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Reliability of 100% Renewable Electricity Supply in the Australian National Electricity Market

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ABSTRACT

Australia has one of the highest per capita greenhouse gas emissions of industrialised countries, mainly resulting from its high dependence upon coal for electricity generation. To explore technological options for the transition to a renewable energy future, we have developed computer simulations for 100% renewable generation to meet hour-by-hour electricity demand in the Australian National Electricity Market (NEM) for the year 2010. Supply is provided by various mixes of concentrating solar thermal (CST) power with thermal storage, wind, photovoltaics, existing hydro, and peaking gas turbine plants running on biofuels. Hourly generation from wind and solar is simulated using meteorological records for 2010.

The 100% renewable mixes are found to be technically feasible and meet the NEM generation reliability standard. The principal challenge in a supply system based on a high solar contribution is to meet peak demand on winter evenings following overcast days. The simulations achieve this in several alternative ways: a large generating capacity of peaking gas turbines; reducing peak demand on winter evenings; increasing CST generating capacity; increasing the CST solar multiple; and increasing the geographic distribution of wind farms. There is no need for any base-load power stations in the system. This research is relevant to other regions with a high potential for CST, such as south-west USA, North Africa, the Middle East, north-west China and north-west India.

Keywords: *Renewable electricity, scenario, simulation, baseload power stations.*

1 INTRODUCTION

This paper reports on simulations to identify, quantify and address the challenges of reliably supplying 100% renewable electricity to the five states and one territory spanned by the Australian National Electricity Market (NEM). Today, the NEM produces around one third of Australia's total greenhouse gas emissions, because the system derives around 90% of supply from bituminous coal, lignite and natural gas, and because of high per capita electricity consumption. If Australia, currently one of the world's highest per capita greenhouse emitters, is to make its fair contribution to global emission reductions, then its emissions intensive electricity industry must rapidly transition to zero carbon sources. The only zero carbon 'sources' that are commercially available and seem likely to be able to make large contributions before 2020 in the Australian context are certain renewable energy sources [1] and demand reduction (eg, through efficient energy use).

Numerous scenario studies have been published that model the potential for several countries [2-10], northern Europe [11], and the entire world [12-15], to meet 80–100% of end-use energy demand from renewable energy by some future date, typically mid-century. These scenario studies do not typically specify a transition path nor do they share a common methodology for analysis. However, they are valuable in showing that aggressive reduction in fossil fuel use is possible and provide a vision of how such a future energy system might look.

Electrical power systems must match time varying and somewhat unpredictable supply with time varying and somewhat unpredictable demand at all times and all locations across the network, and there are currently limited energy storage options. The variability of weather-driven electricity generation introduces additional sources of temporal and spatial variation and uncertainty [16, 17].

This paper reports on simulations of a 100% renewable electricity system in the region spanned by the NEM for the year 2010, using actual demand data and weather observations for that year, all converted to hourly averages. Demand is met by electricity generation mixes based on current commercially available technology: wind power, parabolic trough concentrating solar thermal (CST) with thermal storage, photovoltaics (PV), existing hydroelectric power stations, and gas turbines fired with biofuels. In this paper results reported in our recent publication [10] are reviewed and extended to include a wider geographic distribution of wind farms. By minimising the number of working assumptions and by sensitivity analyses, we aim to provide some insights into the potential contribution from different renewable sources and the reliability implications of 100% renewable electricity for the NEM.

2 METHOD

The computer simulation program, developed by the lead author, is written in the Python programming language. At this stage of the research the entire NEM region is treated as a 'copper-plate': that is, power can flow unconstrained from any generation site to any load site. Hence, demand across all NEM regions is aggregated, as is supply.

In general, dispatch proceeds from the lowest operating cost plants without energy storage (eg, wind and PV) before the dispatch of flexible plant with energy storage (eg, hydro and gas turbines). If supply cannot meet the demand, the shortfall is recorded and the hour is marked unmet. Conversely, if available supply exceeds demand, the simulation attempts to find another generator in the system that can store the excess power (eg, by pumping at a pumped storage hydro station). Any remaining surplus power is then recorded as having been spilled.

