Market pricing and revenue outcomes in an electricity market with high renewables – An Australian case study

Dr Peerapat Vithayasrichareon (J. Riesz and I. MacGill)
Centre for Energy and Environmental Markets and School of EE&T
UNSW Australia, Sydney, Australia

2015 International Association of Energy Economics (IAEE) Conference
Antalya, Turkey, May 27th, 2015

www.ceem.unsw.edu.au
Outline

- Context – Renewables and pricing implications
- The Australian National Electricity Market (NEM)
- Approach and modelling methodology
- The Impact of renewables on market prices
- Revenue and profit of generators
- Key findings
Renewables and market price implications

Growing renewable penetration
- Low short run marginal cost (SRMC)
- Generators bid into the market close to SRMC (assume perfect competition)

Reduction in spot electricity prices
- For energy only wholesale markets
- Market price would be low in most periods

Reduce generator revenues
- Will generators earn sufficient revenue to recover cost (both short run and long run cost)?
- Questions over long-term resource adequacy

- Exploring these issues within the Australian National Electricity Market (NEM) with high wind and PV penetrations
  - Quantitative analysis of spot market prices and generator revenue
  - With a view of assessing the viability of the present energy-only market
  - Mechanisms to ensure resource adequacy and reliability
The Australian National Electricity Market

- Covers all Eastern States – 90% of electricity demand.
- Largely coal, around 15% renewables
- Good wind and solar resources
- Energy only market
  - Gross pool – real-time market
  - 5-minute dispatch with 30-minute trading intervals
  - Reliability criteria: 0.002% USE
  - Market Price Cap: $13,500/MWh (€9,600)
  - Price floor: -$1,000/MWh

Peak: 30 GW
Energy: 190 TWh
Installed cap: 50 GW
Generators obtain revenue through a spot market based on the spot price in each period

- Hourly SRMC bidding, merit order dispatch
- Spot price is set by the marginal generator

Applying a minimum synchronous constraint in each period

- The minimum amount to which aggregate conventional generators can be turned down in any of the dispatch periods

‘Constrained on’ Payments for out of merit order dispatch

- SRMC of the most expensive generator that is dispatched to meet the synchronous constraint

\[
\text{Spot market revenue} = \sum_{t=1}^{T} P_{n,t} \times \text{spot price}_t
\]

\[
\text{Annual revenue} = \text{Spot market revenue} + \text{Constrained on Payments}
\]
Probabilistic generation portfolio modelling

- Taking into account a range of future uncertainties (e.g. fossil fuel prices, carbon price, demand) using Monte Carlo simulation
  - “Expected” annual revenue, cost and profit are the average value across Monte Carlo runs
Modelling different RE penetration in 2030

Examining a wide range of generation portfolios with different PV and wind penetration for 2030 in the context of uncertain *fuel prices*, *carbon pricing* and *electricity demand*.

- Existing capacity is taken into account
- Different mixes of fossil-fuel technologies (coal, CCGT and OCGT)
- Wind and PV are dispatched when available
Modeling Inputs

- Revenue & profit of each generation technology in each generation portfolio are calculated for 10,000 simulated fuel prices, carbon price, and electricity demand.

Histogram of gas price, carbon price and peak demand over 10,000 simulations.
Impact of renewables on market prices

As RE penetration increases:

- Spot revenues are earned in increasingly high price periods.
- Fewer periods of supply demand imbalance but the magnitude of unserved energy is greater (hence higher price spikes).

