Least cost 100% renewable electricity scenarios in the National Electricity Market

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Just about this time next year lots of people may be asking,

“What time is the electricity on today?”

The gloomy prospect that significant areas of this country could reach the point of part time electricity usage seems unbelievable, but it could happen as early as the middle of next year.

This is not the doomsday prediction of an electric utility. It’s the studied conclusion of the Federal Power Commission.

An FPC news release of a staff study declared that by 1975 "many steam electric power plants could be ordered to shut down because they do not conform to air quality standards."

Strident adherence to unreasonable regulations that are not necessary to protect health would only jeopardize the nation’s electric power supply.

The FPC is not talking about the ambient air standards of the Clean Air Act. They refer to the unrealistic requirement that emissions be measured at the top of the stack, instead of at the ground level where people live and breathe.

We completely support the mandate of the Clean Air Act to protect human health. But, like the Federal Power Commission, we question the wisdom of regulations that assume the existence of a workable, reliable and non-polluting commercial technology which doesn’t even exist.

Unless action is taken now even the most diligent conservation of energy, which is so necessary, will fail to avert the forced curtailment of power.

Requirements must be adjusted to allow the use of alternate methods of meeting the standards of the Act. It’s not the method that counts. It’s the result. And we can deliver the result.

One method that does exist... and does work... electronically measures air quality at ground level, and sets in motion constant air quality controls to meet the standards.

Automatically.

The Federal Power Commission recommends it. The government’s own electric power system, the Tennessee Valley Authority recommends it. So do we.

Additionally, the vast resources of clean, inexhaustible coal the government owns in the West must be released. This coal is the people’s coal and the people need it. It takes time to open mines and time is running out. Soon even this solution will come too late.

But if action is taken today, no one need ask “What time is the electricity on?” tomorrow.
Why 100% renewable electricity?

- AR4 (IPCC, 2007) stabilisation target for 2°C
  - 80% to 95% below 1990 emissions by 2050
- Australian Government policy
  - 80% below 2000 emissions by 2050
- Some current jurisdictional RE targets
  - Australia: 20% by 2020
  - Germany: 40% by 2020, 80% by 2050
  - New Zealand: 90% by 2050
  - Denmark: 100% by 2050 (41% in 2011)
- AEMO tasked by MPCCC with 100% modelling
Outline

- Background
  - NEM regions
  - Simulations
- Simulation extensions
- Combining simulations with search
- Least cost search results
- Comparison with a reference scenario
- Conclusions
NEM regions

Map of generation and transmission assets in the NEM (Source: Geoscience Australia)
NEM regions

The diversity of Australian climate zones (Source: Bureau of Meteorology)
Simulation background

- *Simulations of Scenarios with 100% Renewable Electricity in the Australian National Electricity Market*, Energy Policy (45)

- Hourly simulations of supply to meet demand
  - Hourly NEM demand for 2010
  - Simulated dispatch using regional weather observations

- Generation mix chosen by guided exploration
  - Ensure reliability
  - No initial consideration of cost or transmission
Simulation background

Hour-by-hour plot from a week in January 2010
Simulation extensions

• Cost model
  – 2030 projected annualised capital cost ($/kW/yr)
  – Fixed O&M ($/kW/yr)
  – Variable O&M ($/MWh)
  – Optionally including transmission
  – Costs taken from AETA report (BREE, 2012)

• Regional model
  – Each “generator” assigned to a region
  – Dispatch algorithm is now region-aware
  – Tracks hourly energy exchanges between regions
# Assumed technology costs (2030)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Efficiency (GJ/MWh)</th>
<th>Capital cost ($/kW), [Low – high]</th>
<th>Fixed O&amp;M ($/kW/yr)</th>
<th>Variable O&amp;M ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supercritical black coal</td>
<td>8.57</td>
<td>2947-3128</td>
<td>59</td>
<td>8</td>
</tr>
<tr>
<td>Supercritical brown coal</td>
<td>10.59</td>
<td>3768</td>
<td>71</td>
<td>9</td>
</tr>
<tr>
<td>Combined cycle GT</td>
<td>6.92</td>
<td>1015-1221</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Open cycle GT (gas)</td>
<td>11.61</td>
<td>694-809</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Open cycle GT (biofuel)</td>
<td>11.61</td>
<td>694-809</td>
<td>5</td>
<td>92</td>
</tr>
<tr>
<td>On-shore wind</td>
<td></td>
<td>1701-1917</td>
<td>40</td>
<td>14</td>
</tr>
<tr>
<td>CST (15 hours storage) †</td>
<td></td>
<td>5622-6973</td>
<td>65</td>
<td>23</td>
</tr>
<tr>
<td>PV</td>
<td></td>
<td>1482-1871</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Data source: AETA, Bureau of Resources and Energy Economics (2012)

† Capital costs for CST with 15 hours storage derived from AETA data
Combining simulation and search