The original data on NEM demand were 30-minute averages, publicly available from the Australian Energy Market Operator (AEMO). Satellite-derived estimates of global horizontal irradiance and direct normal irradiance in 2010 for the Australian continent were provided by the Australian Bureau of Meteorology at 5km by 5km spatial resolution and hourly intervals. Electricity generation data reported by all wind farms over 30 MW and operating in the NEM in 2010 are also publicly available from AEMO. These data, comprising average wind power at each wind farm over the five-minute dispatch interval, were averaged into hourly values, as was the demand data. Almost all Australia's wind

farms are in essentially the same wind regime in south-eastern Australia and so the fluctuations in total wind power output for scaled up wind penetrations can be large [18]. Therefore, for the research reported in this paper, the wind farm data were supplemented with hourly wind data for 2010 in two locations (Hughenden and Cooranga) in the northern state of Queensland, thousands of kilometers from the wind farms in the south and south-east of the NEM. For these sites, wind speed and direction were generated using the CSIRO's 'The Air Pollution Model' (TAPM). Hourly wind speeds and directions were obtained for four different levels (10 m, 50 m, 100 m, and 200 m) and formatted into a data file suitable for use with a utility-scale wind farm model in the US National Renewable Energy Laboratory's System Advisor Model (SAM), a performance and financial model of various renewable energy technologies. The wind farm model was used to produce hourly electrical power for a 57.6 MW wind farm comprising Vestas V100-1.8 turbines. These data were then scaled to the desired wind farm size in the simulations.

SAM was also used to model the hourly power generation of PV and CST systems in selected locations in 2010, allowing realistic generation data to be included in the simulation.

More details of the method and data sources are given elsewhere [10].

In 2010 NEM peak power demand was 33.6 GW and occurred in summer. The next highest peaks were around 30 GW and occurred in winter.

The generators in the baseline scenario are summarised as follows, in order of dispatch:

- Wind: existing wind farm output scaled to 23.2 GW; average capacity factor 30%; supplying about 30% of annual electrical energy.
- PV: 14.6 GW; average capacity factor 16%; supplying about 10% of annual energy. Flat-plate distributed on the rooftops of the mainland capital cities of the NEM, according to population.
- CST: 6 sites in 3 states, 2.6 GW per site, 15.6 GW total; solar multiple 2.5 and 15 hours storage; average capacity factor 60%; supplying about 40% of annual energy.
- Pumped storage hydro, existing, 2.2 GW. Opportunistically charged using surplus renewable power with a round-trip efficiency of 0.8; dispatched to meet critical peak loads.
- Hydro, existing, without pumped storage, 4.9 GW.
- Gas turbines, biofuelled, 24.0 GW, dispatched last in merit order to meet supply shortfalls; always less than 15% of annual energy because of limited resource of biomass residues.

3 RESULTS

3.1 Baseline simulation

The simulation summary report is shown in Table 1. The baseline scenario meets 2010 demand within the current NEM reliability standard, namely an energy shortfall (unserved energy) no greater than 0.002%, despite six hours on winter evenings when demand was unmet.

Table 1 Baseline NEM simulation 2010 summary report

Annual energy demand (TWh)	204.4
Spilled energy (TWh)	10.2
Spilled hours (all on winter evenings)	1606
Unserved energy (%)	0.002
Unmet hours	6
Electrical energy from gas turbines (TWh)	28.0
Largest supply shortfall (GW)	1.33

3.2 Sensitivity analyses

Five sensitivity analyses examine various options for improving the reliability of the system or reducing the biofuel consumption through lower utilisation of gas turbines. The first four are reported in more detail elsewhere [10] and so graphs are not included here. The fifth is original to this paper.

3.2.1 Reducing demand

A 5% reduction in the six demand peaks that exceed supply is sufficient to bring demand and supply into balance for every hour of the year. As all these peaks occur on winter evenings, this reduction could be readily achieved through energy efficiency measures, particularly by reducing residential heating demand, or by temporarily interrupting controllable loads. Furthermore, when demand is reduced by 19% during unmet hours, the NEM reliability standard can still be met when the gas turbine capacity is reduced from 24 GW to 15 GW.

