The development of a system dynamics model for electricity generation expansion in New Zealand

Thahirah Syed Jalal[1], Pat Bodger[1]
[1] University of Canterbury, Christchurch, New Zealand

Abstract

Many countries exhibit cycles of shortfall and overbuilding (bust and boom cycles) of their installed generation capacity after they restructured their electricity industries in the late 1980s. A similar pattern has also been observed in New Zealand after its electricity industry was restructured in 1987, including power shortages in 1992, 2001, 2003 and 2008. Shortages of power supply are inconvenient to consumers whereas on the other hand, overbuilding indicates an inefficient allocation of resources. This study proposes a system dynamics model to study the problem. Advantages of this model over other approaches are discussed in this paper. The model is customised to incorporate the market structure and electricity industry in New Zealand, including the development phases of constructing a power plant under the Resource Management Act (RMA). The model is then used to study suitable precautionary frameworks that can be used to prevent power shortages and aid in creating an environment for optimum and timely generation expansion in the future. Possible future scenarios such as penetration of electric cars and adverse weather conditions are also included in this study. Some preliminary results are included and discussed.

Introduction

In the last few decades, most of the developed countries have restructured their electricity supply industry with the introduction of competitive power markets to replace the traditional monopolistic vertically integrated systems. The restructuring is a very complex exercise based on national energy strategies and policies, macroeconomic developments and national conditions, and its application varies from country to country [1]. Reforms that are done without careful considerations can be catastrophic and damaging like what has happened in California, United States. Despite having power markets for many years now, uncertainties still remain as to whether the power market is sufficient to provide investments in generation [2-4].

It has been shown in some studies [5-9] that deregulation of the electricity industry causes boom and bust cycles of generation capacity due to reasons such as investment uncertainties. Initially power generators are uncertain on whether they should build a new power plant as that may affect the spot price in the power market and hence affect their profit returns. Then substantial overbuilding occurs because most generators compete to build new power stations. Monte Carlo simulations suggest that for a realistic range of assumptions, the deregulated wholesale power markets are substantially more cyclical than they would have been under a regulated monopoly regime[7]. A shortage of power supply is not only inconvenient to the public but it may harm the economy in the long run. Building a power plant needs years to plan, design, obtain approval and construct; hence a supply shortage may not be quickly fixed. On the other hand, overbuilding indicates an inefficient allocation of resources which defeats the purpose of deregulation in the first place. This boom and bust trend has been observed to happen in the United States [5, 7] and European countries [8, 9] as shown in Figure 1.

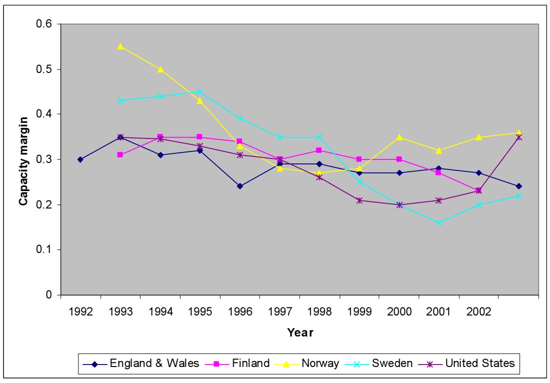

Figure 1: Cycles of capacity margin in the US and some European countries [9]

Generation capacity in New Zealand

Before the restructuring of the New Zealand electricity sector in the 1980s, generation planning was the responsibility of the Ministry of Energy. The last Energy Plan for New Zealand was published in 1985, and after a less thorough Energy Issues Paper in 1986, the publication of public planning documents of the kind produced since the mid 1950s came to an end [10]. After commencement of the wholesale electricity market known as the New Zealand Electricity Market (NZEM) in October 1996, the generation expansion is supposed to be triggered by a prolonged high spot market price indicating the reduced margin between electricity supply and demand. It is expected that when the supply is tight in meeting the demand, the spot price would be high enough to motivate competing generators to build new power plants and gain profit from the electricity sales.

Figure 2 shows that the installed generation in New Zealand has declined for the first time in 1988 before steadily picking up again in 2000, despite the continuous growth of electricity demand within that duration[11]. In May 1992, drought causes the South Island hydro storage lake levels to become low that voluntary savings of 10% of demand were called for until the water inflows to the South Island lakes began to increase again in July.

