Methodology for site selection for wave energy projects

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Abstract

Waveplam is a European project funded under the programme Intelligent Energy Europe, which aims at tackling non-technological barriers that may hinder the installation of wave energy projects and to speed up their introduction onto the European renewable energy market.

Inside *Waveplam*, one of the objectives is to generate recommendations for public or private promoters and investors to guide them through the process of planning and implementing a wave energy project.

The first task for achieving this objective consists of the development of a methodology for site selection. This paper introduces the methodology, which will try to help decision making through the definition of two stages. These stages relate to different levels of detail in the information promoters are going to require when planning installations at the sea.

In the first stage, gathering general information on the site will be necessary. The methodology will list the necessary information, as for example wave resource, availability of grid, proximity to end users, environmental protection areas and interference with other uses of the coast among others.

In the second stage further information gathering will begin. Ideally but not essentially, this will involve integrating the data as layers into a GIS (Geographic Information Systems) tool, given the spatial nature of the project. This tool will provide an accurate and convenient visual aid for choosing a suitable area.

Keywords: GIS, items of information, site selection, wave energy.

1 Introduction

There is a growing interest for new forms of renewable energy, including wave energy, which may be translated in the investment into and the implementation of wave energy projects. Estimates talk about a potential of 10% of the global energy demand being satisfied by wave energy when the technology is mature [1] and thus it can become a significant contributor to the European Renewable Energy market, also estimated at 10%. At the moment, experience is limited to test sites and demonstration projects, and a first incursion into a commercial park has been undertaken by Pelamis Ltd. in Aguçadoura, Portugal. As the interest grows and engineering experience overcomes the major technical problems that are holding it back, the wave energy industry will need other non technical issues to be tackled as well. Identifying and addressing these is the main objective of the *Waveplam* project, and thus speed up the introduction of wave energy into the market [2].

One of the early issues the promoters of this kind of energy will have to face is the selection of a suitable area for the deployment of their infrastructure. This may be a group of experimental devices, a commercial array or a full generation park.

Coastal areas all over the world are typically densely populated and have been so for centuries, this meaning that there is a large proportion of the coastline already committed to other uses, such as commercial ports, fisheries and aquaculture, leisure and sport activities, among others. On the other hand, it also means that there is a high energy demand in these seaboard areas.

The objective of this article is to give an introduction to a guideline through the decision making process, taking into account the available information at each stage. This guidance document will be extended into a publicly available deliverable, as the outcome of the task within *Waveplam* project. The task will aim to create a document that is easily readable for project developers and to advise them on what sort of information is necessary, the availability of this information and provide guidance on where to find it. Therefore, the main target groups for this document are public bodies, private investors, promoters and any other stakeholders that can be involved in the planning of a wave energy project. The current best practices for using the tools and applying the methods to aid the final decision will be listed.

2 Methodology

2.1 Stage 1:

The methodology for site selection proposed in this paper is an approach based on sequential steps, relating to different levels of detail in the information that needs to be gathered.

The first step of the methodology aspires to list all the relevant items of information and to provide guidance on where to find this information. In most cases this should be publicly, but not necessarily freely, available. As a result of this first step, a preliminary assessment of the suitability of the area should be obtained. This will include identification of excluded and permitted zones inside the interest area (i.e. whether it is worth investing time and money planning a project in the area).

Firstly, a step zero or a ground level action has been defined. This includes two activities:

- The definition of a general area of interest for the project; this will be a particular stretch of coastline off which the project may be implemented, and which will be the subject of the proceeding detail studies.
- The definition of the characteristics and requirements of the project as a whole. Factors such as overall power, type of wave energy devices expected to be installed; orientation and size of the delimited area, or no-go sea zones and operation depth range among others must be considered.

Resource assessment will involve investing money and hence it should only begin when there is preliminary evidence that indicates that the selected area does not have too many technical and/or environmental constraints to stop the project.

2.1.1 Gathering information

Once there is a clearer picture of the project characteristics, there are numerous items of information for promoters to consider when planning a wave energy project. Most onshore wave energy projects will be associated with the construction of new breakwaters or similar infrastructures, so the steps to be taken may vary significantly. For brevity, this paper focuses on the installation of offshore wave farms, but further information concerning onshore wave energy will be contained in the *Waveplam* deliverable.

2.1.1.1 Resource: The first parameter that needs to be assessed is what level of power resource is available in the area. A small resource does not necessarily mean that the site is unsuitable, since wave parks, and especially certain wave energy devices, can be scaled to meet the power requirements. There have been several initiatives at a national, European and international level to assess this potential and as a result a number of documents containing this information exist. Not all of them are widely or freely available. Some of these documents are described below.

