Using JADE to model pumped storage

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Outline

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Introduction

What is JADE?

New Zealand case study: Lake Onslow

Interpreting results

Conclusions

Purpose of this talk

- Paper published on EPOC web site: https://www.epoc.org.nz/papers/JADEOnslow.pdf.
- Talk intended to explain the paper findings and seek feedback.
- The paper is part of EPOC research and has not received any financial support from outside sources.
- Promote JADE as a tool to help BCA of NZ Battery options.

Outline

What is JADE?

`SDDP.jl` is an open-source Julia library developed by Oscar Dowson for formulating and solving stochastic optimal control problems using the SDDP algorithm.

`https://odow.github.io/SDDP.jl/stable/`

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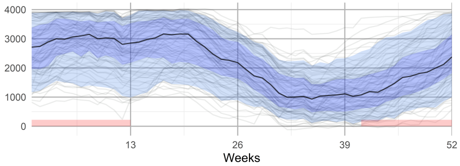
JADE.jl is made available by Electricity Authority.
https://www.emi.ea.govt.nz/Wholesale/Tools/JADE

JADE in steady state

- SDDP.jl can minimize expected discounted cost over an infinite horizon. (In the paper we use discount factor 0.9.)
- JADE.jl at EA uses this feature to compute the expected cost-to-go at the end of the plan year.
- Trained model gives a steady-state policy. Minimum expected discounted cost of this policy divided by 10 yields expected steady-state cost per annum.
- Any policy can be simulated with 89 consecutive years of inflows (1932-2020)



Advantages of JADE

- Open source versus proprietary software.
- No software licence fees (except for LP solver).
- `SDDP.jl` solution algorithm based on published research.
- Flexible `JuMP` model makes changes easy to implement. One model can examine many different NZ Battery options.
- Steady-state behaviour can be modelled.
- JADE is used by Electricity Authority.

Outline

JADE and Electricity Market Modelling

- In the paper, JADE computes a (steady-state) operating policy for hydro reservoirs (and Onslow) to minimize discounted expected social cost of thermal fuel and shortages.
- The policy will yield an optimal set of actions for each hydro chain operating as a risk-neutral price taker in a perfectly competitive wholesale market.
- JADE predicts what generator actions will be under different structural assumptions and different NZ Battery scenarios.
- JADE enables us to determine what levels of market generation investment will emerge in equilibrium.
- The paper illustrates the simplest version of this process. It can be repeated with risk-averse agents[2].

[2] Ferris & Philpott. Operations Research. 2022.

New Zealand electricity network

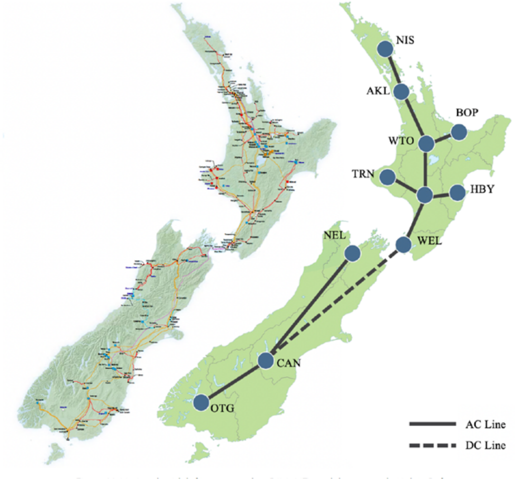


Figure: SPD network on left is approximated by an 11-node transmission system

Assumptions for load estimation

- 11 regions approximate NZ transmission network.
- 2020 regional demand estimated using vSPD.
- 2035 national demand increases from CCC "Demonstration Scenario" broken down by commercial/residential, industrial, PEV load. No reduction in Tiwai load.
- 2035 national supply increases from CCC "Demonstration Scenario" for solar and geothermal.
- Produces a load $\hat{d}_r(p)$ in region r in trading period p (net of extra solar and geothermal).

