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Multi-criteria evaluation of wave energy projects on the south-east Australian coast

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ABSTRACT

In the last decade, multiple studies focusing on national-scale assessments of the ocean wave energy resource in Australia identified the Southern Margin to be one of the most energetic areas worldwide suitable for the extraction of wave energy for electricity production. While several companies have deployed single unit devices, the next phase of development will most likely be the deployment of parks with dozens of units, introducing the risk of conflicts within the marine space.

This paper presents a geo-spatial multi-criteria evaluation approach to identify optimal locations to deploy a wave energy farm while minimizing potential conflicts with other coastal and offshore users. The methodology presented is based around five major criteria: ocean wave climatology, nature of the seabed, distance to key infrastructure, environmental factors and potential conflict with other users such as shipping and fisheries.

A case study is presented for an area off the south-east Australian coast using a total of 18 physical, environmental and socio-economic parameters. The spatial restrictions associated with environmental factors, wave climate, as well as conflict of use, resulted in an overall exclusion of 20% of the study area. Highly suitable areas identified ranged between 11 and 34% of the study area based on scenarios with varying criteria weighting. By spatially comparing different scenarios we identified persistence of a highly suitable area of 700 km^2 off the coast of Portland across all model domains investigated. We demonstrate the value of incorporation spatial information at the scale relevant to resource exploitation when examining multiple criteria for optimal site selection of Wave Energy Converters over broad geographic regions.

1. Introduction

Diminishing fossil fuel reserves and concern about global warming have stimulated the advancement of alternative energy sources. Concurrently, as energy demand and awareness of the need for renewable energy sources increase, interest in alternative forms of energy from marine resources, such as those produced by waves and tides, are receiving global attention. This has the potential to be translated into increased investment into wave energy projects and their implementation in the future.

Australia has long been identified as one of the world's best wave energy resources [63]. Recent studies have shown that the Australian Southern Margin is one of the world's most energetic areas suitable for the extraction of wave energy for electricity production, with an average yearly power of about 30 kW/m at the 25 m isobath [4,31,34]. Moreover, Australia's distinct population distribution with over 80% found within 50 km of the coast [35] strengthen the need to facilitate the development of renewable energy projects within proximity to energy demand centres while also reducing the country high reliance on fossil fuels for electricity production (over 95% in the state of Victoria alone [3]). The state of Victoria has recently released an action plan which principal objective is to accelerate the development of renewable energy generation with a goal of 20% of electricity generation by renewables by 2020 [60].

While several Australian companies have deployed single pilot wave energy converters (WEC) in the marine environment, the next phase of development will most likely be the deployment of full

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generation parks with dozens of units forming wave farms. This next stage is already underway in Western Australia with Carnegie Wave Energy Limited having installed multiple devices in its pilot test site at Garden Island near Perth in March 2015 [65].

The development of wave farms imposes restrictions on the accessibility and use of the surrounding marine space, introducing the risk of conflicts with other marine resource users and stakeholders. Other renewable energy projects, such as onshore [15] and offshore [38] wind farms, have already faced such challenges and benefited from using a transparent and robust spatial planning process, commencing at project inception, to increase the chance for public acceptance and institutional support.

This paper presents a methodology based on geo-spatial Multi-Criteria Evaluation (MCE) in order to identify optimal locations to deploy a wave energy farm while minimizing conflicts with other coastal and offshore users. We present a case study along a stretch of coast in excess of 500 km in south-east Australia where a MCE methodology is applied. The justification for the choice of major criteria, sub-factors used in the study, and sensitivity to parameters employed are discussed. We then present the implications of the MCE approach to the study area including the sensitivity of parameters and influence on site selection.

The paper is structured as follows. Section 2 introduces the methodology and the preliminary screening process with the project stakeholders. Section 3 provides a presentation of all 18 GIS parameters considered within the MCE. Section 4 details the generation process of the five major criteria used to identify the most suitable sites. The application of the methodology and results for the case study are then presented and supplemented with a sensitivity analysis. Finally Section 5 presents conclusions and recommendations for future works.