3.2.2 Increasing solar thermal plant capacity

To overcome the decline in CST generation during winter and consequent increase in bioenergy consumption, we examined the effect of doubling the total generating capacity of CST plants, while keeping the solar multiple constant at 2.5 and the storage at 15 full-load hours. This change reduces the number of unmet hours from six to two, reduces the gas turbine generation modestly, but increases total spilled energy significantly. This, and current high costs of CST technologies, suggest that increasing CST capacity could be a very expensive means of meeting peak demand in winter.

3.2.3 Increasing CST solar multiple

Another strategy to reduce biofuel consumption was tested by increasing the solar multiple of the CST plants from 2.5 to 4.0, while keeping the CST generating capacity and storage capacity constant. In other words, the size of the solar field is increased. This change is much more effective in reducing gas turbine generation than increasing the overall CST generating capacity, but is still likely to be expensive.

3.2.4 Delaying CST dispatch in winter

An alternative winter operating strategy for the CST plants is to delay the dispatch until the evening, so that peak generation coincides with evening peak demand. Delaying CST dispatch, while maintaining reliability fixed, permits the gas turbine generating capacity to be reduced, with the minimum capacity occurring with a five-hour delay. This

confirms the result by others [19] that CST contributes more to the evening peak while PV contributes to supplying daytime demand.

3.2.5 Expanding the diversity of wind regimes

To gauge the effect of greater wind diversity in reducing bioenergy consumption, we substitute part of existing wind energy generation with output from hypothetical wind farms at Hughenden and Cooranga in Queensland, while maintaining total annual wind generation at 66 TWh. As winds at Cooranga and Hughenden are less correlated with the existing NEM wind regime, wind power in these sites reduces the need for supply from biofuelled gas turbines, as shown in Figure 1. Hughenden, being more distant than Cooranga, eliminates more bioenergy.

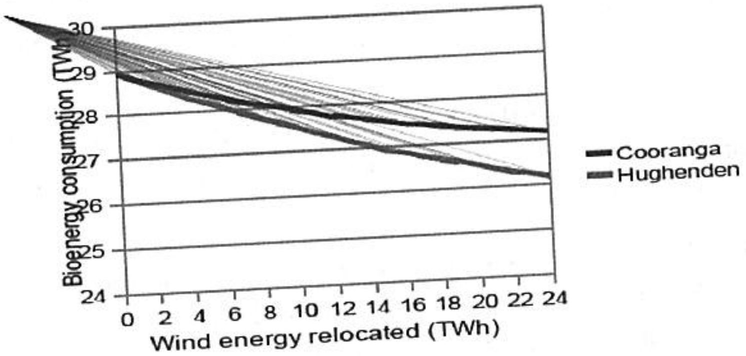

Figure 1- Effect on biomass consumption of relocating wind energy

4 CONCLUSION

This research demonstrates that 100% renewable electricity in the Australian NEM, at the current reliability standard, would have been technically feasible for the year 2010, based on several possible mixes of commercially available renewable energy technologies. This entails a radical 21st century re-conception of an electricity supply-demand system. The focus is shifted away from replacing base-load coal with alternative base-load sources. Instead, generation reliability is maintained in a system with large penetrations of variable renewable sources by having as great a diversity of solar and wind sites as possible, large capacities of flexible peak-load generators, and thermal storage. In a 100% renewable electricity system, the concept of base-load power station is redundant.

In geographic regions with high levels of insolation—such as south-west USA, Mexico, North Africa, the Middle East, north-west China, north-west India and Australia—solar energy sources, both CST and PV, can together make the major contribution to electricity generation. Then the principal challenge is to generate sufficient power during the evening peak demand periods in the winter months. On winter evenings following overcast days there is insufficient energy in the CST thermal energy storage and sometimes there are lulls in the wind. Possible solutions are to install a high capacity of peaking plant; to increase CST generation capacity with fixed solar multiple; to increase the CST solar multiple with fixed CST generating capacity; to delay the dispatch of CST power until evenings in winter; to increase the geographic diversity of wind farms; and to reduce demand peaks, especially for the heating load on winter evenings. An economic analysis is needed to rank such options and this work is now underway.