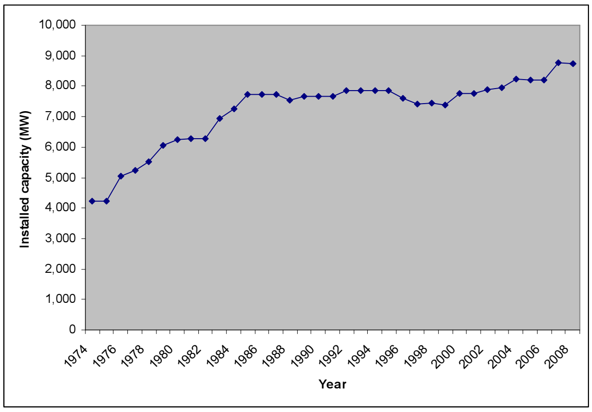

Figure 2: Installed generation capacity in New Zealand from 1974-2008

A similar occurrence happens again from July to September 2001, March to June 2003 and March to July 2008 when low lake levels are coupled with high demand for electricity. Wholesale electricity spot market prices rose sharply as a result. During this period the Government implemented a conservation campaign calling for up to 25% saving in electricity usage[12] to maintain continuous electricity supply. Even though the winter shortages are for only several months in a year, they will not have occurred if there is sufficient installed capacity available. Dry years have happened prior to 1987 even when New Zealand had a higher share of hydro generation mix, but such winter shortages did not occur.

These shortages raise questions as to whether the NZEM is sufficient to provide incentives for investors to build new power plants. The principles behind the NZEM are similar to other markets around the world but with some uniqueness[13]:

1. The generation mix is dominated by hydro (around 60%) but its storage capacity is relatively small compared to some other hydro dominated countries.
2. In some countries, there must be a legal separation of generators, transmitters, distributors and retailers of electricity. However, here the main generators are also retailers (Gentailers) in the various

distribution areas. This affects the way they bid their wholesale electricity as high spot wholesale prices can harm their retailing arms.

This study studies this electricity generation expansion issue in New Zealand and aims to make projections and investigate whether electricity shortages will happen in the future.

Research Objectives

In most countries, restructuring has been done based on a huge act of faith. As a consequence, the strategic and regulatory uncertainties are unprecedented. In such a market, there has been no historical evolution and all the participants including the regulatory institutions have very little understanding of how it will operate in the short term and evolve in the future. In the absence of experience and analogies, analysis and learning from models assume a key role[14].

Dyner and Larsen [15] discuss in details how the planning methods in the electricity industry changes with the introduction of competitive power markets. They mention that in a newly regulated utility such as electricity, uncertainty and risk are high and a simulation model would be useful in the planning process. One of the models they identified is business dynamics or system dynamics (SD). SD is a type of behavioural simulation model. It is a descriptive modelling method based on explicit recognition of feedback and time lags [16, 17]. It has been developed by Prof Jay Forrester of the Massachusetts Institute of Technology.

Traditional simulation models have tried to include as much detail as possible to make the model more precise and thereby generate better predictions. SD, on the other hand, has increasingly focused on understanding the dynamic path into the future. The focus has been on learning: facilitating a better understanding of how the industry (or the system generally) evolves over time, understanding which variables are critical, and where to intervene in the system to create a desirable outcome [18].

Where most traditional simulation models are built by experts, SD models are developed together with the decision makers to provide a platform from which the team can better understand the situation they are facing [17]. Typically, SD models include many “soft” variables, i.e. variables which are not normally captured in traditional simulation models or financial models. Examples of these might be beliefs about how a regulator reacts and beliefs about the behaviour of competitors [8, 19, 20]. The model also does not confine itself to engineering formulae or economic definitions and can combine inputs from multidisciplinary factors in analysing the data and producing results. Where most other methods do not work when there is little available data, SD can still produce results and provide a good understanding of how a regulatory framework or policy plays out [14, 18]. These unique features of SD make it helpful to regulators or policy makers in developing relevant policies or regulations. An SD model can also be useful for countries wishing to embark upon deregulation and help develop the suitable framework and policy.

SD have been used to study different issues in the power industry in some countries such as the United States [5-7, 21-29], United Kingdom [8, 30], Germany [31] and Colombia [32]. An evaluation paper on the system dynamics model for the UK concludes that the model’s outcomes indeed occurred in the UK[14].

