Long-term storage optimization in electricity markets

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(joint work with Eddie Anderson)

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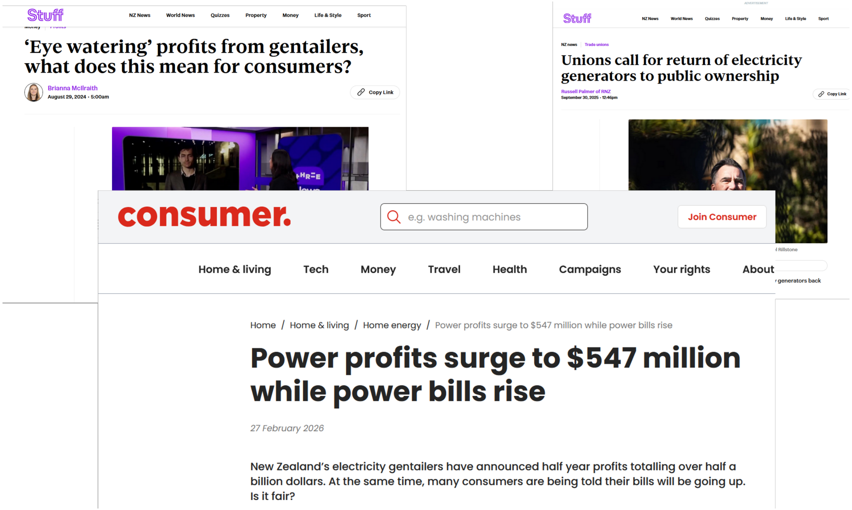
New Zealand news reports on electricity markets 2024-2026



‘Eye watering’ profits from gentailers, what does this mean for consumers?

Brianna McIlraith
August 29, 2024 · 5:00am

Unions call for return of electricity generators to public ownership

Russell Palmer of RNZ
September 30, 2025 - 12:46pm

Home / Home & living / Home energy / Power profits surge to $547 million while power bills rise

Power profits surge to $547 million while power bills rise

27 February 2026

New Zealand’s electricity gentailers have announced half year profits totalling over half a billion dollars. At the same time, many consumers are being told their bills will be going up. Is it fair?

I asked Google AI about New Zealand gentailer profits

AI Overview

In Aotearoa New Zealand, "gentailers" (vertically integrated generator-retailers like Contact, Genesis, Mercury, and Meridian) face intense scrutiny over "excess profits". Critics argue these firms exploit their market dominance to keep retail power bills high, while often paying out dividends to shareholders that exceed their net profits.

The Core Issues and Arguments

- **Excess Dividends vs. Reinvestment:** Unions and advocacy groups like 350 Aotearoa have reported that gentailers distributed billions of dollars more in shareholder dividends than they earned in net profits over the past decade. Critics claim this diverts vital capital away from building new renewable energy infrastructure.
- **High Wholesale Prices:** The spot price for electricity is often set by the highest-cost generator dispatched—which is frequently coal or gas. Because gentailers own the cheaper renewable generation (hydro, wind, solar) as well, they effectively reap massive margins.

How to address these assertions?

- Operations
  - Perfectly competitive equilibrium is a benchmark;
  - Equivalent to optimal social plan;
  - Solve social plan using SDDP;
  - Compare dispatch and prices of social plan with historical outcomes;
  - Dispatch straightforward, prices not so much.
- Investment
  - SDDP with Investment;
  - Screening curves with VRE;
  - Extension of screening curves to hydro

Screening curve ranks plant

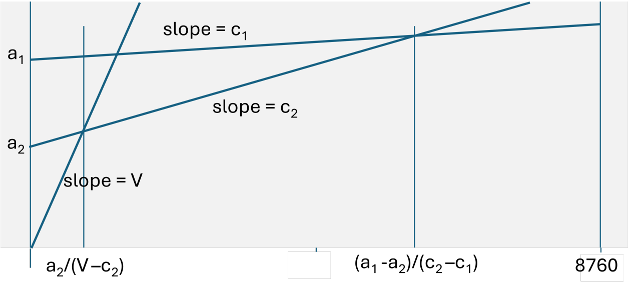
[Boiteaux, 1960, Stoft, 2002]

Base load (SRMC=\$$c_1$/MWh, annual capacity cost =\$$a_1$/MW).

