Impacts of Electricity Markets on Solar Revenues – An Australian Case Study

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***Abstract*—This paper reports on modelling to determine the most significant factors influencing solar generator revenues. The Australian National Electricity Market (NEM) is used as a case study. The most significant driver of variations in solar revenues from year to year and region to region is found to be pool prices (more than variations in solar resource). Peak pool prices (8am-6pm) are found to be a good indicator of solar revenues on a $/MWh basis. Generation during summer periods is particularly important, with a significant proportion of annual solar revenues being earned during a small number of high priced summer events. Based upon forecast pool prices, the regions Queensland and New South Wales are predicted to be optimal regions for solar development, but it is emphasised that pool price forecasts depend upon a wide range of input assumptions with high uncertainty. Finally, time of day correlations suggest that solar generators should be able to achieve significantly higher revenues than wind generators on a $/MWh basis, which should lead to higher valued Power Purchase Agreements for solar generators.**

***Index Terms*-- Australia, National Electricity Market, NEM, Solar, Power Purchase Agreements, renewable, generation.**

I. Introduction

The locations where solar generation should be developed is often considered based upon factors such as the expected capacity factor (based upon the annual average solar resource) in isolation of market factors. However, the market environment can have a substantial influence over the revenues earned by these technologies, and solar developers would benefit from a more detailed explanation of the more subtle market effects. This study explores which factors are important, using the Australian National Electricity Market as a case study.

A. Introduction to the NEM

The National Electricity Market (NEM) is a gross pool market for electricity, covering the five grid-connected regions of Queensland (QLD), New South Wales (NSW) (including the Australian Capital Territory), Victoria (VIC), South Australia (SA) and Tasmania (TAS). This physical market for electricity is managed by the Australian Energy Market Operator (AEMO). Generators submit offers to the market, and are dispatched in order of bid price, subject to transmission constraints, until demand is satisfied. The marginal dispatched generator in each five minute dispatch interval sets the price for that interval, and settlement prices (or pool prices) are the average of the six 5-minute prices over each half hour.

II. Methodology

A. Solar Satellite Data

Solar data was obtained from the Australian Bureau of Meteorology (BOM). Hourly global horizontal irradiance (GHI) and direct normal irradiance (DNI) values for the whole of Australia at approximately the 5km resolution were provided. For each grid cell, brightness data was obtained from visible images taken by geostationary meteorological satellites and a detailed model involving surface albedo and atmospheric conditions was used to convert this to GHI. An atmospheric model was then used by the BOM to separate out the DNI and diffuse components. This data does not replace the need for ground based observations, but comparison with ground based data where available suggests that the satellite data provides a good estimate of solar resource for planning purposes. BOM calibration studies have shown the mean bias difference (average of the satellite - surface difference), calculated on an annual basis across all surface sites available to the BOM, is +11 to +40 W/m^2 and typically around +20 W/m^2. This is +4% of the mean irradiance of around 480 W/m^2.

B. Solar Generation Modelling

ROAM Consulting's Solar Energy Simulation Tool was used to calculate the generation from a 1 MW flat panel solar photovoltaic plant at a variety of locations. Specific locations within each region were selected on the basis of developer interest and announced projects. The sites selected were:

- QLD – Kogan Creek
- NSW – Canberra and Moree
- VIC – Mildura
- SA – Point Patterson

A detailed geometric model was employed to calculate the portion of the direct and global solar insolation on the PV plate. Both the direct and diffuse components were assumed to be utilised by the flat panel solar PV unit.

The name plate capacity of the cells was assumed to correspond to AC power output at Standard Testing Conditions (STC) which correspond to 1000 W/m^2 incident radiation (either beam or global as appropriate) and an operating temperature of 25°C.

Solar PV cells display a generally linear response to incident radiation. However efficiency decreases at high temperatures. A simplified model was used to estimate the cell temperature based on incident radiation and ambient temperature (obtained from BOM), and an energy derating factor of 0.44%/°C is applied.

The maps illustrated in Figures 1 and 2 were developed from averages of solar insolation in 2009, but the same trends are observed over longer term averages from 1990-2008, as illustrated on the Bureau of Meteorology website [3].