Load reduction costs

Proportion	Price ($ / MWh)
0.025	530
0.025	740
0.050	3180
0.150	5290
0.750	10580

Table: Prices for demand response and involuntary lost load.[3]

[3]Source: EA 2020 DOASA files.

Modelling wind

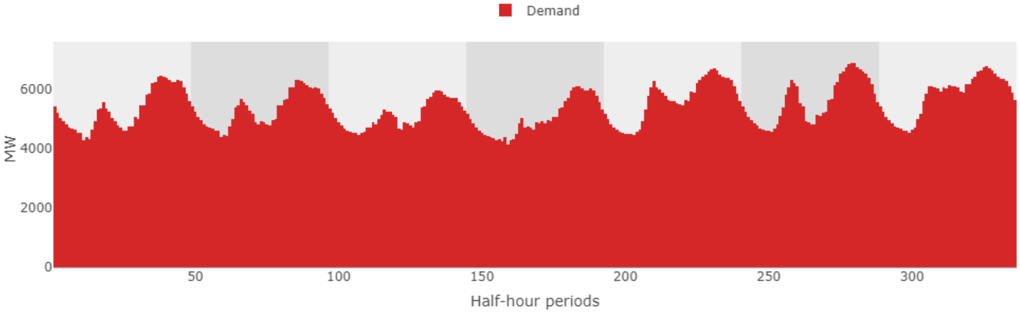
- Assume that wind capacity increases by E MW from 2021 to 2035.
- E is allocated to regions proportional to capacity of current new windfarm consents in each region.
- Load factor estimated from 2021 data for wind in region r in trading period p.
- Produces a forecast wind generation $\hat{w}_r(p)$ in region r in trading period p.
- National net load

$$n(p) = \sum_r (\hat{d}_r(p) - \hat{w}_r(p))$$

  yields a national duration curve with 5 blocks for each week.
- We divide each block of national load into load for each region r.

Load block construction

Half-hourly demand for each week is matched with half-hourly wind generation to form a set of net-demand values that will be converted into a small number of load blocks.



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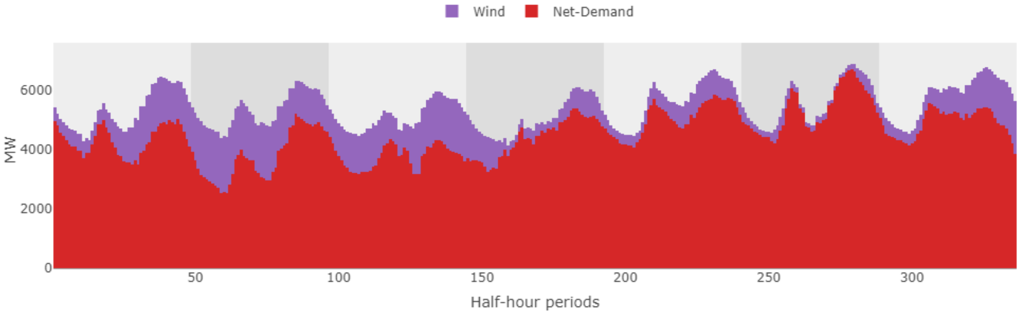


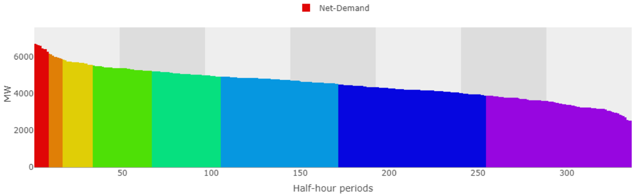
We can see that there is very little wind during the evening peak during the sixth day (period 280). This means that the peak net-load will be similar to the peak load.

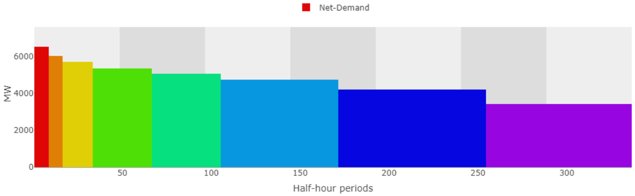
Load block construction

In order to prepare demand data for JADE, net-demand is sorted to give a net-load duration curve.