**Average spot price duration curve for the top 2%**

<table>
<thead>
<tr>
<th>RE Penetration</th>
<th>15%</th>
<th>30%</th>
<th>40%</th>
<th>60%</th>
<th>75%</th>
<th>85%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest price ($/MWh)</td>
<td>1,400</td>
<td>2,400</td>
<td>5,400</td>
<td>6,800</td>
<td>8,000</td>
<td>8,500</td>
</tr>
<tr>
<td>Average price ($/MWh)</td>
<td>135</td>
<td>139</td>
<td>129</td>
<td>114</td>
<td>86</td>
<td>66</td>
</tr>
<tr>
<td>No. of high price periods (&gt; $500)</td>
<td>112</td>
<td>114</td>
<td>77</td>
<td>56</td>
<td>36</td>
<td>28</td>
</tr>
</tbody>
</table>

**Highest spot price:** $8,500/MWh

**85% renewables**

**Medium carbon price**
Unserved energy is concentrated into fewer periods as the RE penetration increases.
Correlation between prices and RE generation

Price duration curve with corresponding wind and PV output.

- Wind and PV do not often generate during high price periods
As renewables increase, revenue and profit of generators decrease due to lower average spot prices influenced by the low SRMCs of wind and PV.

- Profits of PV and wind significantly reduce with higher renewables.
  - Not often generating when prices are high
  - Greatest impact on PV (almost negligible profit at high penetration)
  - Yet to account for annual capital cost repayment.
Key findings and work underway

**Avg. market prices reduce with higher renewables**
- Due to low operating costs of wind and PV
- Less periods of imbalance but the magnitude of imbalance is greater
- Magnitude of price spikes is higher

**Reduced revenue and profit**
- The impact on utility-scale PV are very severe at high renewable penetrations

**Changes in market mechanisms may be required**
- To ensure revenue sufficiency
- Capacity mechanisms?
- Increase (or remove) market price cap?
Acknowledgements: This work has been supported through funding by the Australian Renewable Agency (ARENA) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Thank you,
and
Questions?

peerapat@unsw.edu.au

Many of our publications are available at: www.ceem.unsw.edu.au
Approach and methodology

- Generators obtain revenue through a spot market based on the spot price (market clearing price) in each period
  - Hourly SRMC bidding, merit order dispatch
  - Hourly spot price is the cost to supply the last MW to meet demand (i.e. SRMC of the most expensive generator that is dispatched)
- Applying a 15% minimum synchronous constraint (SC) in each period
  - The minimum amount to which aggregate conventional generators can be turned down in any of the dispatch periods
- ‘Constrained on payments’ for out of merit order dispatch
  - SRMC of the most expensive generator that is dispatched out of merit

\[
\text{Spot market revenue} = \sum_{t=1}^{T} P_{n,t} \times \text{spot price}_t
\]

Annual revenue = Spot market revenue + Constrained on payments
Optimal generation portfolios

‘Cost VS Cost risk Efficient Frontier’ (EF) for each RE penetration

- **Expected cost (mean) and cost risk (SD of cost)** of generation portfolios on the ‘Efficient Frontier’ (optimal generation portfolios)

<table>
<thead>
<tr>
<th>% RE</th>
<th>Cost range ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15%</td>
<td>$110 - $119 (€78 - €84)</td>
</tr>
<tr>
<td>30%</td>
<td>$105 - $113 (€74 - €80)</td>
</tr>
<tr>
<td>40%</td>
<td>$98 - $106 (€69 - €75)</td>
</tr>
<tr>
<td>60%</td>
<td>$92 - $98 (€65 - €69)</td>
</tr>
<tr>
<td>75%</td>
<td>$92 - $100 (€65 - €71)</td>
</tr>
<tr>
<td>85%</td>
<td>$100 - $107 (€71 - €76)</td>
</tr>
</tbody>
</table>

Will focus on the least cost portfolios for revenue analysis
Impact of renewables on market prices

- As renewable penetrations increase, spot revenues are earned in increasingly rare periods

Highest price: $8,500/MWh

Average spot price duration curve for the top 2%

<table>
<thead>
<tr>
<th>Average annual generation (TWh) (across 10,000 simulations)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>15% RE</td>
</tr>
<tr>
<td>30% RE</td>
</tr>
<tr>
<td>40% RE</td>
</tr>
<tr>
<td>60% RE</td>
</tr>
<tr>
<td>75% RE</td>
</tr>
<tr>
<td>85% RE</td>
</tr>
</tbody>
</table>