This study proposes to develop an SD model to study the realistic impacts of restructuring on the installed generation capacity in New Zealand. Different structures, arrangements and competitors' behaviours can be included and studied in the model. From the model, it is hoped that any severe impacts of restructuring onto the generation sector can be avoided by putting relevant policies in place.

Preliminary Work

With the research objectives in mind, an SD model to study the New Zealand generation expansion is developed using the software program known as Vensim[33]. Some of the questions that the research wishes to address are:

- Will the future generation capacity be sufficient to meet the electricity energy demands?
- Will there be other electricity energy constraints in future years?

The model begins with modeling the development phases of power plants in New Zealand starting from the planning to the commissioning stage such as that shown in Figure 3. It shows the loop for hydro plants only but similar loops are have also been built for coal, gas, wind, geothermal, cogeneration and proposed new types of plants like wave and pump storage. Each type of plants is given its own development loop to capture their different phase durations. For example, hydro plants can take longer to build whereas coal plants can be more difficult to approve due to public opposition.

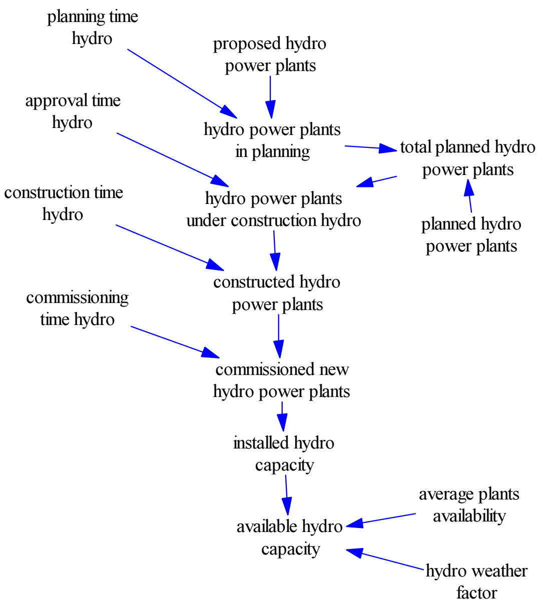

Figure 3: Construction loop example for hydro plants

The output of the development phase provides the installed capacity (in MW) for the type of plants concerned. However, it is not possible to have all plants available throughout a year. Therefore the average plants availability factor is included to calculate the available annual energy capacity (in GWh) for each type of plants. The energy capacity is of interest in this model because New Zealand is usually energy constrained rather than peak demand constrained. The average plants availability factor values are deduced from the Electricity Commission's (EC) records of power plants as of May 2008[34].

For hydro, pumped storage and wind power plants, the variable 'weather factor' is included to capture weather variabilities that determine the plant output. This allows the model to include the impact of dry years and calm wind. The phase durations and other model parameters are set as shown in Table 1.

Plant type	Plant lead time (year)	Planning duration (year)		Approval time (year)		Construction duration (year)		Commissioning duration (year)		Average plant availability factor		Weather factor	
		Base	Range	Base	Range	Base	Range	Base	Range	Base	Range	Base	Range
Hydro	5	1	1-3	1	0.5-2	3	3-5	0.25	0.1-1	0.55	0.4-0.8	1	0.5-1
Coal	4	1	0.5-2	1	0.5-2	2	1-3	0.25	0.1-1	0.9	0.85-0.95	N/A	N/A
Combined cycle gas turbine (CCGT)	3	0.5	0.5-2	0.5	0.5-2	2	1-3	0.25	0.1-1	0.9	0.85-0.95	N/A	N/A
Open Cycle Gas Turbine (OCGT)	2	0.5	0.5-2	0.5	0.5-2	1	1-3	0.25	0.1-1	0.9	0.85-0.95	N/A	N/A
Wind	3	1	1-3	1	0.5-2	1	1-3	0.25	0.1-1	0.3	0.15-0.5	1	0.5-1
Geothermal	3	1	1-3	1	0.5-2	1	1-3	0.25	0.1-1	0.8	0.5-0.9	N/A	N/A
Cogeneration (Cogen)	3	1	1-3	1	0.5-2	1	1-2	0.25	0.1-1	0.9	0.85-0.95	N/A	N/A
Pumped storage	7	1	1-3	2	1-3	5	3-7	0.25	0.1-1	0.8	0.7-0.9	1	0.5-1
Wave	5	1.5	1-3	1.5	1-3	2	1-3	0.25	0.1-1	0.8	0.7-0.9	N/A	N/A

Table 1: Model parameters for the development loop for each type of plants

The base values are the typical values that are used for simulations whereas the range shows how the parameters and durations are varied to study the impacts of different possible factors.

