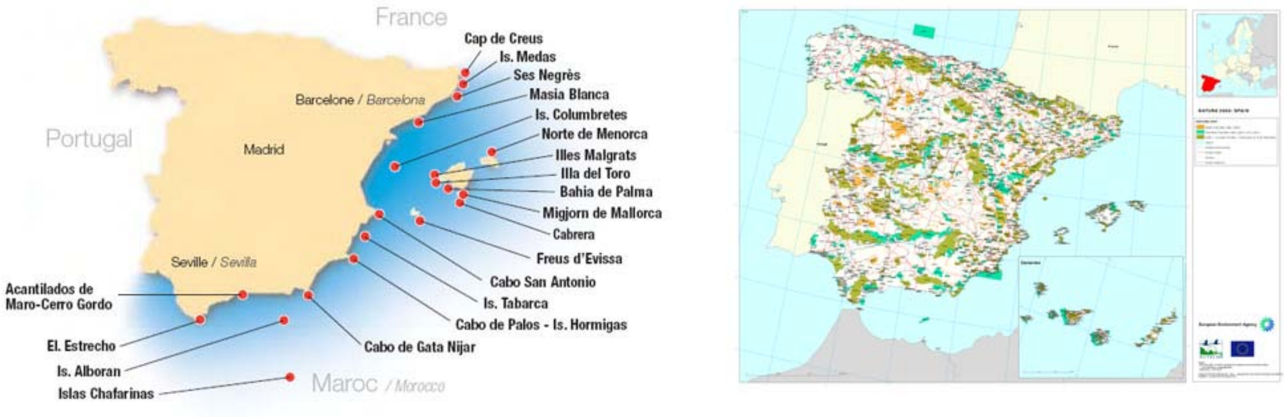


Figure 91: Spanish MPA Maps from MEDPAN[111] (LEFT) and EEA[112] (RIGHT)

Figure 92: French MPA Maps from MEDPAN[113] (LEFT) and EEA[114] (RIGHT)

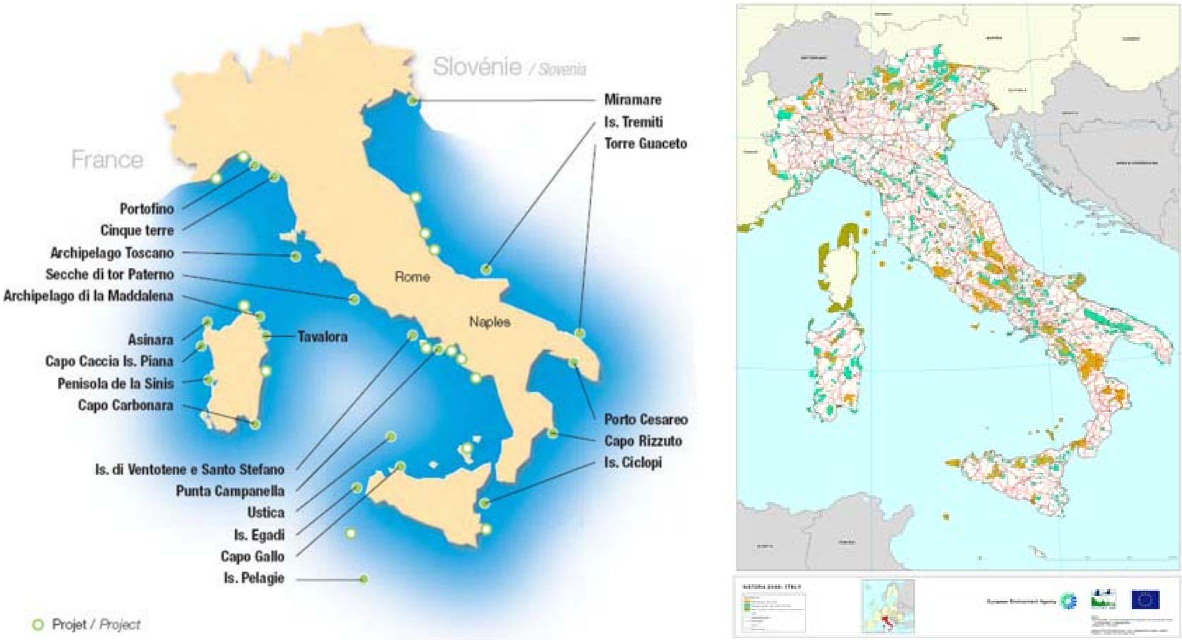


Figure 93: Italian MPA Maps from MEDPAN[115] (LEFT) and EEA[116] (RIGHT)

