On Hydrogen and Electricity Security of Supply

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Security of supply

A water level gauge at Meridian's Lake Tekapo. Photo: Bernard Spragg

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COMMENTS BY Andrew Riddell, John Irving, Molly Melhuish, Bryan Souster

WEEK IN REVIEW

Running dry: NZ works to avert a winter energy crisis

RECOMMENDED READS

ENERGY
ACT MP makes misleading claim
MAR 17 2021

ENERGY
Pumped hydro to take a year longer
MAR 10 2021

ENERGY

Another dry winter (Newsroom: May 5, 2021).

The NZ Battery Project

Feasibility update on $4 billion Lake Onslow project expected next month

2:36 pm on 21 May 2022

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The Energy Minister is expected to provide an update next month on whether a $4 billion pumped hydro storage in Central Otago might be feasible.

The project was estimated to take four to five years to build. Photo: Shellie Evans 2014/Wikipedia

Lake Onslow is one option of NZ Battery Project (RNZ: May 21, 2022).
Others are hydrogen, bioenergy, & geothermal.

Southern Green Hydrogen

BUSINESS / ENERGY

Southland eyed for New Zealand's largest green hydrogen plant

11:07 am on 22 July 2021

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New Zealand could become the world's first large-scale producer of green hydrogen if Contact Energy and Meridian Energy's plans pan out.

Southern Green Hydrogen announced by Meridian and Contact (RNZ, July 22, 2021).

Demand response as a battery

- Increase flexible industrial production (e.g. H_2) that uses electricity.
- Increase renewable electricity supply (wind and solar) for extra industrial demand.
- When electricity is cheap, produce H_2 .
- When electricity is expensive, shut down (e.g. when wind is not blowing and reservoirs not full)
  - hard to do for inflexible plant (e.g. aluminium smelter).
  - easy for flexible plant (e.g. electrolysers making H_2).

Summary

1. Background
2. How to model the H2 option
3. JADE
4. The experiments
5. Conclusions

Summary

Risk in energy-only electricity markets

- New Zealand has an energy-only electricity market.
- Generators invest to make money from selling electricity.
- In a perfectly competitive equilibrium they will invest to make zero risk-adjusted return.
- Risk for consumers comes from dry winters that gives high prices.
- Risk for generators comes from full reservoirs and windy or sunny periods that give low prices.
- If all risk of shortage is eliminated and all generation is renewable then prices collapse and generators divest until risk increases.
- If markets for trading risk are complete and risk measures are coherent then the investment equilibrium corresponds to an optimal social plan that maximizes risk-adjusted social benefit.

A social plan

- Find the optimal level of wind investment to minimize:

  the annual risk-adjusted social cost of extra wind capacity

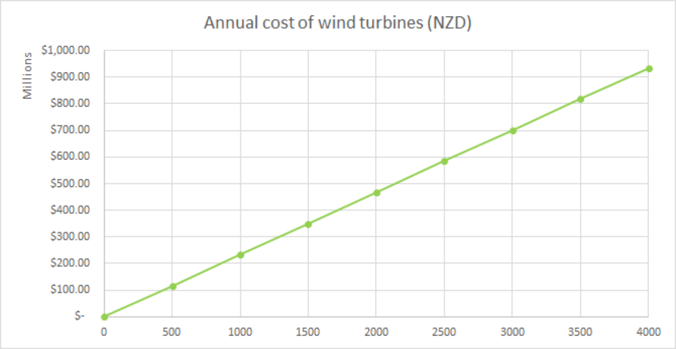
  $+$

  the risk-adjusted cost of energy supply with extra wind capacity

- This talk will value assets assuming a 10% social discount rate. (Results are indicative not prescriptive).

Wind costs

- A wind turbine costs about (USD)1.3 mill./MW[1]
- Converts to (NZD) 2.33 mill./MW[2]
- Over 25 years at 10% discount rate this is (NZD) 233,596/MW p.a.