This is then divided into a set of load blocks, with the user choosing the number of blocks and using another parameter to allocate more blocks in the high demand blocks.

Each block is set to the mean net-load, and the individual periods contributing to each block are recorded.





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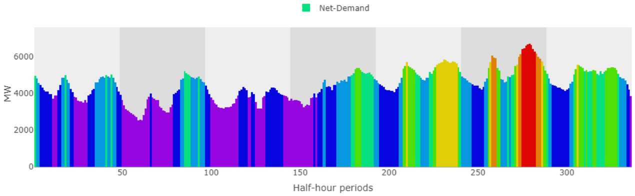
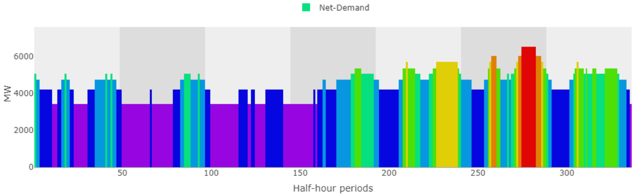




What value of E would we expect in 2035?

"The NZ Battery Project is anticipated to improve incentives for private sector investment as it provides improved balancing of supply and demand and reduced volatility of wholesale prices. Understanding of this will be progressed through Phase 2." [4]

- Compare the level of commercial investment in wind under different NZ Battery Project scenarios for 2035.
- Assuming risk-neutral investors and perfect competition, commercial investment will minimize expected social cost.

[4] p 54, NZ Battery Indicative Business Case

Optimizing E while training JADE

- Trained model with wind expansion E gives expected steady-state cost per annum, C(E).
- Increase E until C'(E) + annualized cost of 1MW of wind = 0.

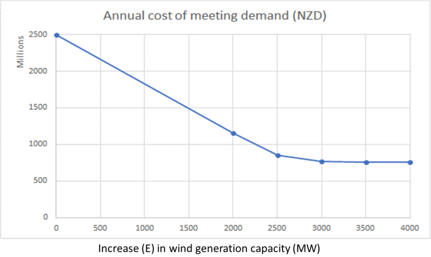


Figure: Annual cost for 2020 demand as E increases.

Optimizing E using historical simulation

- Train model with several different wind expansion values E.
- For each value of E
  - Simulate each trained model with historical inflows 1932-2020.
  - Estimate expected GWAP for wind generation.
- Select E where GWAP for wind generation equals LCOE of wind.

Optimal E for 2035 case studies (historical simulation)

- Wind Only
  - E = 4800 MW;
- Onslow
  - Onslow has 5000 GWh of storage and 1500 MW of capacity;
  - E = 3725 MW;
- Green Peakers
  - 500 MW capacity in Waikato with SRMC \$160/MWh
  - E = 3900 MW;

What transmission upgrades would we expect by 2035?

- The NZ Battery Indicative Business Case estimates extra transmission costs for Onslow as $614 m., mainly from a new substation at Onslow.[5]
- We estimate transmission capacities in 2035 that are the minimum to avoid congestion in simulation of JADE policies.
- These will tend to be overestimates of system optimal capacities, but show differences over the case studies.

[5] p 10, NZ Battery Indicative Business Case

Transmission capacities in 2035

Line	(a) Wind-only	(b) Onslow	(c) Green Peakers
NIS $\leftrightarrow$ AKL	300	270	300
AKL $\leftrightarrow$ WTO	2300	2500	2300
WTO $\leftrightarrow$ BOP	500	500	500
WTO $\leftrightarrow$ CEN	1900	1800	1600
CEN $\leftrightarrow$ TRN	450	450	450
CEN $\leftrightarrow$ HBY	300	300	300
WEL $\leftrightarrow$ CEN	1700	1900	1600
WEL $\rightarrow$ CAN	1400	1600	1200
CAN $\rightarrow$ WEL	1800	2600	1700
CAN $\leftrightarrow$ NEL	250	250	250
CAN $\leftrightarrow$ OTG	1100	2300	1000