An important development phase is the approval phase which involves the Resource Management Act that determines whether the power plants get built or not. This phase may also incur additional delays and costs to the project which can deter the willingness of the investors to continue with the project. If the project is not pursued, then the project does not proceed to the next construction phase in the loop. The power plants development schedules are done in accordance with the 2008 Statement of Opportunities[35], (SOO2008), prepared by the EC. At this stage of the research, it is assumed that all of the plants proposed by the EC will proceed into construction and commissioning.

The outputs of the development phases are then summed to provide the annual available generation capacity in New Zealand, as shown in Figure 4. The outputs from the development loops are shown as shadow variables in the software. The total available generation capacity in the model also includes the plants which are scheduled to be decommissioned and demand side response, as included in the SOO2008.

The simulation is run from 2008 to 2036, similar duration as the models in SOO2008. To study whether the available generation capacity is sufficient to meet the forecasted demand, the energy capacity margin, ECM, is calculated. It is defined as the ratio of available energy surplus over the demand:

Energy capacity margin, ECM = (Available generation capacity – electricity energy demand)/ Electricity energy demand

A positive margin means that the available capacity is sufficient to meet the projected demand. The factors included in the model that can affect the energy capacity margin values are:

- Demand consumption
- Delays in developing new generation capacities
- Plants availability factors
- Weather factors

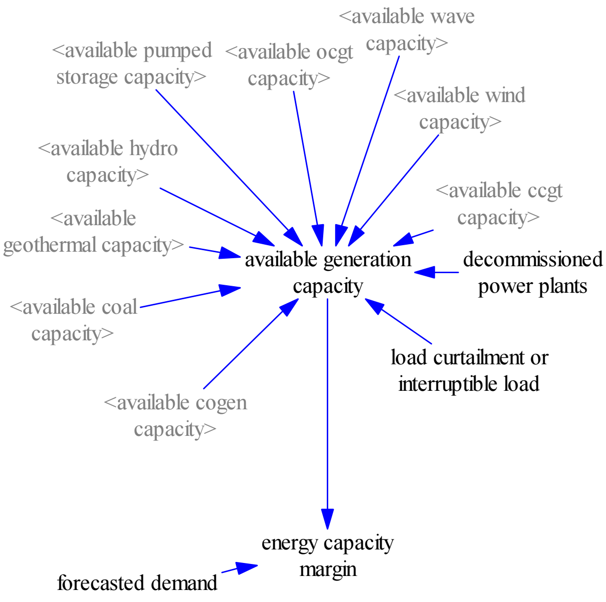

Figure 4: The outputs in the New Zealand generation expansion model

The SOO2008 has outlined five different future scenarios and developed the corresponding power plant schedules. This study explores each scenario and uses each schedule to test whether the resulting available capacity will meet their forecasted demands. The ECM is observed to see whether any serious shortage will occur in New Zealand. A summary of the preliminary simulations results under the Sustainable Path scenario is included here. The Sustainable Path scenario is defined as: "New Zealand embarks on a path of sustainable electricity development and sector emissions reduction. Major existing thermal power stations close down and are replaced by renewable generation, including hydro, wind and geothermal backed by thermal peakers for security of supply. Electric vehicle uptake is relatively rapid after 2020. New energy sources are brought on stream in the late 2020s and 2030s, including biomass, marine, and carbon capture and storage (CCS). Demand-side response helps to manage peak demand"[35].

For the SOO2008, the EC has forecasted the national energy demand projections from 2007 till 2036. From the forecast, high and low demand projections are obtained using an 80% confidence limit. Figure 5 shows the simulated ECM under the different load projections using the base values of the model parameters. In all cases, it is observed that the energy capacity margins remain positive for all demand projections. There is also a possibility of over-investments from 2024 onwards. The ECMs are highest when the demand is lowest.

Figure 5: The ECM under different demand projections

To study some worst case scenarios for different factors, the high demand projection is used in the following analyses. Figure 6 shows the impact of development delays on the ECM. The delays cause the power plants to become available later and hence lowering the energy capacity margins in the early years of simulation. However, the ECM still remains positive indicating no serious shortage is expected in the given situation.