Peaker (SRMC=\$$c_2$/MWh, annual capacity cost =\$$a_2$/MW).

Load shed (SRMC=V)

Peaker runs for $= \frac{a_1 - a_2}{c_2 - c_1}$ hours. Load shed for $\frac{a_2}{V - c_2}$ hours.



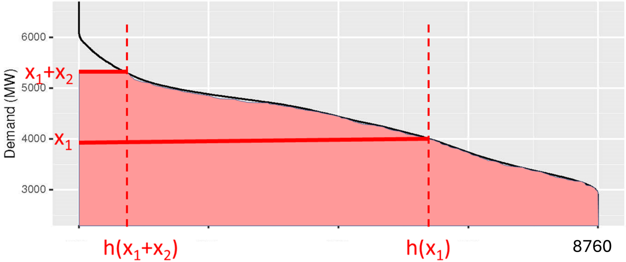
Screening curve showing most economical plant for different durations.

Screening curve capacity choices

Base load (SRMC=c_1) on for 8760 hours in year.

Peaker (SRMC=c_2) on for $h(x_1) = \frac{a_1 - a_2}{c_2 - c_1}$ hours.

Load shed (SRMC=V) for $h(x_1 + x_2) = \frac{a_2}{V - c_2}$ hours.



Load duration curve with base load capacity x_1 and peaker capacity x_2.

Rents pay for capacity choices

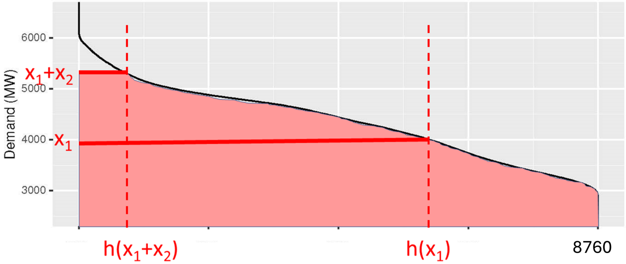
Rent for peaker $= h(x_1 + x_2)(V - c_2) = a_2$.

Rent for base load

$$= h(x_1 + x_2)(V - c_1) + (h(x_1) - h(x_1 + x_2))(c_2 - c_1)$$

$$= a_2 + h(x_1)(c_2 - c_1) = a_1.$$

Plant make zero profit at optimum.



Load duration curve with base load capacity x_1 and peaker capacity x_2.

Alternative view via a mathematical program

[Korpås and Botterud, 2020, Stevens et al, 2024]

Let $\mathcal{N} = \{1, 2, \ldots, 8760\}$, $\mathcal{J} = \{1, 2\}$.

$$
\begin{aligned}
\text{SMP: min} \quad & \sum_{j \in \mathcal{J}} a_j x_j + \sum_{n \in \mathcal{N}} \left(\sum_{j \in \mathcal{J}} c_j(n) y_j(n) + V z(n) \right) \\
\text{s.t.} \quad & \sum_{j \in \mathcal{J}} y_j(n) + z(n) = d(n), \quad \text{for all } n \in \mathcal{N} \\
& 0 \leq y_j(n) \leq x_j, \quad \text{for all } j \in \mathcal{J}, n \in \mathcal{N}, \\
& 0 \leq z(n) \leq d(n), n \in \mathcal{N}.
\end{aligned}
$$

Differentiable elastic demand makes dual variables unique

Let $\mathcal{N} = \{1, 2, \ldots, 8760\}$, $\mathcal{J} = \{1, 2\}$.

