The Development of a System Dynamics Model to Evaluate Electricity Generation Expansion in New Zealand

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Abstract— Many countries exhibited cycles of shortfall and overbuilding (bust and boom) of their installed generation capacity after they restructured their electricity industries. A similar pattern has also been observed in New Zealand after its electricity industry was restructured in 1987. This study proposes a system dynamics (SD) model to study the phenomenon. 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. The model is then used to evaluate the projections made in the New Zealand Electricity Commission (EC)'s planning publication, Statement of Opportunity 2008 (SOO2008). Unlike the Generation Expansion Model (GEM) model used by EC, the SD model predicts that some boom and bust cycles may happen in New Zealand in the future under different projected scenarios.

Keywords-system dynamics; generation expansion planning; policy evaluation; capacity cycles

I. INTRODUCTION

It has been shown in some studies [1-5] that deregulation of the electricity industry causes bust and boom 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 during high market prices because most generators decide to build new power stations at around the same time [6]. This bust and boom pattern has been observed to happen in the United States [1, 3] and European countries [4, 5].

Such cycles have been observed in other markets such as real estates. However, the cycles in generation capacity are more pronounced when there are power plants of large lumpy capacities, enormous capital investment and long lead time. Figure 1 shows that the installed generation in New Zealand declined for the first time in 1988 before steadily picking up again in 2000, despite the continuous growth of electricity demand within that duration[7]. Electricity shortages occurred in July 2001, March 2003 and March 2008. These shortages raise questions as to whether the New Zealand Electricity Market (NZEM) is sufficient to provide incentives for investors to build new power plants with adequate capacity and characteristics to meet the demand trends.

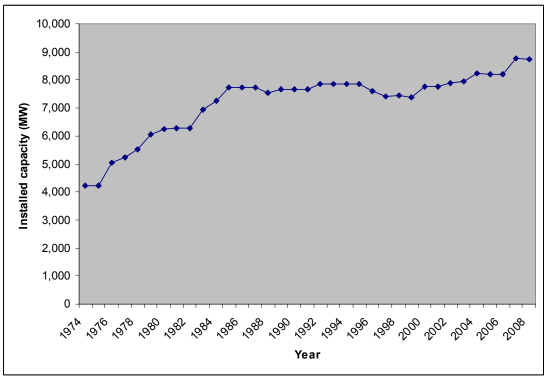


Figure 1. Installed generation capacity in New Zealand from 1974-2008

II. OBJECTIVES

This research studies the electricity generation expansion issue in New Zealand and makes projections to investigate whether capacity cycles will happen here in the future. It compares its results with the existing Generation Expansion Model (GEM) [8] results that are currently used by the New Zealand electricity supply industry. An important document that contains the GEM results and is used for generation and transmission expansion in New Zealand is the Statement of Opportunities 2008 (SOO2008), published by the Electricity Commission. It forecasted five different future scenarios for New Zealand from 2008 till 2050 as shown in Table I. The corresponding load forecasts are shown in Figure 2.

Based on the different projected scenarios shown in Table I, potential power plant schedules from 2008 till 2040 are proposed accordingly using the GEM. The GEM is a

TABLE I. SOO2008 GENERATION AND DEMAND ASSUMPTIONS [12]

Scenario	Generation assumptions	Demand assumptions
Sustainable Path (MDS1)	• High renewable energy penetration backed by thermal peakers • New energy sources are brought on stream in the late 2020s and 2030s	• Active demand side response to manage peak demands • Rapid electric vehicle (EV) uptake after 2020
South Island Surplus (MDS2)	• Renewable development proceeds at a moderate pace, with all existing gas-fired power stations remaining in operation until after 2030 • Wind and hydro generation increase considerably supplemente by thermal peakers	• The demand-side remains relatively uninvolved.
Medium Renewables (MDS3)	• Geothermal development playing an important role supplemented by thermal plants • The coal-fired units at Huntly transition through dry-year reserve to total closure	• Tiwai smelter is assumed to decommission in the mid-2020s.
Demand-side Participation (MDS4)	• New coal- and lignite-fired plants are constructed after 2020 • Geothermal resources are developed. • Little new hydro can be consented • Huntly Power Station remains in full operation until 2030	• Demand-side participation becomes important • EV uptake is high, and vehicle-to-grid technology is used to manage peaks and provide ancillary services.
High Gas Discovery (MDS5)	• Major new indigenous gas discoveries keep gas prices low to 2030 and beyond. • Some existing thermal power stations are replaced by new, more efficient gas-fired plants • New CCGTs and gas-fired peakers are built	• The demand-side remains relatively uninvolved.