C. Historical Pool Prices

Historical pool prices for each region in the NEM in each half hour were applied to the calculated solar generation to determine revenues that would have been achieved by the hypothetical solar plants, had they been in existence in each historical year.

D. Forecast Pool Prices

ROAM conducted detailed, half-hourly market dispatch modelling using 2-4-C, ROAM's proprietary electricity market forecasting package. Network constraints are accounted for in the market dispatch engine through a set of constraint equations. These constraint equations were developed to provide a representation of the network topology in a form that the market dispatch engine can interpret when dispatching the system. As a result of the progressively changing nature of the network, regular updates to the constraint equations also take place to ensure that planned network upgrades are reflected in the market dispatch process. The inclusion of constraint equations in this manner ensures that the impact of network congestion on the generation of solar farms is accounted for.

Pool prices in each region were calculated explicitly using dispatch modelling from 2012-13 to 2024-25.

To account for policy uncertainty ROAM modelled two carbon price trajectories corresponding to the following Australia-wide emissions targets:

- -5% by 2020 (from 2000 levels)
- -15% by 2020 (from 2000 levels)

These carbon price assumptions are likely to cover the range of possible outcomes regarding climate policy in Australia. The price trajectories associated with each emissions target were from the 2008 Australian Government Department of the Treasury modelling [1].

Energy and peak demand forecastswere assumed to be medium economic growth trajectories in all regions. Peak demands with a 50% and 10% probability of exceedence were both modelled, and weighted in the ratio 70/30 respectively in each half hour to produce "likely" pool price outcomes.

Simulations include Monte Carlo modelling of generator forced outages; 25 iterations were simulated and averaged in each half hour.

E. Wind Generation Modelling

Wind traces for each individual wind farm likely to be installed over the forecast timeframe under the 20% by 2020 Large-scale Renewable Energy Target (LRET) were produced using ROAM's Wind Energy Simulation Tool. The 2009-10 year was used as a reference year for wind, solar and demand data to ensure accurate correlation. Thirty minute resolution historical wind data from Bureau of Meteorology ground-based weather stations in locations around Australia were used as representative of hypothetical wind farms in locations nearby. Wind speeds were scaled to hub height and transformed into generation using typical turbine power curves. Capacity factors at each location were targeted, based upon average wind resources reported in the Australian Renewable Energy Atlas [2].

The following existing wind farms were used for analysis:

- NSW – Cullerin Range, Capital
- VIC – Yambuk, Challicum Hills, Waubra
- SA – Lake Bonney, Mt Millar, Starfish Hill, Wattle Point, Canunda
- QLD – Since no significant existing wind farms are located in QLD, the wind data from Capital wind farm (NSW) was applied.

F. Power Purchase Agreements

Long term contract prices for solar and wind generation were calculated based upon ten years of forecast revenues from 2014-15 to 2024-25, including revenues from the wholesale pool, and from Large-scale Generation Certificates (LGCs) under the LRET scheme. LGC prices were forecast using a "shadow pricing" methodology, calculating the LGC price that would be required for wind generators in aggregate to "top up" their pool revenues to meet their long run marginal costs. A discount rate of 9.80% per annum was applied.

To determine the Power Purchase Agreement (PPA) contract price for each generator (wind or solar), the net present value (NPV) of the ten year revenue stream was calculated. The PPA price was then the constant price for energy that would produce an equivalent NPV revenue stream.

III. RESULTS

A. Solar Resource

The solar resource at a location is a key driving factor for the quantity of generation produced, and hence is crucial in increasing revenues, and reducing long run marginal costs. Figure 1 illustrates the average annual solar exposure across Australia; the NEM spans the east coast. From this average annual map, it appears that solar development in the north (Queensland) will lead to the highest capacity factors, and therefore the highest solar plant profitability.

However, solar revenues are strongly affected by extreme peak prices, as illustrated in Figure 5. Most NEM states feature a summer peaking demand, causing extreme high prices to typically occur during summer. As illustrated in Figure 2, Queensland (north) experiences tropical weather patterns which reduce solar exposure during summer. The southern states are not affected by this phenomenon, and therefore during summer peak periods experience the highest levels of solar insolation. On this basis, preferential development of solar generation in the southern states (particularly South Australia and northern Victoria) may be warranted, depending upon the relativity of forecast pool prices in each region.

