Comparison of CST with different hours of storage in the Australian National Electricity Market

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ABSTRACT

The recent ratification of the Paris Climate Change Agreement has significant implications for Australia given its emissions intensive economy. It is likely that the electricity sector will need to decarbonize for Australia to meet medium- and long-term emissions reduction targets. This paper explored the potential role of Concentrating Solar Thermal (CST) in a 100% renewable National Electricity Market (NEM) system under different scenarios of CST configuration and subjected the results to sensitivity analysis.

A Genetic algorithm (GA) was chosen as the optimization algorithm to seek the least cost combination of renewable generation technologies, transmission interconnectors and storage capacity in the NEM system at hourly temporal resolution. The main finding is that the scenario where all three CST configurations (six, nine, and 12 h of thermal storage) can be deployed achieves a lower system cost than scenarios where the size of thermal storage coupled with CST is limited to one option. The results are sensitive to assumptions of the discount rate, renewable resource availability, and the cost of CST technology. This paper found that meeting demand during winter evenings is the most challenging time period for a 100% renewable NEM power system.

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1. Introduction

In October 2016, the Paris Climate Change Agreement was ratified. The main aim of the “Paris Agreement” is to limit global average temperature rise this century to well below 2 °Celsius and to pursue efforts to limit the temperature increase even further to 1.5 °Celsius above pre-industrial levels. This has significant implications for Australia given its emissions intensive economy [1].

Australia’s high ranking in emissions per capita is mainly due to coal-fired electricity generation which accounts for 72.8% of electricity generation in 2015 [2]. The dominance of coal masks Australia’s rich diversity of renewable energy resources (wind, solar, geothermal, hydro, wave, tidal, bioenergy). Except for hydro and wind energy which currently account for most renewable generation connected to the transmission system, these resources are largely undeveloped and could contribute significantly to Australia’s future energy supply [3].

While hydro, biomass, wind and solar photovoltaic (PV) are considered mature renewable technologies, other less deployed technologies such as Concentrating Solar Thermal (CST), enhanced geothermal systems, wave and tidal may become more attractive in the future due to less variability and less unpredictability in their output. These characteristics could prove more desirable in a high penetration renewable power system with significant deployment of wind and solar PV.

Studies examining 100% or zero emission renewable electricity systems are a relatively recent development in the literature. In the global context [4–8], examine the extent of renewable resource availability and find that there is sufficient diversity in resource availability to meet a 100% renewable system although this requires significant infrastructure investment in certain countries to ensure reliability of supply. Similarly [8], conducted a statistical analysis and found demand reductions through energy efficiency were crucial in meeting a 100% renewable system by 2050. In contrast [5], posit that the high economic growth and hence demand assumed in their work, prevented a 100% renewable scenario globally on a pure cost basis. That is, sufficient renewable resources remained, but became prohibitive compared to other near-zero emission generation such as carbon capture and storage (CCS).
There are also a number of country studies in the literature. Two U.S. studies [9,10] use an hourly simulation model for a 100% renewable energy system finding that significant electrification of space and water heating in buildings, private transport and industrial processes is required to substitute for natural gas use. They also identify a critical role for thermal storage and hydrogen in such a system [11]. examined the UK. positing that some nuclear generation was preferred rather than a 100% renewable system. It also suggested possible changes to market or regulatory structures that would likely assist the transition to a high penetration renewable system, but did not explicitly model the impacts of the changes themselves.

European studies [12][13][14] also found sufficient diversity of renewable resources across the interconnected continent (particularly hydro and wind) with future links to North Africa adding increased solar resources. They also found a key role for biomass, assuming that biomass residues could be stored or biofuels obtained after conversion can provide longer-term storage, implying year-round availability. Other European country studies for Denmark [16], Germany [17], Ireland [18] and Portugal [21] that used hourly temporal simulation models at different spatial scales, were more focussed on diversity in the supply side and had limited consideration of possible transmission constraints. The co-

Examination of a 100% renewable energy system in China [15], highlighted some challenges in accessing sufficient data to evaluate the potential for some renewable resources such as geothermal, wave and tidal energy. Few studies in the literature explicitly consider the impact of demographic change (e.g., ageing of the population) on future electricity demand, although the Japanese study [19] is a notable exception. For New Zealand [20], model a 100% renewable electricity system considering wind, biomass, geothermal and hydro resources, and find a crucial role for biogas as a storage medium, for use in gas turbine peaking plant.

