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Economic modelling of the potential of wave energy

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ABSTRACT

Wave energy is increasingly being seen as an alternative source of low-emissions power particularly for Australia, as Australia has abundant wave resources. This paper, using the performance characteristics of wave energy converters (WEC), resource measurements along Australia's southern coastline and global resource estimates, models projections of the future uptake of wave energy globally and in Australia. Globally, wave farms are projected to be installed up to a presumed maximum limit of 500 GW. In Australia there is more variability in the amount of wave farms installed, with differences across the different WEC. The outcome globally and in Australia depends on variations in the average power generated by the WEC and the carbon price path. In Australia, the majority of projected WEC installations are in the state of Victoria, which has relatively high demand and currently highly-emissions intensive sources of generation compared to states with better wave resources. When a dispatchable, or continuous power ability is added to wave energy's output the uptake of wave energy increases in Australia, in those states with the best resources. When the amount of wave energy extractable in any region is increased or decreased it has a large effect on output in Victoria in particular, which generates power from wave energy up to 30% of the total extractable resource under the dispatchable power scenario. Wave energy has the potential to make a significant contribution to electricity generation globally and in Australia. This paper is part two of a series of papers, the first being [1].

1. Introduction

Australia is fortunate to have some of the world's best wave resources along its southern coastlines. For example, Hemer and Griffin (2010) determined that the total wave energy crossing the 25 m depth isobath[1] between Geraldton and the southern tip of Tasmania is over 1300 TWh/yr, which is about five times the total electricity requirements of Australia [2].

The potential to generate large amounts of electricity from wave energy has been known since the 1970's when the first wave energy demonstration devices were deployed. Globally, after a long period of stagnation, there is now renewed interest in wave energy due to increasing awareness of climate change and specific national policies focused on renewables to reduce carbon emissions. There are currently roughly 200 different wave energy devices in various stages of development and testing. Of these, about half a dozen have been scaled up and tested at sea with at least some of their test data published [3].

This paper, using actual resource measurements along Australia's southern coastline and the performance characteristics of two types of wave energy devices examines the results of modelling using two of CSIRO's energy models: the "Global and Local Learning Model" (GALLM) [4] and the "Energy Sector Model" (ESM) [5]; to project the future uptake of wave energy in Australia.

GALLM is an international and regional economic model that features endogenous technology learning. GALLM projects the global uptake of electricity generation technologies in a given policy environment [4]. The projected reductions in global and local technology costs as a result of learning-by-doing are provided to ESM for further analysis. ESM repeats the process of projecting technology uptake in Australia but with more detailed constraints on local energy resources and trade between states [5].

Each of the two device types modelled belongs to a different class of device: *Device 1* is a point absorber and *Device 2* is a terminator. These have been described in a companion paper, which also explains the production of energy from the different WEC under consideration and how that production varies with WEC and ocean resource [1].

Generic runs of both GALLM and ESM have been performed, no particular wave energy technology was assumed but rather chose parameters that were consistent with the majority of these technologies. Technology-specific scenarios were also performed, actual data for *Device 1* and *Device 2* was used, and assumed that in both models only one type of device will be built [3,6].

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[1] Contour line of constant depth.

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This paper is organised as follows: Section 2 discusses the economic models used in the analysis of the potential of wave energy, Section 3 describes the parameters used to describe wave energy in the economic models, the global and Australian results and discussion then follow for the generic case studies in Section 4 and the technology-specific case studies in 5. Finally, the conclusions are presented in Section 6. Note that this paper uses year 2006 Australian Dollars to describe all costs unless otherwise specified.

2. Model overview

In GALLM, most technological development occurs as a result of global technology deployment such that all countries benefit from the spill over effects of other countries investing in new technologies; wind power and photovoltaics (PV) are exceptions. Both wind power and PV were assigned two experience curves; wind a global curve for wind turbines and a local curve for installation costs; and PV a global curve for modules and a local curve for installation and balance of system (BOS) costs [4]. This treatment of learning curves reflects the fact that wind turbines and PV modules are sold on an international market, however, installation is handled locally. This dual approach is the preferred methodology but can be implemented only if the necessary data are available. Unfortunately, data on ocean energy local installation costs are not available since it is currently at the early stages of being developed, tested and gradually deployed internationally. A learning rate cannot be found in the literature for any ocean energy converter technologies since these are emerging technologies. A similar technology is offshore wind, since this is employed in the ocean, therefore the offshore wind learning rate of 9% was used in this paper for wave energy [7].