B. Pool price

The NEM is a regional market, with different regions having different pool prices. Pool prices are a crucial determining factor in solar revenues, and are influenced by a wide array of factors. Figure 3 illustrates NEM pool prices in each region from 2003-04 to the present. Historically, average pool prices are observed to vary significantly year to year, driven by a range of unpredictable external factors. For example, in 2007 persistent drought conditions forced the reduction in output of several wet-cooled and hydro powered units, causing a supply shortage and high average prices.

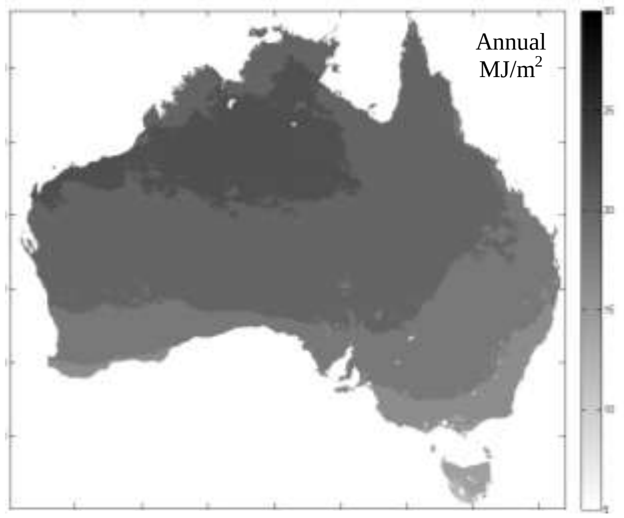

Fig. 1. Average annual daily solar exposure in Australia (MJ/m^2). On an annual average basis, the highest solar resource in the NEM (eastern states) is available in Queensland (north).

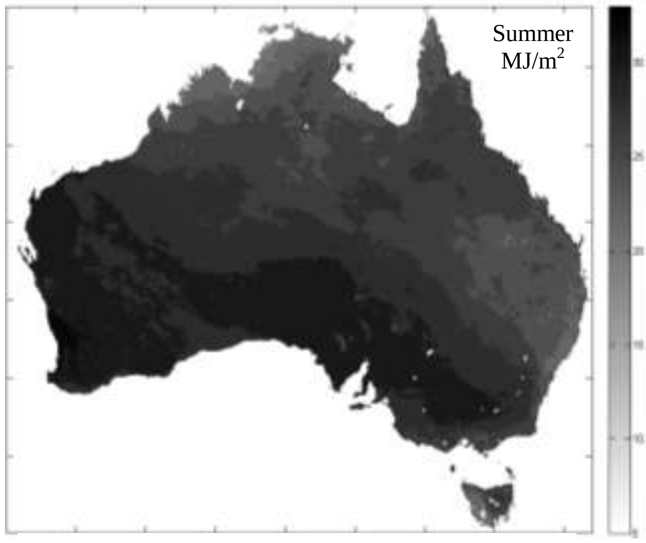

Fig. 2. Average daily solar exposure in December (summer) (MJ/m^2). Most NEM states feature a summer peaking demand, causing high prices to typically occur during summer. Since solar revenues are strongly driven by peak prices and extreme price events, average solar exposure during summer periods is likely to be more significant than the annual average in determining solar revenues.

Figure 3 also illustrates two possible projections of future electricity pool prices based upon a -5% and -15% by 2020 (from 2000 levels) carbon price trajectories for Australia. Carbon pricing is assumed to begin in 2013-14, and demonstrates a high pass through rate in the electricity market, due to the high average emissions intensity of NEM generators. Carbon pricing therefore acts to strongly increase electricity prices in all regions.

In the past, an abundance of generation in Queensland provided low average pool prices. In future, however, strong load growth is likely due to anticipated expansion of the liquid natural gas export industry in Queensland. For this reason, Queensland (along with NSW) is forecast to have the highest electricity prices. By contrast, electricity prices in South Australia and Victoria increase relatively less, being depressed by the entry of significant quantities of wind generation under the LRET. However, it is emphasised that these relativities are dependent upon a range of input assumptions with high associated uncertainty. Therefore, wise investors will choose development sites that demonstrate prices robust to a range of likely input assumptions.

