Future high renewable electricity scenarios – Insights from mapping the diversity of near least cost portfolios

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Abstract — **This paper reports on future electricity generation scenarios modelled using NEMO, a model that applies a genetic algorithm to optimise a mix of simulated generators to meet hourly demand profiles, to the required reliability standard, at lowest overall industry cost. The modelling examined the least and near least cost technology portfolios for a scenario that limited emissions to approximately one quarter of those from the Australian National Electricity Market (NEM) at present. It was found that all the near least cost solutions (within 15% of the least cost solution) involved wind capacity in the range of 31-51 GW, with 98.8% of these near least cost portfolios having at least 35 GW of wind installed. In contrast, the near least cost solutions consistently involved much lower quantities of PV, with 90% of the near least cost portfolios having less than 4.9 GW of installed PV capacity. This suggests that policies to promote high levels of wind deployment and grid integration are likely to be important for achieving low cost, low emissions outcomes, while policies to promote significant PV deployment may be less warranted in the absence of cost effective supporting technologies, such as battery storage or significant demand side participation.**

Index Terms— **Renewable, Australian National Electricity Market (NEM)**

I. Introduction

Given falling costs for some renewable energy technologies and a growing urgency to reduce greenhouse gas emissions, future electricity markets with a high proportion of renewable energy generation now appear likely.

The Australian National Electricity Market (NEM) provides an interesting case study for analysis of future high renewable scenarios. Covering a wide geographic area, the NEM is a large electricity grid, but has a long, stringy transmission network that is predominantly oriented north-south (hence offering limited time zone variation) and has no international connections. Fortunately, the NEM does cover a range of climate zones and Australia has abundant renewable energy resources including wind and solar radiation.

Previous studies on future high renewable scenarios in the NEM have typically explored outcomes for only a limited number of portfolios [1, 2]. For policy makers contemplating transition pathways from the present fossil-fuel dominated system under what are invariably very high levels of uncertainty, there is considerable value in understanding the range of possible future generation portfolios that might deliver reasonably low-cost industry outcomes. A number of the optimisation tools used in these types of studies, however, provide only limited information regarding the solution space around the "optimal" result. Scenario and sensitivity analysis are often used but have their own limitations.

By contrast, searching for a least cost solution using evolutionary computation necessitates that many near-optimal solutions be evaluated as a matter of course. The use of evolutionary computation in this study allows analysis of a wide range of generation portfolio solutions that may be close in cost to the least cost solution. Examination of these near-optimal solutions can provide insight into the various factors driving overall portfolio costs, and the sensitivity of costs to the precise composition of the portfolio.

II. Methodology

The scenarios described in this paper are simulated using NEMO, a model developed by the lead author and previously described in detail [3, 4, 5]. This model applies a real-valued genetic algorithm to optimise a mix of simulated generators to meet hourly demand profiles, to the required reliability standard (unserved energy), at lowest overall industry cost.

The following commercially available technologies were included: coal, combined cycle gas turbines (CCGT), open cycle gas turbines (OCGT), utility-scale photovoltaics (PV), wind power, concentrating solar thermal (CST) with storage, existing hydro and pumped storage hydro (PSH), and turbines fuelled with biomass-derived fuel. The capital and operating costs of each technology were based upon 2030 projections made by the Bureau of Resources and Energy Economics (BREE) in the 2013 Australian Energy Technology Assessment (AETA) [6].

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Hourly wind and solar profiles were applied, sourced from modelling by the Australian Energy Market Operator (AEMO) [1].

The following constraints were applied in the model in all scenarios:

(i) Annual hydroelectric generation was limited to historical levels at 12 TWh per year;

(ii) Annual bioenergy generation was limited to 20 TWh per year; (iii) the NEM reliability standard (0.002% annual unserved energy) was maintained; and

(iii) Greenhouse gas emissions were limited to 50 MtCO2-e per year – approximately one quarter of current NEM emissions.

(iv) A maximum instantaneous non-synchronous penetration limit of 75% was applied.

III. Results

In a single run, the model simulates 20,000 candidate portfolios during its search for the lowest cost portfolio (200 individuals over 100 generations). In the run examined, 14,799 portfolios satisfied all constraints. The lowest cost portfolio was found to have an average cost of $69.70/MWh, and comprised the technology proportions listed in Table 1. The limit on greenhouse gas emissions necessitates the inclusion of significant quantities of renewable energy.

