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Assessing the Capacity Value of Variable Renewable Generation in the Australian National Electricity Market

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Abstract

Renewable energy generation in Australia has seen extraordinary growth in the past decade, especially from wind and solar photovoltaics (PV). While this renewable generation provides valuable economic and environmental benefits, its significant variability does pose some challenges for power system security. One key issue is ensuring sufficient generation capacity to meet expected future peak demand periods. While conventional dispatchable generation is generally assumed to be available with high assurance, there is less clarity regarding how wind or PV's potential contribution should be assessed. Some electricity industries have formal capacity markets and there are a variety of methods for assessing the capacity value of different generation technologies. While the Australian National Electricity Market (NEM) does not currently have such a market, the Australian Electricity Market Operator (AEMO) is still required to undertake assessments of future system adequacy which necessarily involve assessing the capacity value of variable generation. Hence, AEMO has developed a set of techniques to assess the contribution of wind farms across NEM during peak demand periods.

In this study, we explore AEMO's present approach in more detail, and other possible measures of the capacity value of wind and solar PV in the NEM. AEMO's current approach estimates the wind contribution across the states in NEM by examining the wind generation at the top 10% of peak demand in summer and winter periods. The minimum wind generation over 85% of these peak periods is the estimated assured wind contribution towards meeting peak demands. This study first undertakes a validation of the AEMO findings applying this method. Our study then extends the AEMO work in four ways: 1) assessing the capacity value of utility solar PV, 2) assessing capacity values for wind and solar for smaller percentages of peak demand periods (1% and 5%), 3) assessing wind and solar capacity value at times of peak prices rather than peak demand and, finally, 4) assessing the capacity value of potential wind and solar farms in different regions of the NEM. Existing renewable generation, demand and price data is obtained from AEMO dispatch outputs while potential new wind and solar plant generation is simulated using ROAM consulting data sets provided to AEMO for modelling high renewables penetrations in the NEM.

Results applying AEMO's approach but with smaller proportions of peak demand periods highlight that wind and PV's capacity value is typically higher when a smaller number of peak periods is considered. Solar can have particular value in meeting summer peaks. By contrast, analysis of the capacity contribution wind makes during peak price periods highlights the role that its absence seems to play in periods of very high prices. Finally, different wind and solar regimes across the NEM potentially offer quite different capacity values, highlighting the role that renewables' location might play in facilitating renewable energy integration.

1. Introduction

Secure and reliable electricity supply requires sufficient generation to meet demand at all times. Peak demand periods in summer and winter pose particular challenges, and hence there is considerable value in generating capacity (capacity value) that is available with a high level of assurance at such times. No generator is 100% reliable, so assessing capacity value requires probabilistic assessment and a range of techniques have been developed. Growing deployments of variable wind and solar generation are now adding to the challenges of capacity assessments within future system adequacy studies.

A variety of methods for calculating renewable generation capacity values have been proposed or applied across different jurisdictions. These methods can be broadly divided into three approaches: reliability-based, approximation and time-period based. Reliability-based approaches are more accurate but involve complex and iterative computations with large data requirements. Effective Load Carrying Capability (ELCC) is a common capacity value method taking this general approach (Dent and Zachary, 2012). It is based on a Loss of Load Expectation (LOLE) metric and examines the probability of load exceeding available generation in the network (Milligan and Porter, 2008). An IEEE Power and Energy Society Task Force has proposed a method to calculate the wind generation capacity value based on the ELCC method (Keane et al., 2010). It treats variable wind generation as negative load and adds it to the underlying system demand before estimating the extra load which the system can serve while providing the same reliability as the system without wind. Equivalent Conventional Power (ECP) and Equivalent Firm Capacity (EFC) are other capacity value methods taking a reliability approach (Madaeni et al., 2012a, 2012b, 2013). Approximation methods are simpler but offer reduced accuracy (Madaeni et al., 2012a). They can be used when there is insufficient data or computational capability to undertake reliability based methods. For example, Garver (1966) proposes a non-iterative approximation method to estimate the ELCC of a generator. The method is modified and further refined in D'Annunzio and Santoso (2008) so that it can be applied to multi-state problems, such as wind or conventional generators with multiple outage stages.

