POWER GENERATION PORTFOLIO ANALYSIS WITH HIGH PENETRATIONS OF PHOTOVOLTAICS: IMPLICATIONS FOR ENERGY AND CLIMATE POLICIES

Peerapat Vithayasrichareon (peerapat@unsw.edu.au), Iain MacGill (i.macgill@unsw.edu.au)
Centre for Energy and Environmental Markets, School of Electrical Engineering and Telecommunications,
University of New South Wales, Sydney, Australia

Overview

Growing concerns over climate change and energy security due to uncertainty in fossil-fuel prices and their availability have contributed to the rapid growth of renewable energy (RE) over the past decade. Solar photovoltaic (PV) has been one of the fastest growing RE technologies due to rapid technological progress and major cost reductions. PV has low operating costs and zero operational emissions. Its costs are also increasingly competitive with conventional generation options, particularly if greenhouse emissions are priced. However, it offers highly variable and somewhat unpredictable generation. A key policy question, then, is what role might PV play in addressing the economic, environmental and energy security challenges facing the electricity industry. Potentially high penetrations of emerging RE technologies such as PV increase the challenge for generation investment decision-making in the electricity industry due to their unique technical and economic characteristics. In addition, the decision making context is becoming more complex with multiple and potentially conflicting criteria including estimated generation costs of course, yet also associated cost risks, greenhouse gas emissions and fossil fuel vulnerability. Generation investment and planning criteria is, therefore, increasingly moving beyond minimising estimated generation costs to incorporating risks and uncertainties and a wide range of industry objectives. This paper is intended to provide quantitative analysis and insights into the future role and potential value of large-scale PV in the electricity industry in the context of the Australian National Electricity Market (NEM). The study employs a probabilistic generation portfolio modelling tool developed in [1] to analyse future generation portfolios with large-scale solar PV under a range of potential future uncertainties. The tool has previously been applied to explore the potential impacts and value of high wind penetrations in the NEM [2].

Methods

The modelling tool employed in this study extends the commonly applied load duration curve (LDC) based optimal generation mixes by using Monte Carlo simulation (MCS) to incorporate key cost uncertainties into the assessment. The tool determines a probability distribution of annual generation costs and CO2 emissions for different possible generation portfolios. The "expected" cost and emissions for a particular portfolio represent the average of all the simulated costs and emissions from every Monte Carlo run. The cost spread is denoted by the standard deviation (SD), which represents associated 'cost risk'.[1] The tool then applies portfolio analysis techniques to determine the efficient frontier (EF)[2] of expected costs and associated cost risks for different portfolios. Portfolios that are not on the EF are considered suboptimal in terms of cost-risk since there are other portfolios which have lower expected costs for the same risk or vice versa.

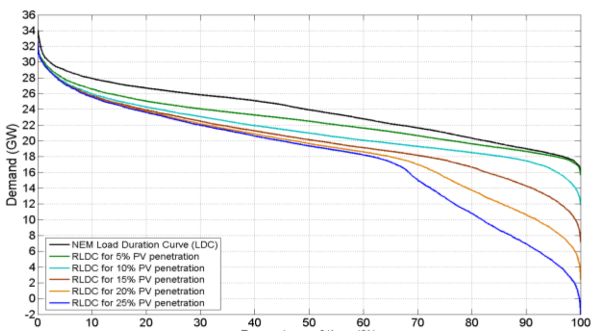

Fig. 1: RLDC for different PV penetrations

The paper considers a case study of the Australian National Electricity Market (NEM) that faces uncertain future fuel prices, carbon pricing policies, electricity demand and plant capital costs. The study assumes five generation options: brown coal, black coal, combined cycle gas turbine (CCGT), open cycle gas turbine (OCGT) and solar PV. PV is subject to prioritised generation dispatch since it can offset the need to dispatch fossil-fuel generation. An actual year of hourly NEM demand and weather data were used in order to simulate PV generation distributed across the NEM in order to capture the diversity value of PV plants. This simulated hourly PV generation is subtracted from hourly demand over the year to obtain residual (net) demand. The resulting residual demand is rearranged in descending order of magnitude to obtain a residual load duration curve (RLDC), which is to be served by fossil-fuel technologies in the portfolio. Fig. 1 shows RLDC for different PV penetrations. Different PV penetrations from 0% to 25% are simulated for all of the possible conventional generating plant portfolios. Additional transmission costs associated with new PV plants are also taken into consideration. Future plant and fuel costs are taken from recent Australian government estimates [4]. This study assumes considerable uncertainty in future coal and gas prices, carbon price and plant capital costs. These are characterised by lognormal distributions rather than the commonly used, yet less realistic, normal distributions.

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[1] Note that since the tool is based on MCS techniques it also supports other forms of risk-weighted uncertainty measures.
[2] The efficient frontier (EF) concept is used in Mean Variance Portfolio (MVP) theory for financial portfolio optimisation [3].

Results

The frontiers showing cost-risk tradeoffs among optimal generation portfolios for different expected carbon prices and PV penetrations are shown in Fig. 2. For a low carbon price (i.e. \$20/tCO_2), higher PV penetrations increase overall industry costs and cost risk as indicated by the upward movements of the EF as PV increases. With a low carbon price, the optimal conventional generation portfolios consist mainly of brown and/or black coal. For higher carbon prices (i.e. \$60/tCO_2), however, it is possible for the overall industry costs and associated cost risks to fall as PV penetration increases. The reason is that PV reduces fossil fuel consumption and emissions, and hence the impacts of uncertain fossil fuel and carbon prices. For high carbon prices, the optimal mix of conventional generation changes as PV penetration increases– in particular, away from coal and towards gas generation.