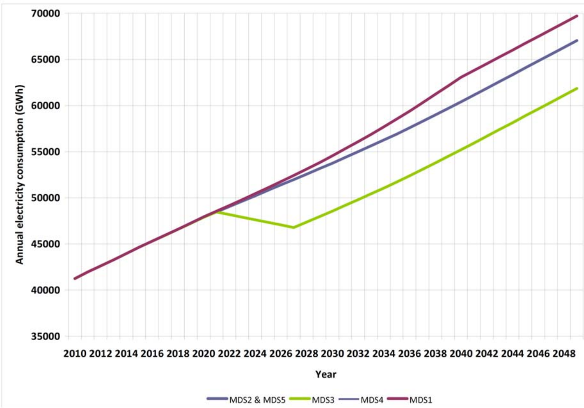


Figure 2. Load input data for the different projected scenarios [12]

generation capacity expansion program formulated as a mixed integer programming (MIP) problem, written using the GAMS [9] optimisation software with a CPLEX solver. The model takes into account cost minimisation, future demand, HVDC link energy transfer and hydro inflows in formulating the build schedules. However, the model does not include the effects of market supply and demand interaction in developing the schedules.

After NZEM commenced in 1996, the spot market price becomes a major indicator for power plant investment. Under a perfect competition and not taking transmission constraints into account, the spot market price indicates the marginal difference between the electricity supply and demand. A sustained high price indicates that new investments are required and there is a high chance for the investors to profit from the investments. This encourages one or more investors to build new power plants. However, commissioning of new power plants affects the spot market price by reducing the margin between the supply and demand and may deter or delay other future investments until the spot price is deemed to allow profitable new investments again. These circumstances show a dynamic relationship between the spot market price and investments. This paper attempts to include this dynamic interaction and investigates whether the outcomes would be any different to the ones projected by the SOO2008.

III. METHODS

This research utilises a system dynamics (SD) approach in its model. SD is a type of behavioural simulation model. It is a descriptive modelling method based on explicit recognition of feedback and time lags [10, 11]. Rather than model the electricity supply and demand using the concept of cause and effects, SD captures a more realistic dynamic relationship between them by incorporating feedbacks.

To provide a fair comparison, the new SD model uses the same inputs and assumptions as the model used to prepare the SOO2008. These inputs are the demand forecast under each scenario (Figure 2) and the plant's long range marginal costs (LRMC) (Table III and IV). Figure 2 shows the annual load forecast from 2010 to 2050. Both models use the same load data but at monthly resolution to capture the winter peak electricity demands. It then includes the market component in the model to study the trends of installed capacity from 2010 till 2050. The model components are shown in Figure 3.

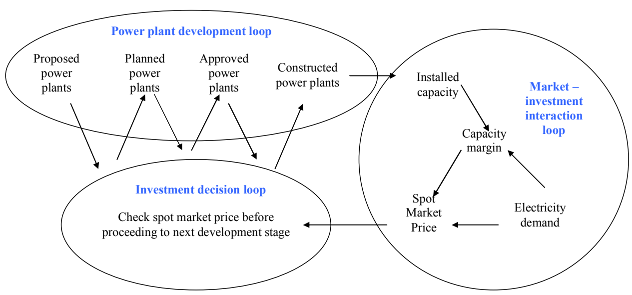


Figure 3. The SD model components

The three main loops in the model are the power plant development loop, market-investment interaction loop and investment decision loop. The plant development loop is individually constructed for each plant technology type to incorporate the different lead time and phase duration within them. The model uses the power plant schedules proposed by the SOO2008 as inputs to the power plant development loop. The scheduled plants are given a lead time and allocated different development phase durations depending on the plant type as shown in Table II.

TABLE II. PLANT LEAD TIME AND DEVELOPMENT PHASE DURATION

Plant type	Plant lead time (year)	Planning duration (year)	Approval time (year)	Construction duration (year)
Hydro	5	1	1	3
Coal	4	1	1	2
CCGT	3	0.5	0.5	2
OCGT	2	0.5	0.5	1
Wind	3	1	1	1
Geothermal	3	1	1	1
Cogeneration	3	1	1	1
Pumped storage	7	1	2	5
Wave	5	1.5	1.5	2

The plant development loop is closely linked to the investment decision loop. In the investment decision loop, before allowing the power plants to proceed into different cost incurring development phases, their LRMC are compared against a forecasted spot market price. They are allowed to proceed into the next development phase only if the spot market price is more than the plant's LRMC. The LRMC values are shown in Table III and IV. This investment decision process is summarized in Figure 4.