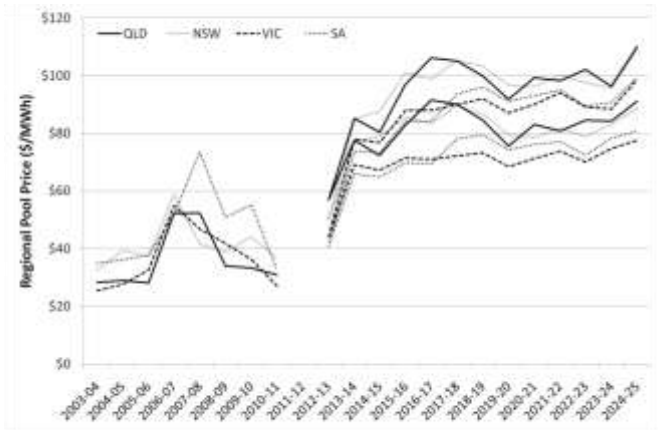

Fig. 3. Historical NEM pool prices, and two possible projection of future prices based upon -5% (lower line) or -15% (upper line) by 2020 (from 2000 levels) carbon price trajectories for Australia.

Historical data indicates that regional pool prices provide a stronger predictor of solar plant revenues year to year and state to state than the capacity factor (based upon solar resource), as illustrated in Figure 4. This is because solar plant capacity factors are much less variable than pool prices. Over the historical timeframe examined in this study, the energy produced by a solar plant varied by 5-7% year to year, and by 2-10% from region to region. However, regional average peak pool prices in the NEM over the same period varied by 70-180% year to year, and by 20-150% from region to region. Therefore, variation in pool price is likely to be a much more significant driver of variations in solar plant revenues.

As illustrated in Figure 4, in the year 2006-07 neither the capacity factor nor the pool price was a strong indicator of solar revenues. This is due to unusual high prices during winter in 2006-07 in QLD, NSW and VIC, which did not translate into high solar revenues due to lower solar insolation levels during winter (refer to Figure 6).

C. Correlation of solar generation with pool price

The correlation of generation with pool price is also an important consideration when comparing various intermittent technologies. While wind generators in many locations demonstrate minimal time of day generation trends (operating equally, on average, overnight or during the day), solar generation exhibits a strong correlation with peak demand periods (with operation solely during the day). In most markets this means that solar generators will generally operate during higher priced periods, and can therefore achieve higher $/MWh revenues than wind farms. This is illustrated in Figure 5, which shows that solar generator revenues are more closely related to average peak prices than annual average prices. Average peak prices are therefore likely to provide a good indication of anticipated solar revenues.

However, under a moderate carbon price, peak and off-peak prices are expected to be closer in the future. This is because overnight prices are typically set by higher emissions intensity coal plant, while lower emissions intensity plant (e.g. gas) set the price during peak periods.