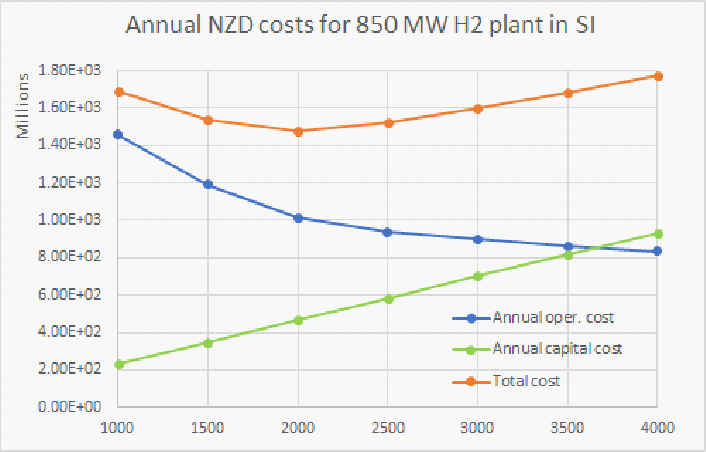


Annual wind turbine costs versus rated capacity (MW)

[1] https://weatherguardwind.com/how-much-does-wind-turbine-cost-worth-it/

[2] Converted at October 14 exchange rate.

Total cost of meeting demand with extra wind



Total cost per annum in 2020 with increasing wind investment (MW).

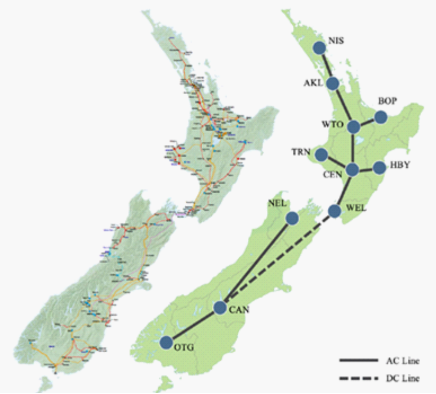
Summary

JADE =JuliA Doasa Environment

- JADE applies SDDP.jl (Dowson, Kapelevich, 2015-18) to NZ hydrothermal scheduling problem.
- Adopted by Electricity Authority, 2022.
- Given inflow W_t and cost $c_t(s)$ of renewable energy shortfall s to meet demand d_t in week t, and reservoir storage x find releases of energy U_t from reservoirs to solve

$$\begin{aligned} V_t(x) &= \mathbb{E}\big[\min_{0\leq U_t\leq x+W_t}\{c_t(d_t - U_t) + V_{t+1}(x - U_t + W_t)\}\big] \\ t &= 1, 2, \ldots, T, \\ V_{T+1}(x) &= C(x) \text{ (known expected future cost at } T \text{ given } x) \end{aligned}$$

Physical electricity system



11 regions with approximate transmission system

Estimating regional demand

- Let $d_r(t)$ = demand in region r in period t (for all periods in 2020).
- Need to account for intra-regional losses.
- Historical electricity generation $g_r(t)$ and transmission $f_{rs}(t)$ between regions r and s is computed using vSPD and recorded.
- Set

$$d_r(t) = g_r(t) + \sum_s f_{sr}(t) - \sum_s f_{rs}(t)$$

Wind modelling

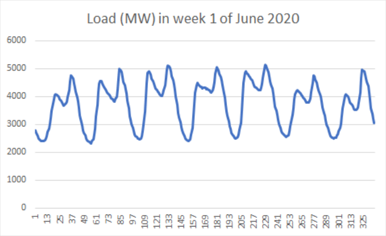
- Existing regional wind capacity k_r for region r. ($\sum_r k_r = 690$ MW)
- Existing wind generation $w_r(t)$ for 2020 gives wind generation in region r in period t.
- Wind capacity factor $\alpha_r(t) = w_r(t)/k_r$.
- Consented wind farms give maximum capacity increases M_r in each region.
- Increase of M MW of wind capacity gives capacity increase $m_r = M * M_r / \sum_r M_r$.
- Wind expected in period t is $(m_r + k_r)\,\alpha_r(t)$, which is subtracted from demand $d_r(t)$.

