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Using GIS to evaluate the impact of exclusion zones on the connection cost of wave energy to the electricity grid

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Abstract

An increase in the planning and environmental restrictions associated with wind energy has led to a growth in interest towards wave energy. However, as the connection cost of a wave energy development is a driving factor in the development's feasibility, existing wind farm cable-routing techniques used by renewable energy developers may not be satisfactory. A Geographical Information System (GIS) method is presented which optimises the cable route between a wave farm and the electricity network, while taking a range of exclusion zones, such as native vegetation, into account. The optimisation is presented for a South Australian study area, which subsequently showed that exclusion zones reduce the number of suitable locations for wave energy by almost 40%. The method presented also assesses the effect that each exclusion zone applied has upon the number of suitable locations within the study area. The analysis undertaken showed that National Parks and cliffs pose a significant limitation to the potential of a wave energy industry within South Australia. Allowing the transmission route to travel through a National Park, or traverse a cliff, resulted in an increase in the number of locations from which a connection could be made to the electricity grid for less than $10 million of 33% and 50%, respectively. Conservation Parks, Wilderness Areas and native vegetation also have an effect upon the number of suitable locations for wave energy within South Australia. The GIS methods developed may be of assistance to governments in setting appropriate marine renewable energy policy, and also in identifying existing policy which may require amending if the government wishes to pursue and support the development of wave energy.

Keywords: Environmental policy; Spatial analysis; Cable route

1. Introduction

The implications of anthropogenic climate change and global warming are a serious threat to the world's ecosystems and the prosperity of human civilisations. Climate scientists argue that in order to stabilise the earth's climate and prevent further global warming, the earth requires a 70% cut in present carbon dioxide emissions by 2050 (Flannery, 2005). This urgent need for a reduction in greenhouse gas emissions has forced policy and decision makers to take a more sustainable approach to development.

As traditional forms of power generation such as coal and gas emit large quantities of greenhouse gases, governments worldwide are currently implementing policies, which aim to increase the development of renewable energy. In 2001, 'new renewables,' which include modern biomass, wind, solar, small-scale hydropower, marine and geothermal energy, comprised 2.3% of the world's primary energy consumption. However, by 2020, Goldemberg (2006) estimates that new renewables will contribute between 6.7% and 12.9% of the world's total energy consumption. Over the past decade, wind power has been the fastest growing renewable energy technology in the world with an average growth rate of 39% per annum (Caglar et al., 2006). However, the growth of wind energy in many countries has been accompanied by an increase in planning and environmental restrictions, predominantly in

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space-limited countries such as the UK (Baban and Parry, 2001). This has led to the development of offshore wind farms, and greater research and development towards marine renewable energy. Jones and Rowley (2002) report that although offshore wind energy is the fastest growing ocean-based renewable energy, growth in the wave energy industry is expected to reach US$100 million per annum by 2010. The UK Government is currently in the process of introducing marine renewable energy legislation, with the objective of speeding up the deployment of wave and tidal renewable energy technologies.

The British Wind Energy Association (BWEA) claims that the worldwide potential extractable wave resource has been estimated to be between 1 and 10 Terawatts (TWs) (BWEA, 2006). Considering worldwide electricity demand is just over 1 TW (IEA, 2004), wave power has significant potential to contribute to global energy demand. Bauen et al. (2003) state that wave energy devices are able to convert between up to 80% of the available resource to useful energy, which is a significant advantage over the 50% conversion rate attained by modern wind turbines (Davies, 2005). Further to this, Agren et al. (2003) specify that the capacity factor, which is the actual amount of power a renewable energy device produces per year divided by the amount of energy that the device could produce per year according to its rated capacity, is critical to the economic feasibility of a renewable energy development. Wave energy devices can generally produce significantly higher capacity factors than offshore or onshore wind energy devices. An additional advantage of wave energy is the ability to predict energy output in advance with more confidence than wind energy (Bauen et al., 2003), which is essential to the successful integration of intermittent renewable energy supply into national electricity grids.

Baban and Parry (2001) suggest that one of the biggest issues facing the exploitation of renewable energy is the selection of suitable sites. Geographical Information Systems (GIS) can be of assistance in this task. Multi-criteria decision analysis (MCDA), within the framework of GIS allows multiple competing site selection objectives to be taken into account at once by renewable energy developers. GIS and MCDA techniques are ideally suited to the spatial nature of site selection decision-making problems (Jankowski, 1995). The use of MCDA within GIS analysis has grown significantly in recent times; Malczewski (2006) reports that over 300 GIS-MCDA articles have appeared in refereed journals since 1990. GIS have previously been used in the siting of wind and wave farms in the UK. Baban and Parry (2001) took a range of factors into account in order to evaluate possible wind farm locations in Lancashire, England. Graham et al. (2003) completed a similar study, which evaluated potential wave farm locations off the Scottish coast. Meentemeyer and Rodman (2006) recently completed a study that used GIS to evaluate the site suitability for wind turbines in Northern California, which took a range of physical, environmental and human impact factors into account. In addition to evaluating potential sites for a certain technology, Yue and Wang (2006) have shown that GIS can also be used to evaluate between the suitability of a range of renewable energy technologies, such as wind, solar and biomass, over a specified study area. The use of GIS to assist decision-making in this field is clearly rapidly expanding.

Cavallaro and Ciraolo (2005) evaluated four different wind turbine configurations on an Italian Island using non-spatial MCDA techniques. As four locations were evaluated by Cavallaro and Ciraolo (2005) rather than a study area, the use of GIS was not necessary. However, many of the wide range of environmental, economic, social and technical factors, which Cavallaro and Ciraolo (2005) incorporated into the MCDA process, are transferable to the development of spatial site selection tools. One of the most important factors that needs to be taken into consideration within the MCDA process is the connection of the renewable energy farm to the electricity grid. This paper focuses on the development of an electricity cost GIS layer as it is a critical component of a GIS-MCDA site selection tool. The cost involved in transmitting power to the electricity network from an offshore location is much more expensive than from an onshore location, due to the cost of underwater electricity cable infrastructure. Consequently, the significant amount of capital required for a wave energy farm is hindering the development of the wave energy industry (Jones and Rowley, 2002). As the connecting transmission route constitutes a major proportion on the development cost, optimising the cost of the route will be imperative to the feasibility of wave farm developments.

Several factors need to be taken into consideration in the planning of a power transmission route between a renewable energy development and the electricity network. The cost obviously needs to be kept to a minimum, which would be achieved by following a direct route between the renewable energy farm and the network. However, Dey and Gupta (2000) discuss that optimal pipeline routing in the oil and gas industry requires the consideration of not only the shortest total distance, but also a range of accessibility and government stipulations. In the case of an electricity cable between a wave farm and the network, taking the shortest path will generally not be possible due to areas such as National Parks, in which development approval for a transmission line would be unlikely to be obtained from government authorities, and accessibility considerations such as cliffs. There are also many other environmental, social and cultural 'exclusion zones' which need to be taken into account. A review of the method used to plan the transmission route by an Australian-based wind energy developer revealed that possible exclusion zones are taken into account individually, in order to visually devise a route between the wind farm and the network, which avoids exclusion zones. Whilst this method may be satisfactory in the case of a wind energy development, it is unlikely to be sufficient for a wave energy development,