Report to the Queensland Conservation Council

Preliminary questions about 100% renewable energy in Queensland

Prepared by Dr Ben Elliston
Independent consultant

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Introduction

An assessment of the energy mix with 100% renewable energy in Queensland was carried out using the National Electricity Market Optimiser (NEMO). NEMO is an open source techno-economic electricity model that couples a machine learning search algorithm to a chronological hourly dispatch model. Realistic renewable generation data (modelled from weather observations in 2010) and measured demand data from the same period are used.

The tool searches for the least cost system subject to a small number of constraints: limited bioenergy availability (set to 1.7 TWh per year for Queensland) and ensuring that the National Electricity Market (NEM) reliability standard of 0.002% unserved energy is met over the modelled period. Being an hour by hour dispatch model, known capacity factors for various technologies and locations are not explicitly modelled. Instead, capacity factors are calculated based on the dispatch of each simulated generator.

The following questions were posed by QCC.

Q: How much renewable energy capacity do we need to get to provide 100% of Queensland energy needs and maintain reliability?

A 100% renewable scenario was developed for Queensland as follows:

- Demand is adjusted up from 2010 levels to present day levels by increasing the demand uniformly by 10% to 57.6 TWh per year. This is reflective of the increase documented in the Australia Institute's Electricity Update in February 2019 (The Australia Institute, 2019). Note that the shape of the demand curve is not altered.
- Unserved energy does not exceed 0.002% of demand to satisfy the existing NEM reliability standard. As is the case for our current electricity system, demand will not be met every hour of the year, but this is not required to meet the reliability standard.
- The bulk of Queensland energy in the scenario is met using renewable energy sources located within the state. A very small amount of supplementary energy is

imported via a modelled AC interconnector from New South Wales. This interconnector has been assigned a 2,000 MW capacity in the NSW to Queensland direction which assumes there is a future upgrade from the present 1,2000 MW capacity. This NSW energy is priced in the model at an average of $80/MWh (in the 2030 scenario) or $60/MWh (in 2040). This assumes that the wholesale price of electricity will be lower ten years hence due to more and more generation from sources with no fuel cost.

- For the purposes of frequency control, NEMO employs a simple mechanism of ensuring that generation from non-synchronous sources such as PV and wind are limited to a maximum of 75% of the hourly power demand for every hour of the year. This means that sometimes synchronous generators with higher marginal costs of generation must be dispatched (out of merit order) to satisfy this requirement (eg, using concentrated solar thermal (CST), gas turbines running on renewable fuels or AC interconnection to New South Wales). In these situations, some available power from wind and PV is necessarily curtailed. This tends to make the overall mix more costly than it would otherwise be if this restriction were not in place. Reducing the requirement for synchronous generation is an active area of power engineering research in countries like high RE penetrations such as Ireland and Australia.
- Wind, rooftop solar PV, utility-scale solar PV and concentrated solar thermal (CST) plants are modelled using the renewable energy resource data produced for the AEMO 100% Renewable Energy study (AEMO, 2012). Renewable generation data sets are provided for each of the 43 NEM polygons (see Figure A.1). Rooftop solar PV installed capacity is fixed at 1.9 GW, the approximate installed capacity in 2019. These behind-the-meter systems are treated as having no grid-level investment cost and zero marginal cost of generation.
- Existing pumped hydro at Wivenhoe is included in the scenario (500 MW, 10 hours storage). Additionally, the Kidston pumped hydro facility is assumed to have been completed (250 MW, 8 hours storage). The operation strategy for the pumped hydro plants is to pump whenever there is surplus renewable electricity available and to only dispatch to prevent the gas turbines (which consume fuel) from operating. The pumped hydro plants are treated as sunk costs and are not included in the costings. The plants are also assumed to have zero marginal cost of generation.
- Capital costs, fixed operating and maintenance (O&M) costs and variable O&M costs for the various renewable energy technologies (on-shore wind, utility-scale PV, CST, open cycle gas turbines) are taken from the Integrated System Plan (AEMO, 2019) for both the 2030 and 2040 time horizons. The 2040 capital costs are generally lower for all technologies, but particularly for CST and utility-scale PV. The costs are summarised in the table on the next page. Note that costs are shown down to individual cents due to the use of the CSIRO Global and Local Learning Model (GALLM) which adjusts future costs according to learning rates. The GALLM model just outputs the calculated costs without rounding.

Technology	2030 Capital Cost ($/kW)	2040 Capital Cost ($/kW)	Fixed O&M ($/kW/yr)	Variable O&M ($/MWh)
On-shore wind	1722	1593	43.91	3.25
CST (8 hours storage)	5283	3967	103.62	6.59
Utility-scale solar PV	819	678	17.60	0
Biofuelled gas turbines	890	876	5.12	12.34 (plus fuel[1])

Table 1: ISP costs for technologies in the 100% RE Queensland scenario

Model results

The results of the two least cost optimisation runs are summarised in the following tables.