- Drive simulations with a genetic algorithm
- Trivial example: closest point to the origin

Representation: \( <x, y> \)

Evaluation function: minimise

\[
f(x, y) = \sqrt{x^2 + y^2}
\]
Combining simulation and search

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\]

Generation 3
Combining simulation and search

- Drive simulations with a genetic algorithm
- Trivial example: closest point to the origin

Representation: <x y>

Evaluation function: minimise

\[ f(x, y) = \sqrt{x^2 + y^2} \]
Combining simulation and search

- Drive simulations with a genetic algorithm
- GA representation
  - 25 generators in simulation
    - Some specific (eg, Woomera CST, Sydney PV)
    - Some regional (eg, Tasmanian hydro, VIC gas turbines)
  - Exclude the 5 hydro generators (fixed capacities)
  - Vector of 20 real numbers
- GA objective is to minimise annual cost
- 100 generations, population 100 = 10,000 runs
GA evaluation function

- **Sum of**
  - Annualised capital cost for all generators
  - Fixed O&M costs for all generators
  - Variable O&M costs for all generators
  - Penalty functions
    \[
    f(x) = \max(0, x - D/50000)^3 \quad \text{(rel. std. for demand D)}
    \]
    \[
    g(x) = \max(0, x - 20 \text{ TWh})^3 \quad \text{(limit bioenergy)}
    \]
    \[
    h(x) = \max(0, x - 12 \text{ TWh})^3 \quad \text{(limit hydro)}
    \]
  - Optionally, costs for simplified transmission network at $800 per MW-km
- **Varied by discount rate, low/high capital cost**
Regional interconnections (no capacity limit)
Dashed connections are not present today.
Progress of a single GA run

Plot showing satisfactory convergence in around 70 generations
## Preliminary results of least cost search

<table>
<thead>
<tr>
<th>Discount rate</th>
<th>Without transmission</th>
<th>With transmission</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Low cost</td>
<td>High cost</td>
</tr>
<tr>
<td>5%</td>
<td>19.6</td>
<td>22.1</td>
</tr>
<tr>
<td>10%</td>
<td>27.5</td>
<td>31.5</td>
</tr>
</tbody>
</table>

Annualised cost for least cost solutions (2012 $B)
Generation mix
5% discount rate

By capacity
- Low cost
- High cost

By energy
- + 8.8 TWh spilled
- + 24.9 TWh spilled

Legend:
- Wind
- PV
- CST
- Pumped hydro
- Hydro
- GTs
Generation mix
10% discount rate

By capacity

Low cost

By energy

+ 6.8 TWh spilled

High cost

+ 27.1 TWh spilled
Peak energy exchanges (when costing transmission)

<table>
<thead>
<tr>
<th></th>
<th>NSW</th>
<th>QLD</th>
<th>SA</th>
<th>TAS</th>
<th>VIC</th>
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<tbody>
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<td>4.5</td>
<td></td>
<td>9.6</td>
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<tr>
<td>QLD</td>
<td>8.5</td>
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<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SA</td>
<td>7.8</td>
<td>8.6</td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>TAS</td>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>VIC</td>
<td>10.7</td>
<td></td>
<td>6.6</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

Peak energy exchanges (GWh per hour) in 2010 between NEM regions
What are we going to do?

Thermal efficiency versus plant age in the NEM (coal only). Source: Noone (2012)
Replacement scenario

• Replace every ageing plant with a substitute
  - Direct substitute
    • eg. supercritical black coal like-for-like
  - Some upgrading
    • eg. subcritical brown coal to supercritical brown coal
  - 3 miscellaneous cases
    • eg. steam turbines fired by natural gas to CCGT

• Fuel type unchanged
Replacement scenario

- Calculate cost to meet 2010 demand
  - Assume carbon pricing would not alter generator dispatch
  - Re-calculate SRMC for every plant
  - Calculate 2010 operating costs using dispatch data
  - Exclude plant if not dispatched in 2010
  - Price paid on all emissions

- Emissions from replacement fleet 19% lower
Comparison
5% discount rate

Plot showing the cross-over range between $50-65/tonne CO2-e
Comparison

10% discount rate

Plot showing the cross-over range between $70-100/tonne CO2-e
When could such carbon prices apply?  
(SGLP, 550 ppm)

Limitations and further work

- 2010 only, hourly resolution and small number of generator sites due to limited data
- Reference scenario not a likely future
- No modelling of plant or network failure
- Network model not complete, no constraints
- Further work
  - Improve temporal, spatial data resolution
  - Additional scenarios (CCS, all gas, nuclear/gas)
Conclusions

• 100% RE worthy of consideration
• Complex operational problem dependent on technologies, sites, capacities, dispatch – GAs perform well searching the problem space
• Least cost 100% scenarios dominated by wind
• CST value demonstrated in helping to meet demand, despite higher capital cost
• Cost implications of transmission modest
• At carbon prices to address CC, 100% RE is lower cost than replacement scenario