Table: JADE line capacities (MW) for each case study

Outline

Total storage over 6 reservoirs not including Onslow

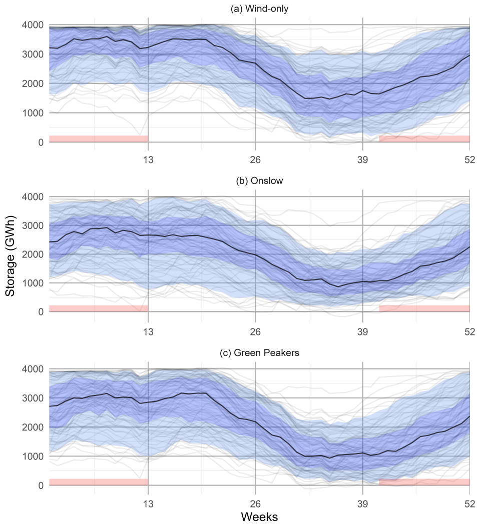


Figure: Total hydro-storage trajectories in existing reservoirs, simulated 1932-2020.

Total national storage with Onslow built

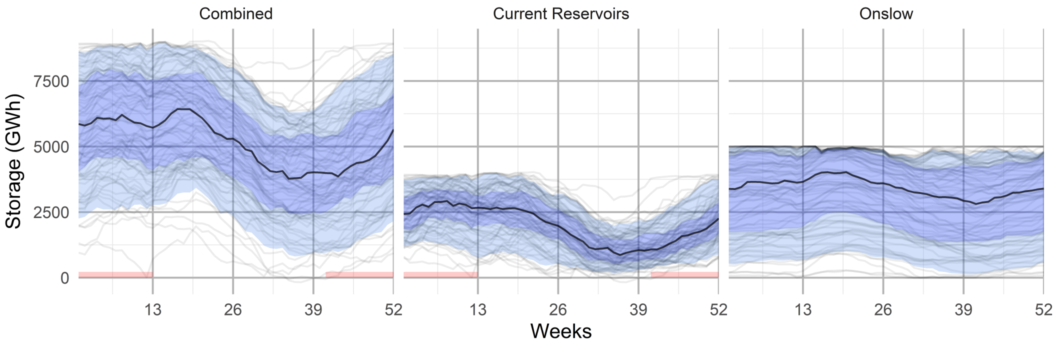


Figure: Hydro-storage trajectories in all reservoirs simulated 1932-2020.

Marginal water values 1932-2020

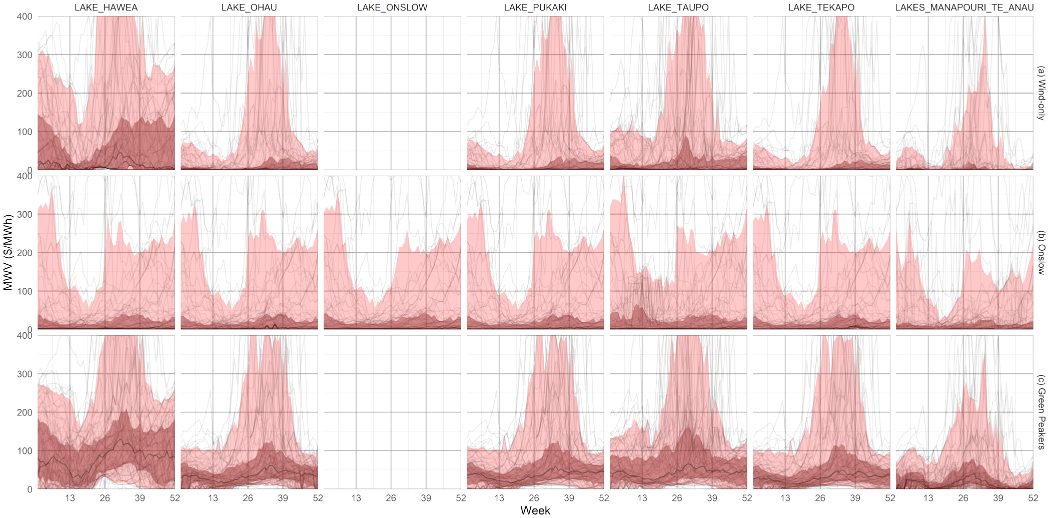


Figure: Marginal water value simulated from 1932 to 2020 for each case.

