Grid divestment optimisation under uncertainty
Insights from a simple stochastic grid expansion model

Kiti Suomalainen, Energy Centre, University of Auckland, +64 9 923 1807, k.suomalainen@auckland.ac.nz
Liam McKenzie, Engineering Science, University of Auckland, lmck640@aucklanduni.ac.nz
Juliette Foley, Engineering Science, University of Auckland, jfol408@aucklanduni.ac.nz
Geoffrey Pritchard, Statistics, University of Auckland, g.pritchard@auckland.ac.nz
Golbon Zakeri, Engineering Science, University of Auckland, g.zakeri@auckland.ac.nz
Basil Sharp, Energy Centre, University of Auckland, b.sharp@auckland.ac.nz

Overview

Polynesian island states are among the most vulnerable in a changing climate, experiencing more frequent and more powerful storms than before. This demands new ways of thinking about both safe-guarding existing grid infrastructure and developing new systems in remote areas. Using renewable resources to expand access to affordable, reliable, and clean energy is a priority for governments in the region and a common focus for aid programmes. However, too rapid deployment of decentralized solutions may lead to an economically suboptimal transition, through underutilisation of the existing infrastructure – which often is still being paid for – and investment in new off-grid solutions.

Existing research has concentrated on the economics of meeting renewable energy targets, with a focus on generation, while the electricity transmission technology has generally been omitted. Our contribution comes from investigating optimal pathways to a renewables-based electricity system taking a whole system's perspective which includes grid transmission costs. With this consideration, we explore what the optimal transition pathway to a more resilient, distributed system looks like under demand uncertainty.

Methods

In this work we apply a stochastic dynamic programming framework and rolling horizon implementation of the model to explore the optimal economic transition pathways under uncertainty. Applying a stochastic modelling approach to optimising solar uptake and long-term grid divestment decisions, and characterising demand uncertainty in terms of representative scenarios, we analyse the effect of parameter variation on decision making. Through experimentation, general optimal trends in energy planning are identified, and an optimised divestment procedure is simulated over many demand realisations to validate our approach.

Electricity demand at the current time-step is correlated with the previous time-step of demand, and the interaction of GDP and population. Both population growth and GDP are conceptualised a stochastic processes, contingent on birth and death rates, tourism influxes and internal migration within the locale. Each of these determining factors are modelled as random walks with drift, and future values of electricity demand are solved for numerically. We generate 100 demand scenarios for the next time period with the procedure above, given the current demand level. The 5th, 50th, and 95th percentile cases are chosen as representative cases, and assigned probabilities based on the number of scenarios within the 100 generated which are closer to them than either of the other representative candidates. These representative cases and their probabilities are used as the possible outcomes of the stochastic grid expansion model.

In this paper, we solve the model for two distinct grid configuration: a spur line and a radial grid. Parameter variation is presented for incrementing diesel price, varying the level of line losses and the penalty for unmet demand. We also simulate decision making over a `rolling horizon', solving a five stage model to within a 1% optimality gap to produce investment decisions, then stepping forward five years, under the decisions made, and running the model again, to generate the next set of decisions.

Results

Our results and key insights are the following.

(i) Incrementing diesel prices: We increment diesel costs, starting from 0, and observe how initial spur line and radial network configurations adapt differently over different time horizons. In all cases we observe the following shifts in the energy system investment plan as diesel prices are increased:

1. Supplementary arcs, which facilitate efficient distribution from the diesel hub, are instituted.
2. Supplementary arcs are instituted while suboptimal arcs are divested from.
3. Solar is introduced at all nodes except the current hub of diesel generation.
4. Solar is introduced everywhere, with some capacity left to be supplemented by diesel generation.
5. Diesel generation is virtually discarded, and we get divestment of existing transmission lines, but no new line investments.

(ii) Line losses: In the two-stage case, the spur line network fully divests from transmission arcs as soon as any line loss occurs, whereas for the radial layout, no divestment occurs and solar investment very much mirrors the base case demand distribution until a line loss increases to 40%. At this point solar investment is scaled up noticeably at the central generation node, presumably because supplementing demand shortfall with excess generation from any of the other four nodes has become uneconomic. Line loss must be incremented to as high as 80% before any arc divestment in the radial case though, underlining again that the compounding effect of multiple inefficient transmissions in series is the key issue here. When the model extends to three stages, divestment occurs at trivial line loss for both networks, as the extra cost of maintenance, and the extra time in which to recoup solar investment, become the defining considerations.

(iii) Undersupply penalty: While paying the penalty is cheaper than producing electricity, as an economic optimisation model, it will do just that.

(iv) Rolling horizon decision making: The networks, although starting from very different transmission configurations, end up converging to an almost identical template of structure and capacity, namely a decentralised grid with solar generation in each node, and diesel generation remaining only in its original node, and decreased in quantity.

Conclusions

The following insights were gained from this study:

- Where a central generation hub exists, which produces electricity at competitive price, radial networks are preferable to spur line layouts to ensure efficiency and flexibility of supply.
- Internal valuation of energy supply is as important to a network's performance as exogenous factors. If central authorities responsible for energy planning do not set `penalty costs' for under-supply at sufficiently high levels, whatever these may represent in reality, grid reliability will always suffer.
- As the planning horizon is extended, initial grid layout is immaterial, and divestment in favour of localised solar generation is prioritised, provided, again, that generation is economically competitive.
- Subsidiary generation capacity is always preferred, especially at nodes which face higher scales of demand.
- As the planning horizon extends, and decisions take on time lags, the apt provision of energy resources becomes significantly more difficult, due to impaired foresight and limited reactive capability.

Ultimately, we conclude that solar uptake and grid divestment are promising strategies for energy transition to sustainable and economic generation, but lack robustness in the face of uncertainty. We recommend careful systems planning when transitioning to more resilient, climate adapted energy systems in climate vulnerable island states.

Future work will focus on improving the demand forecasting approach and further developing our energy system optimisation model.