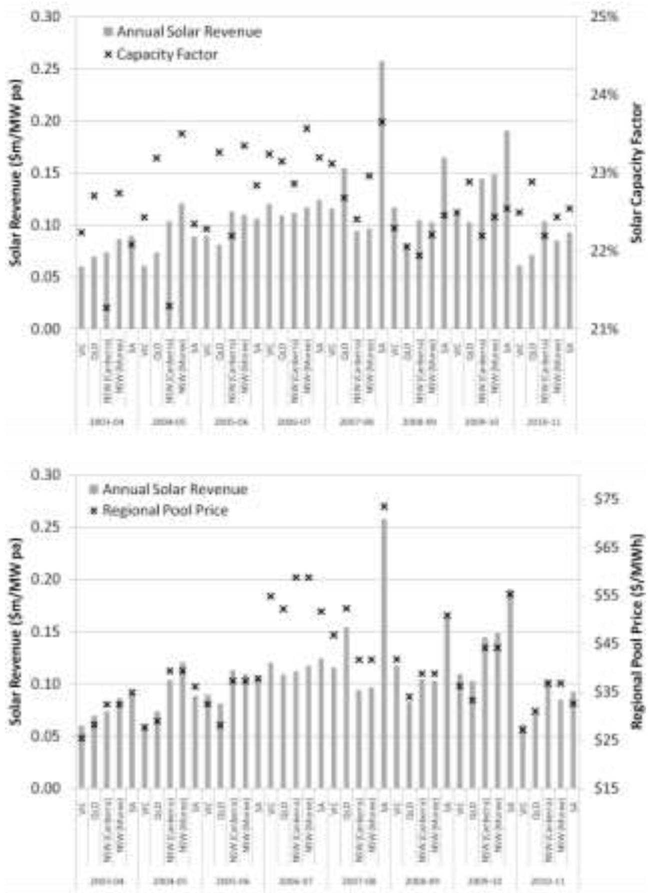

Fig. 4. The average regional pool price provides a stronger predictor of solar plant revenues year to year and state to state than the capacity factor (based upon solar resource). In 2006-07 neither is a strong indicator, due to unusual high prices during winter (refer to Figure 6).

D. Extreme Priced Events

Average daily Queensland pool prices are illustrated in Figure 6; the other regions display similar features. Clear "spikes" are evident across the summer months (Dec, Jan, Feb), but prices are typically lower and more constant during the winter months. 2006-07 provides an exception to this, with high prices also evident in the 2006 winter months. In this year unusually high prices were sustained throughout autumn and into winter because of the effect of:

- The continuation of summer temperatures well into autumn;
- Record winter demand driven by cold weather;
- Generating plant withdrawn because of the drought;
- Generating plant shut down for maintenance in anticipation of lower pool prices generally experienced during the anticipated shoulder season;
- Snowy Hydro, which is generally a price setter, operated increasingly in the more expensive pumped storage mode; and
- Overnight prices were increased by $20/MWh by the reduced generation and an additional 500 to 600 MW demand to operate the Snowy pumps.

These high winter prices did not translate into high solar revenues, as indicated in Figure 6, due to the lower solar insolation experienced during winter.

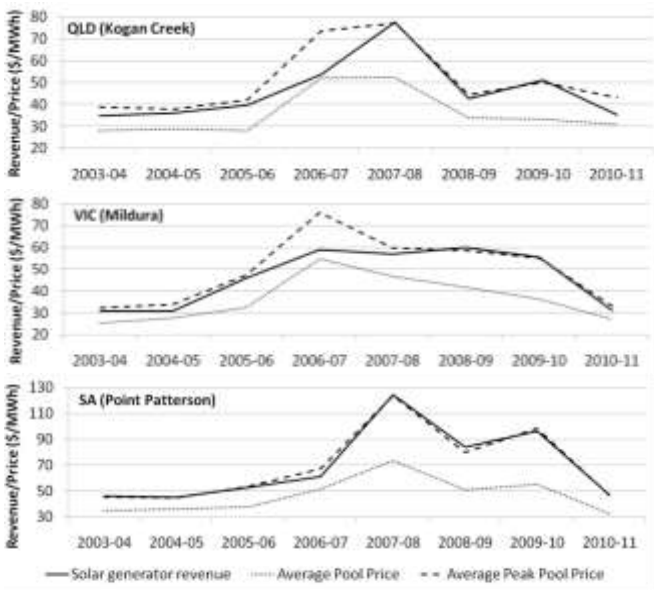

Fig. 5. Solar generator revenues are more closely related to average peak prices (calculated 8am to 6pm) than annual average prices. Average peak prices are likely to provide a good indication of anticipated solar revenues. 2006-07 featured an unusual high priced event during winter which increased annual average peak prices, but did not increase solar revenues as significantly due to lower solar insolation during winter (refer to Figure 6).

Over the period 2003-04 to 2009-10 Queensland pool prices averaged $36/MWh. However, on 10 days each year (on average) the daily average price exceeded $100/MWh, and on 1.5 days each year (on average) the daily average price exceeded $500/MWh. One year in two, the daily average price on one day exceeded $1,000/MWh.

