# Modelling for Energy Transitions: Optimization in Action

Golbon Zakeri and a long list of co-authors:
We gratefully acknowledge the support of the NZ Energy Education Trust

# The tale of three models

1. Climate change and its potential effects on the NZ electricity sector.
2. A word about industrial demand response models.
3. The half hourly stochastic dispatch work.
4. Most of the talk will concentrate on the first model.

# Outline

- Climate change and NZ
- NZEM brief description
- Hydro inflow modelling
- Climate change adjustments
- Effects on the electricity sector.

# Climate change and NZ

- Net zero emissions of all greenhouse gases other than biogenic methane by 2050.
- 24 to 47 per cent reduction below 2017 biogenic methane emissions by 2050, including 10 per cent reduction below 2017 biogenic methane emissions by 2030.

# NZ Electricity sector

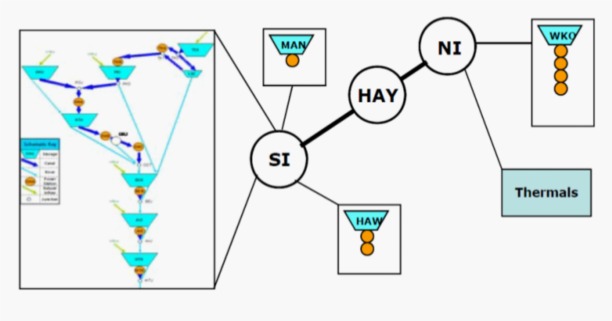
- Approximately 85% of electricity generation in NZ is met through renewable resources.
- Approximately 55% of generation is from hydro and times of stress on the system are dry winters.
- Government has banned exploration for natural gas in NZ, and a big question is the retirement of Huntly thermal plant (all units run on gas, some on coal as well).
- There are many uncertain factors in the future, however the aim of this study is to model changes in the inflow patterns, as effected by climate change, and assess the performance of electricity generation, all other factors remaining the same.

# NZ Electricity sector

# Multistage stochastic optimization for energy generation

- To evaluate the performance of the electricity system, we will use a hydro-thermal planning model.
- The model is based on uncertainty in inflows and assumes that resources are balanced by a central planner.
- It runs over a time horizon of a year, broken up into 52 weeks.
- It takes as input demand, weekly inflows into various catchments. It has a small network (of 2 nodes) embedded in it.
- The objective is to minimize the expected total cost of generation over the time horizon. Load shedding can occur at a high price (10,000 NZD per MW).

# Hydro reservoirs detailed in DOASA



# Quantile regressions for hydro inflows

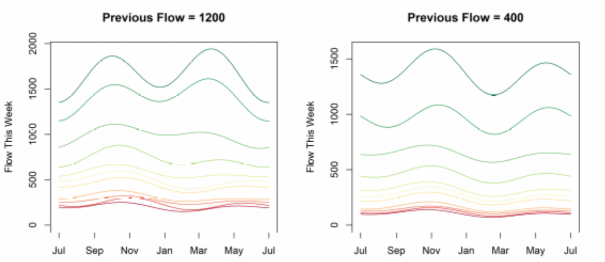
- We fit quantile regression models to explain the relationship between observed inflow and week in the year.
- The quantile regression form provides a set of possible scenarios from which we can sample to stochastically generate new inflow sequences.
- We use a so called Fourier regression, where the regressors are a set of third-order trigonometric polynomials interacting with lagged inflows.
- This provides a sinusoidal type relation between inflow and time to capture seasonality patterns as well as a linear relation between current inflow and previous inflow to capture elements of persistence in the system.

# Functional form

$$F_t = \beta_0 + \beta_1 F_{t-1} + \beta_2 F_{t-1} \sin t + \beta_3 F_{t-1} \cos t + \beta_4 F_{t-1} \sin 2t + \beta_5 F_{t-1} \cos 2t.$$

- $t$ is the week in the year scaled so that $0 \leq t \leq 2\pi$.
- $F_t$ is the inflow at time $t$.
- $\beta_i$s are the regression coefficients.

# Illustration of the quantiles



## Generating an inflow sequence

- We generate our inflow scenarios using random sampling.
- Given a starting week's inflow amount, we can use any random sampling methodology to choose a quantile model.
- Now use the starting inflow amount to generate a subsequent week's inflow amount from the quantile model.
- The best "random generation" strategy was that of sampling from the quantiles, based on the probability associated with them.

# Adjusting our models for climate change

- We utilized NZ specific reports on the impact of climate on average rain fall and changes to snow pack/snow melt. (See citations in the report.)
- The effects climate change are categorized by scenario of concentration of GHG in the atmosphere, and the scenarios pertain to different time horizons.

# NF RCP8.5

Table: Seasonal inflow adjustments under NF RCP 8.5

| Catchment | Summer | Fall | Winter | Spring |
|---|---|---|---|---|
| MAN | -0.08 | 0.01 | 0.12 | -0.05 |
| TEK | -0.1625 | 0.0625 | 0.1875 | -0.0625 |
| PUK | -0.1625 | 0.0625 | 0.1875 | -0.0625 |
| OHA | -0.15 | 0.05 | 0.2 | -0.1 |
| HAW | -0.0875 | -0.05 | 0.1875 | -0.075 |
| TAU | 0.05 | -0.025 | 0.125 | -0.025 |

# Inflow adjustments

To modify our stochastic inflow models in a way that reflects these changes to the marginal distributions of inflows, we developed the following process.