Time-period methods are the simplest and most straight forward, estimating the capacity value of generators based on their historical performance. The capacity markets in United State, such as Pennsylvania-New Jersey-Maryland (PJM), has implemented this approach to assess the capacity value of wind generators in high demand periods (Milligan and Porter, 2005; PJM, 2014; NERC, 2011). While the Australian National Electricity Market (NEM) does not currently have a capacity market, the Australian Electricity Market Operator (AEMO) is still required to undertake assessments of future system adequacy which necessarily involve assessing the capacity value of variable generation. Hence. AEMO has developed a set of time-period techniques to assess the contribution of wind farms across NEM during the peak demand periods.

In particular, AEMO defines the capacity values of wind generation in each state in Australia as the average percentage of installed wind capacity that provides reasonably assured generation during the top 10% of peak demand periods over summer and winter seasons (AEMO, 2015a, 2015b). Summer is defined as the 1st of November through the 31st of March while winter is defined as the 1st of June through the 31st of August. This approach uses historical five-minute dispatch interval data for demand and wind farm generation looking back over the past five years. Non-scheduled wind farms are treated as negative load and are added into the total demand. The corresponding wind farm generation at the top 10% of the peak demand periods are selected to perform frequency analysis. The reasonably assured contribution of this wind farm generation is estimated at the 85% interval and represents the proportion of installed capacity which wind generation can contribute for at least 85% of the top 10% peak demand intervals.

In this study, we explore AEMO's present approach in more detail, and other possible measures of the capacity value of wind and solar PV in the NEM. This study first undertakes a validation of the AEMO findings applying this method. It then extends the AEMO method in four ways:

- assessing the capacity value of utility solar PV as well as wind, given that the NEM now has three semi-scheduled utility PV plants in operation, with more than a dozen further utility PV projects under development,
- assessing capacity values for wind and solar for smaller percentages of peak demand periods (1% and 5%) than the 10% used by AEMO, noting that the choice of what proportion of peak periods should be included involves trade-offs between the uncertainties of infrequent events versus the particular challenges posed by the highest peaks
- assessing wind and solar capacity value at times of peak prices rather than peak demand, given that these high price events represent a market response to tight supply-demand balance, and
- assessing the capacity value of potential wind and solar farms in different regions of the NEM.

This paper is structured as follows. In Section 2 we outline the procedures used to emulate the AEMO approach and how the extensions of the approach were achieved. The key findings applying these extensions are presented in Section 3, and their implications discussed in Section 4. Finally, the study's conclusions are summarised in Section 5.

2. Method

2.1. AEMO Approach

The AEMO approach can be summarised into the following steps:

1. The historical five-minute dispatch interval data of individual wind farms and regional demand in summer and winter periods of the chosen years for each NEM market region (State) were collected using the commercial market insight software NEMSight (Creative Analytics, 2016). AEMO's definition of summer when assessing capacity value is from 1st of November to 31st of March the following year while winter is from 1st of June to 31st of August.

2. Non-scheduled wind farm generation is treated as negative load. Hence, the equations for total regional demand and wind generation are:

Total Regional Demand = Scheduled Demand - Non-Scheduled Generation

Total Regional Wind Generation = Semi-Scheduled Wind + Non-Scheduled Wind

3. The data is sorted in descending order of the total demand

4. The highest 10% of the peak demand periods with corresponding wind generation data are used to plot a wind generation 'duration' curve. The percentage of installed capacity

generating for at least 85% of the time is taken to be the reasonably assured total wind farm capacity for each NEM State in the summer/winter periods of the chosen year.

Since Tasmania is connected with Victoria through the Basslink interconnector, the demand period used in assessing wind contribution in Tasmania is the sum of Tasmania and Victoria demand (AEMO, 2015b). When assessing the wind contribution of the Tasmania during peak price periods, the market spot prices of Tasmania and Victoria at each half-hour were also added together. **Figure 1** presents a flowchart summarising the AEMO approach.