Technology	Generating capacity (GW)	Share (%)	Energy (TWh)	Share (%)
Rooftop solar PV	1.9	5.5	1.7	2.9
Utility solar PV	10.0	28.9	5.4	6.2
Wind	11.8	34.3	32.8	57.0
CST	4.7	13.8	15.4	37.1
Pumped hydro	0.8	2.2	0.6	1.0
Gas turbines	3.3	9.5	1.7	2.9
Interconnector	2.0	5.8	< 0.1	0.1
Total	34.5	100	57.6	100

Table 2: Model run results using ISP 2030 costs

1 Bioenergy for gas turbines is priced at $12/GJ.

Technology	Generating capacity (GW)	Share (%)	Energy (TWh)	Share (%)
Rooftop solar PV	1.9	6.0	1.9	3.2
Utility solar PV	6.5	20.7	6.2	10.8
Wind	11.4	36.4	31.7	55.1
CST	5.2	16.6	15.5	26.9
Pumped hydro	0.8	2.4	0.6	1.0
Gas turbines	3.6	11.5	1.7	3.0
Interconnector	2.0	6.4	< 0.1	0.1
Total	31.4	100	57.6	100

Table 3: Model run results using ISP 2040 costs

The average cost of electricity per MWh is $92 (ISP 2030 projected costs) and $81 (2040 projected costs).

Q: What needs to be done to make sure the grid copes with the summer demand peak as we transition to 100% renewables?

As we transition to 100% renewables, one option is to keep existing fossil fuelled power plants, particularly gas turbines, in service and available to be started as required. The 100% renewable mixes shown above include 2.2–2.9 GW of gas turbines running on gaseous renewable fuels. In the short term, these could be operated using existing natural gas pipelines. In the medium to long-term, these gas turbines could be converted to renewable fuels such as bio-methane or renewable hydrogen. Renewable hydrogen could be generated during periods of excess renewable electricity generation (particularly in the summer) and stored as a form of seasonal storage. NEMO does not currently model hydrogen electrolysers, but this could be added relatively easily so that this scenario could be considered.

Note that much of the year, the system has vast amounts of overcapacity, particularly in summer. The combination of PV and CST means that summer peaks are unlikely to pose major supply adequacy problems.

The more problematic period is calm winter evenings when CST storage is not fully charged due to the lower solar radiation, wind speeds are low and there is no sunlight available for PV. These are the periods when the model dispatches gas turbines to meet shortfalls. These gas turbines have a low capital cost and high operating cost, but this is how we already structure the fleet of generators to meet seasonal peak demands at manageable cost.

It should be noted from the table above and the plots below that PV generation is fairly limited (7-13% of total generation). This is because all PV generation is currently limited to daylight hours, is highly correlated around midday, and is further correlated by the somewhat limited range of longitude in Queensland. Therefore, the 25% synchronous generation requirement leads to additional PV being curtailed, especially around midday. Figure 1 shows how around 25% of the midday power is coming from CST because no more wind or PV can be accepted onto the system.

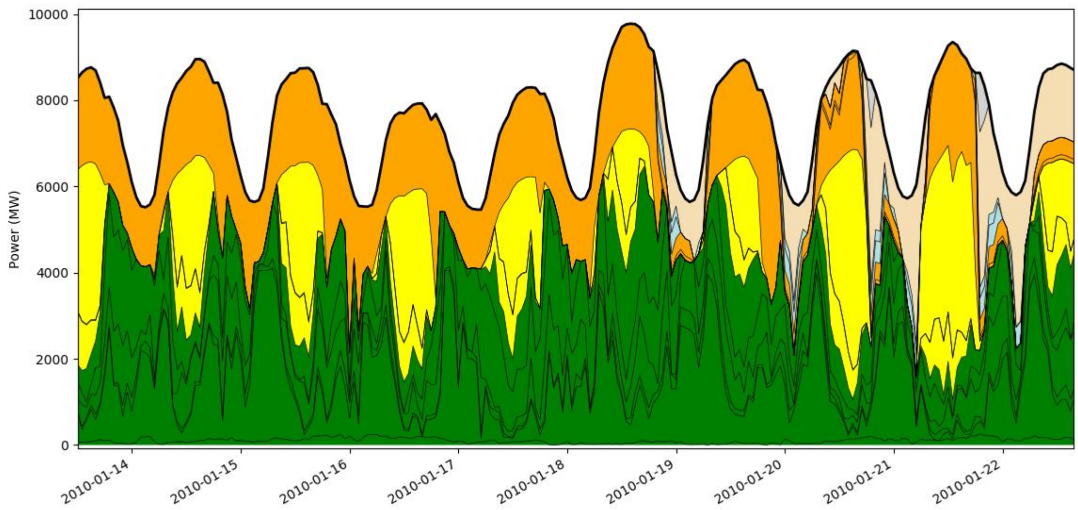

Figure 1: Several summer days with demand being met with minimal gas turbine operation. Green = wind, yellow = PV, orange = CST, tan = gas turbines (renewable fuel), blue = pumped hydro, grey = NSW interconnector.