- Each value of $F_t$ was recorded for $(t, F_{(t-1)})$ in a discretized grid of 52 equally-spaced times of year $t$ and an equally-spaced sequence of prior-inflow values between zero and the maximum historically observed inflow for the catchment.
- For each entry in this table, the $F_{(t-1)}$ and $F_t$ values are adjusted by multiplication by the appropriate entry from the above table (or its counterparts for other concentration pathways).
- The quantile regression models are then re-fitted to this adjusted data.

# Some results

- Once we apply DOASA to the sequences of inflows generated from the post climate change distributions we find that the resulting thermal costs increase in almost every week of the year.
- This demonstrates significant increase in the utilization of thermal resources particularly during the summer in the Southern hemisphere.

# Observations

- Such results are note-worthy as they may imply that with further penetration of wind, we may need even more thermal back up due to the changing inflow patterns.
- The thermal utilization results may also be of interest to find the best time of year for unit maintenance. It is unlikely that this will be the antipodian summer.

# Lake levels

- It is also interesting to track the lake levels of a catchment throughout the year, when hydro-thermal scheduling is utilized.
- We note that using post climate change inflow scenarios result is wider volatility in the lake levels and the levels approach their minimum possible allowed level more frequently. This means that there are plausibly greater risks of outages in the future.

# Historical vs post climate change

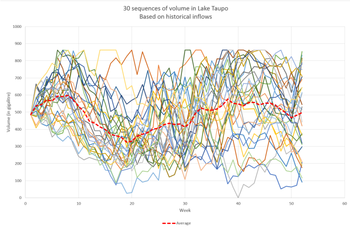



Figure: 30 historical sequences

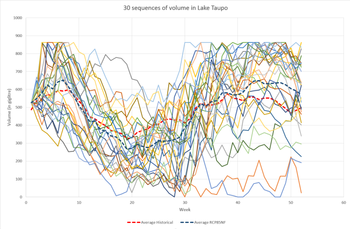
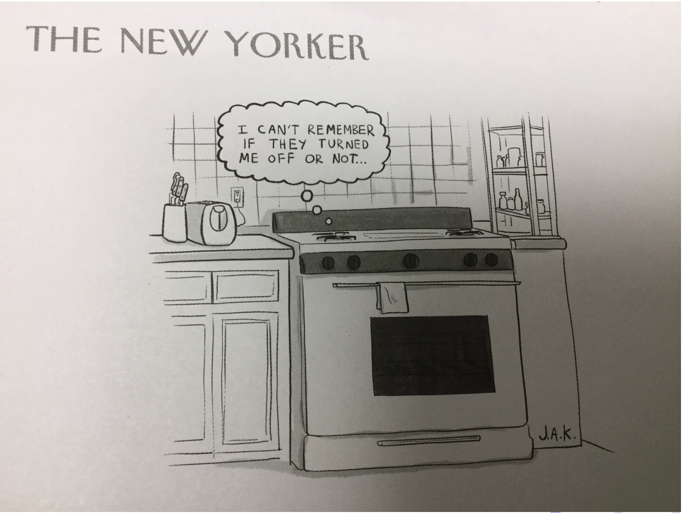



Figure: 30 NF RCP8.5 sequences

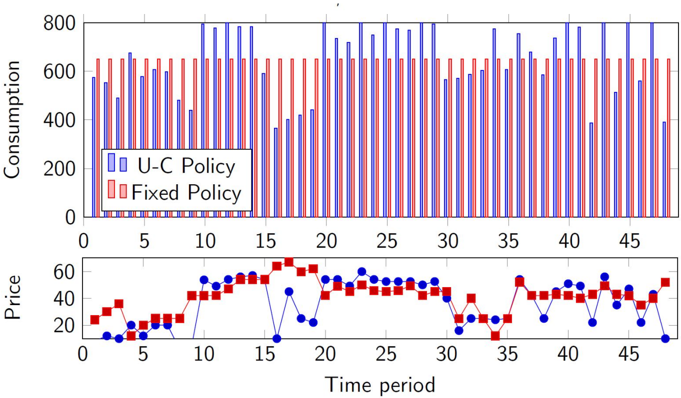
# DR but not "smart appliances"



# Model specs

- Such a model will run over a time horizon of weeks.
- It is designed for a consumer whose actions may influence the price of electricity.
- The consumer is capable of offering interruptible load reserves and this is important for NZ.
- We need such models when we consider sector coupling.
- DR is crucial as indicated in Alison's talk yesterday.
- The model has the above ingredients, decides (near) optimally under uncertainty and we have some out of sample tested results.

# Case Study



800
600
400
200
0
Consumption
U-C Policy
Fixed Policy
0 5 10 15 20 25 30 35 40 45
Price
60
40
20
0 5 10 15 20 25 30 35 40 45
Time period

# Hourly market design

- This work surrounds utilizing more information in the form of distribution of uncertainty.
- We propose a stochastic auction that combines energy and flexibility markets.
- The mechanism tested on the full NZ market, tested using out of sample wind scenarios, on a full two year data set produces very positive results.