Extreme peak price events make a significant contribution to the revenues of all generators. Figure 6 illustrates how summer pool price spikes translate to high solar revenue events. Figure 7 illustrates the percentage of annual revenue earned on the highest single day, and highest 20 days for representative solar and wind generators in each region of the NEM. On average across the sites considered, solar generators earn 12% of their annual revenue on the highest single day, and 40% of their annual revenue on the highest 20 days. By comparison, wind generators earn 8% of their annual revenue on the highest single day, and 33% of their annual revenue on the highest 20 days. This indicates that extreme peak price events are very important to the revenue of all generators in the NEM, but are particularly important for solar generators.

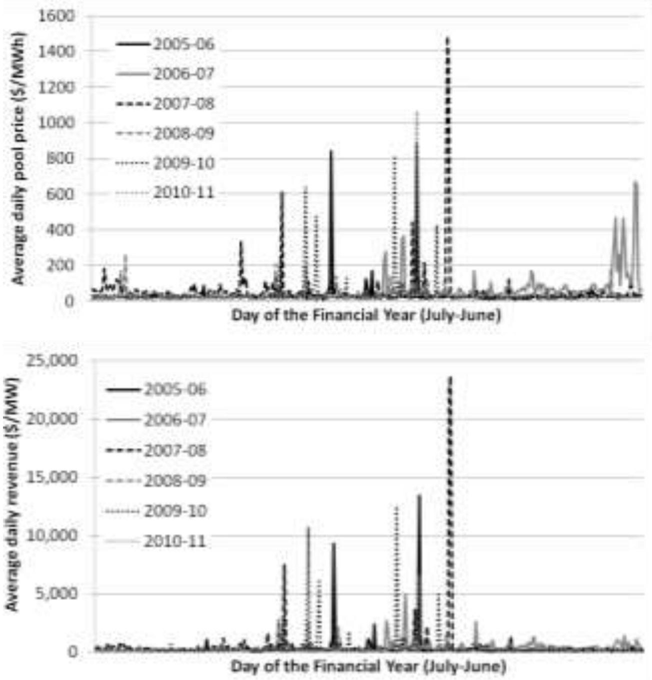

Fig. 6. Average QLD daily pool prices (top chart) and solar plant revenues (bottom chart). Extreme high prices are evident across the summer months (Jan, Dec, Feb), but are less frequent in winter. 2006-07 was an exception, with high prices during winter. These did not translate into high solar revenues, due to lower winter insolation. This emphasizes the importance of generation during summer in determining solar revenues.

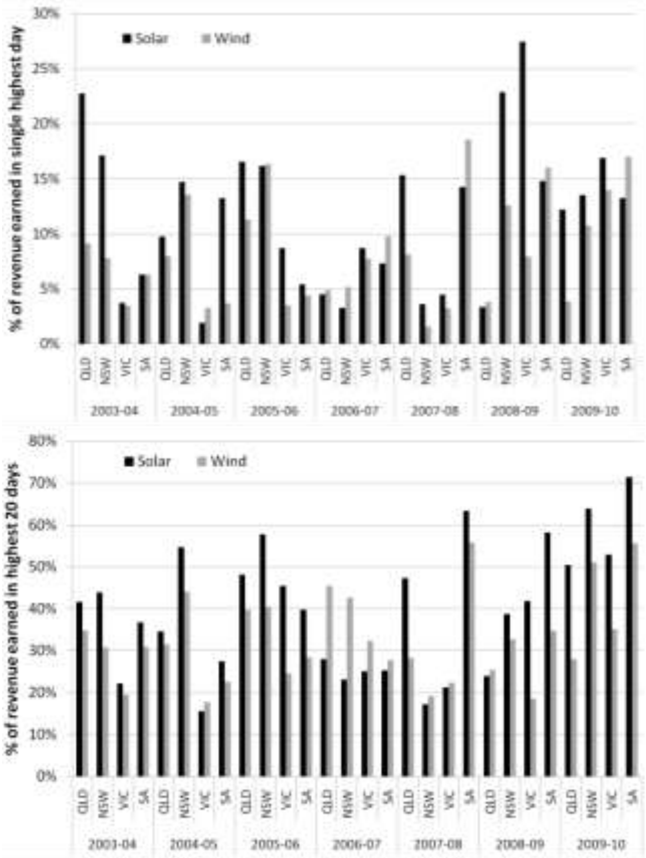

Fig. 7. The proportion of revenues of representative solar and wind generators earned on the single highest day, and the highest 20 days. Extreme price events contribute significantly to the revenues of both generator types, but more significantly for solar generators.