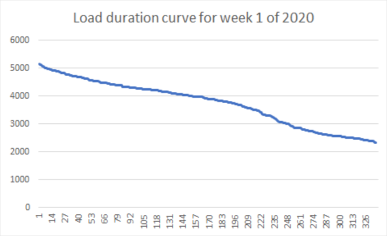
Load duration curves

- Demand minus wind generation in region r in period t is

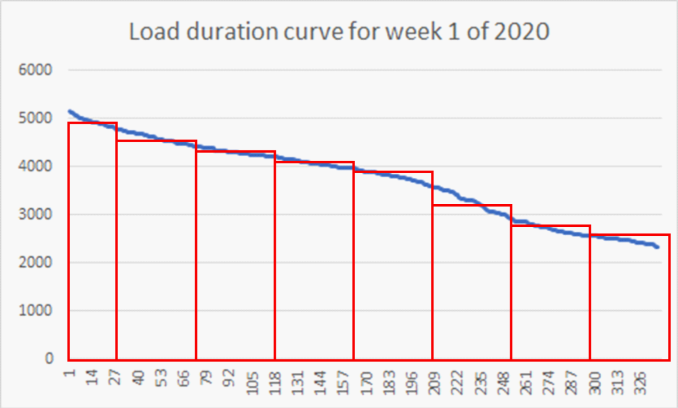
$$N_r(t) = d_r(t) - (m_r + k_r)\,\alpha_r(t)$$

- National (net) demand in period t is $\sum_r N_r(t)$. For each week in the year we can construct a national load duration curve for net demand.





Load blocks



Eight load blocks (B1,B2,. . . ,B8) are identified based on ordering $\sum_r N_r(t)$ from peak to offpeak using a lot sizing model.

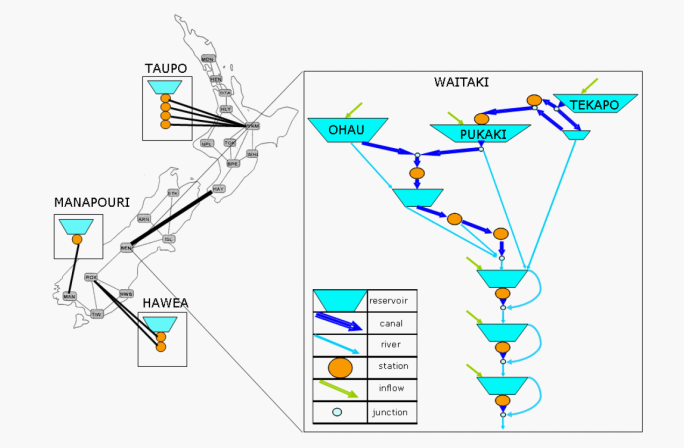
Demand response

- Assume all thermal plant is shut (Huntly, Whirinaki and Taranaki gas generation).
- Assume Tiwai Point smelter is shut.
- Assume EMI demand response from market (at $> \$530/\text{MWh}$).
- Suppose H_2 plant in Southland has constant demand 850 MW.
- H_2 load is shed in any load block up to 850 MW when price exceeds $150/MWh.
- Maximum total load shed in a week = 850*168 =142.8 GWh.

HydrogenPlantSI	Power	H2P	all	all	all	power	absolute	850	0
HydrogenPlantSI	Tranche	H2P	all	all	all	energy	absolute	142.8	150

Demand response for H2 plant

Inflows and reservoirs



JADE default is six major reservoirs with stagewise independent inflows sampled from historical record.

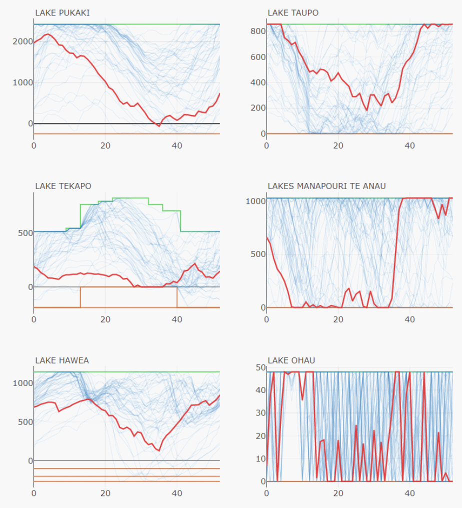
JADE over infinite horizon

- JADE solves stochastic dynamic program over 52 weeks of 2020.
- Infinite horizon mode assumes discount factor $\beta < 1$.
- Solve recursion

$$V_t(x) = \mathbb{E}\big[\min_{0 \leq U_t \leq x + W_t} \{f(d_t - U_t) + V_{t+1}(x - U_t + W_t)\}\big]$$

where $V_{53}(x) = \beta V_1(x)$.