REFERENCES

[1] Australian Department of Resources, Energy and Tourism, 2011. *Draft Energy White Paper 2011: Strengthening the foundations for Australia's energy future.* Canberra: Commonwealth of Australia.

[2] Lehmann, H. 2003. *Energy Rich Japan.* Technical Report. Institute for Sustainable Solutions and Innovations. Retrieved December 15, 2011 from: http://energyrichjapan.info.

[3] Lund, H. and Mathiesen, B. 2009. Energy system analysis of 100% renewable energy systems–the case of Denmark in years 2030 and 2050. *Energy* 34:524 – 531.

[4] Mason, I., Page, S. and Williamson, A. 2010. A 100% renewable electricity generation system for New Zealand utilising hydro, wind, geothermal and biomass resources. *Energy Policy* 38:3973-3984.

[5] Kemp, M. and Wexler, J. 2010. Zero Carbon Britain 2030: A *New Energy Strategy.* Technical Report. Centre for Alternative Technology. Retrieved December 15, 2011 from: http://zerocarbonbritain.com.

[6] Wright, M., Hearps, P. 2010. *Zero Carbon Australia Stationary Energy Plan.* Technical Report. Beyond Zero Emissions. Retrieved December 15, 2011, from: http://beyondzeroemissions.org/zero- carbon-australia-2020.

[7] Connolly, D., Lund, H., Mathiesen, B. and Leahy, M. 2011. The first step towards a 100% renewable energy-system for Ireland. *Applied Energy* 88:502-507.

[8] German Advisory Council on the Environment, 2011. *Pathways towards a 100% renewable electricity system.* Tech. Report. Berlin, Germany. Retrieved Dec. 15, 2011 from: http://www.umweltrat.de/EN.

[9] Krajacic, G., Duić, N., da Graça Carvalho, M. 2011. How to achieve a 100% RES electricity supply for Portugal? *Applied Energy* 88: 508-517.

[10] Elliston, B., Diesendorf, M. and MacGill, I. 2012. Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market. *Energy Policy* doi:10.1016/j.enpol.2012.03.011

[11] Sørensen, B. 2008. A renewable energy and hydrogen scenario for northern Europe. *International Journal of Energy Research* 32:471–500.

[12] Sørensen, B. and Meibom, P. 2000. A global renewable energy scenario. *International Journal of Global Energy Issues* 13:196–276.

[13] Jacobson, M.Z. and Delucchi, M.A. 2011. Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy* 39:1154-1169.

[14] Delucchi, M.A. and Jacobson, M.Z. 2011. *Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies.* Energy Policy 39: 1170-1190.

[15] WWF 2011. The Energy Report: 100% *Renewable Energy by 2050*. Technical Report. World Wide Fund for Nature. Retrieved December 15, 2011 from: http://wwf.panda.org/energyreport.

[16] MacGill, I. 2010. Electricity market design for facilitating the integration of wind energy: Experience and prospects with the Australian National Electricity Market. *Energy Policy* 38:3180-3191.

[17] Outhred, H. and Thorncraft, S. 2010. Integrating non-storable renewable energy into the Australian electricity industry. *In Proceedings of 43rd Hawaii International Conference on System Sciences* (HICSS), pp. 1-10.

[18] AEMO 2011. South Australian Supply and Demand Outlook. Section 5.4. Retrieved March 21, 2012 from: http://www.aemo.com.au/planning/SASDO2011/sasdo.html

[19] Denholm, P. and Mehos, M. 2011. Enabling Greater Penetration of Solar Power via the Use of CSP with Thermal Energy Storage. Technical Report TP-6A20-52978. Golden, Colorado: National Renewable Energy Laboratory.