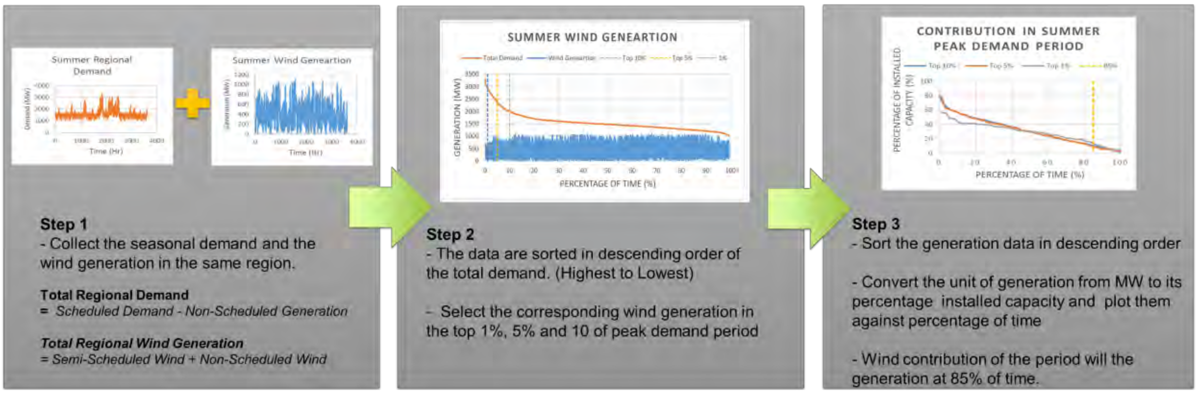

Figure 1: Flowchart outlining the AEMO Approach to calculating wind capacity value in the NEM

2.2. Extensions to the AEMO method

Our assessment of the capacity value of utility solar PV utilised generation data from two utility PV plants in NSW at Nyngen and Broken Hill over the summer of 2015. These plants were only recently commissioned so no earlier summer or winter period could be assessed. There was insufficient data to assess the even more recently commissioned utility PV plant at Moree in NSW which is particularly unfortunate as it utilises single-axis tracking which might have a considerable impact on its capacity value. The assessment of wind and solar capacity for smaller percentages of peak demand periods required only minor modifications to the standard AEMO method. Assessing wind and solar capacity value at times of peak prices rather than peak demand also only involved minor changes to the AEMO method, using pricing data for each market region rather than demand data.

Finally, our estimations of the capacity value of potential wind and solar farms at different regions of NEM was undertaken using Roam Consulting Solar and Wind simulation modelling data that was provided to AEMO in order to facilitate their high renewable integration modelling work (AEMO, 2013). In this data set, the NEM region is broken up into 43 blocks named “Polygons”. The AEMO Polygon Map is shown in **Figure 9** in **Section 3.4**. For each polygon, the dataset provides simulated hourly output of a representative 1 MW wind and single-axis tracking PV generating plant derived from wind speed and irradiance measurements from Australian Bureau of Meteorology (BOM) weather stations in each region, as well as satellite and NWP techniques (ROAM Consulting, 2012). The available periods of these generation data were slightly different, hence the latest 5 years of data were selected. The corresponding demand data for each State were also obtained using NEMSight. They were also assessed under the same scenarios as the existing wind and solar farm analysis.

3. Results

3.1. AEMO Approach Result Validation.

The study first undertook a validation of AEMO's work by comparing the emulated wind contribution curves resulting from our application of the AEMO method with the published AEMO results for 2010-14 presented in the NEM Historical Market Information Report 2015 (AEMO, 2015c). While there are some discrepancies in the applied method in terms of data (for example, AEMO uses 5-minute data while we used 30-minute averages), for most years, the emulated curves align closely with the published AEMO results. For example, **Figure 2** presents a comparison between the AEMO findings and our modelling for South Australia (SA) winter in 2014 and shows an excellent fit.

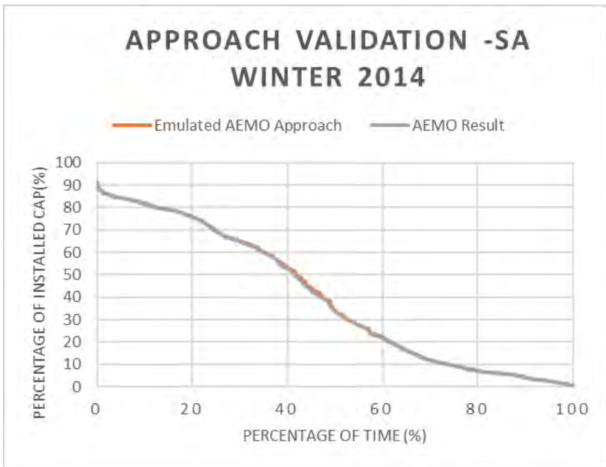

Figure 2: Comparison between published AEMO capacity value findings and this study's emulation of the AEMO method for SA Winter 2014.

