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’.

The tool then applies portfolio analysis techniques to determine the efficient frontier (EF) 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.

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/tCO₂), 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/tCO₂), 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.

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