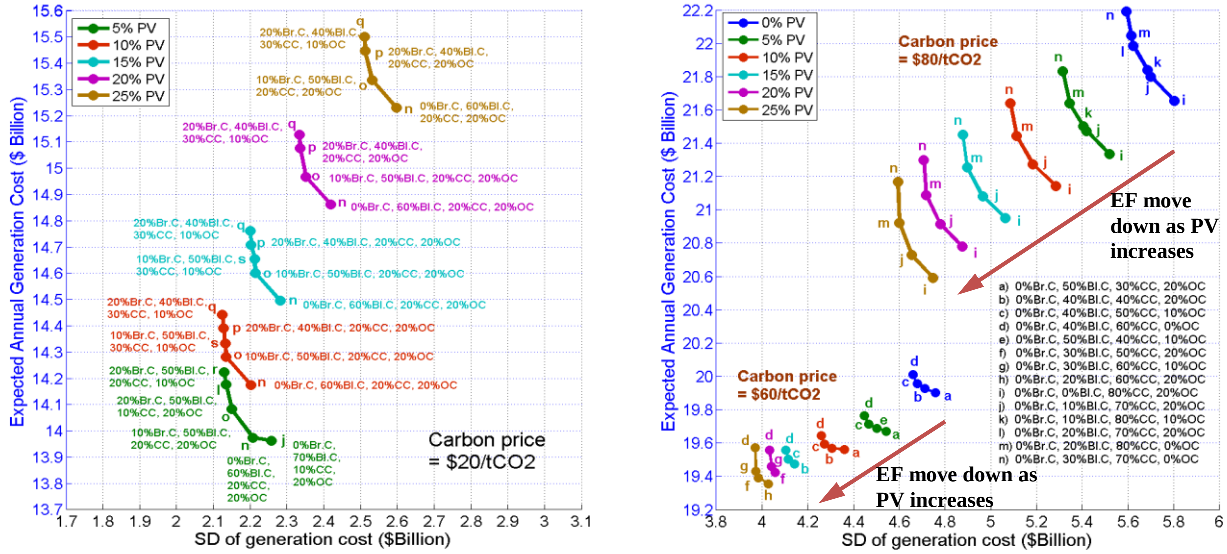

Fig. 2: EF containing optimal generation portfolios for different PV penetrations for different expected carbon prices.

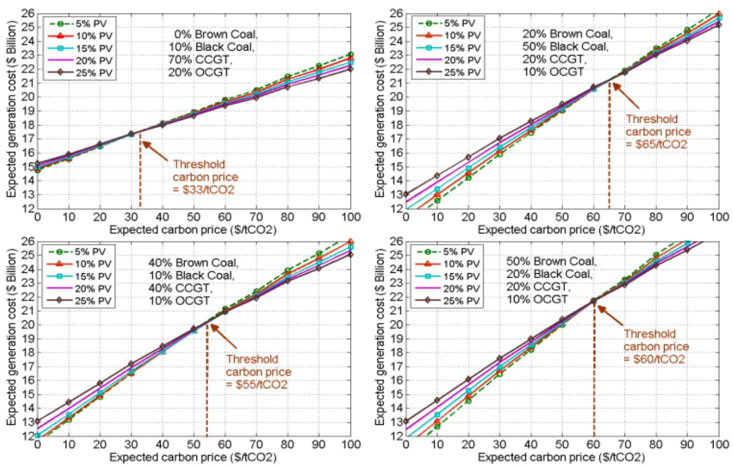

Figure 3: Expected portfolio costs for different carbon prices and PV

Fig. 3 shows that portfolio generation costs generally increase with increased PV penetration for a range of carbon prices. However, the cost increases become smaller as carbon price increases until at a "threshold" carbon price where the portfolio costs are the same for any PV penetration level. Beyond the threshold carbon price, the portfolio expected costs would begin to fall as PV increases. The higher the carbon price, the more cost reductions can be achieved with a higher share of PV. The level of threshold carbon price is influenced by the share of gas-fired generation.

Conclusions

- The value of PV in the future Australian electricity industry depends largely on the level of future carbon price. Given a sufficient carbon price, PV can play a significant role in reducing the overall industry generation cost and exposure to cost risk due to reduced exposure to future uncertainties in fossil-fuel and carbon prices.
- The necessary level of carbon prices appear significantly less than many modelled estimates of required future carbon prices [5] suggesting that PV can play a valuable role in electricity industry decarbonisation.

References

[1] Vithayasrichareon P, MacGill IF. A Monte Carlo based decision-support tool for assessing generation portfolios in future carbon constrained electricity industries. Energy Policy. 2012;41:374-92.

[2] Vithayasrichareon P, MacGill IF. Assessing the value of wind generation in future carbon constrained electricity industries. Energy Policy. 2013;53:400-12.

[3] Markowitz H. Portfolio Selection. The Journal of Finance. 1952;7:77-91.

[4] BREE. Australian Energy Technology Assessment 2012. Bureau of Resources and Energy Economics; 2012.

[5] IEA. World Energy Outlook 2011. Paris: International Energy Agency; 2011.