E. Power Purchase Agreements

Figure 8 illustrates the relativity between total revenues of solar and wind generators in different regions of the NEM. Ten year contracts (PPAs) were calculated for the forecast prices in each NEM region from 2014-15 to 2024-25 under two carbon price trajectories.

PPA prices were found to differ minimally between the two carbon price scenarios, due to the nature of the LRET scheme. LGC prices are set via the market, and therefore are projected to decrease in scenarios with higher pool prices, allowing average renewable generators to meet costs. This means that the bundled PPA price (which includes both the "black" and "green" components of electricity) are naturally hedged against shifts in the carbon price.

This data indicates that solar generators can justify significantly higher PPA prices than wind generators. Due to operation primarily during peak periods, solar generator revenues are uplifted compared to the average. This means that solar generators should be able to negotiate PPAs around $10/MWh higher than their wind counterparts (other factors being equal). Notably, the same calculation for historical years would exhibit a greater difference, because historical peak prices were higher relative to off-peak prices due to the absence of a carbon price.

Revenues are observed to be consistently higher in QLD and NSW, and consistently lower in SA and VIC. This is strongly driven by trends in pool prices rather than solar resources. It is emphasised that pool price forecasts depend upon a range of factors with high uncertainty, including future load growth in each region, the distribution of future renewable development, thermal plant retirements and the bidding strategies employed by generators as the market changes over time (with the entry of carbon pricing and high penetration renewable generation).

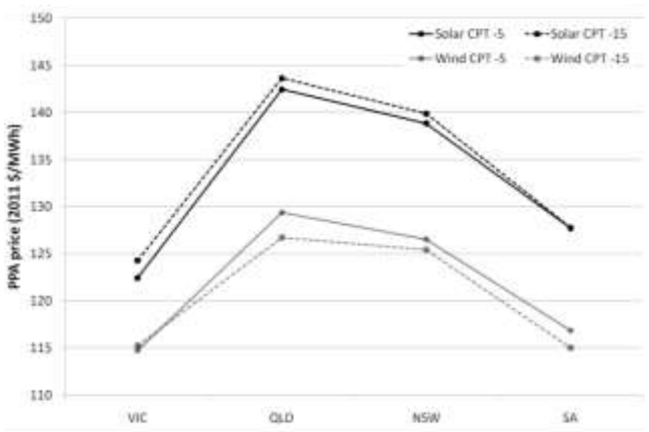

Fig. 8. Projected Power Purchase Agreement (PPA) prices for ten year contracts (2014-15 to 2024-25) for solar and wind generators in various regions of the NEM. Generators in QLD and NSW generally receive the highest revenues, with solar and wind revenues in SA and VIC being lower on average. Furthermore, due to capturing peak prices solar generators can justify significantly higher PPAs than wind farms.

F. Marginal Loss Factors

Marginal Loss Factors (MLFs) provide a measure of transmission losses. They are intended to incentivise generator development in locations that are undersupplied by generation (featuring an excess of local load), or are supplied by a strong transmission network.

Each major point on the Australian transmission grid has an annually calculated MLF (published by AEMO), which is a number more or less than 1. The price that a generator receives for their electricity is directly multiplied by their MLF, so it can be a very significant factor in the viability of a particular location for a new generator. Furthermore, MLFs can change substantially when new generation is introduced, particularly in weak parts of the grid.

Intermittent renewable generators (such as wind and solar) are likely to be particularly strongly affected by MLF as an investment driver, for the following reasons:

- The calculation methodology for MLFs utilises volume weighted losses. For intermittent plant, transmission losses in the local network are typically highest when the plant is operating at high levels, meaning that their volume weighted loss factor will fall more rapidly than the time weighted loss factor at the same location. An equivalent schedulable plant at the same location, producing the same quantity of energy over a year will typically operate in a more consistent manner, reducing network losses and achieving a more favourable loss factor (closer to the time weighted loss factor).
- Renewable resources tend to be remotely located, typically far from strong transmission network connection points and large loads. At locations of this type MLFs typically lack robustness, and will decrease rapidly as the size of the plant is increased.
- Renewable generators such as wind and solar feature modular units, such that plant sizes can be relatively small whilst maintaining efficiency and economies of scale. This allows distributed development and minimises negative impact on MLFs.

