100% Renewables for Australia?

Challenges and Opportunities

Dr Jenny Riesz

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Who am I?
Overview

100% renewables – worth thinking about?

100% renewables – technically feasible?

100% renewables – costs?

100% renewables – will the market work?
Renewables investment outpaced fossil fuels for the last 5 years (net investment in power capacity additions).

In 2014, renewables accounted for 59% of net additions to global power capacity.

Source: Frankfurt School–UNEP and BNEF
In 2014, wind power met more than 20% of electricity demand in Denmark, Nicaragua, Portugal, and Spain.

Additions are net of repowering.

REN21 Renewables 2015 Global Status Report
Solar PV Capacity and Additions, Top 10 Countries, 2014

Gigawatts

<table>
<thead>
<tr>
<th>Country</th>
<th>Added in 2014</th>
<th>2013 total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>1.9</td>
<td>10.6</td>
</tr>
<tr>
<td>China</td>
<td>10.6</td>
<td>9.7</td>
</tr>
<tr>
<td>Japan</td>
<td>9.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Italy</td>
<td>0.4</td>
<td>6.2</td>
</tr>
<tr>
<td>United States</td>
<td>0.9</td>
<td>~0</td>
</tr>
<tr>
<td>France</td>
<td>0.9</td>
<td>2.4</td>
</tr>
<tr>
<td>Spain</td>
<td>2.4</td>
<td>0.9</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Australia</td>
<td>0.7</td>
<td></td>
</tr>
</tbody>
</table>

REN21 Renewables 2015 Global Status Report

UNSW Centre for Energy and Environmental Markets
What about Australia?

<table>
<thead>
<tr>
<th>Keep using what we’ve got?</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ageing generation fleet</td>
</tr>
<tr>
<td>• By 2030, 65% of Australia’s coal-fired power stations will be over 40yrs old</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New coal?</th>
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<tbody>
<tr>
<td>• New coal now costs more than renewables</td>
</tr>
<tr>
<td>• Regulatory risks means very high cost of capital, if they can get financing at all</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Gas?</th>
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<tbody>
<tr>
<td>• Baseload CCGT can’t get competitive gas supply contracts</td>
</tr>
<tr>
<td>• Competition with LNG export market</td>
</tr>
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<table>
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<tr>
<th>Nuclear?</th>
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<tbody>
<tr>
<td>• More expensive than renewables</td>
</tr>
<tr>
<td>• No existing industry or experience</td>
</tr>
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</table>

UK: Hinkley Point C
$154/MWh
35yr PPA
Lowest cost trajectory for the National Electricity Market

Given projected gas and carbon prices, and cost risk profiles

GHG emissions ranges as recommended by the Australian Government Climate Change Authority

Power systems with very high renewable proportions of renewables appear inevitable – It’s not a question of “if”, it’s a question of when.

100% renewables – worth thinking about?

But is it even technically feasible?!?
Renewable technologies

Variable & non-synchronous
Optimising generation mix

- System cost
- Generation capital cost
- Integration cost (Voltage/Frequency management)

Proportion of variable renewables

- Least cost mix
- 0% variable
- 100% variable
J. Riesz, J. Gilmore, (2014) “Does wind need “back-up” capacity – Modelling the system integration costs of “back-up” capacity for variable generation”. International Energy Workshop (Beijing)

Wind displaces baseload generation

A new power system paradigm
Least Cost Mix (UNSW modelling)

AEMO Modelling of 100% Renewables

- Australian Energy Market Operator (AEMO)
  - Landmark modelling study in 2013
  - Most detailed analysis of 100% renewables to date
  - First time 100% renewables considered by an official planning body in Australia
A massive data collection process

Hourly traces for wind/solar technologies developed based upon historical observations (2003-04 to 2011-12)
• Generation mix to meet the Reliability Standard:

• Diverse portfolio is key
New transmission
Example: Summer, Scenario 1, 2030

![Graph showing supply and demand of energy sources over a week in 2030, with contributions from Geothermal, Biomass, Rooftop PV, Wind, and PV (utility)].

- **Geothermal**
- **Biomass**
- **Rooftop PV**
- **Wind**
- **PV (utility)**
- **CST**
- **Utility PV**

Legend:
- Red: Geothermal
- Dark Green: Bagasse
- Light Green: Biogas
- Brown: Biomass (wood)
- Blue: Wave
- Light Blue: Wind (onshore)
- Orange: PV (rooftop)
- Yellow: PV (utility)
- Dark Blue: Hydro (incl. pumped hydro)
- Grey: Nominal demand
- Dashed line: Demand using flexibility

The graph illustrates the hourly average supply and demand of energy sources, showing peaks and troughs throughout the week.
Example: Winter, Scenario 2, 2030

Model constrained to minimum 15% synchronous generation in all periods (maintain inertia, fault level feed-in, etc)
AEMO’s assessment

- Reliability standard maintained
- Operational issues “appear manageable” (high level review, based upon international research)

“High penetrations of semi-scheduled and non-synchronous generation would constitute a system that may be at or beyond the limits of known capability and experience anywhere in the world to date…”

but…

“There are no fundamental technical limitations to operating the given 100 per cent renewable NEM power system generation portfolios that have been identified.”
Renewable integration challenges

What makes renewables different?