$$\begin{aligned}
\text{SMP: } \min \quad & \sum_{j \in \mathcal{J}} a_j x_j + \sum_{n \in \mathcal{N}} \left(\sum_{j \in \mathcal{J}} c_j(n) y_j(n) - U_n(d(n)) \right) \\
\text{s.t.} \quad & \sum_{j \in \mathcal{J}} y_j(n) = d(n), \quad \text{for all } n \in \mathcal{N} && [\pi(n)] \\
& 0 \leq y_j(n) \leq x_j, \quad \text{for all } j \in \mathcal{J}. && [\rho_j(n)]
\end{aligned}$$

$$\pi(n) = U_n'(d(n)).$$

Fix optimal capacities at x^*, and solve dispatch problem

Let $\mathcal{N} = \{1, 2, \ldots, 8760\}$, $\mathcal{J} = \{1, 2\}$.

$$
\begin{aligned}
\text{DP: min} \quad & \sum_{j \in \mathcal{J}} a_j x_j^* + \sum_{n \in \mathcal{N}} \left(\sum_{j \in \mathcal{J}} c_j(n) y_j(n) - U_n(d(n)) \right) \\
\text{s.t.} \quad & \sum_{j \in \mathcal{J}} y_j(n) = d(n), \quad \text{for all } n \in \mathcal{N} \qquad [\pi(n)] \\
& 0 \le y_j(n) \le x_j^*, \quad \text{for all } j \in \mathcal{J}. \qquad [\rho_j(n)]
\end{aligned}
$$

This decouples into 8760 dispatch problems, where plant j offers x_j^* at marginal cost $c_j(n)$, and demand bids marginal utility $U_n(d)$.

DP has same primal and dual solution as SMP.

Optimality conditions for SMP imply DP rents cover costs

$$\pi(n) = U'(d(n))$$

$$0 \leq c_j(n) + \rho_j(n) - \pi(n) \perp y_j(n) \geq 0$$

$$0 \leq x_j - y_j(n) \perp \rho_j(n) \geq 0$$

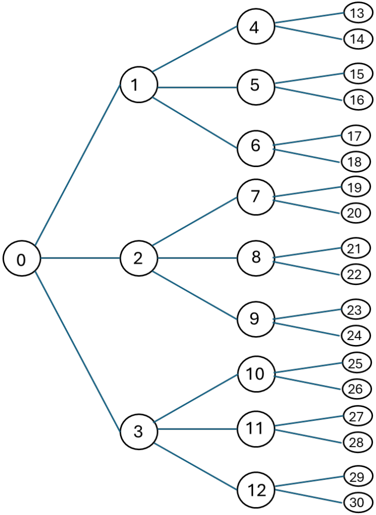
$$0 \leq a_j - \sum_{n \in \mathcal{N}} \rho_j(n) \perp x_j \geq 0$$

$$\begin{aligned} \text{Annual rent } (R_j) \text{ for technology } j &= \sum_{n \in \mathcal{N}} (\pi(n) - c_j(n)) y_j(n) \\ &= \sum_{n \in \mathcal{N}} \rho_j(n) y_j(n) \\ &= \sum_{n \in \mathcal{N}} \rho_j(n) x_j = a_j x_j \end{aligned}$$

The story so far...

- Assume
  - perfect competition
  - complete markets
  - linear capacity cost $a_j x_j$
  - linear production cost $c_j(n) y_j(n)$
  - concave differentiable utility $U(d)$
- Solve investment problem SMP to give optimal capacities for each technology.
- With capacities fixed, solve dispatch problem DP in each hour to give system marginal prices.
- The total annual Ricardian rent (R_j) earned by each technology j exactly covers its annual capital cost $a_j x_j$.
- SMP solution is a competitive equilibrium.

Uncertain supply: $n \in$ scenario tree with probability $p(n)$.



A scenario tree with $n \in \mathcal{N}$. Here $\mathcal{L} = \{13, 14, \ldots, 30\}$, $3+ = \{10, 11, 12\}$, and $9- = 2$.