2. Methodology

2.1. Multi-criteria evaluation (MCE)

Most of the recent efforts in relation to WEC planning in Australia have been on resource characterisation, at a regional scale at best [4,31,34]. While it is obvious that the wave energy resource will have a great influence on the choice of a project site, studies in Europe [16,26,46,48,68,69] North Africa [58] and North-America [39] recently highlighted the need to take in account the technical and socio-economic factors in the marine spatial planning process at a resolution relevant to resource exploitation.

A recommended approach for such a planning exercise is to apply geo-spatial multi-criteria evaluation methodology employing geographic information systems (GIS). MCE is usually defined as the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process. MCE in GIS is concerned with the allocation of (marine) space to suit a specific objective on the basis of a variety of attributes derived from spatial information that the selected areas should possess and provide an approach to take in account other resource uses [11]. Advantages in using this methodology is its applicability for stakeholder engagement, by immediately generating visual information on geographical maps, as well as a way to communicate alternative scenarios and the evaluation of trade-offs that are needed when using a holistic approach. It has been used in the past two decades in urban planning [5], water resource management [61] and more recently site selection for wind farms [2,12,30,42] and aquaculture precincts [54].

Standardised factors are combined by means of weighted linear combination, where each factor is multiplied by a weight of relative importance, with results being summed to arrive at a common Suitability Index (SI) [21]. In addition, each result may be multiplied by the product of any Boolean constraints (restriction) that may apply. It effectively allows the creation of a Suitability Index (SI) based on information from conflicting factors and parameters and is typically formulated as follows:

$$SI = \sum_{i=1}^{n} w_i X_i \times \prod_{j=1}^{m} C_j \quad (1)$$

where w_i is a weight assigned to factor i, X_i is a criterion score for factor i. Since the various factors considered are likely to be measured in different units, it is necessary to transform them on a normalised scale, typically ranging from 0 to 1, where 1 is considered the best possible value and 0 the least suitable [11]. C_j is a constraint (value of 1 or 0 = restricted), and n and m are the total number of considered factors and constraints, respectively.

2.2. Choice and weighting of criteria

The main objective of this study is to identify the best sites for wave energy projects while minimising the risks of conflict with other users of the coastal and offshore space. Thus, it is essential to base the selection of parameters, major criteria and associated weights in the MCE methodology on the judgment and knowledge of experts with different backgrounds and the stakeholders involved in such projects.

This decision process is usually highly iterative and as such is best to be carried on at the early stages of the project. For the purpose of this study, the weights attributed to each parameters used to generate the major criteria were initially chosen based on existing literature and subsequently presented and discussed during a workshop with a panel of stakeholders and experts including developers, coastal and marine engineers, environmental scientists, utility representatives, member of governmental agencies and users of the marine space.

Based on the outcome of the preliminary discussions with stakeholders and experts, the weighting of each the parameters was agreed on in order to create the five different major criteria as well as the associated major weights to perform the base case for best site identification:

- Assessment of wave climate (WC): as it is a clear indicator of the energy resource available and the economic potential of the project;
- Seabed characteristics (SB): as it allows to identify suitable sites for installation of subsea infrastructure based on the geology and slope of the seabed, as well as provide indication on the benthic habitat and local fisheries resources;
- Distance to infrastructure (DI): as it will be of a great importance in the technical and economic success of the project, both at the development stage and during its operation;
- Environmental factors (EF): in this study limited to pre-existing restrictions related to the protection and maintenance of biodiversity; and
- Other users and stakeholders (OU): as a detection measure of potential conflict of use with other socio-economic users of the marine space.

These five major criteria considered in the present study were generated by combining physical, environmental and socio-economic geo-spatial parameters (18 in total), as described in Fig. 1 and presented in Section 3. The five major criteria were in turn combined together, as per Eq. (1), to obtain a final SI, calculated using map algebra in ArcGIS 10.3 [22], allowing the identification of the potential best location for the installation of wave energy