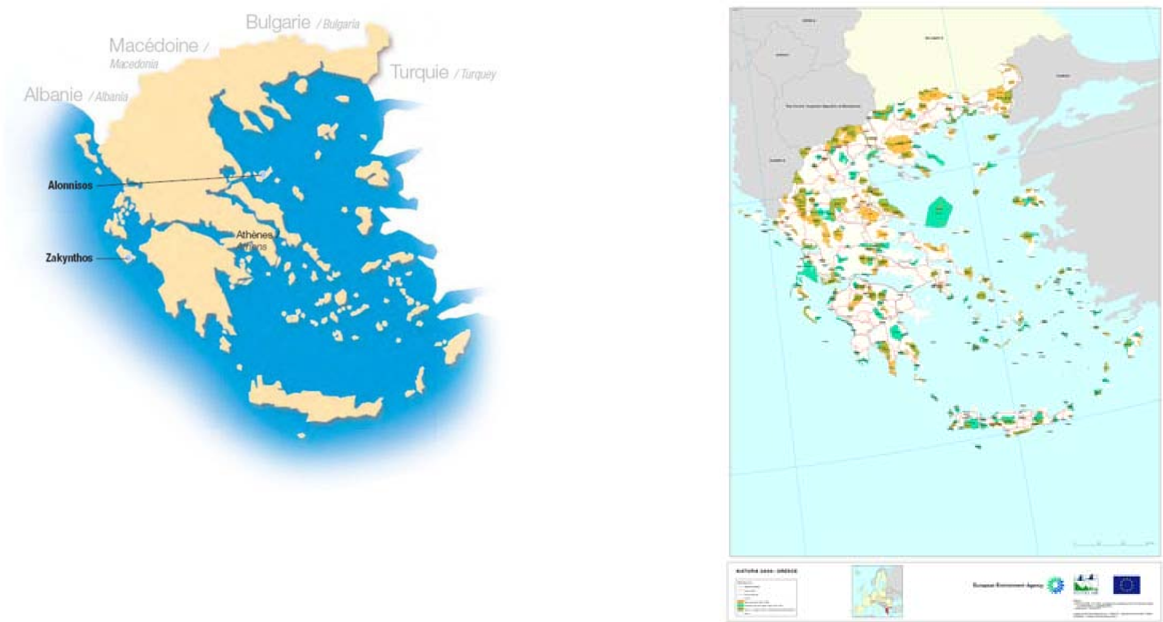


Figure 94: Greek MPA Maps from MEDPAN[117] (LEFT) and EEA[118] (RIGHT)

8.5.2 ***Navigation & Shipping Lanes***

Shipping traffic density is generally high in the Mediterranean particularly through the Straits of Gibraltar where all global traffic must enter the basin. The EU funded SAFEMED[119] project provides maritime traffic flows and risk analysis in the Mediterranean basin and a web GIS is available to identify the main ports and traffic routes in the region.