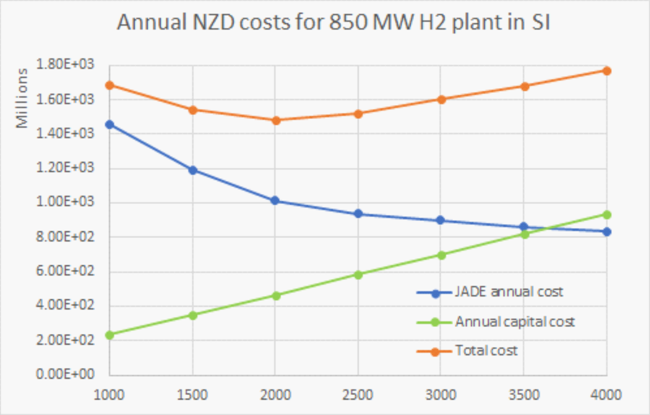
Storage trajectories from JADE



Simulated storage trajectories for optimal policy with inflows 1970-2020. Dry year 2012 shown in red.

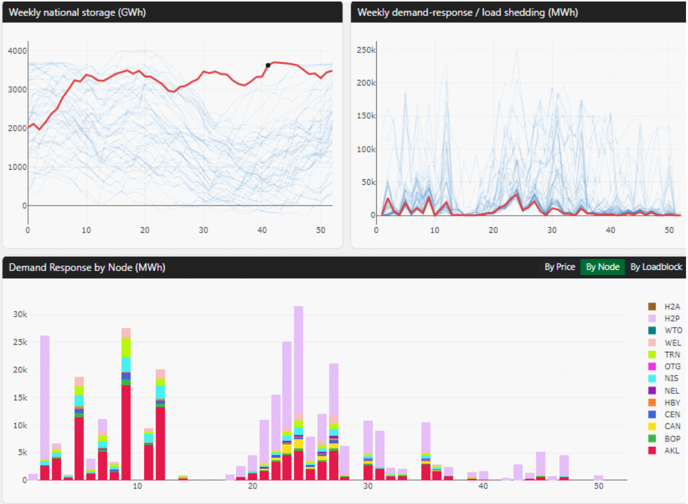
Summary

H2 plant in Southland replaces Tiwai smelter



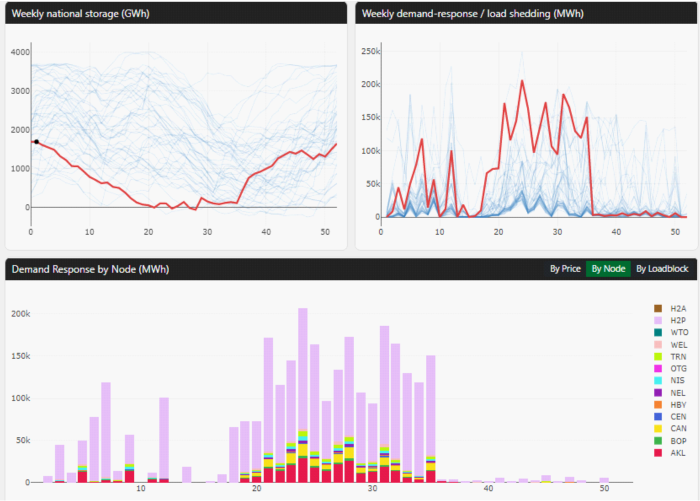
Total cost per annum with increasing wind investment (MW).

2000 MW wind solution (wet year)



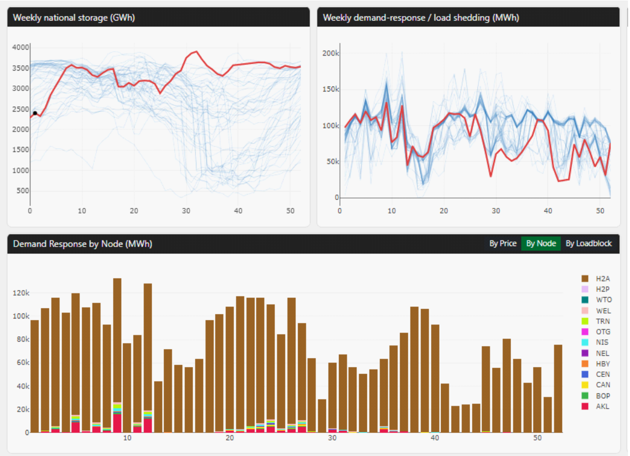
Results from simulating optimal policy with 1998 inflows.