Previous studies in the Australian context, the main focus of this paper, have explored different facets of 100% renewable electricity systems [22], considered such a system by 2020 and focused on whether there is sufficient renewable resources available and if sufficient capacity can be deployed rather than the specific policy or regulatory measures that would drive the transition. In a comprehensive study [23], found a 100% renewable power system was technically and economically feasible using a potentially wide range of renewable technologies in the National Electricity Market (NEM) [24–26], examined whether it is technically feasible to meet electricity demand with estimated renewable generation output based on historical data of demand and primary renewable resource availability in the NEM [27], used mesoscale numerical weather models to examine cross-correlations between solar and wind generation with demand for the state of Victoria [28], find that incremental costs of high renewable electricity systems increase approximately linearly as the 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. Analysis by Ref. [29] suggests that the market price cap may have to rise to ensure supply adequacy in the energy-only market of the NEM. In contrast [30], was more focused on employment gains as renewable energy production tends to be more labour intensive than non-renewable energy production.

Many studies examining high renewable penetration systems do not co-optimize the renewable mix and transmission system expansion in hourly temporal resolution modelling. The co-

Optimization is useful for system expansion planning, such as the tradeoff that exists between transmission investment, the quality of primary renewable resources, and the capacity of the storage devices. This is important given the large transmission investments that are anticipated to promote power exchange and renewable integration. An exception is [26] where an optimized power system is built up by wind farms, PV, CST with 15 h storage, existing hydro and bio-fueled gas turbines. It used 2010’s historical demand data and projected generators’ cost data by AETA [32]. The model used a simplified transmission algorithm, without the capacity constraints imposed on the interconnections. Batteries are not considered in that study.

Despite a burgeoning literature on 100% renewable electricity systems, no previous studies have explored the impact of CST with different sizing of thermal storage. This paper seeks to address this gap. The purpose of the study is to simulate the role of CST (with different hours of storage) in a 100% renewable system in the National Electricity Market (NEM), the main power system in Australia. It explores CST configurations of six, nine and 12 h of storage versus battery storage and other renewable technologies to meet a given demand at hourly temporal resolution.

In order to answer these research questions, the model framework developed in Ref. [26] is amended with an alternative dispatch module and a new transmission module. Projected demand data for 2030 from AMEO [33] is used, which is based on 2010’s demand with additional consideration on demand change in the future. The demand series includes projections of rooftop solar PV installed in the NEM and increased demand from new LNG facilities in the future. Updated cost data of renewable technologies are also used.

The paper is structured as follows. The second section of the paper explains the model and key data assumptions. The third section uses an optimized renewable mix in CST all scenario as a base case to discuss the role of CST in the 100% renewable system. Then the scenarios of different CST hour of storage options are compared. Section four discusses the relative deployment of storage devices when CST cost changes and the sensitivity of the results to different renewable resource availability and demand assumptions is also discussed. Section five concludes.

2. Model and data

2.1. Renewable technology and battery technology

This study considers numerous renewable electricity generation technologies: utility-scale solar photovoltaic (PV), onshore and offshore wind, run-of-river hydro and pumped storage hydro, CST (with different hours of thermal storage capacity), biomass (wood or bagasse) and biogas using open cycle gas turbine (OCGT). There are other renewable electricity generation technologies identified in previous studies that are not modelled, including enhanced geothermal systems, hot sedimentary aquifer geothermal systems, or ocean renewables (e.g., wave and tidal).

Hydro, on-shore wind turbines and solar PV are currently the most cost competitive and mature of renewable technologies [34]. Both pumped storage and run-of-river hydro can provide synchronous electricity to the system, which is critically important for frequency control of the power system [35]. Tasmania and the Snowy Mountains region in NSW and Victoria have rich hydro resources which are already exploited, while other regions in Australia lack quality sites. For this reason, the research here does not consider the expansion of hydro capacity in the NEM. The run-of-river and pumped storage hydro capacity data are obtained from the Australian Energy Market Operator (AEMO) data published in 2016 [36]. The study applied the monthly water inflow data and initial storage levels at the beginning of 2010 to the run-of-river hydro generators in the model. The total generation from run-of-river hydro generators is limited to 13 TWh per year.

AEMO also provide hourly generation traces of wind and single-axis tracking solar PV from 2004 to 2010 at sub-region spatial
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