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Wave energy for Australia's National Electricity Market

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ABSTRACT

This paper examines the opportunities for the renewable resource of wave energy in Australia's National Electricity Market (NEM). Using 9 years of hourly wave resource data and a typical terminator wave energy converter performance curve, hourly electricity generation profiles and normalised annual wave energy capacity factors were calculated in spatially distributed “polygons” of the NEM. A conservative wave farm design with 3.35 wave energy converters per km, and environmental, marine park and general exclusion zone constraints, has been assumed. The polygon spanning western Victoria has the greatest capacity factor of 0.44. Integrating the hourly electricity generation data revealed that polygons in Tasmania can generate the most electricity, equal to 44.4 TWh/yr. Total generation over all NEM polygons was calculated to be 275 TWh/yr. This exceeds Australia's total electricity generation of 255 TWh for the 2011–2012 financial year. Therefore, wave energy could potentially provide sufficient electricity generation to meet demand in the NEM region.

1. Introduction

It has been known since 1799 that electricity can be extracted from the ocean's waves, when the first wave energy converter (WEC) was patented in France [1]. However, the first modern wave energy converters were researched in Japan from 1940 onwards [2]. Since the 1970's world oil crisis, ocean renewable energy is being rediscovered as a future source of zero-emissions electricity, due to concerns about climate change and government policies focussed on the development of renewable technologies to reduce CO_2 emissions [3]. Australia has committed to reducing emissions by 5% below 2000 levels by 2020, and has a renewable energy target in place to stimulate investment in zero- and low-emission technologies. Wave energy is an abundant renewable resource; resource mapping has shown that the total global wave resource is 2.11TW. This tends to be concentrated between the 40–60° latitudes in both northern and southern hemispheres [4,5].

Wave energy is particularly abundant along the Australian southern coastline. Hemer et al. [6] estimated the resource is approximately 3 times Australia's total installed capacity. Turning just 10% of that into electricity would involve a large investment of capital but it could satisfy roughly half of Australia's electricity demand. Hence, harvesting wave energy using WECs could provide a sustainable alternative for electricity generation for Australia.

This paper examines the opportunities for the renewable resource of wave energy in Australia's National Electricity Market (NEM) region. The NEM spans the east coast of Australia and South Australia. It operates on the world's longest interconnected power system, at a distance of ≈5000 km. The majority (81%) of electricity in the NEM is supplied by coal. Natural gas generation supplies 12%, hydro 5% and wind and other forms of generation make up the remaining 2% [7]. Each state (i.e. Queensland (QLD), New South Wales (NSW), Victoria (VIC), Tasmania (TAS) and South Australia (SA)) in the NEM has its own sources of generation, which tend to make up the majority of supply in each state. Interconnectors are used to transfer electricity between states. These can become congested if there is high demand in the states with greater populations, namely NSW and VIC. Therefore, it is important to examine opportunities for renewable resources in all states of the NEM to potentially avoid these issues and/or expensive interconnector upgrades. VIC in particular is vulnerable as it has a relatively poor solar resource compared to other states [8] and therefore must look to other renewable technologies, such as wind and ocean renewable energy, to meet demand. TAS has abundant renewable resources, including hydro and wind, and is connected to VIC via the high voltage direct current (HVDC) BASSlink.

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Expansion of renewable energy in TAS could help meet demand in VIC. It has been found in previous modelling studies that wave energy has the potential to make a significant contribution to electricity generation in VIC [9,10].

This study builds on the work of [9,10,12], by including greater detail in terms of time resolution and by improving the spatial aspects through incorporation of GIS data. In order to make meaningful comparisons of regions within the NEM, it has been divided into 17 approximately equally sized "polygons", as shown in Fig. 1 [11]. The polygons were designed to cover areas where it is expected the wave energy resource will be roughly similar within each polygon but not between polygons. The optimal location of the WEC chosen for the study is in water of 25 m depth. Accordingly, the length of the 25 m isobath in each polygon and the corresponding polygon area is shown in Table 1.

Previously, the average annual resource was examined, therefore as this study seeks to include greater detail, wave resource data have been compiled on an hourly basis per polygon as follows: hourly renewable resource profiles spanning 9 years; hourly renewable energy supply as generated from a wave energy converter, normalised to 1 MW per polygon; and the total amount of wave energy plant capacity that could potentially be constructed per polygon. By interpolating 3 hourly wave resource data, the intermittency of wave energy output will be exposed. Calculating WEC electricity generation on an hourly rather than annual basis should lead to a more accurate estimation of the amount of electricity that could potentially be generated in the NEM by wave energy. As the hourly information could potentially be used to assist with grid integration of this intermittent supply in Australia, it has been made available online in Microsoft Excel format [11]. In addition to improving the time resolution of the data, we have also improved the spatial resolution by using GIS-based information to exclude areas along the coastline where wave farms would not be constructed due to marine parks and shipping lanes.