Distribution of spilled energy for 2035 case studies

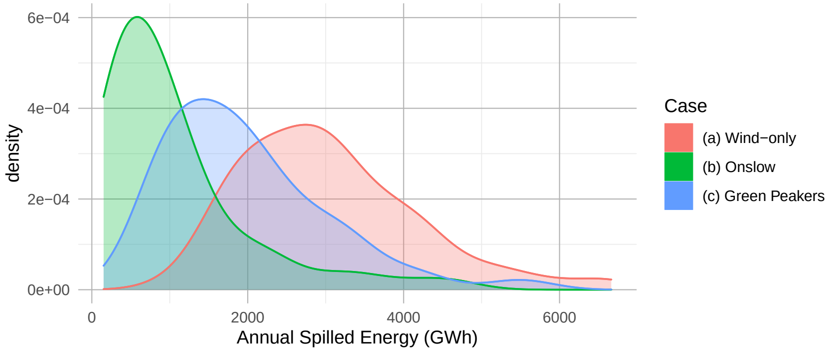


Figure: Distributions of annual spilled energy (in GWh) for each case.

Distribution of lost load for 2035 case studies

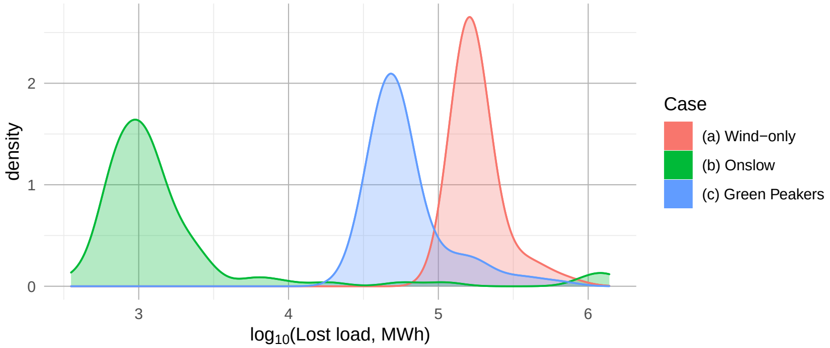


Figure: Smoothed distributions of annual lost load (in MWh) for each case (transformed using $\log_{10}$).

Distribution of annual expected cost for 2035 case studies

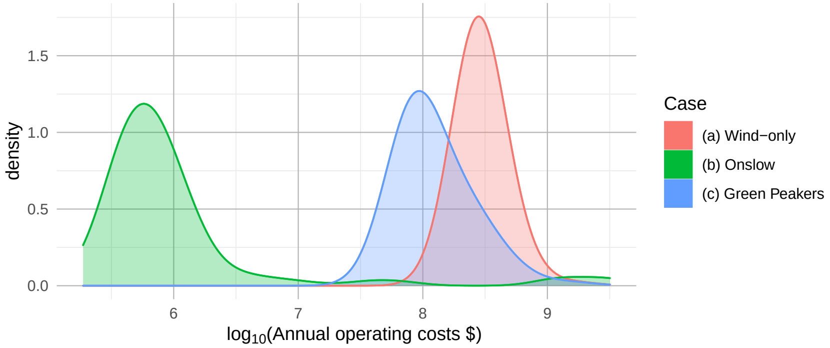


Figure: Smoothed distributions of annual load shedding + fuel costs (in $) for each case (the data has been transformed using $\log_{10}$).