Wind/solar generator with uncertain supply $\omega(n)$

$$\begin{array}{llrcll} \text{SMP:} & \min & \theta x & + & \sum_{n\in\mathcal{N}} p(n)(C(g(n)) - U_n(d(n))) & \\ & \text{s.t.} & z(n) & = & d(n) - g(n) & [p(n)\pi(n)] \\ & & z(n) & \leq & x\omega(n) & [p(n)\phi(n)] \end{array}$$

$$0 \leq \pi(n) - \phi(n) \perp z(n) \geq 0$$

$$0 \leq x\omega(n) - z(n) \perp \phi(n) \geq 0$$

$$0 \leq \theta - \sum_{n\in\mathcal{N}} p(n)\omega(n)\phi(n) \perp x \geq 0$$

$$\begin{aligned} \mathbb{E}[R] \text{ (rent)} &= \sum_{n\in\mathcal{N}} p(n)\pi(n)z(n) = \sum_{n\in\mathcal{N}} p(n)\phi(n)z(n) \\ &= \sum_{n\in\mathcal{N}} p(n)\phi(n)\omega(n)x = \theta x \end{aligned}$$

Run-of-river plant with inflow $\omega(n)$

$$
\begin{array}{llcll}
\text{SMP: min} & \theta x & - & \sum_{n\in\mathcal{N}} p(n)\left(U_n(d(n))\right) & \\
\text{s.t.} & z(n) & \geq & d(n) - g(n) & [p(n)\pi(n)] \\
 & z(n) & \leq & \omega(n) & [p(n)\lambda(n)] \\
 & z(n) & \leq & x & [p(n)\phi(n)]
\end{array}
$$

$$0 \leq \pi(n) - \lambda(n) - \phi(n) \perp z(n) \geq 0$$

$$0 \leq x - z(n) \perp \phi(n) \geq 0$$

$$0 \leq \omega(n) - z(n) \perp \lambda(n) \geq 0$$

$$0 \leq \theta - \sum_{n\in\mathcal{N}} p(n)\phi(n) \perp x \geq 0$$

Run-of-river plant optimality conditions

$$0 \leq \pi(n) - \lambda(n) - \phi(n) \perp z(n) \geq 0$$

$$0 \leq x - z(n) \perp \phi(n) \geq 0$$

$$0 \leq \omega(n) - z(n) \perp \lambda(n) \geq 0$$

$$0 \leq \theta - \sum_{n\in\mathcal{N}} p(n)\phi(n) \perp x \geq 0$$

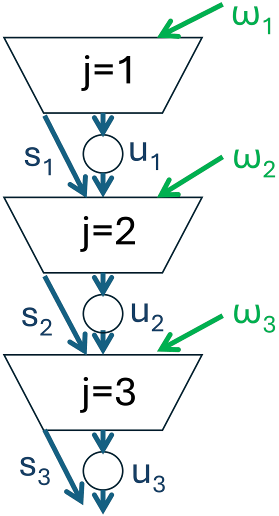
$$\begin{aligned}\mathbb{E}[R] = \sum_{n\in\mathcal{N}} p(n)\pi(n)z(n) &= \sum_{n\in\mathcal{N}} p(n)(\phi(n) + \lambda(n))z(n)\\ &= \sum_{n\in\mathcal{N}} p(n)\phi(n)x + \sum_{n\in\mathcal{N}} p(n)\lambda(n)\omega(n)\\ &= \theta x + \sum_{n\in\mathcal{N}} p(n)\lambda(n)\omega(n)\end{aligned}$$

Pumped hydro with storage capacity h, turbine capacity x

$$
\begin{array}{llcll}
\text{SMP: } \min & \psi h + \theta x & - & \sum_{n \in \mathcal{N}} p(n) U_n(d(n)) & \\
\quad \text{s.t.} & \bar{y}(n) & = & y(n) - u_D(n) + u_C(n) & [p(n)\lambda(n)] \\
 & y(0) & = & 0 & [\lambda(0)] \\
 & y(n) & = & \bar{y}(n-) & [p(n)\tau(n)],\ n \notin \{0\} \\
 & \bar{y}(n) & = & 0 & n \in \mathcal{L} \\
 & g(n) & \geq & d(n) - u_D(n) + \beta u_C(n) & [p(n)\pi(n)] \\
 & u_D(n) & \leq & x & [p(n)\rho(n)] \\
 & u_C(n) & \leq & \delta x & [p(n)\sigma(n)] \\
 & y(n) & \leq & h,\ \ n \notin \{0\} & [p(n)\mu(n)]
\end{array}
$$

$$
\mathbb{E}[R] = \sum_{n \in \mathcal{N}} p(n)\pi(n)(u_D(n) - \beta u_C(n)) = \psi h + \theta x
$$