WERAtlas, [3] the European Wave Energy Resource Atlas, was partially funded under the JOULE II programme, and it contains annual and seasonal (yearly, winter and summer) wave-climate and wave-energy statistics for a set of offshore locations distributed along the European coastline. 10 years of data were used to make this atlas. WERAtlas is user-friendly software for PC's running under WINDOWS. It enables the user to browse easily through the statistical information, and print and save it for future use. It consists of software to be used with Windows and a technical report. Both are available on purchase.

EUROWAVES [4], also funded by the EU, is a prototype tool to assess wave climate at any coastal or shallow water point in Europe with reliable accuracy and fine spatial resolution. It is a MatLab Toolbox containing long-term data (6-8 years) for H_s (H_{m0}), T_m (T_{01}) and mean wave direction at a large number of offshore points. The package transforms these values to an operator selected inshore location.

Ondatlas, [5], the Wave Energy Atlas of Portugal, is an electronic Atlas compatible with Internet access that contains comprehensive wave climate and wave energy statistics. These comprise monthly and yearly values, variability and probability data for significant height, mean period, peak period, and wave power and directional histograms for wave and power direction. A summary of this model is available from the article of Pontes, Aguiar and Pires.

IWERA [6] is a report that aims to study the total, feasible and practical nearshore wave energy resource off the Irish Atlantic coast. It is based on the WAM prediction model andso addresses issues such as the validation of computer models of wave climate with actual recorded data before conversion of the estimated annual average energy to electrical output. The accessible resource includes the expected efficiency of a pattern technology and all the data is graphically presented in the atlas. 3 years of data were used in it.

The Atlas of UK Marine Renewable Energy Resources [7] is an update of the 2004 Atlas with the inclusion of new data and enhanced presentation. The atlas incorporates offshore wind, tidal and the total wave resources around the whole coastline of the British Isles. The original atlas comprised of only 3 years and 3 months worth of data. This was extended to 7 years, covering from June 2000 to June 2007, for the current version. The records are taken from both the regional UK Waters Wave Model which has a grid resolution of 12km, and the Global wave model which has a node spacing of 60km. The atlas is freely available on the WEB.

2.1.1.2 Seabed morphology: Seabed morphology plays an important role in the installation of buoyant wave energy devices (WECs). As well as influencing the wave field, very irregular rocky seabed may hinder the installation of certain elements, such as the moorings for the wave energy converters.

Bathymetry is the distribution of depth in a sea area; wave energy devices can operate either onshore, offshore or near shore but they are all designed to function at certain depths. Knowing the bathymetry in an area is therefore crucial, as the cost of the installation will directly depend on the distance from the shore at which the required depth is reached. Maps of isobaths exist for most coastal areas, and are contained in nautical charts used for navigation. These will typically have low resolution information on bathymetry, but they will give a preliminary idea of whether the seabed is flat or has steep slopes. Later in the project, a bathymetry study may be necessary to produce a detailed map of the bottom.

Information on the type of seabed is not so readily available, but there are some areas that have been already surveyed. It will always be worthwhile to browse for existing papers and literature and to consult both national and regional authorities, as well as Universities and marine research bodies for information.

2.1.1.3 Existing infrastructures: Establishing a wave energy park involves installation and deployment works, special vessels and many other maritime activities. In summary, a full support network is required around it.

- Availability of grid:

The ultimate objective of a wave energy farm is to transport and distribute the produced electricity. So, even for test facilities whose main objective is research and demonstration of one or various technologies, the existence of the electric grid in the vicinity is essential. Technical details such as the existence of connection points, the voltage and the injection capacity must be found. This is related to another well discussed issue and that is the proximity of the resource to the consumption point. These are the densely populated areas, where the energy demand is high and thus it is likely that there is a strong grid supplying the area already. Information on existing distribution lines and substations is relatively easy to obtain, but to find out about connection points and injection capacity may not be so straightforward. In Spain, an official application for connection to a network needs to be sent to a utility.

- Ports and harbours: The proximity to a sizeable port will be necessary for the installation and good servicing of the facilities. Cable installing operations are a delicate process; cabling ships are costly and works can take weeks, so a nearby port is needed. Apart from the initial installation other vessels will be needed to aid deployment of new devices and for routine maintenance operations.
- Supply industry: For a similar reason to the above, the existence of local industries that can manufacture and supply some of the elements is beneficial. They must provide various services required during the life span of the project thereby disadvantaging more remote sites. These would involve such facilities and skills as shipyards, monitoring equipment, ROVs, divers, maintenance boats for in-situ works, maintenance in harbour and installation-decommissioning activity. Close proximity of the services is indeed an advantage for the project.