TABLE III. LRMC FOR NON THERMAL PLANTS [12]

Plant types	Load factor (%)	LRMC ($/MWh)
Hydro	50	85
Geothermal	90	80
Cogeneration	70	130
Marine	45	125
Wind	45	80

TABLE IV. LRMC FOR THERMAL PLANTS [12]

Plant types	Load factor (%)	LRMC ($/MWh) – gas at $7/GJ, no carbon charge	LRMC ($/MWh) – gas at $10/GJ, carbon at $30/tonne
Combined Cycle Gas Turbine (CCGT)	90	75	107
Open Cycle Gas Turbine (OCGT)	20	215	261
Coal	90	85	111

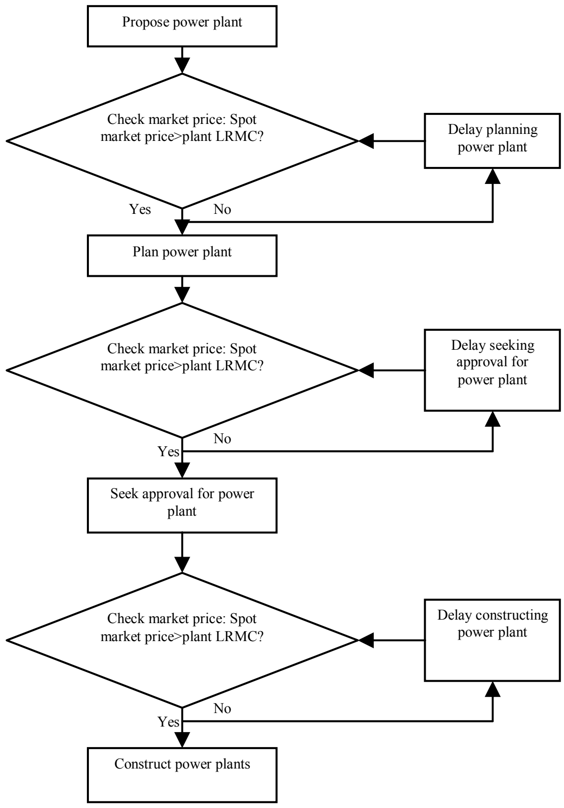


Figure 4. Investment decision based on New Zealand market model

The market-investment interaction loop connects the total installed capacity from the plant development loop to the investment decision loop. It compares the generation capacity and demand and formulates the spot market price. The price then determines the timing of generation investments as illustrated in Figure 4.

The SD simulations are run from 2010 till 2050. Eventhough the SOO2008 only schedules plants up to 2040, the SD model is simulated to 2050 to observe when delayed plants will be commissioned and when new capacities are needed.

IV. RESULTS & DISCUSSIONS

The results of the SD model is discussed and compared with the EC forecasts in this section for each scenario described in Table I.

A. *Sustainable Path (MDS1)*

Figure 5 gives a comparison between the results of the two models under MDS1. The SD model predicts that there are delays for capacities to come on line and not all the scheduled capacity will be installed. Looking at the results for each plant type, it is observed that not all the scheduled OCGT capacities will be installed as shown in Figure 6. The reason for this is due to the insufficient difference in the supply and demand margin that results in spot market prices not reaching high enough to trigger generation investments in OCGT technology after 2022. Figure 7 shows that the forecasted prices after 2022 are lower than the OCGT's LRMC. Hence, only 450MW out of 950MW scheduled capacity is predicted to be commissioned.

