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What cost for more renewables? The incremental cost of renewable generation – An Australian National Electricity Market case study

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ABSTRACT

This study evaluates the incremental costs of higher levels of renewable energy (RE) supply using an optimisation tool to find least cost electricity generation portfolios. The Australian National Electricity Market (NEM) in 2030 is used as a case study for exploring various generation portfolios from low to high shares of RE, low to high greenhouse gas emissions caps, and low to high carbon prices. Incremental costs are found to increase approximately linearly as the RE share grows from zero to 80%, and then demonstrate a small degree of non-linear escalation, related to the inclusion of more costly renewable technologies such as solar thermal electricity. Similarly, costs increase approximately linearly as a greenhouse gas emissions cap is lowered from 150 megatonnes (Mt) to 30 Mt, and then demonstrate a small degree of non-linear escalation for caps below 30 Mt. However, in both cases this escalation is moderate, and does not appear to provide a strong argument for long-term policies that aim for RE shares lower than 100%, or electricity sector emissions caps higher than zero as one option for rapid decarbonisation.

1. Introduction

It is clear that RE is becoming a mainstream electricity generation option. RE sources now provide almost 20% of global energy consumption, with more than half of that coming from sources other than traditional uses of biomass [20]. The rate of growth is substantial; in 2014, renewables accounted for more than 59% of net additions to global power capacity [20], with new wind and solar both exceeding new hydro capacity. This includes growth in developing countries; for example, in 2013, China's new renewable power capacity surpassed new fossil fuel and nuclear capacity [19]. While a number of countries have electricity industries with high levels of hydroelectric generation including Norway and Austria, these trends towards other forms of renewable energy suggest that a growing number of countries may have high penetrations of wind and solar power in coming decades.

Certainly, many countries and regions are accelerating the shift to renewable electricity through various policy mechanisms. For example, Denmark, Scotland, and the small-island state of Tuvalu have announced policies to derive 100% of their electricity from renewable sources [19]. Germany has a stated goal of 80% renewable electricity by 2050. Hawaii has the highest target of any state in the United States requiring 100% renewable electricity by 2045 [16]. These policies often involve setting a jurisdiction target for RE at one or more particular time horizons, as done by 164 countries as of early 2015 [20]. A range of mechanisms are available to drive deployment towards these RE targets. Other climate policy mechanisms such as carbon taxes and emissions trading schemes may not specifically target RE deployment, but can support it. When developing policies based on such mechanisms and determining the appropriate target, it is important to understand how the average cost of electricity might increase to achieve a particular target. It might be reasonable to expect that there could be diminishing returns from the higher levels of investment. For example, 90% renewable electricity may be significantly less expensive to achieve than 100%. This study explores this hypothesis.

Few studies have quantified how the incremental costs change as higher levels of renewable generation are approached. Most studies focus on moderate levels of RE, approximately 30–50% of energy. Some have explored 100% renewable energy scenarios on a variety of geographic scales [6]. For example, in the Australian

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National Electricity Market (NEM), analysis of 100% renewable scenarios has been conducted by the market operator [2] and others [9–11,25]. These studies are useful for understanding the limiting case and placing a potential upper bound on the costs. Less often, studies such as the National Renewable Energy Laboratory's Renewable Electricity Futures Study [17] explore pathways including high renewable penetrations. This analysis quantified costs for power systems with 30%–90% renewable energy, focusing on 80%. [17] quantified the change in retail electricity prices as the US power system was transformed over time to various levels of renewable penetration in 2050. The study found an additional cost of around $5 per MWh for each additional 10% in renewable generation, but did not explore the additional cost or the generating mix that would be involved in achieving 100% renewable electricity. [12] examined costs in the Portuguese electricity system associated with a small number of renewable penetration levels including 100%.

For this analysis, we use the Australian NEM as a case study. The NEM supplies approximately 80% of the electrical load in Australia, with a peak demand of 30–35 GW in summer, and annual energy consumption of around 200 TWh [3]. The NEM provides a useful and relevant case study for several reasons. First, Australia has abundant and diverse renewable resources including solar radiation, wind, biomass, deep geothermal, wave, and hydro [13]. This makes scenarios with very high renewable generation technically and economically feasible using a potentially wide range of RE technologies [2]. Second, the NEM is currently operated predominantly on fossil fuels, with 75% of electricity generation coming from coal [18]. This means that high renewable scenarios are far from the present situation, and therefore of interest when considering the full spectrum of renewable penetration levels, and in setting intermediate and long-term RE targets. Third, the NEM is a moderately sized but significant electric power system, therefore having relevance to the many other similarly sized power systems around the world.