Distribution of GWAP for wind for 2035 case studies

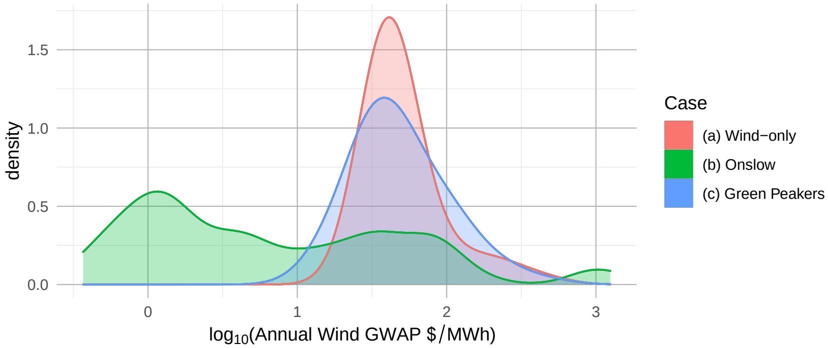


Figure: Smoothed distributions of annual GWAP for wind (transformed using $\log_{10}$).

Annual GWAP 1932-2020

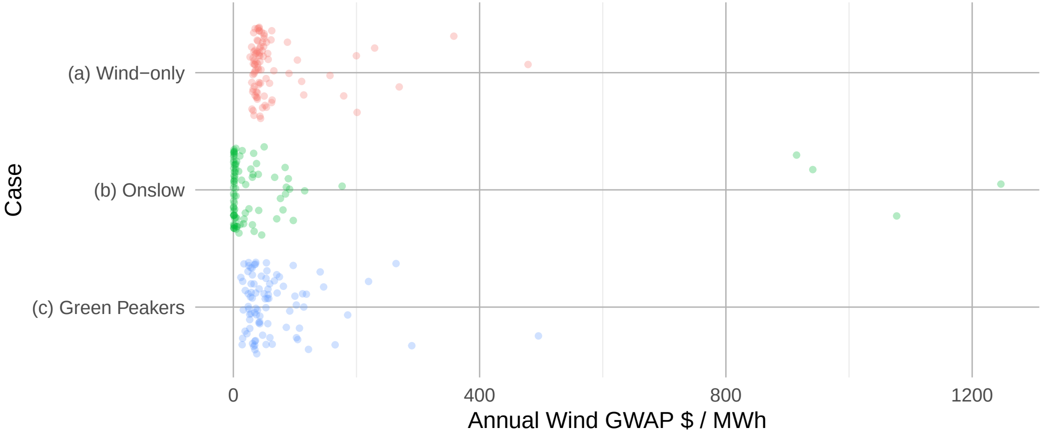


Figure: Annual GWAP for wind. Each dot shows a single year from the sequence of 89 years.