Therefore, in the case of large-scale solar development, MLFs may tend to incentivise smaller installations. Solar plants in the size range 10-30 MW are likely to have minimal impact on the local MLFs at a wide range of suitable locations, whilst remaining sufficiently large to capture economies of scale. However, larger solar plant installations (50+ MW) will tend to depress local MLFs in all but a few suitable locations. Optimal plant sizing will depend upon an optimisation of maximising economies of scale, whilst minimising negative impact on the MLF.

G. Conclusions

A clear understanding of present and future factors likely to influence pool prices and their correlation with solar resource availability in all regions is essential to allow maximisation of solar revenues.

IV. References

[1] Australian Government, Australia's Low Pollution Future. http://www.treasury.gov.au/lowpollutionfuture/

[2] Australian Government, Renewable Energy Atlas, Department of Climate Change and Energy Efficiency. http://www.climatechange.gov.au/what-you-need-to-know/renewable-energy/atlas.aspx

[3] Bureau of Meteorology website, average daily solar exposure 1990 to 2008. http://www.bom.gov.au/jsp/ncc/climate_averages/solar-exposure/index.jsp

V. Biographies

Dr Jennifer Riesz is the Principal of Renewable Energy and Climate Change at ROAM Consulting. She joined ROAM Consulting in October 2007, and models and advises on topics related to climate change, such as carbon pricing, the Renewable Energy Target, and the anticipated impacts of these on electricity systems (including pool prices, transmission congestion, and changes in dispatch).

Dr Joel Gilmore is a member of ROAM Consulting's team of energy market modellers, specialising in renewable energy technologies and applications, and greenhouse gas emissions forecasting. Since joining ROAM in November 2008, he has conducted a number of major modelling exercises in the NEM related to renewables, including work on the proposed 1GW of solar power for the Australian Government, and on the changes resulting from the introduction of the carbon pricing and the 20% Renewable Energy Target.

Dr Melinda Buchanan joined ROAM Consulting in March 2009. She specialises in customised long-term electricity system planning using ROAM's Integrated Resource Planning software suite. Her recent projects include network augmentation and congestion analysis for the Australian Energy Market Commission and Grid Australia, and modelling work for the Australian Government's Energy White Paper.

Ben Vanderwaal has been a core member of the ROAM Consulting team since the company was formed in early 2000. Prior to this Ben was employed as an undergraduate engineer in the Queensland Government generation planning body, to assess the impacts of the fledgling National Electricity Market. His combined experience equates to more than 12 years in the industry. Ben's knowledge covers a wide range of market analysis from 5 minute dispatch intervals to the 30 year planning time frame.

Dr Ian Rose co-founded ROAM Consulting in 2000, and is principal power systems consultant. He has more than 35 years of electricity network modelling software development and application experience in Australia, New Zealand, Canada, the USA and China, and has been involved in generation and transmission operations and planning throughout that period. Throughout the 1980's, Ian was responsible for development of all power system software and then for daily dispatch of all Queensland power generation for four years from the state control centre, now AEMO's northern control centre. For the following six years he was requested to plan Queensland's fuel requirements for all thermal power stations, in conjunction with hydro stations, including Wivenhoe, Barron Gorge and Kareeya. For several years he was also the key technical adviser for the sale of Gladstone power station and associated contractual arrangements. He was Queensland's technical representative on the three state (NSW, VIC, SA) Interconnection Operating Committee investigating interconnection between Queensland and the southern states for several years during this period, leading to setting the major parameters for the future QNI interconnector. When the Queensland Electricity Industry was disaggregated in the mid-1990's he was appointed Manager Planning and then General Manager Technology for the Queensland Generation Corporation, responsible for all GOC generation, until founding ROAM.