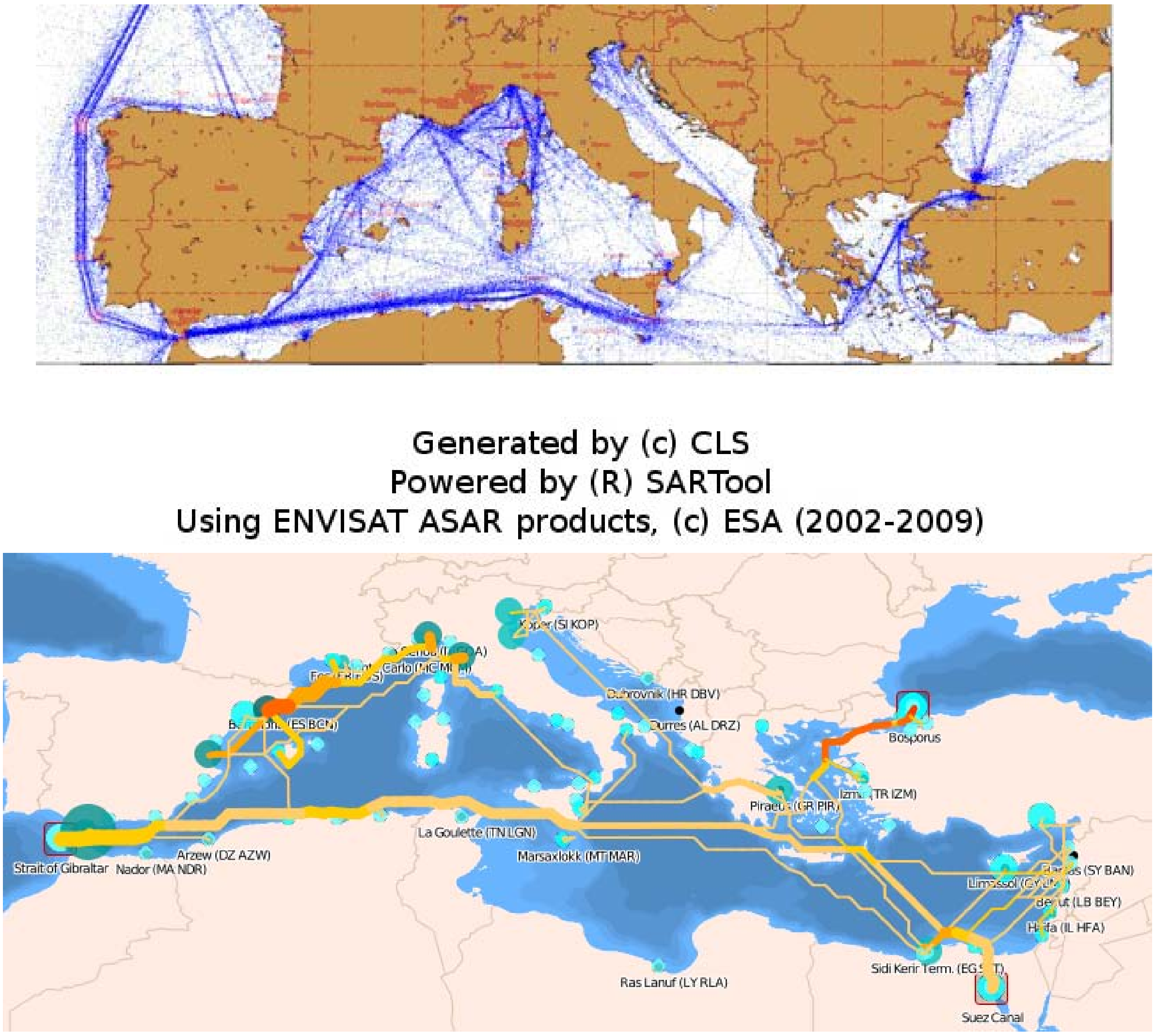


Figure 95: Mediterranean and Black Seas: Shipping Routes from TOP: Satellite Imagery[120] and BOTTOM: SAFEMED Project[121]

It is evident from Figure 95 above that the Straits of Gibraltar wind and tidal site will have the greatest conflict with shipping traffic while the other identified sites appear to have low-medium densities of sea traffic.

Country	Shipping Density	Site Selection Points
	WIND & WAVE	
France	Medium	6
Italy	Low	10
	WIND & TIDAL	
Spain	High	1
Italy	Low	10
Greece	Medium	6

Table 42: Mediterranean and Black Seas: Shipping Density Site Selection Points

8.5.3 Military Exercise Areas

National military exercise maps are difficult to acquire without national knowledge and therefore military exercise maps could not be found for the relevant countries however the relevant ministry of defence websites are available.