This paper is structured as follows. In Section 2, we provide a brief summary of the modelling tool used for the scenarios presented in this paper, including a number of recent enhancements to the tool. Section 3 describes the scenarios that were modelled. Section 4 presents and discusses the results. Section 5 addresses the policy relevance of the results and concludes the paper.

2. The model

The scenarios presented in this paper are simulated using a techno-economic optimisation model known as the National Electricity Market Optimiser (NEMO[1]). NEMO couples an evolutionary program to a chronological hourly dispatch model[2] using realistic renewable generation data and measured demand from the same period. The evolutionary program searches for the least cost system subject to a small number of constraints: limiting bioenergy consumption, limiting hydroelectricity generation to the NEM long-term average, and ensuring that the NEM reliability standard of 0.002% unserved energy is met over the modelled period. Optionally, a limit on CO_2 emissions and a minimum share of renewable generation can be included as constraints. NEMO has previously been used to find least cost future 100% renewable electricity systems in the NEM [9,10] and to compare the costs of these with lower emissions fossil fuel systems based on combined cycle gas turbines(CCGTs), coal with carbon capture and storage (CCS), and CCGT with CCS [11]. A number of improvements have recently been made to the model. These enhancements include revising some assumptions, using superior renewable energy resource data, and incorporating revised technology costs. Each of these will be discussed in the following subsections.

2.1. Revised O&M costs

The [5] released an update for the Australian Energy Technology Assessment (AETA) in December 2013. The update contains revised cost and performance data for the 40 different electricity generation technologies covered after consultation with industry and other parties. These revisions have reduced the operating and maintenance (O&M) costs of some renewable technologies including two of interest in this study: concentrating solar thermal (CST) and wind power. Capital costs for all technologies are unchanged. In some cases, O&M costs have been redistributed between fixed and variable O&M, and we acknowledge the difficulty in accurately assigning such costs. The first edition of AETA was met with some criticism [4,23], however the most recent set of RE costs are now comparable to costs reported from other parts of the world; for example, wind power in the United States [24] and other RE technologies elsewhere [15].

2.2. Mid-point capital costs

In earlier work, two sets of capital costs were taken from AETA data to perform sensitivity testing on the annual system cost [10]. For the low end costs, the lowest capital cost in the range was selected for each technology. Similarly, for the high end costs, the highest costs were selected. For this work, where the focus is the change in costs, mid-point values are used ("Capital cost" column of Table 1).

2.3. Renewable generation data

The model incorporates improved renewable generation data. The Australian Energy Market Operator (AEMO) contracted the CSIRO and an Australian consulting firm, ROAM Consulting, to produce input data to support its 100% Renewable Electricity study [2]. These data cover the years 2003–2011 and span almost all of the geographic area of the NEM (Fig. 1). The NEM is divided into 43 polygons which provides a higher spatial resolution than previously available data. Importantly, the data set provides synthetic wind power data for regions where wind power is weakly cross-correlated with existing wind farms in the NEM. The improved data set includes:

- Wind – Hourly traces of wind generation obtained from the ROAM Wind Energy Simulation Tool based on the Bureau of Meteorology ACCESS-A numerical weather prediction model [21]. The wind resource data for a number of sites in each polygon are fed through a power curve function, normalised to 1 MW, and a weighted average is calculated for the polygon based on capacity limits at each site and the total capacity limit for the polygon.
- PV – Hourly traces of electrical power from a nominal 1 MW single-axis tracking solar photovoltaic (PV) system based on the average of four to six sites in each polygon; and
- CST – Hourly traces of electrical power obtained using a reference central receiver system (100 MW power block, solar multiple of 2.5, and a small amount of thermal storage) sited in four to six locations in each polygon. At each site, the heliostat field was optimised in System Advisor Model (SAM). The reference

[1] NEMO is free software licensed under the GNU General Public License so that others can use and modify the model. The project website is at https://nemo.ozlabs.org. Suggestions, enhancements, and bug reports from other users are welcome.

[2] The model allows the time step to be any duration but 1 h is used for this work.