The PRISM model

Simulating the future

of the New Zealand electricity sector

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Aims

- Produce some self-consistent snapshots of the NZ electricity sector, representing possible scenarios during 2006-2025.
- Where possible, assign probabilities to these.
- Evaluate the outcomes (prices, return on capital, etc.)

For definiteness, consider for each year:
- Winter (July) and summer (January).
- Peak (TP 35-39) and off-peak (TP 3-10).

Since we are looking at a point in time, seasonal energy balance is not considered.
Factors to consider

- Demand growth?
- Special loads: Comalco, Auckland electric rail, wood processing, irrigation and dairy farming, etc.?
- Natural gas supply? Imported gas (LNG)?
- Future generation development (hydro, geothermal, wind, coal, etc.)?
- Prices and costs - fuels, exchange rate?
- Transmission grid upgrades?

All of these are subject to *uncertainty*.

– so we need a stochastic model.
Simulation

Simulate a future year/season/time of day by making random choices for uncertain parameters:

- General demand
  - lognormally distributed growth factor.
- Size and existence of new power stations and major loads.
  - probabilistic (assets may be present or not).
- Gas availability
  - scenarios, PJ/year available for thermal power generation.
- Fuel prices, exchange rate, carbon tax.
  - lognormal factors; the more distant future is less certain.
  - reduce gas-fired generation available in the event of gas shortage.
- Rainfall (for hydro inflows)
  - dry, normal, or wet.
- Wind
  - possibly at multiple sites.

Repeat to build up a sample of possible futures.
Offering behaviour

How is the generation offered in?

Realistic answer:

• In reality, generation companies can ask any prices they like.
• This leads to a complex dynamic game.

Simple answer:

• Payment for power produced or consumed is at the \textit{nodal} price (not asking price).
• Theoretically, this suggests generators should ask for the marginal cost of production (fuel cost).
• In practice, this is a good model only when the generator is small (a price-taker) or has zero fuel cost (run-of-river hydro, geothermal, cogeneration, wind).

Prism’s approach:

• Allows fuel-cost offering
  
  \textit{or}

  historical offering scenarios (large hydros)

  \textit{or}

  a user-defined offer.

• Does not attempt to model gaming directly.
Dispatch model

Simulate the operation of SPD.

Given:

• A network
• Generation offers
• Loads;

Solve for:

• Dispatch of power stations
• Prices
• Flows on lines.

PRISM uses PERM, an 18-node dispatch model implemented in AMPL/CPLEX.

Reserve markets are not represented.
Antithetic sampling

- In a Prism-type simulation, we are evaluating

\[ f(u_1, \ldots, u_n) \]

where \( u_i \) are i.i.d. uniform\([0, 1]\) random variates.

- Include

\[ f(u_1, \ldots, u_n) \quad \text{and} \quad f(1 - u_1, \ldots, 1 - u_n) \]

in the sample, instead of

\[ f(u_1, \ldots, u_n) \quad \text{and} \quad f(u'_1, \ldots, u'_n) \]

where \( u_i, u'_i \) are independent. This evens out the extremes.

- **Example**: In Prism, rainfall can be

<table>
<thead>
<tr>
<th>state</th>
<th>dry</th>
<th>normal</th>
<th>wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>prob</td>
<td>0.25</td>
<td>0.5</td>
<td>0.25</td>
</tr>
</tbody>
</table>

- Antithetic sampling ensures that the sample contains equal numbers of “dry year” and “wet year” scenarios.
Common random numbers

• Prism is typically used to investigate
  – Several alternative cases (e.g. with/without Comalco aluminium smelter);
  – over several years (e.g. 2006, . . . , 2025);
  – with four samples per year (summer/winter, peak/offpeak).

• We don’t want results for the various runs to differ due to sampling error alone.

• Use the same underlying random variates $u_1, \ldots u_n$ in all runs.

• To achieve this: reset the random number generator seed between runs.

• Need to keep the random-number sequence aligned (e.g. if one run has an extra power station).

• A multi-stream RNG implementation makes this easier.
Wind power - sampling correlated variates

- Output from a wind farm is random.
- Prism generates the output from a single wind farm as

\[ g(u) \]

where \( u \) is a uniform\([0,1]\) random variate, and \( g \) is an “output duration curve” function (empirical quantile function) fitted from historical data.

Output duration curve for Te Apiti, 31/10/04 – 9/6/05
Wind power - sampling correlated variates

- Outputs from different wind farms are correlated.
- For wind farms $i, j$, Prism generates variates $u_i, u_j$:
  \[ u_i = u_j = u \], with probability $c_{ij}$
  \[ u_i, u_j \text{ independently} \], otherwise.

  Note $c_{ij} = \text{corr}(u_i, u_j)$.

- Set $c_{ij} = e^{-c|w_i - w_j|}$, where $w_i, w_j$ are positions on a line (the latitude of the wind farm is used as a proxy for this).