8.5.4 Oil and Gas Fields

Oil and gas exploration in the European part of the Mediterranean Sea is primarily concentrated in the Adriatic coast of Italy and Sicily as can be seen from Figure 96 below. There are also a few fields off the south coast of France and the Atlantic south coast of Spain, identified by red and green dots in the images. The location west of Sicily is the only identified combined offshore renewable site which may be affected by oil and gas activities.

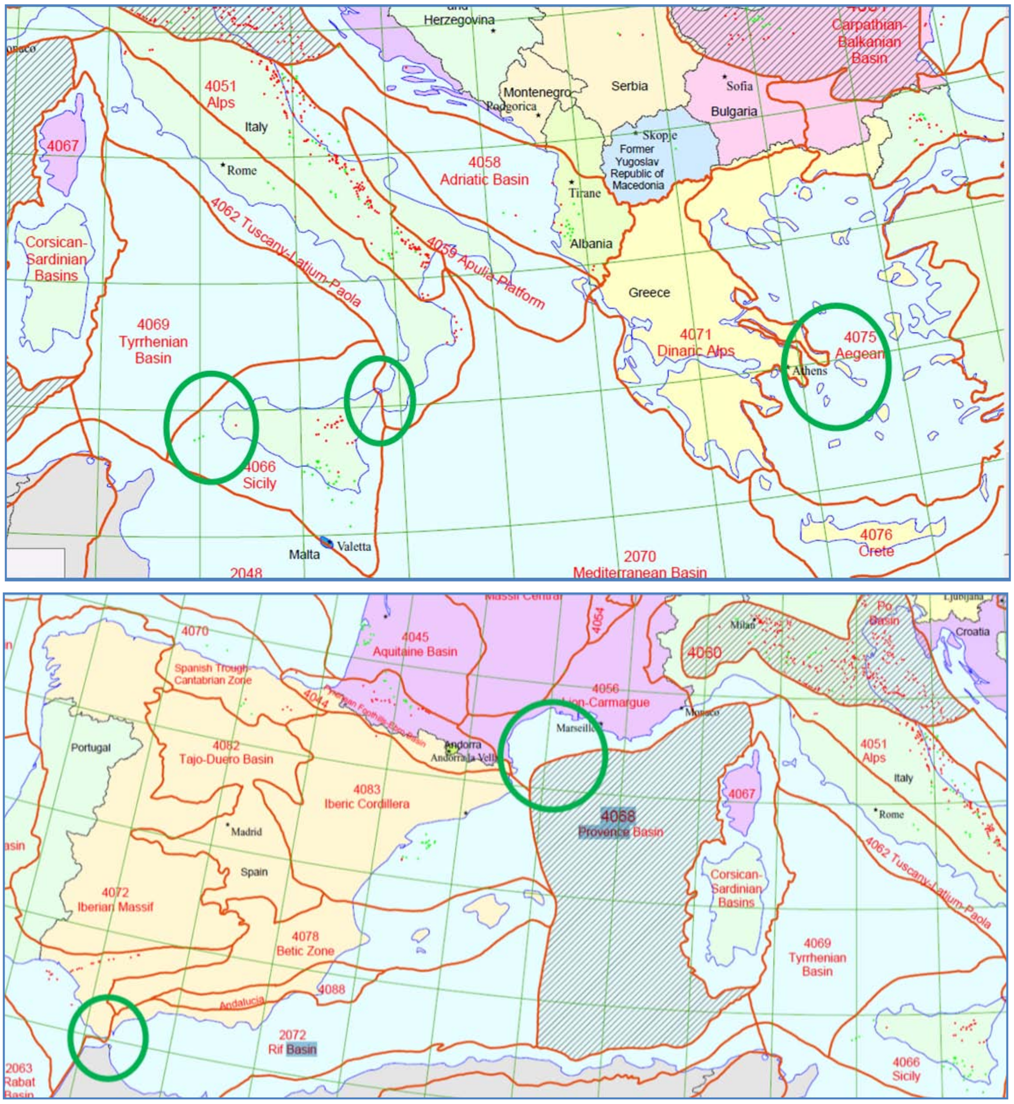


Figure 96: Oil and Gas Fields in Mediterranean Sea[122] (TOP: Italy and Greece, BOTTOM: France and Spain)

8.5.5 <u>Fishing Zones</u>

Figure 65 shows the distribution of the fishing fleet by coastal region in the Mediterranean Basin. It is evident that there is a large number of fishing ports along the Italian and Greek coastlines (indicated by the blue dots). This also shows that there are on average 100-500vessels in the most coastal regions all along the European coast of the Mediterranean Sea indicating a very active fishing industry which may need to be considered when implementing a more detailed site selection.