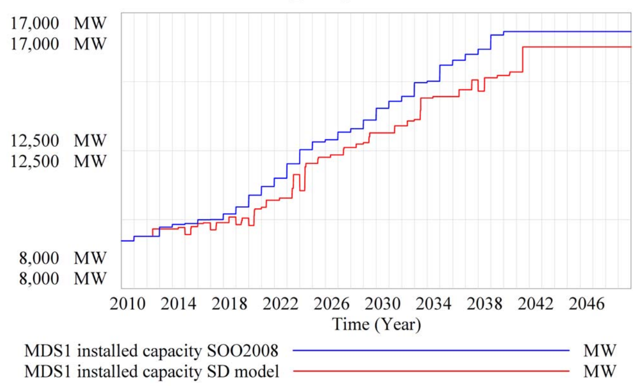


Figure 5. Results comparison for MDS1

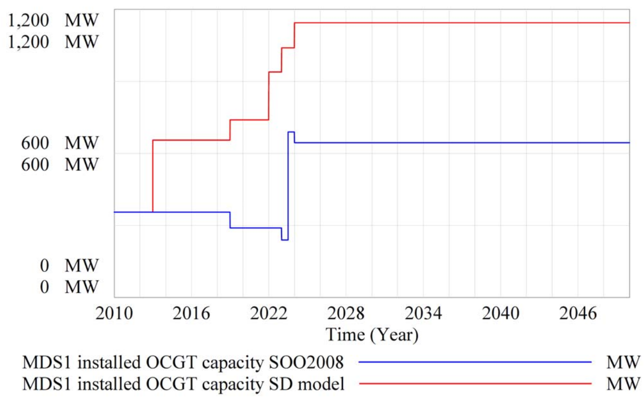


Figure 6. Results comparison for installed OCGT capacity under MDS1

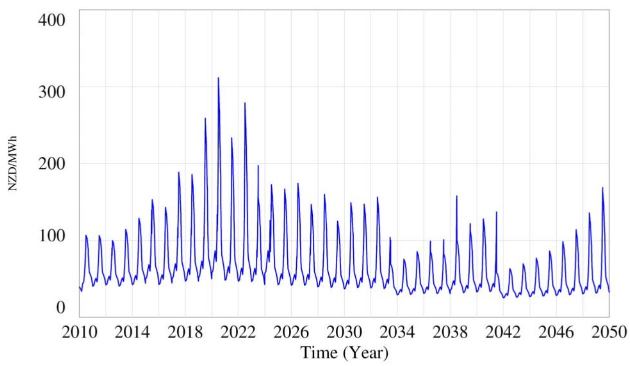


Figure 7. Forecasted market price under MDS1

B. *South Island Surplus (MDS2)*

Figure 8 shows that the SD model predicts slower capacity growth and the gap between the two models generally grows bigger throughout the years. The SD model predicts that the all the scheduled capacity comes on line only in 2046 after the spot market prices spike around 2038 (see Figure 9). Prices also spike after 2048 indicating the need for more plants to meet the increasing demand.

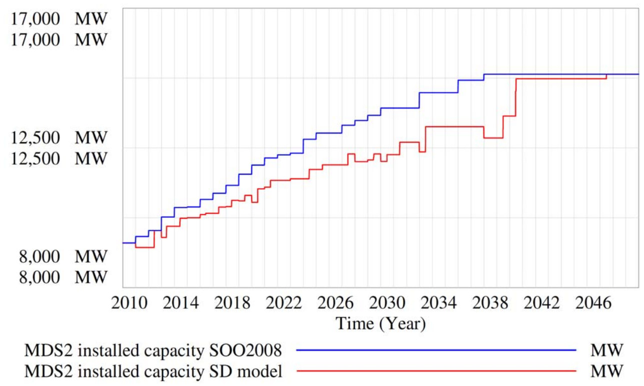


Figure 8. Results comparison for MDS2

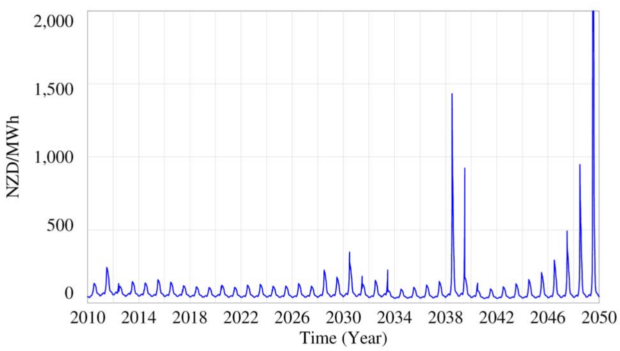
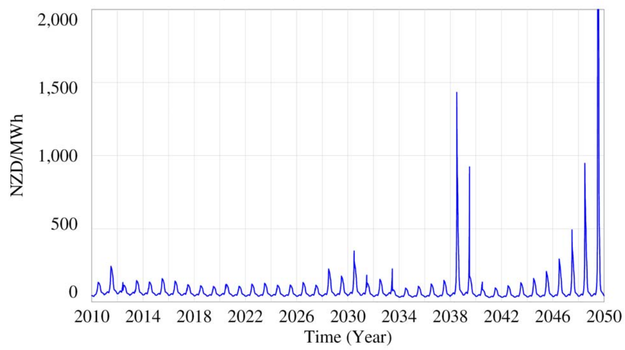


Figure 9. Forecasted market price under MDS2

C. *Medium Renewables(MDS3)*



In MDS3, the SD model predicts a slower growth in installed capacity compared to the SOO2008. Its growth is not fast enough to replace the thermal plants which are decommissioned after 2020. Despite the reduced load with Tiwai aluminum smelter decommissioning in the mid 2020s, supply shortages occur and cause prices to spike around 2030 (see Figure 11). More plants get installed by 2034 and all the scheduled plants get commissioned by 2044. Prices spike after 2044 indicating the need for more power plants.