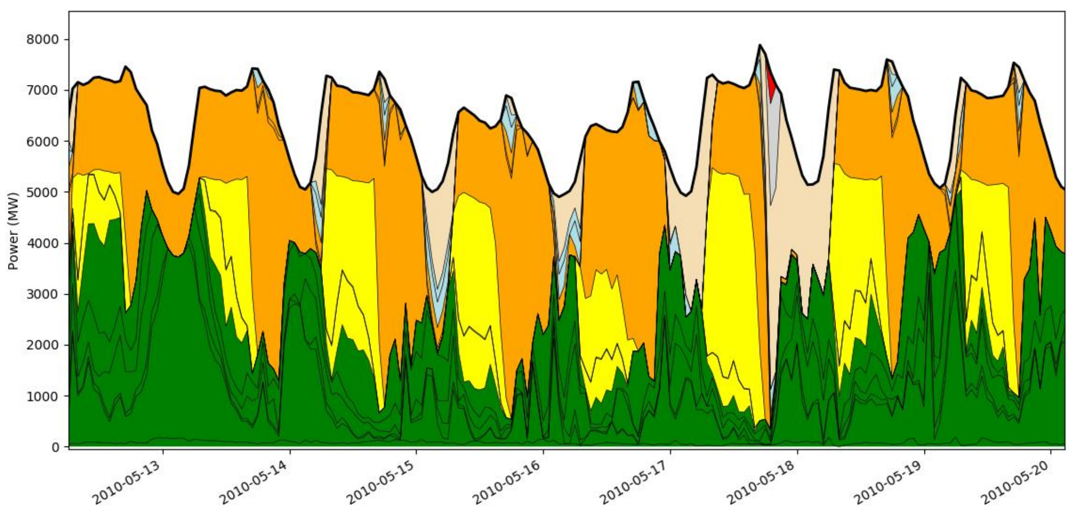

Figure 2: A more challenging week with some gas turbine operation in the evenings. In the centre of the plot, the red tip shows unserved demand. The grey area is NSW imports. Colours as indicated for Figure 1, plus red showing unserved energy.

References

Australia Institute, 2019, National Energy Emissions Audit: Electricity Update, February 2019, https://tai.org.au/

AEMO, 2012, *100 per cent Renewables study – Modelling Outcomes*, https://bit.ly/2meiv8E

AEMO, 2019, *Integrated System Plan*, https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan

Appendix

This following table contains the capacities and locations (by polygon) of renewable generation for 2030 and 2040.

Technology	Polygons (2030 costs)	Polygons (2040 costs)
Rooftop solar PV	State-wide	State-wide
Wind	4, 6, 7, 11, 17	4, 5, 10, 11, 14, 17
Utility-scale solar PV	4, 6, 7, 10, 15	1, 8
CST	2, 8, 15	1, 9, 16
Pumped hydro	Wivenhoe (500 MW, 10 hours) Kidston (250 MW, 8 hours)	Wivenhoe (500 MW, 10 hours) Kidston (250 MW, 8 hours)
Gas turbines (renewable fuels)	3.3 GW	3.6 GW

Table A.1: Renewable generation capacities and locations in 2030 and 2040.

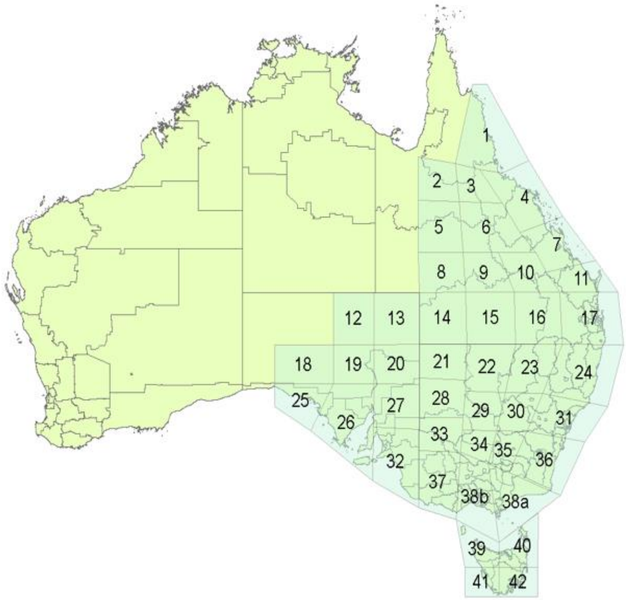

Figure A.1: AEMO polygon map