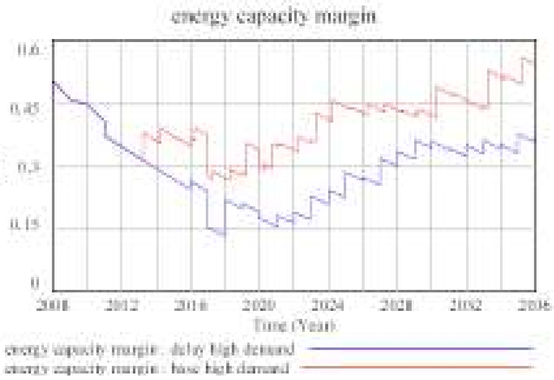

Figure 6: The impact of development delays on the ECM

Figure 7 shows the impact of low plants availability on the ECM. The ECM drops to low and negative values from year 2016 to 2027, indicating potential shortages within those years .

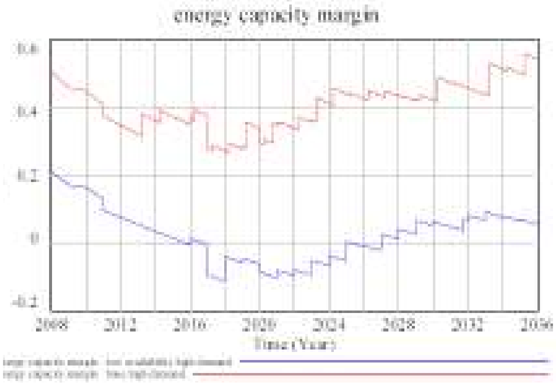

Figure 7: The impact of low plant availability on the ECM

Figure 8 shows the impact of worst weather conditions on the ECM, resulting in some negative ECM values from 2012 to 2028. This indicates that weather conditions may cause shortages within those years.

Figure 8: The impact of worst weather conditions on the ECM

These preliminary results show that the basic model is working as theory suggests. To provide a more realistic forecast for the generation expansion, the next stage of this research includes the NZEM operations in triggering the investments suggested by the SOO2008. Figure 9 shows how the market structure can be incorporated in the model by introducing a loop in the previous model structure shown in Figure 4.

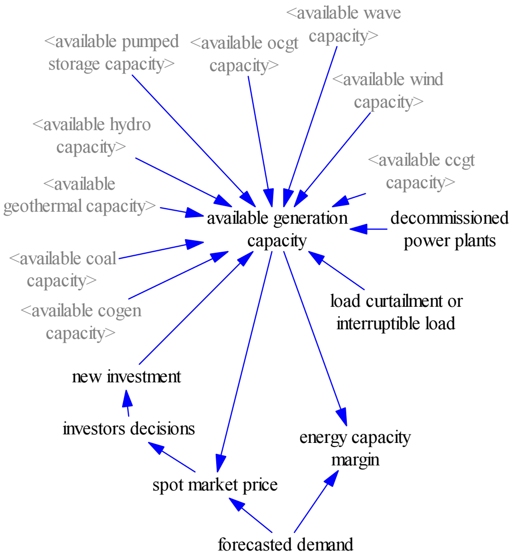

Figure 9: The incorporation of the market structure in the model

This incorporation demonstrates the unique ability of an SD model in analysing the dynamic interaction between the generation capacity and demand with the spot market price. The price then influences the decision on whether a new generation capacity is required. Once a new capacity comes on line, the spot market price will then be affected and this will influence the investment decision of other new generation investments.

Investors will only proceed with the development of new power plants when they deem the investments to be profitable. Different competitors' behaviours will be taken into account, including the natural hedge behaviours by gentailers and how they decide in starting a new generation investment. Some projects may also face delays in approval, causing investors to cancel if the market conditions change within the approval duration. Hence, not all suggested projects will proceed onto construction.

Once the market structure is incorporated, all five scenarios listed in SOO2008 will be simulated under different model parameters to investigate any possible shortages. It will also be observed whether a boom occurs where there are over-investments in building new generation capacity.

Conclusion

The electricity market approach that replaced conventional central planning for generation expansion has introduced several uncertainties in terms of providing the correct stimulus for new investments. Boom and bust cycles have been observed in other countries around the world which have adopted the approach. The development of an SD model for New Zealand will provide the ability to check whether a similar occurrence happens here. Energy shortages can also be forecasted and preventive measures can then be taken.

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