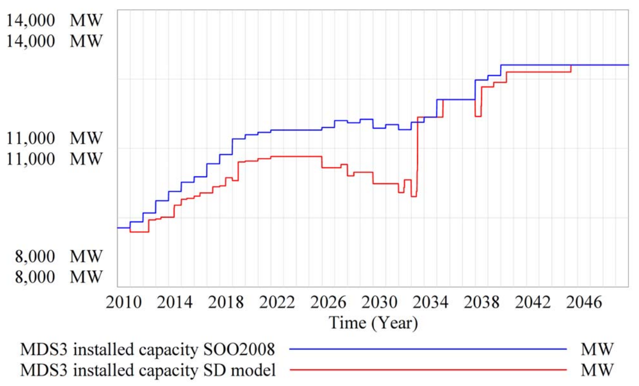


Figure 10. Results comparison for MDS3

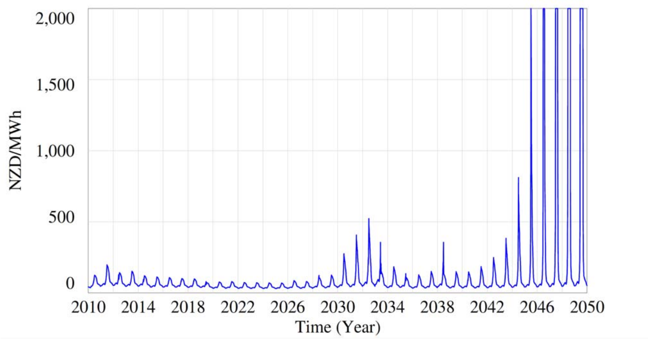


Figure 11. Forecasted market price under MDS3

D. Demand-side Participation (MDS4)

The SD result for MDS4 shows that from 2010 to 2020, most plants will be commissioned as scheduled. However, due to the low spot market prices, plants are delayed after 2020 until the prices spike up again in 2028. Not all the scheduled capacity will be installed. Looking closer at the results for each plant type, it is shown (Figure 13) that not all the scheduled coal plants will be commissioned. This is because MDS4 assumes high carbon prices after 2018, increasing the LRMC for coal plants. On the other hand, high demand side participation allows the spot market prices to remain low and avoids the need for a new coal plant after 2030.