3.2. Existing Wind Generation Capacity Contribution.

The total wind generation duration curve for each state for the top 1% and 5% as well as 10% of both peak demand and peak price periods were calculated for the years 2010-14. **Figures 3** and **4** present these generation duration curves for South Australia in Winter 2014, for peak demand and peak price periods respectively. Two things are apparent. Reducing the proportion of peak demand periods included in the analysis does result in less smooth curves, an outcome of the reduced data involved. Still it is clear that wind's assured contribution in this case is higher when a smaller proportion of peak demand periods is included, rising from just over 6% assured capacity contribution for the top 10% of peak demand periods, to just under 9%. for the top 1% of peak demand periods.

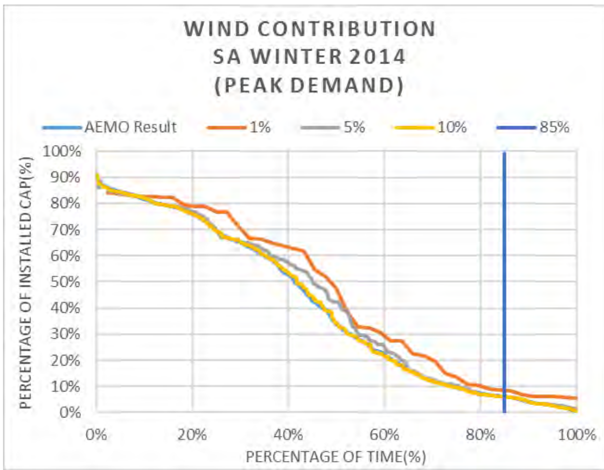

Figure 3: Wind generation duration curves for different proportions of peak demand periods.

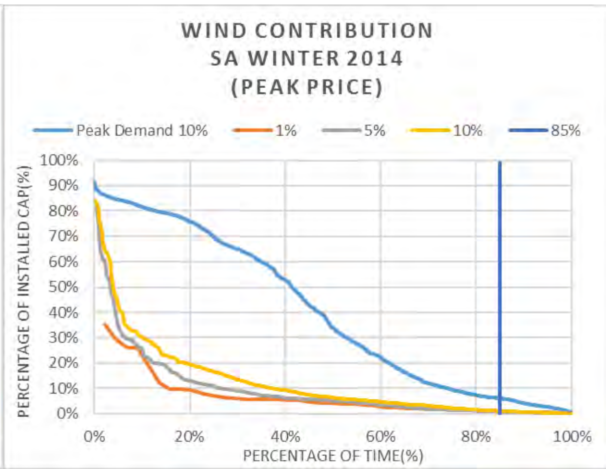

Figure 4: Wind generation duration curve for different proportions of peak price periods

The outcome is very different when looking at wind generation's assured capacity contribution at times of peak prices. In this case, wind's contribution falls as the proportion of peak price periods is reduced. This reflects the complex relationship between wind generation and pricing in South Australia. Wind generation represents more than 30% of annual State demand and there is an apparent merit order impact whereby periods of high wind generation are associated with lower prices. Furthermore, there is some evidence that periods of low wind generation and high demand present opportunities for the exercise of market power.

3.3. Existing Solar Generation Capacity Contribution.

Utility PV has lagged considerably behind wind generation deployment within the NEM but a number of large plants have been commissioned over the past year and more projects are coming. The potential capacity contribution of such plant is therefore growing in importance for AEMO and other NEM participants. The variability of utility is very different from that of wind, notably in terms of the daily cycle of potential irradiance, and longer-term seasonal variations. **Figure 5** presents the generation duration curve of the Broken Hill utility PV plant over the summer of 2015-16 over the top 1%, 5% and 10% of peak demand periods. Some differences between PV and wind's capacity value are immediately apparent. The plant operates at a high capacity factor (above 50%) for over 50% of peak demand periods provides particularly useful assured capacity value for the top 1% of peak demand periods.