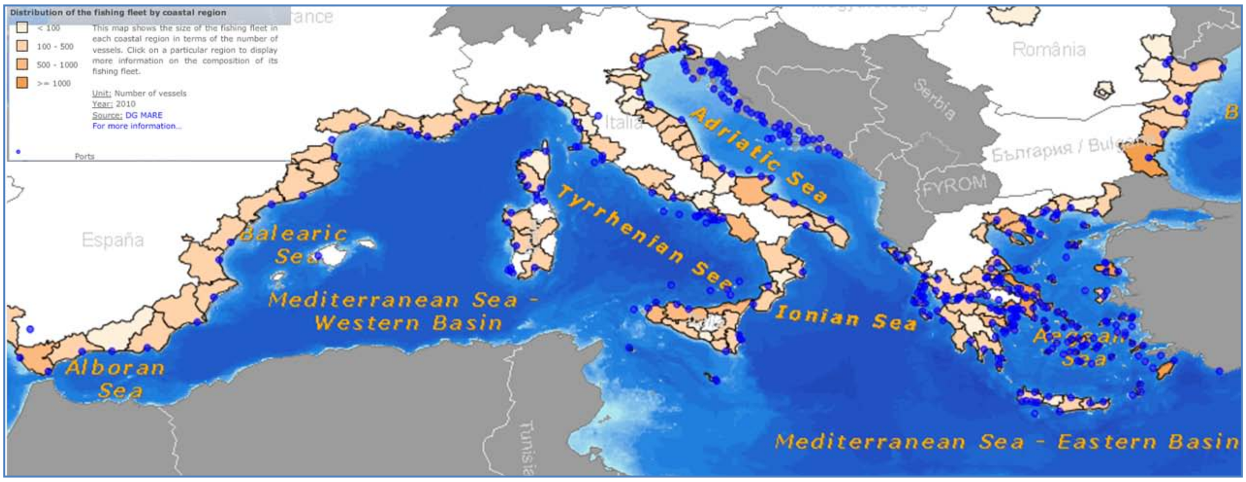


Figure 97: Mediterranean and Black Seas: Distribution of fishing fleet by coastal region and location of fishing ports[123]

8.6 Physical characteristics of the Site

8.6.1 <u>Seabed Type</u>

The EU INTERREG project, MESH[124] is provides a forum for researchers working in this area and the GEOSEAS[125] Project is an EU FP7 Infrastructures Project aiming to catalogue all available seabed mapping and geotechnical data from studies carried out in European waters.

The European Marine Observation and Data network (EMODnet) Project[126] provides a web GIS of seabed and habitat types for seas in the EU. Figure 98 below shows the EMODnet map for the western Mediterranean sea however data is also available for the Aegean, Adriatic and Ionian Seas.

The Mediterranean is unique in Europe in that it has a protected seagrass known as Posidonia oceanica (identified by green in Figure 98) which tends to grow in shallower waters typically suitable for fixed offshore wind technologies. This grass is identified in the image below off the western tip of Sicily. However it does not seem to exist in the other locations identified as potential combined offshore renewable sites. The majority of the locations have sandy mud, sand or mud as seabed material according to this survey.