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

- Coastal morphology: the geographical elements such as cliffs, beaches, rivers and deltas, will all ensure the need for different, adaptable planning measures for the installation works. Some features may make it non viable to install a submarine cable whilst some others will be more operation friendly. Cartographic information is usually available from regional public authorities, either in the form of maps or as satellite images (even Google Earth contains useful data).
- Climatic conditions: wind regimes (speed and predominant direction), tidal range and currents, and temperature are additional conditions that will influence the installation. It should be noted that the useful life of these kinds of projects is typically 25 years, so extreme event records and return period data should be gathered.
- Seismicity, volcanicity and other phenomena related to active tectonic margins. Since they pose a considerable risk for any kind of facility, these should be taken into account.

2.1.1.5 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. At the very least, international rules must be consulted, such as areas included in Natura 2000 Networking and the RAMSAR wetlands catalogue. Apart from these, every regional government has a zoning plan that should be accommodated to avoid conflicts. Information on the presence of marine mammals, marine birds and their migration routes should be collected if it exists. Special attention should be paid to find out if there are any endangered species habitats in the area.

Environmental Impact Assessment (EIA) is an administrative step that a project of this nature will usually (depending on the country) have to pass, so planning with this in mind in the initial stage can help in the licensing and permissions procedure in later steps.

2.1.1.6 Interaction with other human activities: As there are many different activities taking place in the seas, this can be seen as a broad category. Some of the activities will directly prevent the installation, while others will create a conflict with the local socio economy, and thus none of them should be disregarded. This analysis should involve 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. As has been mentioned before, coastal areas are subject to great anthropic pressure and there are many parts of the coasts that are devoted to other industrial and/or economic uses. On top of that, an important part of mans' leisure activities are concentrated in coastal areas. The landscape and seascape themselves are regarded as public heritage and there is growing awareness of the need of preserving them. Some ongoing activities will exclude the project from a given area whilst other factors will impose limitations and/or make the area less suitable.

The activities include:
Oil & Gas Extraction
Aquaculture
Military Activities
Sand & Gravel Extraction
Dredging
Navigation routes
Submarine telecom/electric cables, pipelines, sewage pipes
Fisheries
Submarine Archaeology
Sports and leisure use of the coast
Landscape and seascape as public heritage

Table 1. List of the typical activities that are likely to interact with wave energy projects

Apart from the general issues listed here, there may be other aspects that are locally relevant at specific sites, and should also be taken into account.

2.1.2 Assessing the resource

After a preliminary collation of the information has been completed, a developer should have an overall idea of whether the selected area has the potential to house a wave energy farm or not, due to lack of evidence of a good resource or because of other technical impediments. If it can be assumed that the area has the potential, a more detailed study of the resource needs to be undertaken. This may present a problem since there is no consensus on how to measure the potential energy for a given stretch of coast, and estimates from different organisations/bodies give considerably variable results.

Another difficulty concerning resource assessment is that, apart from the aforementioned documents [3–7], in situ measured data are rarely available to carry out a detailed assessment of resource for a particular area. This situation varies between countries with the few that have widely available detailed assessment of large parts of their coasts being in the minority. In Spain for example, it is possible to apply for measurement data from the buoys belonging to ***Puertos del Estado***. These are freely accessible; however they do not offer extensive coverage. Promoters should note that this is not possible in every country as in most of them such information is private or inaccessible.

One way of estimating wave resource is with the use of numerical models [8]; however, these need to be calibrated with real measurement data from a wave buoy. After validation with real data, propagation models can predict the wave height and energy that will reach a particular stretch of coast, by extrapolating the data and characterising the loss of energy when approaching the coast by friction with the bottom and the change in module and direction due to reflection and refraction. The model accuracy is a function of the complexity of the topography.

With the use of wave time series data, a seaway occurrence matrix (scatter diagram) can be obtained. This is a table containing probabilities (monthly or yearly, etc) of occurrence for different significant heights and mean periods.

Developers of WECs usually produce power matrixes for their devices, which show the performance of a device in every significant height and period condition. They therefore represent the power a device can extract at every given state of the sea, and are expressed in kW.

By convoluting the two matrixes, the actual power that the device can harness in a period of time is calculated.

