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Multi-criteria site selection for offshore renewable energy platforms

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ABSTRACT

Geographical Information Systems (GIS) are commonly used in renewable energy resource analysis to establish optimal locations for development. Previous work focuses either on a single technology with fixed site-selection criteria, or on small, localised areas. The potential for combining or co-locating different offshore energy technologies, particularly over a large region, has been explored previously but at a relatively low level of detail. Here, bespoke resource data from high resolution co-located, co-temporal wind and wave models are presented in a GIS with a range of additional environmental and physical parameters. Dedicated decision-support tools have been developed to facilitate flexible, multi-criteria site selections specifically for combined wind-wave energy platforms, focusing on the energy resources available. Time-series tools highlight some of the more detailed factors impacting on a site-selection decision. The results show that the main potential for combined technologies in Europe is focused to the north and west due to strong resources and acceptable depth conditions, but that there are still obstacles to be overcome in terms of constructability and accessibility. The most extreme conditions generally coincide with the maximum energy output, and access to these sites is more limited.

1. Introduction

The MARINA Platform EU FP7 project (Grant agreement number 241402) aimed to develop ideas for offshore renewable energy platforms, combining wind, wave and/or tidal current power with shared infrastructure. Over one hundred designs were initially considered, with ten selected for further investigation; a final three designs have been studied in detail. To establish the locations around Europe where such platforms might be constructed, a key outcome of the project is a dedicated geographical information system (GIS). This paper presents the GIS and the bespoke site-selection support tools developed within the project, focusing primarily on the suitability of sites in terms of the available energy resource.

1.1. Combined platforms

A recent review paper [1] presents a wide-ranging overview of many of the possibilities and challenges of developing combined offshore energy platforms. The authors discuss the potential synergies to be exploited, including those relating to legislation for marine spatial planning and technology or project-specific aspects. A key benefit of combining different offshore renewable energy technologies on a single platform relates to potential for sharing space and infrastructure, thus reducing the cost per unit of installed capacity of, for example, the foundations or electricity network cabling. A further advantage is in the combination of power outputs from two types of generation. Managing the inherent variability in power output from wind and wave generators is a prominent issue in renewable energy research. It was shown in Ref. [2] that for sites along the coast of California, co-locating wind and wave devices would reduce hypothetical power variability and increase the allocated capacity credit, compared with either technology operating alone.

A similar study for Ireland [3] showed that on the south and west coasts, the variability of wind and wave power is reduced over several time scales when combined, compared to either type acting alone. In the more fetch-limited Irish Sea, there was little or no advantage to combinations, as the two individual resources were strongly correlated in time. Analysis of the particular correlation between the wind and wave resources was demonstrated in Ref. [4], for three Atlantic-facing sites in Europe. The time lags between

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the peaks and troughs in the series were identified, and different optimal proportions of wind and wave devices were found at each site.

Further studies on combining wind and wave energy at specific sites emphasise the importance of the correlation between wind and wave resources and the desired output characteristics of the platform [5–7]. Clearly the benefit of combination is site-specific and must be carefully considered as part of a site characterisation study.

1.2. Using GIS for site selection

Using GIS to choose locations for renewable energy technology has become relatively common. Developers might typically employ GIS at a number of stages, from screening a whole region to identify suitable sites, down to the point of designing array and detailed cable layouts. On a more general scale, national and regional assessments have been reported in the literature. In Ref. [8], sites around Portugal's coast were classified by their suitability for wave energy installations. Exclusion zones were identified using criteria such as environmental sensitivity and depth. The remaining area was then assessed by measurement and weighting against a second set of criteria. All factors were combined to produce a map highlighting the relative suitability of sites for wave energy development.

An extensive list of criteria was developed for identifying suitable onshore wind power development sites in the UK in Ref. [9], by consultation with a number of public and private organisations. These included basic resource parameters, but the majority were related to proximity to existing features, such as dwellings and historic sites. Sites for a small region in England were rated according to the criteria and their weightings, based on perceived importance.

Ref. [10] followed a similar approach, considering parameters relevant to wind and solar developments (individually). The energy resource parameters were given the highest weighting, followed by transmission line proximity, and then other features such as distance to roads and cities. The authors analysed the suitability of sites within areas containing different types of land-cover, indicating the types of land use where future development could take place.

