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100% renewable electricity in Australia

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ABSTRACT

An hourly energy balance analysis is presented of the Australian National Electricity Market in a 100% renewable energy scenario, in which wind and photovoltaics (PV) provides about 90% of the annual electricity demand and existing hydroelectricity and biomass provides the balance. Heroic assumptions about future technology development are avoided by only including technology that is being deployed in large quantities (>10 Gigawatts per year), namely PV and wind.

Additional energy storage and stronger interconnection between regions was found to be necessary for stability. Pumped hydro energy storage (PHES) constitutes 97% of worldwide electricity storage, and is adopted in this work. Many sites for closed loop PHES storage have been found in Australia. Distribution of PV and wind over 10–100 million hectares, utilising high voltage transmission, accesses different weather systems and reduces storage requirements (and overall cost).

The additional cost of balancing renewable energy supply with demand on an hourly rather than annual basis is found to be modest: AU$25–30/MWh (US$19–23/MWh). Using 2016 prices prevailing in Australia, the levelised cost of renewable electricity (LCOE) with hourly balancing is estimated to be AU$93/MWh (US$70/MWh). LCOE is almost certain to decrease due to rapidly falling cost of wind and PV.

1. Introduction

In this paper, Australian dollars are used and an exchange rate of AU$1.00 = US$0.75 is assumed.

It is interesting to consider the practicalities of supplying all of Australia's electricity from renewable energy. In this study a scenario is developed in which the National Electricity Market (NEM) is exclusively supplied by renewable energy. The focus is on hourly energy balance (meeting demand for every hour of the year).

Deployment of wind and solar photovoltaic (PV) electricity is overwhelmingly dominant in terms of new low emissions generation technology because they cost less than alternatives. PV and wind constitute half of the world's new generation capacity installed in 2014–16 (Fig. 1). In recent years, these sources provided nearly all new generation capacity installed in Australia.

In Australia, wind and PV are unconstrained by land or resource availability or water requirements or material supply or security issues. Hydro power is unable to keep pace due to the constraint that there are a limited number of rivers to dam, and bioenergy is severely limited by sustainable biomass availability [4,5]. Heroic growth rates are required for other renewable or low emission technologies (nuclear, carbon capture & storage, concentrating solar thermal, ocean, geothermal) to span the 10–1000-fold difference in annual deployment (GW per year) to approach the scale of wind and PV – which are moving targets since both industries are themselves growing rapidly and both access large economies of scale.

Currently, two thirds of Australian electricity comes from coal fired power stations. However, by 2030, three quarters of these power stations will be more than 40 years old, and replacement of these generators by coal, gas or renewable energy will be a looming necessity. For instance, Wallerawang C 960 MW (NSW), Anglesea 150 MW (Victoria) and Northern 530 MW (South Australia) and Hazelwood 1640 MW (Victoria) were closed during 2013–17 [6,7]. It seems unlikely that more coal fired generators will be constructed in Australia due to public opposition and risk aversion of financiers. In contrast, there is strong financial support for wind and PV in Australia, as evidenced by the fact that about 9 GW of wind and PV will be constructed over the next 3 years [8] in an economy whose GDP is about one thirteenth that of the United States of America.

Australia has excellent wind and solar resources. If current deployment rates of PV and wind (approximately 1–2 GW per year of each) continue then about half of the electricity generated in

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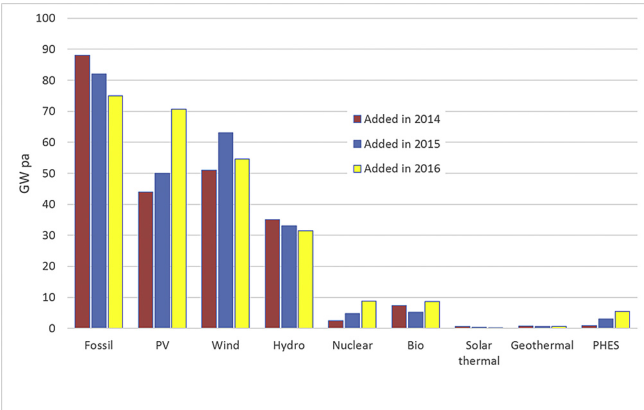

Fig. 1. Net new generation capacity added in 2014–16 by technology type. In 2016, about 125 Gigawatts (GW) of net new wind and PV was deployed, which is similar to everything else combined [1–3].