Variability & Uncertainty

- Wind
- PV
- Solar Thermal with storage
- Run-of-river hydro
- Solar Thermal w/o storage
- Hydro
- Geothermal
- Biomass
- Non-synchronous

SRMC = $0/MWh
## Engineering challenges identified by AEMO

<table>
<thead>
<tr>
<th>Frequency control - seconds (inertia)</th>
<th>Frequency control - minutes (regulation)</th>
<th>Frequency control - hours (ramping)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Displacement of synchronous generation</td>
<td>• Increasing variability and uncertainty → increase in regulation reserves</td>
<td>• Managing long wind &amp; PV ramps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fault level in-feed</th>
<th>Grid code performance standards</th>
<th>Reliability and Resource Adequacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Non-synchronous technologies don’t provide sufficient fault feed-in</td>
<td>• New reactive power and voltage support capabilities required during disturbances</td>
<td>• Need to assess differently to present</td>
</tr>
<tr>
<td>• Protection systems may no longer be able to determine when and where a fault has occurred</td>
<td></td>
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AEMO Conclusions:

“Many issues remain to be determined without doubt, but it is valuable to note that this operational review has uncovered no fundamental limits to 100% renewables that can definitely be foreseen at this time.”

- Transition will occur dynamically over time, allowing proper scope for learning and evolution with additional experience gained.

100% renewables – Technically feasible? A question of cost…
## Cost for 100% renewables (AEMO)

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total capital cost including transmission</td>
<td>$219 - 332 billion</td>
</tr>
<tr>
<td>Wholesale cost including opex</td>
<td>$111 - 133 /MWh</td>
</tr>
</tbody>
</table>

### Chart Description

The chart illustrates the wholesale electricity price (in $/MWh) from 1998-99 to 2014-15 for different states and regions in Australia, including QLD, NSW, VIC, SA, TAS, SNY, and the average. The 100% Renewables band is shown with a green background, indicating the cost range for a full transition to renewable energy sources.
Components of retail prices

- Increase of 6-8c/kWh on retail tariffs (20-30c/kWh)
- 20% increase
How much will electricity prices go up anyway?

2030

- Treasury - No carbon price
- Treasury: 550ppm
- CSIRO (Low, Medium, High fuel prices)
- Treasury: 450ppm
- AEMO 100% Renewables Scenarios (original, with trajectory costs)
How much will electricity prices go up anyway?

![Graph showing greenhouse emissions vs. wholesale cost.]

- **Treasury - No carbon price**: 2050
- **CSIRO (Low, Medium, High fuel prices)**
- **AEMO 100% Renewables Scenarios (original, with trajectory costs)**
- **Treasury: 550ppm**
- **Treasury: 450ppm**
UNSW modelling

- 10-20% RE: $54 /MWh
- 100% RE for $71 /MWh (only $17/MWh more)
- High wind, low PV
- Costs increase ~ linearly to 80% RE
- Wind displaces coal
- 50% RE < $60/MWh, only $3/MWh more than 10% RE

Technology availability

- Can meet reliability standard with various technologies unavailable
  - Robust ability to achieve 100% RE
- Costs $65 - $87 /MWh
  - Wind typically provides ~70% of energy, most expensive scenarios don’t have wind

- 100% renewables (or very high renewables) appears similar in cost to other possible power systems in the future

100% renewables – Cost competitive?
What about the *market*?

- Competitive market
- Generators offer close to SRMC
- Price close to zero in majority of periods

How do generators recover costs?

How do we maintain accurate investment incentives?

**SYSTEM ADEQUACY**
Will the market work with high renewables?

Constant monitoring is wise – new issues will arise over time.
Summary

100% renewables – worth thinking about?

• Inevitable - a question of when

100% renewables – technically feasible?

• Yes, with high confidence, although many technical issues to address

100% renewables – costs?

• Appear manageable, and likely lower than other generation types (given anticipated gas and carbon costs)

100% renewables – will the market work?

• Will challenge existing market models, but dramatic market reform is unlikely to be warranted at this time.
Thank you
ceem.unsw.edu.au
jenny.riesz.com.au