Hydro cascade with stations $j \in \{1, 2, 3\}$



Cascade with inflow ω, spill s and station flow u.

Optimize headpond capacity h_j and station capacity x_j

$$
\begin{array}{llcll}
\text{SMP: min} & \sum_{j\in\mathcal{J}}(\theta_j x_j & +\psi_j h_j) - \sum_{n\in\mathcal{N}} p(n)U_n(d(n)) & & \\
\text{s.t.} & \bar{y}_1(n) & = & y_1(n)+\omega_1(n)-u_1(n)-s_1(n) & [p(n)\lambda_1(n)] \\
 & \bar{y}_j(n) & = & y_j(n)+\omega_j(n)-u_j(n) & \\
 & & & +u_{j-1}(n)+s_{j-1}(n)-s_j(n) & [p(n)\lambda_j(n) \\
 & y_j(0) & = & 0 & \\
 & y_j(n) & \leq & \bar{y}_j(n-) & [p(n)\tau_j(n)], \\
 & \bar{y}_j(n) & = & 0 & n\in\mathcal{L} \\
 & \sum_{j\in\mathcal{J}} u_j(n) & = & d(n) & [p(n)\pi_j(n)] \\
 & 0\leq u_j(n) & \leq & x_j & [p(n)\rho_j(n)] \\
 & 0\leq y_j(n) & \leq & h_j & [p(n)\mu_j(n)] \\
 & 0\leq s_j(n) & & &
\end{array}
$$

Hydro cascade with headpond capacity h_j station capacity x_j

- The hydro cascade does not admit a simple dispatch mechanism for node n where each station submits an offer curve.
- Need a mechanism to price water transfers between stations.
- Can calculate expected rent $\mathbb{E}[R_j]$ for each station from solution to dispatch problem as a stochastic program.

$$\mathbb{E}[R_j] = \sum_{n\in\mathcal{N}} p(n)\pi(n)u_j(n) = \psi_j h_j + \theta_j x_j + \sum_{n\in\mathcal{N}} p(n)\lambda_j(n)\omega_j(n)$$

What have we learnt?

- Run-of-river hydro plant with inflow $\omega(n)$ makes surplus rent $\sum_{n\in\mathcal{N}} p(n)\lambda(n)\omega(n)$.
- Cascade hydro plant j with inflow $\omega_j(n)$ makes surplus rent $\sum_{n\in\mathcal{N}} p(n)\lambda_j(n)\omega_j(n)$.
- Though market power is important to curb, these surpluses occur in energy-only markets under perfect competition.
- The size of the hydro plants is socially optimal given the SMP model. Paying dividends instead of capacity expansion is economically rational...
- ...but if there were more river chains with unused inflows to exploit then the SMP capacity outcomes would be suboptimal; entry would be profitable.

Does it work in practice?

- JADE.jl (SDDP.jl inside) is the EPOC hydrothermal optimizer.
- We can run a version of JADE to optimize investments in first stage (see `Hole, P., Dowson, 2025`) and operations over infinite horizon with discounting.
- Gives nearly optimal investments, but inaccurate future prices.
- Kotuitui (`Robinson & P.,2026`) solves a tree-based version of SMP with 81 scenarios, and end-of horizon cuts from investment JADE. This replicates JADE investments.
- In Kotuitui solution:
  - Expected rents for thermal plant cover annual investment costs.
  - Expected rents for run-of-river plant exceed annual investment costs by expected value of inflows.

The end

Thank you all for being here!