Australia in 2030 will come from renewable energy sources. In the state of South Australia wind and PV already provide about half of the annual electricity generation. The nearly zero marginal cost of PV and wind generation means that PV and wind electricity (when available) are used in preference to electricity from coal and gas. This causes declining system capacity factors for coal and gas power stations, which causes economic pressure on their continued operation. However, closure of coal and gas power stations removes the ancillary benefits that they provide, including coping with periods of poor solar and wind availability and managing short term supply fluctuations over differing time periods via inertia, spinning reserve and dispatchability.

This work differs from previous international work that examines high renewable energy futures in a range of countries. Bogdanov and Breyer [9] provide a good summary of previous work. Key differences from previous work are summarised in section 3.2.

This paper is divided into a modelling section and a results section. Within the modelling section we discuss generation, transmission, storage, grid stability, environmental considerations, economic parameters and the modelling methodology. Within the results section we include modelling outcomes, a sensitivity analysis and comparison with previous work. Finally, we include a discussion to place the modelling in context.

2. Modelling

2.1. Assumptions

We model the Australian National Electricity Market (NEM) which services 19 million people [10], but exclude the much smaller systems that exist in Western Australia, the Northern Territory and remote regions in other states (which are not connected to the NEM).

In our modelling, we make the following conservative assumptions:

- NEM demand remains stable at 205 TWh per year (including roof-mounted PV). NEM demand has changed little since 2008 [11], with energy efficiency offsetting growth in demand (driven mostly by population growth). Electrification of land transport (which could add 30–35% to electricity demand in the future [12]) is excluded in order to focus on the current electricity system.
- Batteries are excluded. Batteries located in homes and electric cars may contribute very substantially to future energy storage, either directly through bi-directional energy flow or indirectly through control of the timing of battery charging.
- Heroic assumptions about future technology development are avoided: the only low emission technologies considered are those that are being deployed in large quantities (>10 GW per year), namely PV and wind. On this basis, nuclear, bio, solar thermal, geothermal and ocean energy are excluded. We also exclude nuclear energy because of the unlikelihood of its deployment in Australia.
- High voltage DC (HVDC) and AC (HVAC) transmission and pumped hydro energy storage (PHES) is included to help provide balancing between supply and demand.
- Existing hydroelectricity generation and pumped hydro stations are included but additional river-based hydroelectric deployment are excluded due to lack of significant further rivers to dam in Australia. Existing biomass generation (based on agricultural waste) is included, but additional deployment of biomass is excluded because utilization competes with food, timber and ecosystem values for the provision of land, water, fertilisers and pesticides. Wind and PV contributed about 18 TWh in Australia in 2015, compared with hydroelectricity (14 TWh) and biomass electricity (3 TWh) [13].
- Our scenario is that wind and PV contribute about 90% of annual electricity consumption, while existing hydro and biomass contribute the balance.
- Energy balance modelling is undertaken using historical data for wind, sun and demand for every hour of the years 2006–10 and ensuring that there is sufficient electricity to meet demand in every hour through utilization of sufficient PV, wind, PHES and HVDC/HVAC. The Levelised Cost of Energy (LCOE) for each solution is then calculated.
- A modified and extended version of the National Electricity Market Optimiser (NEMO) model [14,15] is used to identify solutions which meet the energy balance requirement. NEMO is a chronological dispatch model. Several adjustments to the NEMO model have been made to better utilise the capability of synchronous, fast-ramping PHES to integrate fluctuating solar and wind energy. This includes pre-charging PHES facilities from existing bio and hydro plants to help ride through critical periods based on advanced weather forecasting; and changing the merit order of existing hydro ahead of PHES in critical periods to ensure PHES is not exhausted before the most difficult moments arrive.
- The NEM standard for unmet energy demand (0.002%) is required except where stated otherwise.
- Dynamical simulation for robustness under fault conditions is not included, such as unexpected transmission line breakdown, bushfires or widespread severe weather. However, we note that PHES provides significant inertia, spinning reserve and rapid response capability to help maintain a high level of dynamical grid stability. Although outside the scope of this study, dynamical stability will be included in future work.

2.2. Off-river (closed loop) pumped hydro energy storage

Pumped hydro energy storage (PHES) entails using surplus energy to pump water uphill to a storage reservoir, which is later released through a turbine to recover around 80% of the stored energy. PHES constitutes 97% of electricity storage worldwide (159 GW [3]) because it is much cheaper and has much greater technological maturity than alternative sources, including batteries.