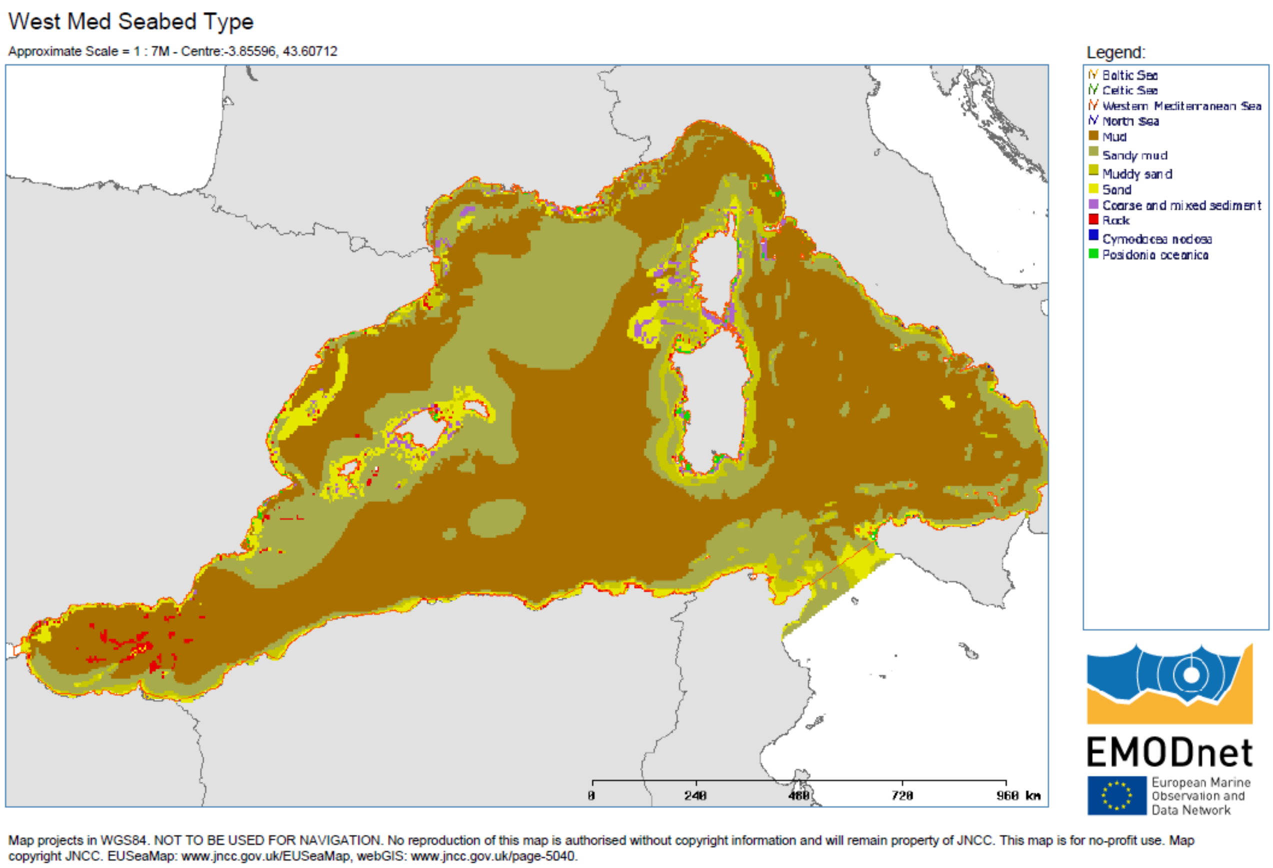


Figure 98: West Mediterranean Sea: Seabed Map[127]

8.7 Final Selection

Table 43 summarises the final site selection figures for each of the locations considered, which were given points for each parameter in the preceding sections. Based on these weighting and point allocations, the Italian combined wind and wave site appears to be the most promising receiving points of 6.75 while the French site received 5.65. This is primarily due to the better incentives available in Italy for ocean energy. It should be noted however that these locations both have a much lower wave energy resource than that of the sites chosen in the Atlantic or North Sea.

Parameter	Weighting	France		Italy	
		Points	Weighted	Points	Weighted
Resource	0.3	3	0.9	2	0.6
Incentives	0.2	4.6	0.92	9.6	1.92
Water Depth	0.2	8	1.6	8	1.6
Location	0.2	8.17	1.63	8.17	1.63
Other Uses	0.1	6	0.6	10	1
Total	1		**5.65**		**6.75**

Table 43: Mediterranean and Black Seas: Combined Wind and Wave Site Selection

8.7.1 Site 1 – Fixed, high resource area

The Italian location is situated off the west coast of Sicily. It has been shown in preceding sections however that there are a number of other users of the sea in this region such as oil and gas, MPAs, Posidonia seagrass and potentially fishing also which would need to be considered in a more detailed site selection process in order to accommodate all users of the sea.