Table 1 – Technology composition of lowest cost portfolio

Technology	**Capacity (GW)**
Coal	3.6
CCGT	0.7
OCGT	10.3
PV	3.7
Wind (on-shore)	38.2
CST	5.4
Bioenergy GTs	2.2

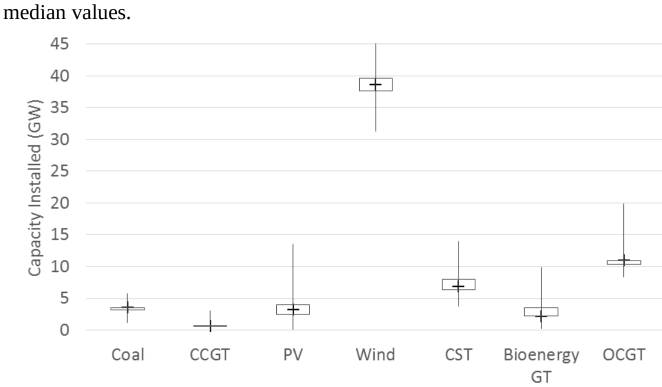
Figure 1 illustrates the composition of generation technologies in the portfolios found to be within $10/MWh (around 15%) of the lowest cost portfolio (more than 8,200 portfolios fell within this range).

These portfolios include an average of 38 GW of wind power, with all portfolios having installed wind capacity in the range of 31-51 GW. 98.8% of these near least cost portfolios have at least 35 GW of wind installed. This indicates that the relatively low cost of wind power makes it the key technology to produce a low cost portfolio to meet a stringent emissions target. From a policy design perspective, this suggests that policy frameworks that facilitate major wind deployment are a key priority. It also highlights the potential implications of other policy considerations with wind power – for example, opposition from small, vocal community groups in Australia to large wind farms – could pose major challenges to an economically efficient future low-carbon electricity industry. Portfolios with a smaller share of wind energy are certainly possible and may have only modest cost impacts, but only up to a point.

All of the lowest cost portfolios include coal and CCGT plant within a narrow range, dictated by the stringent emissions limit applied to these scenarios. The amount of bioenergy GT and OCGT plant varies more considerably. These technologies have relatively lower capital costs and operate infrequently, so a wider range of capacity values for these technologies can enter into the lowest cost portfolios.

The near least cost portfolios are found to include a wide range of PV capacity values. Some of the lowest cost portfolios have almost no PV (140 MW), while others have up to 13 GW of capacity installed. Half of the lower cost portfolios have 2-4 GW of PV capacity, and 90% of the near least cost portfolios have less than 4.9 GW of PV installed capacity. There is already more than 4 GW of PV installed in the NEM, almost entirely on residential rooftops. Projections by the Australian Energy Market Operator (AEMO) suggest that by 2030 rooftop PV installations could reach 12 GW in a moderate uptake scenario, or up to 18 GW in a rapid uptake scenario [7]. This modelling highlights that there are some limitations to cost-effective PV deployment given that the technology can only operate during daylight hours and does not yet offer cost-effective energy storage. Possible policy implications include the potential future value of demand-side participation and direct electrical energy storage to facilitate PV deployment, and may indicate that policies and mechanisms to promote PV deployment in the absence of these supporting technologies are unwarranted.

Figure 1 - Box and whisker plot of the technology composition of portfolios within $10/MWh of the lowest cost portfolio. Boxes indicate 1st and 3rd Quartiles, lines indicate maximum and minimum values, crosses indicate the median values.



IV. Conclusions

This modelling examined the least and near least cost technology portfolios for a scenario that limited emissions to approximately one quarter of those from the Australian NEM at present. It was found that all the near least cost solutions (within 15% of the least cost solution) involved significant quantities of wind generation. In contrast, the near least cost solutions consistently involved much lower quantities of PV. The findings also highlight considerable portfolio diversity among the near least cost solutions except for coal-fired and CCGT generation; an outcome of the stringent emissions limit imposed in the optimisation. As always, techno-economic modelling exercises such as these do not include a range of other costs. In this study, network costs, short-term operational costs and environmental externalities other than greenhouse gases are not included. There are also important non-economic factors in decisions regarding our energy future.

Mapping the diversity of near-optimal generation portfolios in the manner shown in this study assists policy makers in better understanding the implications of the broader policy context – for example, social consensus regarding particular technologies – on future electricity industry economics.

V. References

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