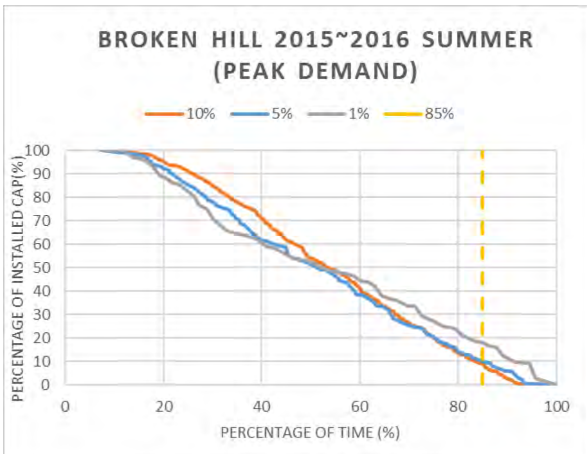

Figure 5: Broken Hill Solar Farm contribution in NSW summer peak demand period (2015~2016)

3.4. Potential Wind and PV Generation Contribution in Different NEM Regions

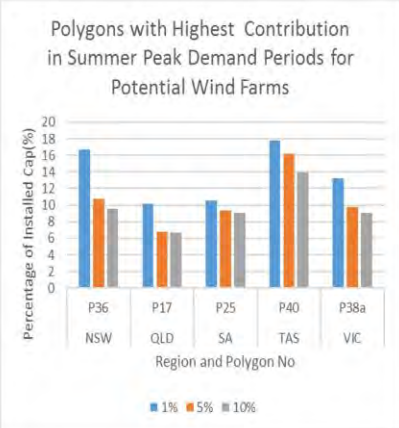

Figure 6: Polygons with the highest summer wind capacity contribution

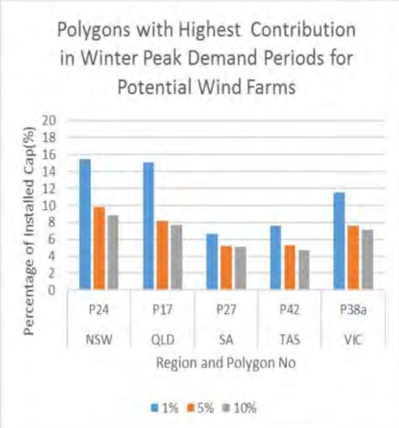

Figure 7: Polygons with the highest winter wind capacity contribution

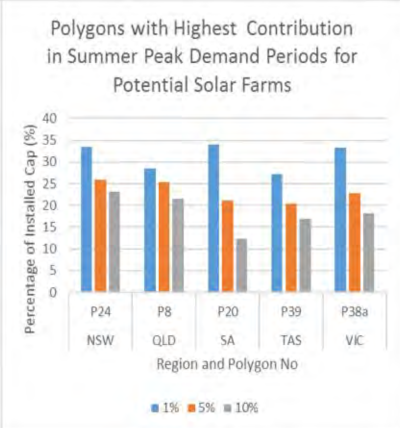

Figure 8: Polygons with the highest summer PV capacity contribution

Figure 6 and Figure 7 present the polygons with the highest estimated reasonably assured (85%) capacity contribution during the summer and winter demand periods in each State. The best summer location in the NEM is at Polygon 40 in Tasmania with potential contribution of almost 18% of installed capacity during the top 1% of peak demand periods. The optimum winter location is in Polygon 24 in NSW with the highest potential generation at 15.5% of installed capacity. Even though the average winter capacity contribution from the wind generation is generally slightly lower than the summer periods, they can still provide useful capacity for some locations. **Figure 8** highlights that the estimated capacity contribution of utility PV plant in summer is much higher than for wind farms, with reasonably assured generation with the generation up to 34% of its installed capacity. The capacity value across adjacent polygons is reasonably similar, however, due to the dependency of PV generation output on solar irradiance, its winter contribution is generally very low. **Figure 9** summarizes the Polygon locations with the highest potential wind and solar contribution in the peak demand period.