The approaches described so far are mainly focused on individual, mature technologies (with the exception of [8]) and concern relatively small areas, meaning that a fixed set of selection criteria and limits can be chosen with confidence. A predecessor to MARINA, the EU FP7 project, "Offshore Renewable Energy Conversion Platforms – Coordinated Action" (ORECCA), carried out Europe-wide site selection for combined offshore energy platforms using web-based GIS, looking at a number of contributing factors including resource, water depth, and port facilities, among others [11]. The project made the first attempt at identifying the areas in Europe suitable for wind and wave in combination, by allocating ratings to sites based on their resources.

The ORECCA methodology, described in detail in Ref. [12], split the region into three parts (the North and Baltic Seas, the Atlantic, and the Mediterranean). Wind resource maps for these regions were based on wind conditions derived from scatterometer data measured by the NASA QuickSCAT satellite. The authors state that there is, however, a high degree of inherent uncertainty within this data, and it is particularly problematic close to coasts. The wave resource maps were provided by Fugro-OCEANOR via a product called 'WorldWaves' which combines ECMWF WAM modelling and validation using satellite records. To provide information on the tidal resource, ORECCA used a combination of datasets from different sources but concentrating only on a small subset of points with a resource above a specific threshold. For the purposes of considering site-selection, the ORECCA methodology considered a set of resource classes, based on the annual mean wind speed, annual wave power density, or tidal velocity from the resource databases listed previously. Scenarios of required wind and wave resources for combined offshore energy platforms were evaluated. For the combined platform resource scenarios, the available resource in each of 5 depth and 4 distance classes was evaluated, along with the total available sea area in each of the three regions.

Considering a large climatically diverse continental area, a need was identified for a spatially coherent resource dataset at an appropriately high resolution for continent-wide marine spatial planning. The temporal coherence of such data would also help to identify synergies for combined offshore energy technologies. A tool with the ability to vary different needs and priorities was also required to carry out in-depth analysis and facilitate flexible decision support for designers of combined offshore energy platforms. Where ORECCA considered in Ref. [12] the available resource in depth, distance and regional categories and qualitatively evaluated the impact of factors such as ports and environmental considerations, a quantitative analysis of the sensitivity of the amount of area available for exploitation was not explicitly presented, and thus this idea was developed in MARINA.

2. Methodology

In order to consider European-wide site-selection for combined wind-wave energy platform designs, two significantly different concepts were chosen from the final three considered in the MARINA Platform project [13], and will be labelled hereafter as 'Platform 1' and 'Platform 2'. For comparison, a generic floating wind turbine platform which encompasses a wide range of possible designs ('Platform 3') is analysed alongside these. A set of fundamental physical and resource criteria, dictated by the design of the devices, were chosen to form the basis for initial site-selection decisions for these concepts, using the specialised resource data developed for the MARINA project. Following this initial selection, a secondary analysis was carried out, building upon the analysis techniques from the ORECCA project, to quantify the sensitivity of the selection to decision criteria where the limits are not clearly defined, for example, distance to port and environmental exclusions. Finally, a number of 'case study' sites were chosen for further detailed analysis of their suitability based on parameters that are too complex to consider continent-wide but where the bespoke resource data offers useful insight. Where insufficient design information was available for the combined platforms, floating wind turbine designs were used under the assumption that processes for combined platforms would be somewhat similar. Basic GIS techniques along with bespoke decision tools were applied for each aspect of the selection process and analysis.

2.1. Data

The foremost consideration for site selection for marine renewable energy platforms is, of course, that of the wind, wave and current energy resources. A bespoke model was created for the project to produce a 10 year (2001–2010) hindcast of the key wind, wave, oceanographic and tidal current parameters at an hourly resolution on a co-located $0.05^\circ \times 0.05^\circ$ grid, referred to hereafter as the 'Wind-wave-current (W2C) atlas'. The models and processes used to generate this atlas are described further in Appendix 5.1. Statistics based on the hindcast parameters from the W2C atlas have been calculated and form the resource map layers in the GIS. The following parameters are available for analysis: