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# Least cost 100% renewable electricity scenarios in the Australian National Electricity Market

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ABSTRACT

Least cost options are presented for supplying the Australian National Electricity Market (NEM) with 100% renewable electricity using wind, photovoltaics, concentrating solar thermal (CST) with storage, hydroelectricity and biofuelled gas turbines. We use a genetic algorithm and an existing simulation tool to identify the lowest cost (investment and operating) scenarios of renewable technologies and locations for NEM regional hourly demand and observed weather in 2010 using projected technology costs for 2030. These scenarios maintain the NEM reliability standard, limit hydroelectricity generation to available rainfall, and limit bioenergy consumption. The lowest cost scenarios are dominated by wind power, with smaller contributions from photovoltaics and dispatchable generation: CST, hydro and gas turbines. The annual cost of a simplified transmission network to balance supply and demand across NEM regions is a small proportion of the annual cost of the generating system. Annual costs are compared with a scenario where fossil fuelled power stations in the NEM today are replaced with modern fossil substitutes at projected 2030 costs, and a carbon price is paid on all emissions. At moderate carbon prices, which appear required to address climate change, 100% renewable electricity would be cheaper on an annual basis than the replacement scenario.



## 1. Introduction

This paper presents the findings of a study seeking to investigate least cost options for supplying the Australian National Electricity Market (NEM) with 100% renewable electricity in 2030. Different scenarios of technology mix and locations were assessed through simulations of electricity industry operation. A genetic algorithm was used to identify the lowest investment and operating cost scenarios.

The electricity sector is a prime candidate for rapid decarbonisation due to its significant greenhouse gas emissions yet wide range of zero emission supply options. The NEM is highly emissions intensive by world standards (Garnaut, 2011a), producing in excess of 190 megatonnes (Mt) of greenhouse gas emissions per year. This is the single largest source of emissions in Australia (Ison et al., 2011) and represents around one third of Australia's greenhouse gas emissions. Over the past decade, however, and even with relatively modest renewable energy targets, there has been significant deployment of wind and solar generation.

Recently announced renewable electricity targets for 2050 by Germany (80%) and Denmark (100%) are a bottom-up approach to mitigating greenhouse gas emissions at the national level, simultaneously addressing other objectives such as energy independence (Lilliestam et al., 2012) and competitiveness in clean technology industries (Schreurs, 2012). Although there is a well established body of academic literature going back over a decade evaluating 100% renewable energy scenarios on various geographic scales, more detailed studies are now emerging from government and industry (German Advisory Council on the Environment, 2011; Hand et al., 2012). In Australia, the Federal Government Multi-Party Climate Change Committee (2011) has requested the Australian Energy Market Operator (AEMO) to expand its current planning scenarios to “include further consideration of energy market and transmission planning implications in moving towards 100% renewable energy”.

Previous work by the authors has demonstrated the potential technical feasibility of using 100% renewable energy sources to supply current NEM demand while meeting the market's reliability standard in a given year[1] (Elliston et al., 2012b). We simulated a 100% renewable electricity system for one year, using actual hourly demand data and weather observations for 2010. In the simulations, demand is met by electricity generation mixes based on current commercially available renewable energy technologies: wind power, parabolic trough concentrating solar thermal (CST) with thermal

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[1] The NEM reliability standard is currently set at 0.002% unserved energy per year.

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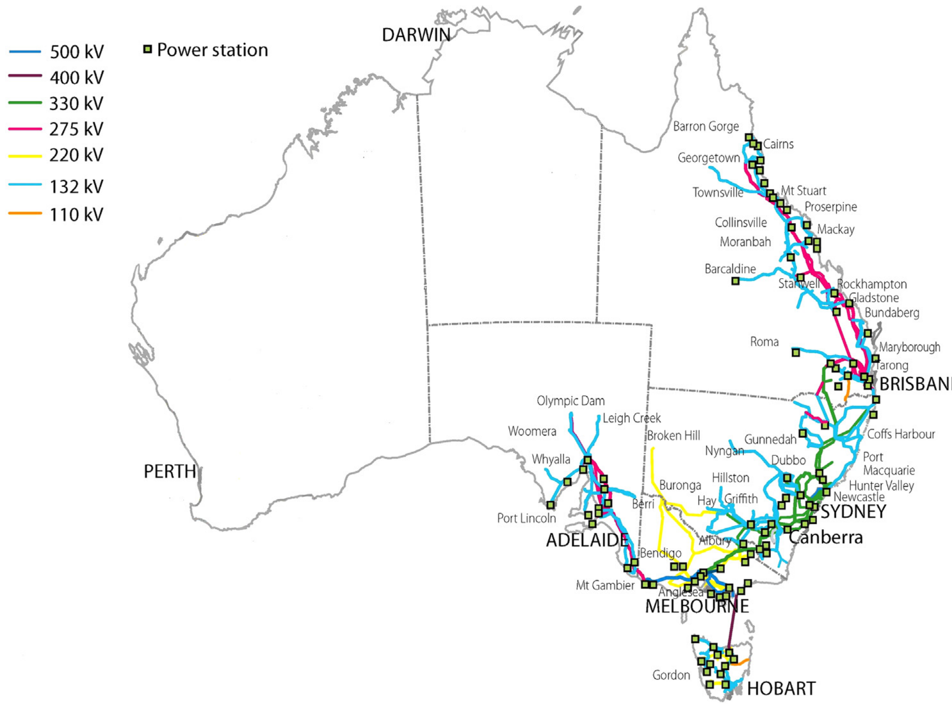


**Fig. 1.** Existing power stations and transmission lines in the National Electricity Market. Locations are indicative only. Source: Geoscience Australia.

storage, photovoltaics (PV), existing hydroelectric power stations, and gas turbines (GTs) fired with biofuels.

For the second phase of this study the simulation framework has been extended in three ways. First, the program now calculates the overall annual cost of meeting demand in the simulated year including annualised capital costs, fixed operating and maintenance (O&M) costs, variable O&M costs and, where relevant, fuel costs. Second, the simulation can now make high level estimates of transmission costs associated with different spatial deployments of renewable energy technologies. Third, the simulation framework can now be driven by a real-valued genetic algorithm[2] to search for the lowest cost configuration in the simulated year that fulfills certain constraints such as meeting the NEM reliability standard.

The earlier research contained a simplifying assumption that treated the NEM area as a 'copper plate': that is, power could flow unconstrained across the NEM. Australia is an increasingly urbanised country with 64% of the population living in the eight capital cities, mostly on the coast (Australian State of the Environment Committee, 2011). The present transmission network is oriented towards fossil fuelled generators situated close to the points of fuel extraction (Fig. 1). Some renewable energy sources are more abundant in rural and remote regions of Australia. For example, the Eyre Peninsula of South Australia has high average wind speeds, and the centre of the continent has very high direct normal insolation by world standards. Spatial mismatches between renewable electricity generation and demand may require an extensive reconfiguration of the transmission network. Transmission network refurbishment, expansion, and greater interconnection have been identified as urgent priorities for European countries to fulfil their renewable electricity objectives (Schellekens et al., 2011).

In the present paper, the 'copper plate' assumption is partially removed by separating the NEM into its five existing market regions and by introducing regional interconnections to the simulation framework. The regions are connected by a simplified transmission network with interconnectors between all adjacent regions. By accounting for regional energy exchanges, the balancing requirement between regions and the investment cost becomes evident. The ability to simulate the operation and overall costs of particular renewable technology portfolios, including transmission requirements, supports the use of evolutionary programming techniques to determine lower cost generation mixes through repeated simulations of a population of possible options.

The outline of this paper is as follows. Section 2 describes previous literature of these types of scenario studies. Section 3 presents some background to the NEM regional structure and the existing transmission network. In Section 4, an overview of the simulation program is given. Although there is a focus on the extensions made since earlier work was published, enough background information is provided to assist the reader. Section 5 describes the application of a genetic algorithm to explore the problem space of generation mixes—sites, technologies and capacities—that minimise annual cost within several constraints. Section 6 presents the results of the search. As a preliminary basis for comparing a 100% renewable system with alternative scenarios, Section 7 calculates the annualised cost of a replacement generation fleet for the NEM, where each present power station is replaced with the most suitable fossil-fuelled substitute. Section 8 provides an analysis and discussion of the results. Section 9 concludes the paper.

## 2. Previous literature

Numerous scenario studies have been published that model the potential for countries, regions, and the entire world, to meet 80–100% of end-use energy demand from renewable energy by some future date, typically mid-century. National scenarios exist for Australia (Wright and Hearps, 2010; Elliston et al., 2012b), Ireland (Connolly et al., 2011), New Zealand (Mason et al., 2010), Portugal

[2] Real-valued genetic algorithms use real numbers for chromosome values in contrast to binary digits.