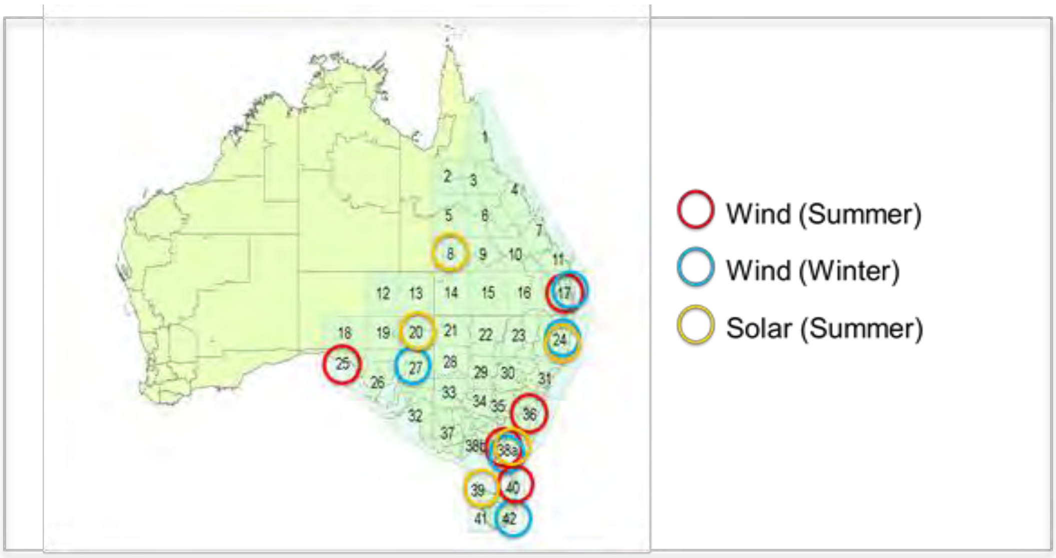

Figure 9: NEM Polygon map and Polygons with highest wind and solar contribution (AEMO, 2013)

4. Discussion

Tim-period methods provide a relatively straightforward, transparent and robust way to estimate the capacity value of variable renewables such as wind and solar. Our study findings suggest that there are some possible extensions to AEMO's present techniques that provide additional insights regarding wind and now utility PV's likely capacity value at times of peak demand, and opportunities to improve this capacity value. In particular:

- Utility PV looks to offer useful capacity value for the NEM summer peak periods. While the NEM States vary in terms of whether they typically experience higher summer or winter peaking, summer peaks often involve additional challenges for the power system due to equipment deratings under high ambient temperatures.
- Wind's capacity value under some circumstances (notably summer) may be greater if a smaller proportion of peak periods is considered. However, under different circumstances (eg. SA winter) capacity value may be greater when a larger proportion of peak periods is considered. There is no 'correct' proportion of peak periods given the additional uncertainty as you include less, hence more extreme, events versus the particular challenges posed by the highest peaks in terms of ensuring system reliability. Across all States and seasons, a 5% threshold for peak events offered highest capacity value.
- Wind's capacity contribution at times of peak prices is much less than its contribution towards times of high demand. In the NEM, periods of high prices generally reflect some combination of high demand, particular power system circumstances such as failed network or major generating assets, and the exercise of market power. Periods of high wind generation typically see lower prices and less potential opportunities to exercise market power, hence lower revenues to wind generation.
- Different regions of the NEM with different wind and solar regimes can offer very different potential capacity values for utility wind and PV plants. This suggests that formal mechanisms to incentivise capacity value in the NEM could see project

developers targeting particular regions and technologies to increase the market value of their projects.

More generally, there are opportunities to provide more detailed and useful assessments of wind and PV capacity value through analysis of wind and PV generation duration curves beyond just setting a 'reasonably assured' contribution at, for example, 85% of peak time periods.

5. Conclusion

This study has explored AEMO's present approach in more detail, and other possible measures of the capacity value of wind and PV in the NEM. It was able to validate its approach against AEMO's published work, and then explore a number of possible extensions that have highlighted the promise of utility PV, the issue of what proportion of peak periods are considered, and opportunities to improve the capacity value of wind and solar by building plants in particular regions of the NEM. Our study has, of course, a number of limitations. In particular, the analysis performed in this study was based on historical demand and wind and PV generation data, as well as simulated wind and PV generation for different NEM regions to those where utility wind and PV are located. The past provides only a partial guide to the future – a general limitation of time-period methods while simulated wind and PV generation has its own limitations. Beyond this, other possible extensions to this work include:

- Assessing existing wind and solar farm individual capacity contributions in peak demand periods.
- Assessing existing conventional generator contributions in the peak demand and peak price periods.
- Exploring optimal locations in NEM with the highest potential contribution of tracking and fixed tilt PV systems in NEM.

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