The paper begins with a brief explanation of Australia's wave resource followed by a description of the wave energy converter used in the study. The methodology used follows in Section 4 which includes wave farm design and constraints based on the GIS-data and the methods used to determine the wave energy results per polygon. Results are then presented followed by conclusions.

2. Australian wave resource

Wave energy is ultimately derived from the sun. The sun warms the earth which drives winds, which drives waves. The transfer of energy from the wind to the waves occurs locally over short distances (kilometres) resulting in "wind waves", or remotely over long distances (thousands of kilometres) resulting in ocean swell. Swell periods range from about 8–14 s with wavelengths in the deep ocean of 100–300 m. The maximum wave height measured in Australian waters, over an approximately 30 year record, is 19.83 m on the west coast of Tasmania in July 1985 [11].

Average significant wave height is defined as the mean height (peak-to-trough) of the largest third of the waves. They range from approximately 2 m in the summer months, with mean peak periods of about 12 s, to approximately 3 m, with mean peak periods of about 13.5 s, in the winter months [13]. Along the NSW coast, average significant wave heights are approximately 1.5–2 m throughout the year, with a strong seasonal cycle in wave lengths and directions. During summer months, typical waves are east-north-easterly with mean wave periods of about 7.5 s, and in the winter months, typical waves are south-easterly with mean wave periods of about 8.5 s [14].

The National Oceanic and Atmospheric Administration (NOAA) WaveWatch III (NWW3) model is a global implementation of the WaveWatch III 3rd generation spectral wave model [15,16] developed at NOAA/National Centers for Environmental Prediction (NCEP) in the methodology of the 3rd generation Wave Model (WAM). The NWW3 model has been run operationally on a 1 × 1.25 latitude–longitude grid since the beginning of 1997. Significant wave height (H_s), peak wave period (T_p) and peak wave direction (D_p) have been archived at 3 hourly intervals since the model's

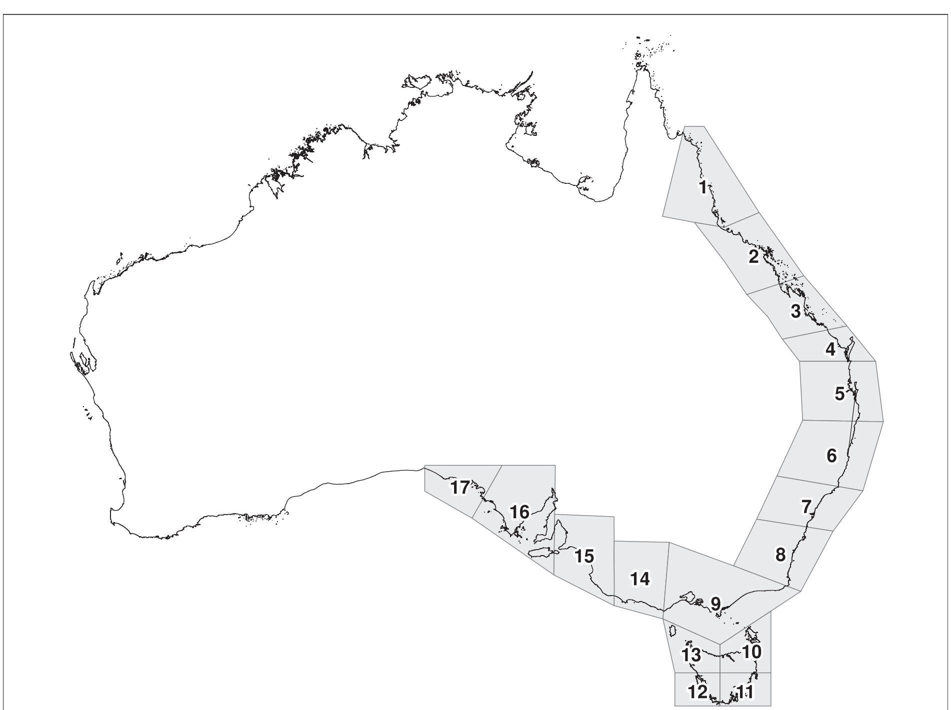

Fig. 1. Australian coastal polygons [11].