Before the global economic crisis in 2008, the capital cost of energy technologies was high. For wind energy for example, the price rise was due to high demand and the resultant increased profit margins and higher materials prices that this allowed [8]. These market forces have been included in GALLM as a “penalty” constraint or price premium; if demand for one technology exceeds one third of total required new installed capacity, then a premium will be placed on the price of that technology. One effect of implementing the penalty constraint in the model is that it creates a disincentive for too rapid an uptake of any single energy technology [4,9].

ESM is a more detailed, Australian state-resolved model of electricity generation and transport within Australia. This has proven to be particularly useful for wave and ocean current/tidal energy modelling since the wave resources vary widely from Australian state to state [3].

Both models were run under two different carbon price scenarios, which varied within regions in GALLM (developing world accepts a carbon price by 2025): low-price path and high-price path [10]. The low-price path is consistent with a target of 550 ppm $CO_2 - e$ concentration while the high-price path has a target of 450 ppm $CO_2 - e$. In each of these cases Australia is assumed to take part in a global greenhouse gas reduction effort where initially developed countries, but eventually all countries, contribute to abatement by 2025. The carbon prices associated with each of these scenarios is shown in Fig. 1 [10]. They were adapted in recognition of government announcements about delaying the emission trading scheme until 2013. However, since the modelling has been performed in this article, the Australian government has announced it will begin a carbon price followed by an emissions trading scheme to begin in July 2012 [11].

3. Parameters used in modelling

3.1. Initial year capital and installation assumptions - generic case studies

An initial (year 2006) capital cost for wave energy was assumed to be $7000/kW sent-out based the range provided by the International Energy Agency (IEA) [7] and is consistent with costs observed in the literature [4]. Experience curves operate on the principle of a rate of cost reduction for each doubling of cumulative capacity of wave farms. For this reason the existing level of capacity can affect the calculation of costs changes. To limit the propensity for this assumption to affect the results cumulative capacity in the same year was assumed to be 1 MW for wave energy although in reality, wave power plants are not yet at this level of deployment. It has also been assumed that no commercial wave energy farms will be built before the year 2015, due to

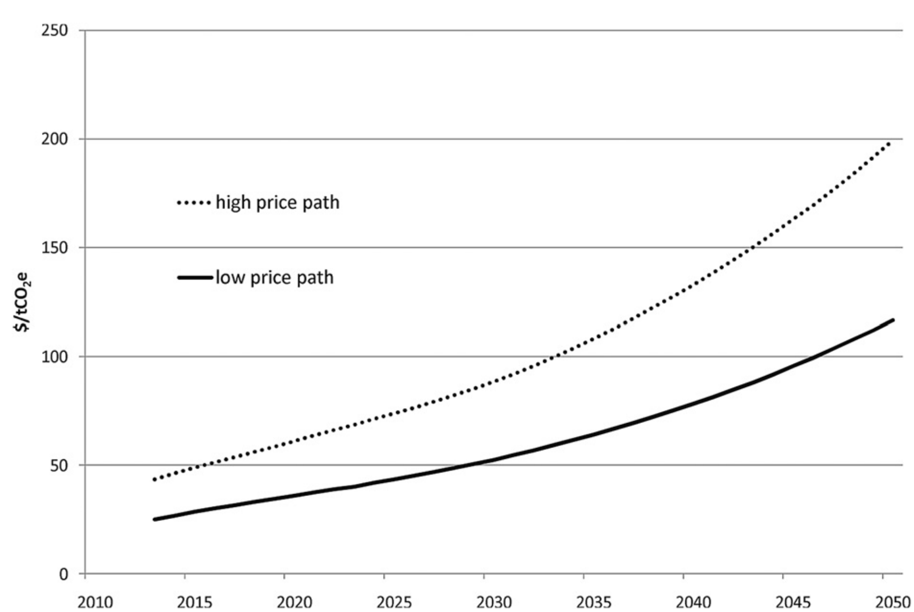

Fig. 1. Carbon price paths used in study [10].