Since most WECs are resonant devices, knowledge of the wave frequency components, or spectral shape, of the encountered seaways is required to conduct this assessment accurately. Obtaining such information can be difficult without the specific deployment of wave measuring sensors. This procedure would be analogous to erecting an anemometer mast prior to wind turbine installations. The level of detail required for this procedure will be described in the project report.

2.2 Stage 2:

Once the information with the potential of conditioning or influencing the project has been gathered, a tool that allows geographical modelling is needed. In Stage 2, all this valuable information is integrated into a GIS package, a tool that allows easy visualisation of geographically referenced information.

Every item of information that has been taken into account is now transformed into a GIS layer, rendering a patchwork of excluded zones, and areas from least to most suitable. This second part of the procedure is very similar to that one used by government bodies for the Marine Spatial Planning processes.

Geographic Information Systems is a suitable software for this task since it can integrate, process, represent and analyse geographically referenced data [9]. It allows quick visualisation of conflicts of use and interactions, analysis of alternatives, and it allows easy alterations, if needed, of position, shape, orientation, size and other parameters of the elements of the wave farm, to fit in more suitable areas and enables observation of how the conflicts change with these modifications. Fig 3 and Fig 4 show pictures of the coast overlapped by GIS layers (in different colours). These contain the geographic information converted to geometric figures that represent the restrictions.

The method followed to carry out the GIS analysis is the definition of a Suitability Index [10], which will rely on all the previous information. At present, for any stretch of coast, estuaries should be considered exclusion areas, since they are not suitable for this kind of installation due to the typically shallow depth and low energy regime. Large installations could also produce a big environmental impact. Apart from these, the rest of the coast opens up with equal probability of accommodating the facilities.

The previous items of information, now grouped in environmental, technical and socioeconomic factors, are divided into exclusive and limiting factors. Exclusive factors should be transformed in a layer in a way that the areas where they are present appear as blank, hereby given a null value so that their Suitability Index is 0. All the rest of the factors can be transformed into one layer each or grouped in the most convenient way, and given weighted values depending on the strength of the limitations. Like this, areas with best resource, least constraints and other advantages like grid and support industry can be highlighted.

The value of the Suitability Index in each point is the result of multiplying the values of all the layers that are present at that point. This value can be given in a percentage, 0-100% format, in 0 to 1 numbers or in any other suitable way.

In those regions where there is an exclusive factor, the Suitability Index turns automatically to zero, and in the rest of the areas, the Suitability depends on the number of limitations and the weight of each of these.

Technical Factors

The aspects that may interfere with the installation of the infrastructure from a technical point of view are listed below:

- Wave energy flux: this information is likely to be in the form of a continuous grid. Values for the layer must be weighted, so that high energy flux is more suitable than low energy flux.
- Type of seabed: installation methods can vary significantly depending on the nature of the bottom. For this reason, in the layer, sedimentary and rocky bottoms should be given different values. The rating will depend on the preferences of the technology or technologies that will be installed in the site.
- Access to ports and anchor zones: these areas are avoided so as to guarantee normal access and functioning of the ports and safety for navigation.
- Submarine cables: a buffer zone at each side of the cable line should be considered exclusive.
- Submarine pipelines: sewage pipes, communication cables, water pipes and others; the same principle as above can be applied, the cable and surrounding meters being taken as exclusive.

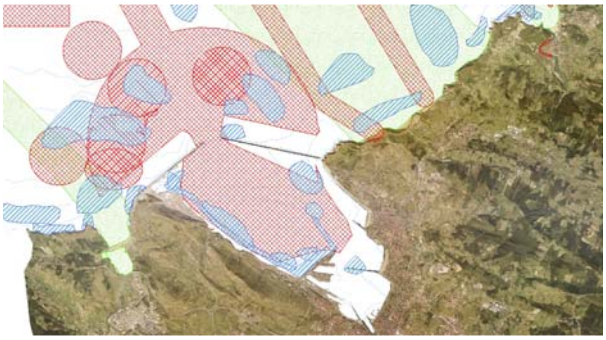

Figure 1. Multiple technically and socioeconomically restricted areas outside Bilbao port. Blue areas correspond to traditional fishing areas and red areas represent anchoring zones and the access channel to the port

- Marine military areas: in many countries, these will be considered as no go areas. But as government policies change, a negotiation could be possible in some other countries or even priority may be given to energy extraction.
- Oil &Gas extraction: platforms and deposits are considered exclusion areas, and they will typically have safety areas around them that will vary in each country. Regulations on this should be consulted. This situation can radically change in the mid term future, as renewable energies progressively substitute the use of fossil fuels.
- Maritime routes: busy marine traffic lines should also be mapped to avoid interference with them. They can be rated exclusive or limiting depending on the importance of the route.
- Areas where dredged material is dumped.
- Sand and gravel extraction zones.
- Distance to a sizeable port: as explained before, proximity to a port is considered an advantage, so the layer should contain higher values for smaller distances and lower values for long distances.