Storage and LWAP 2005-2008

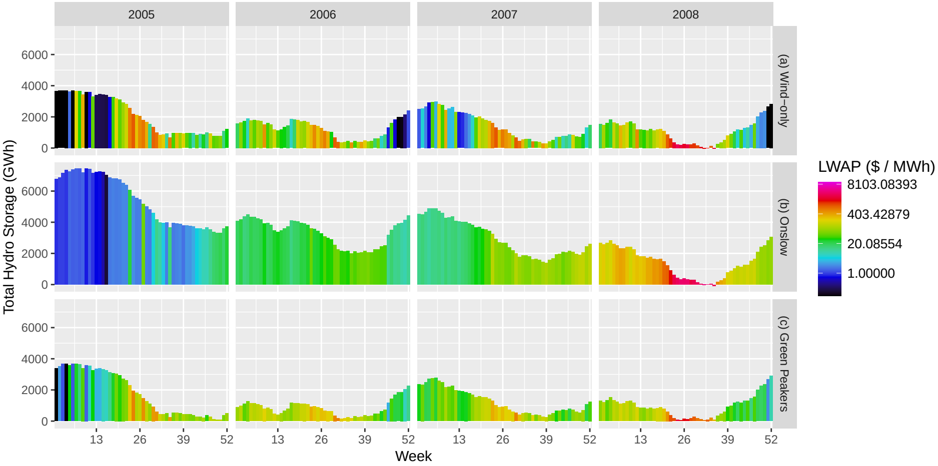


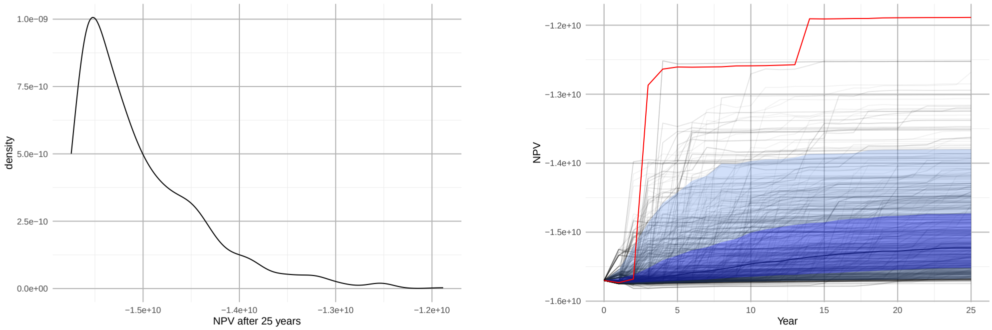
Figure: Storage and LWAP for each case from 2005 to 2008.

Prices for 2035 case studies

Metric	(a) Wind-only	(b) Onslow	(c) Green Peakers
TWAP	145.1	72.4	99.0
LWAP	181.0	75.8	116.0
Wind GWAP	65.0	67.1	65.7
Hydro GWAP	237.1	64.0	126.5
Peaker GWAP	NA	NA	590.6
Pump GWAP	NA	18.3	NA
Release GWAP	NA	67.6	NA

Table: Prices for each case study ($/MWh).

NPV for Onslow at $15.7 B



(a) (b)

Figure: NPV distribution for Onslow: (a) after year 25 and (b) over time $ simulated over 1000 sequences of 25 hydrological years.

Onslow storage for maximum revenue

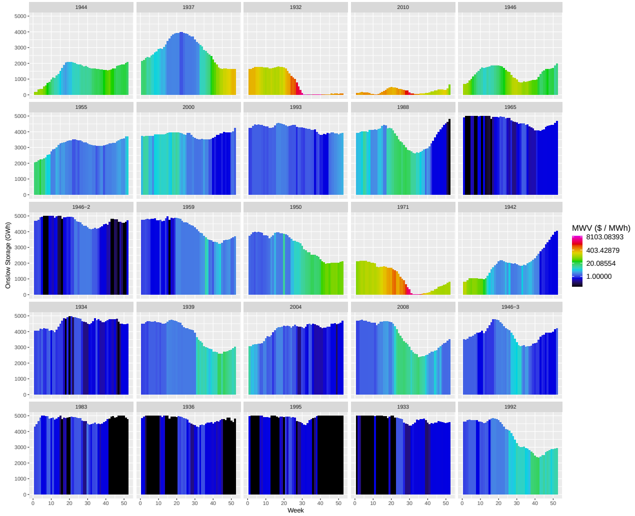


Figure: Onslow storage (GWh) and the corresponding marginal water value ($/MWh) over the most profitable sequences of hydrological years sampled.

Outline

What does JADE show us?

- Optimal operation of electricity system with storage is not simple. With more renewables, SRMC energy offers to WEM will not follow historical patterns. Need a model like JADE to understand such a system.
- Wholesale energy prices when offers at SRMC.
  - Onslow lowers LWAPs. (Good for consumers, but $15.7 B still to pay.)
  - Onslow lowers GWAPs. (Leads to lower investment in other plant.)
- Water values in a competitive market. Generally lower for Onslow case, but can peak higher when consecutive dry years.
- Optimal capacity investments in a competitive market. Presence of a large storage facility yields lower levels of wind investment than its absence (but less energy is wasted).

The future ...

- The paper studies one 2035 demand case from CCC. More are easy to do.
- The paper studies three NZ Battery scenarios. JADE can easily be configured to apply to any scenario.
- JADE 2.0 will solve for optimal wind/peaker/transmission automatically.
- NZ Battery Project should be using JADE.

The End

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