Seismic activity is an issue unique to the Mediterranean region in Europe and is of particular importance when assessing sites near Italy and Greece.

It can be seen from Figure 99 below that there is a significant amount of seismic activity, both in terms of number and magnitude, in the Mediterranean region around Italy and Greece in particular.

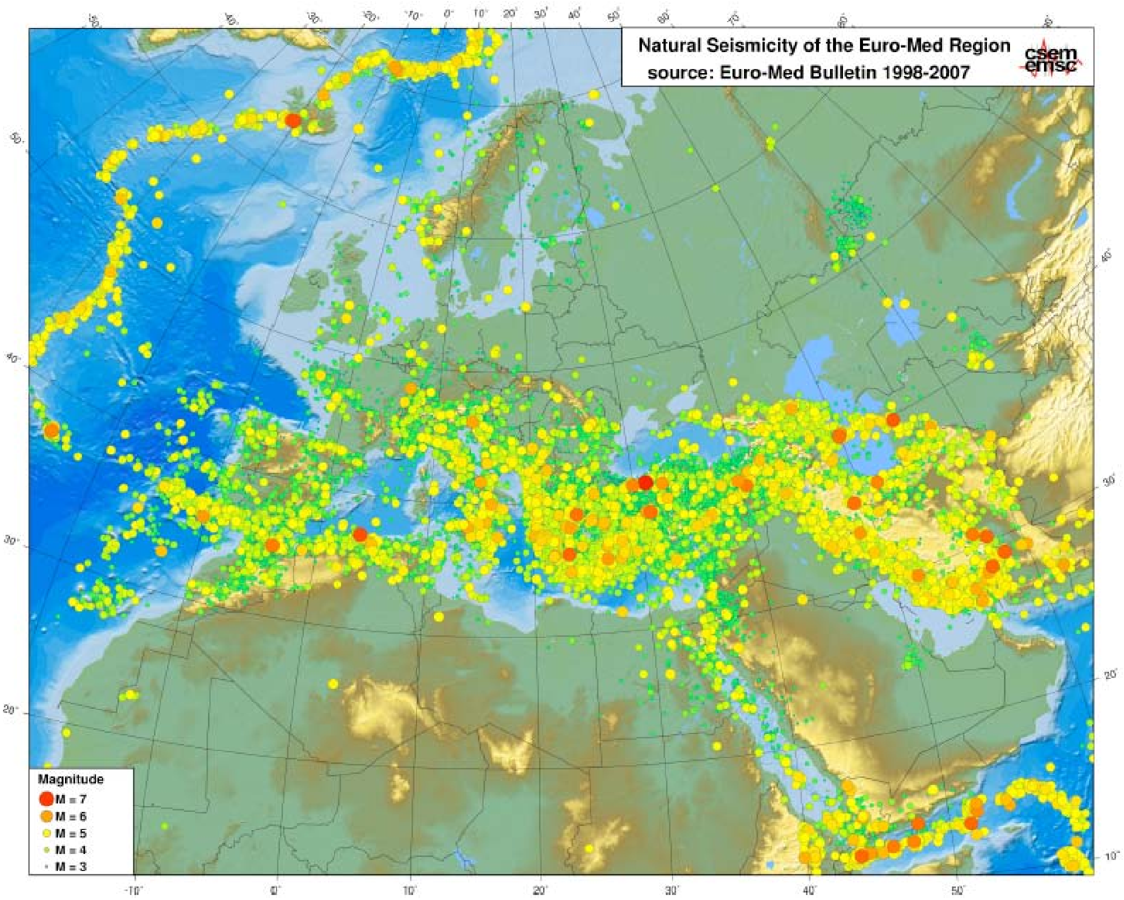


Figure 99: Distribution of Seismic Activity from 1998-2007[128]

8.7.2 Site 3 –High wind and tidal current resource area

Figure 100: Kobold Tidal Turbine in the Straits of Messina (courtesy of Ponte di Archimede[129])

The site selection methodology has shown the Italian site in the straits of Messina as the most promising combined wind and tidal location in the region. This is supported by the fact that a floating tidal turbine prototype, the Kobold, was tested in the Straits from 2001-2005 and was subsequently connected to the grid[130].