Environmental Factors

Land and coastal areas are usually subject to spatial planning by the competent authorities. All different (local, regional, national and international) legislation affecting an area and its resources need to be consulted in order to find out which areas have restrictions upon them from an environmental point of view. The following are some points on the directives that should be taken into account.

- Spaces included in Natura 2000 network:
    - Special Protection Areas.
    - Special Areas of Conservation

Whether these are exclusion areas, not recommended or indifferent will depend on how demanding the national legislation is. As the impacts on the environment in the long term are still unknown, experience gathered from the test sites that are currently installed and planned will likely provide valuable recommendations on how to proceed.

- Spaces included in the Emerald Network: Areas of Special Conservation Interest.
- RAMSAR: International Wetland Conservation treaty
- Habitats of endangered species
- Marine mammal breeding areas and migration routes: limiting factor
- Regional and national planning and zoning directives: sometimes certain coastal areas will be considered as exclusive.

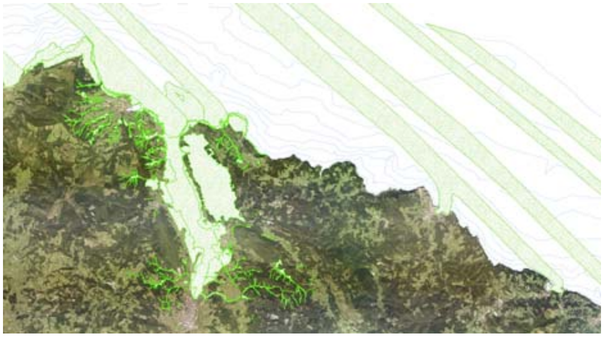

Figure 2. Biosphere reserve in Urdaibai estuary and stretches of sea where the installation could affect the dynamics of nearby beaches

- Beaches affected by the shadow of the wave farm: effects on sediment transport and beach morphology. A layer is created where stretches of sea from the beaches are drawn in the direction of the predominant wave regime, to visualise the limitation.

Socioeconomic Factors

The following do not represent technical non-viabilities, but they are factors that can hinder the installation because they are related to local population and public acceptance.

- Fishing activity: traditionally all coasts have been exploited by fisheries. Nevertheless, there are some particular areas where this activity has developed more intensely and so these can be limiting areas.
- Economic exploitation of other resources: shellfish, algae, and other marine resources are also commercially exploited; they may be considered limiting areas.
- Submarine archaeology: ship wrecks with a historical value are not found in every coast, but this may be a locally relevant factor.
- Swimming, surfing and beach leisure; the effect of a wave energy installation on tourism is unknown, but it is unlikely that leisure activities are incompatible with wave energy parks due to sufficient distance from the coast.

3 Conclusions

The selection of a suitable site for wave energy projects is not a trivial task and much information is required to conduct an informed evaluation. An accurate assessment of the available resource remains the most important factor, and this in itself demands considerable effort. Although up-to-date mathematical models can provide elements of the extensive data base required, some specific physical monitoring should be expected and budgeted for. Accurate establishment of the resource is closely followed in significance by a thorough analysis of all the possible interactions, negative or positive, of the project with existing infrastructures and the baseline environment. GIS has proven to be an ideal tool for multi-criteria spatial analysis and to considerably aid decision making.

This paper has described the methodology and all the information that would be ideally required and hence should at least be taken into account. This is as comprehensive as possible so that no factor is overlooked. Nevertheless, the authors are conscious and wish to warn the promoters that in some cases, some information can be difficult to obtain, or even impossible.

Apart from this, the situation will differ between countries, or even regions in the same country. Differences in legislation can cause the significance of the information to change as well; a factor that is no-go in one country may mean no major constraint in another country, data that is crucial in one region may be irrelevant in another one.

The *Waveplam* project will produce a deliverable that will exhaustively analyse availability of information in different countries, concerning buoy data for resource assessment and other important factors, so that the methodology results in a useful guideline for the promoters of wave energy projects. This deliverable is expected to be published and available together with other *Waveplam* documents after the end of the second year of the project in November 09.

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Legal disclaimer

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