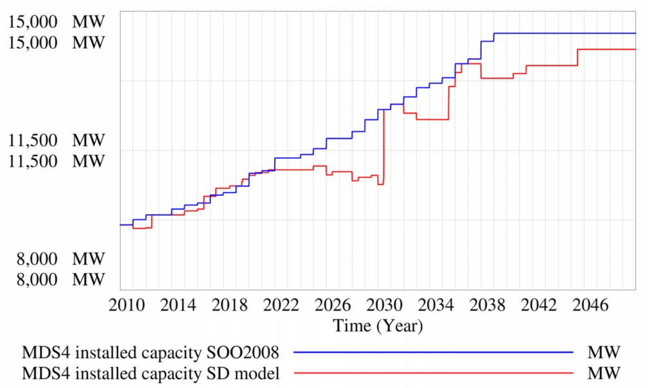


Figure 12. Results comparison for MDS4

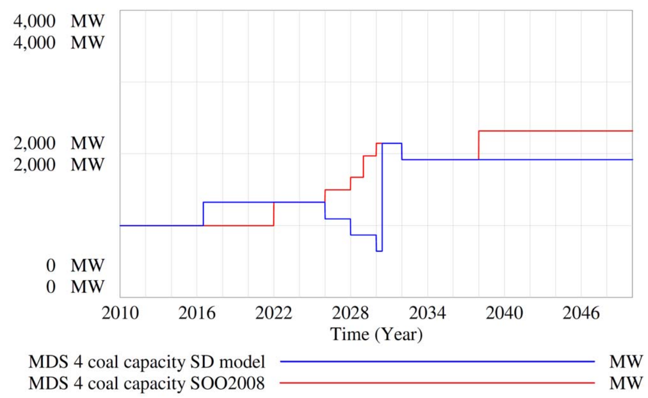


Figure 13. Results comparison for installed coal capacity under MDS4

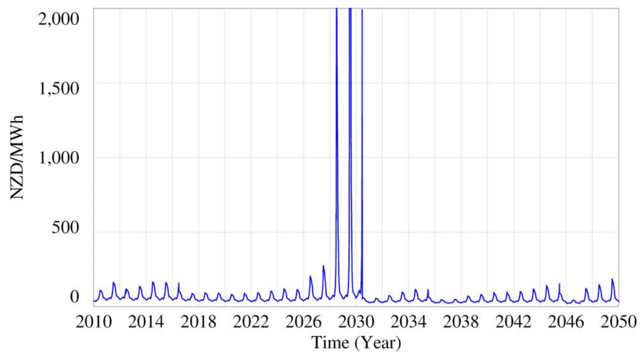


Figure 14. Forecasted market price under MDS4

E. High Gas Discovery (MDS5)

Under MDS5, the results from the SD model (Figure 15) and the SOO2008 are rather close from 2010 to 2028. This is because the scheduled plants within those years are small and cheap renewables with low LRMC. However, the SD predicts a slower plant development after 2028. This is because with high gas discovery, more large capacity gas plants are scheduled. Since they have high LRMC, the plants are delayed until the spot market prices (Figure 16) are high enough to provide profit. All scheduled plants are commissioned by 2040. More plants are needed after 2046 to meet demand.

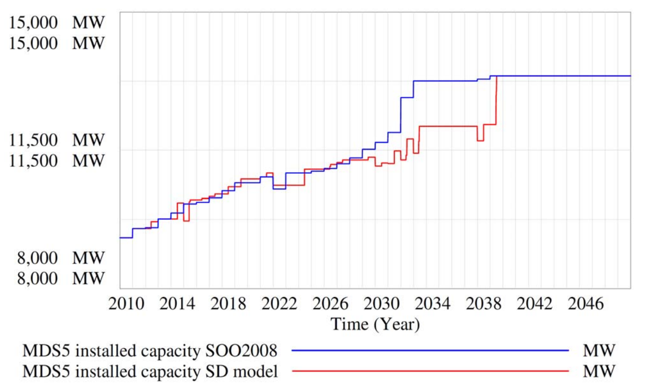


Figure 15. Results comparison for MDS5

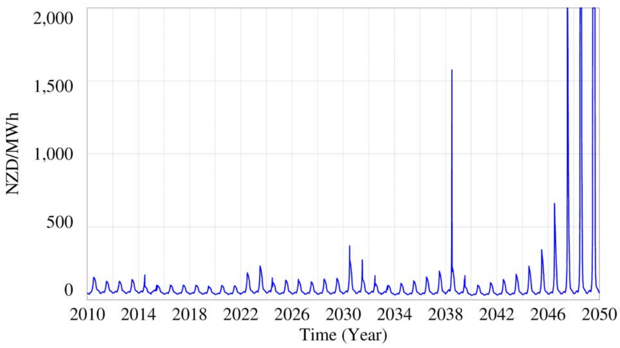


Figure 16. Forecasted market price under MDS5

F. *Results discussion*

The SD results for all five scenarios predict that there will be some boom and bust cycles in New Zealand generation capacity in the future. Some scenarios like MDS3, 4 and 5 produce more pronounced cyclic results. This is because these scenarios imply that large capacity thermal plants will be scheduled rather than small capacity renewable plants. This paper does not discuss supply adequacy and the impacts of delays on plant development because they will be discussed in other future publications.

V. Conclusion

The SD approach captures the dynamic relationship between the electricity market and generation investment. It gives an ability to study a system as a whole rather than as different sections, providing an understanding on how all the objects in a system interact with one another. It is not confined to engineering formulae nor economic equations and hence is able to capture any multidisciplinary aspects of a system.

The SD results for all five scenarios indicate some boom and bust cycles in the generation capacity regardless of generation mix and load demand. This implies that the current market structure in New Zealand is the likely cause of the cycles. This is in agreement with what has been discussed in some publications on energy only markets [13, 14].

The capacity cycles make it difficult to predict whether the future electricity supply will be able to meet an ongoing increase in demand. A severe bust period may cause electricity shortages that might take years to correct and cause long term economic impacts. The current market structure in New Zealand might need suitable modifications to mitigate these capacity cycles.

Acknowledgment

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