It should be noted that this assessment methodology does not take into account the tidal velocities available in the three sites and considers them as sites with a resource greater than 1.75m/s.

Parameter	Weighting	Spain		Italy		Greece	
		Points	Weighted	Points	Weighted	Points	Weighted
Resource	0.3	8	2.4	8	2.4	10	3
Incentives	0.2	2.1	0.42	9.6	1.92	1	0.2
Water Depth	0.2	9	1.8	9	1.8	9	1.8
Location	0.2	6.33	1.27	5.67	1.33	6.33	1.27
Other Uses	0.1	1	0.1	10	1	6	0.6
Total	1		6.00		8.25		6.87

Table 44: Mediterranean and Black Seas: Combined Wind and Tidal Site Selection

9 Summary and Conclusion

The ORECCA combined resource site selection study as documented in this report is the first time such an analysis has been carried out on a European scale. There are many national and European atlases, reports etc. which provide information on the most suitable wave, wind and tidal sites but none that link the various technologies together not only in terms of the resource level but also in relation to other relevant parameters. This study required analysing site selection methodologies as have already been applied and developing a specific procedure for combined technologies that fitted into the constraints of the information that was available to the project.

The site selection analysis identified many suitable areas, particularly in the Atlantic and North Sea regions that combined wave/wind energy parks could be developed. Wind/tidal sites have also been proposed but it is not envisaged that these have the same potential for development, given the limited numbers of sites and their general proximity to the shoreline where there are restrictions on the installation of wind turbines. The methodology as used is appropriate for locating general suitable areas rather than pinpointing specific sites which would require more refined input data. It accounts for various relevant aspects that affect the viability of a development and these are then weighted to provide an overall rating for each site. Whilst the weightings applied are subjective to the authors of the report, the methodology is sufficiently robust that different stakeholders could apply different weighting values to suit their particular requirements. A Geo-spatial multi-criteria method of analysis is also discussed in Section 2 which in the absence of any industry standard is becoming more accepted as the various case studies show in section 3 indicate.

The site selection considered the potential use of different foundation types both in terms of the fixed foundations that are currently limited to about 60m water depth and floating platforms which become more economical for larger depths. Most offshore wind developments in the pipeline for the next ten years plan to use fixed foundations but floating platforms will become more important as the number of suitable shallow water sites diminish.

The results of the site selection analysis show that, based on the criteria as defined in the report, the Scottish coastline, both Atlantic and North Sea, have the highest ratings. This is largely attributed to the high resource and fiscal incentive that are available. Norway is another country that rates highly but falls short mainly due to the lack of incentives for developers. However it should be noted that as a country with one of the highest penetration of renewables on the grid, there is less of a political incentive there to invest in offshore wind. This can be seen as an advantage to the rest of the North Sea and Atlantic region where the high resource could be harnessed and provided to the rest of the continent. Irelands Atlantic coastline and the south-west coast of England would be suitable for combined floating systems whilst an area of Denmark's EEZ could potentially incorporate fixed combined wind/wave platforms. Generally the Mediterranean and Black Sea did not indicate many suitable sites due to the low wave resource levels but there are possibilities for limited wind/current developments. It should be noted that Iceland was not generally considered in the analysis even though it has a high combined wind/wave resource due to it's isolated nature from continental Europe.

Areas/countries that have not been rated in this analysis should not be considered as being excluded from combined resource developments. For instance there are various developments ongoing in the

Mediterranean and also it is unlikely that the first deployments will be in the most energetic wave climate locations which are indicated in the analysis in this report. Furthermore as the industry develops the economics might change which may make marginal sites feasible. However based on the information as was available for this study, the sites as indicated should provide a starting point for examining where combined resource developments could be located.

An EU wide Marine Spatial Plan and associated mapping for coastal zones as well as farther offshore (approximately 200km or further) would be very useful in future site selection activities in line with the methodology outlined in this document.

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