2000 MW wind solution (dry year)



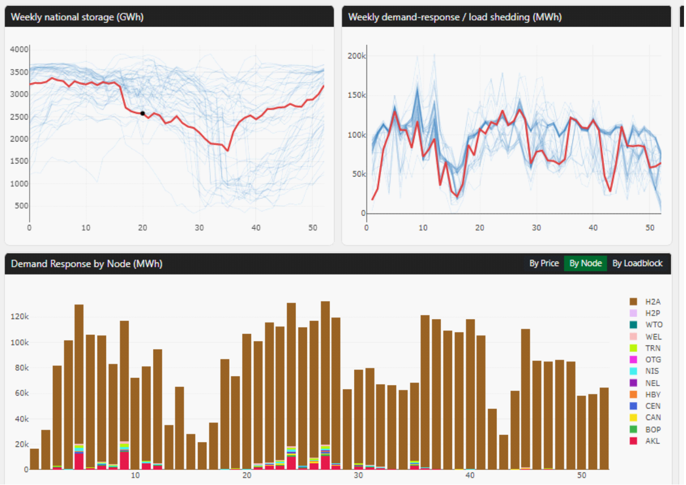
Results from simulating optimal policy with 2012 inflows.

H2 plant in Auckland with 2500 MW wind (wet year)



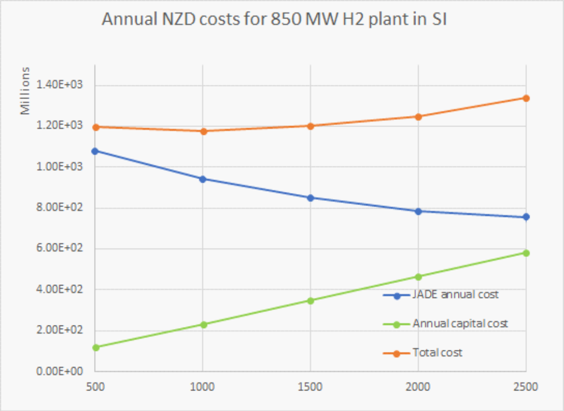
Results from simulating optimal policy with 1998 inflows.

H2 plant in Auckland with 2500 MW wind (dry year)



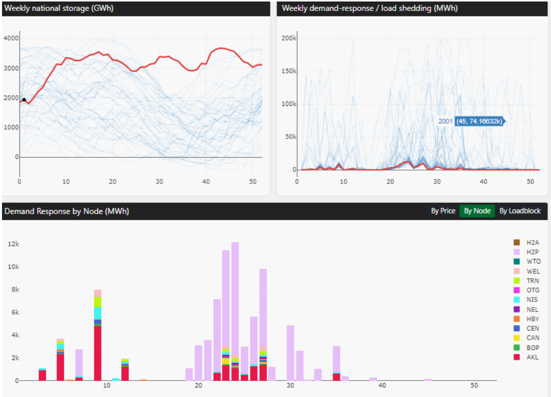
Results from simulating optimal policy with 2012 inflows.

H2 plant in SI: gas plant at HLY (e3p+peaker)



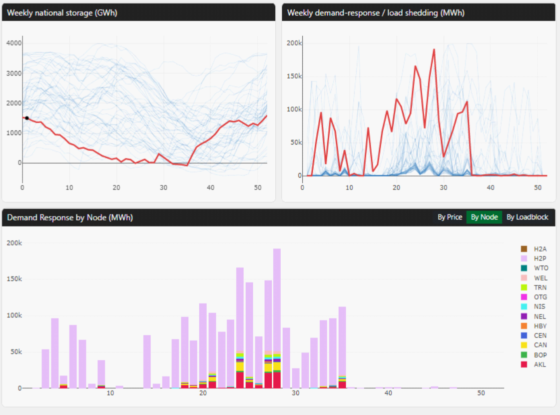
Total cost per annum with 554MW thermal at Huntly and increasing wind investment (MW).

H2 plant in SI: e3p+peaker at HLY (wet year)



Results from simulating optimal policy with 1998 inflows.

H2 plant in SI: e3p+peaker at HLY (dry year)



Results from simulating optimal policy with 2012 inflows.

Summary

Observations

($M p.a)	SGH	AKL	HLY
1998	244	769	141
2012	1273	785	861
Average	624	974	426
Wind	467	584	233
Total	1091	1558	659

Annual costs (million NZD) (average over 1970-2020).

- Optimal location of H2 plant must account for transmission constraints (future work to include transmission expansion).
- Wind expansion to socially optimal level does not eliminate shortages.
- Costs reduce (at 2020 carbon prices) if some thermal generation is allowed to manage peaks.