The impacts of generation mix on New Zealand's susceptibility to dry year shortages

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Abstract

After the commencement of the New Zealand Electricity Market (NZEM) in October 1996, generation expansion was made based on the wholesale electricity prices rather than through coordinated government planning. Since then, the installed generation capacity in New Zealand has been observed to follow a bust and boom pattern, resulting in energy shortages during dry winter years. A System Dynamics (SD) model has been developed to study the bust and boom trend. The model is then extended to evaluate the impacts of generation mix on New Zealand's susceptibility to future dry year shortages under the current market mechanism. The evaluation takes into account New Zealand's main storage lake cycles and the El Niño-La Niña Southern Oscillation (ENSO) phenomenon. Dry year occurrences have a major impact on the electricity supply in New Zealand due to its high reliability on hydro. Its effects vary under different generation mix. This paper discusses the impacts of the different generation mix under five different future generation scenarios proposed in the Statement of Opportunities 2008(SOO2008). It then highlights any potential problems identified by the study.

I. Introduction

The restructuring of the Electricity Supply Industry (ESI) in New Zealand has brought several changes to the way the infrastructures are planned and expanded. After the commencement of NZEM in October 1996, generation expansion was made based on wholesale electricity spot price in the energy market. Since then, electricity shortages occurred in July 2001, March 2003 and March 2008. These shortages raise questions as to whether NZEM is sufficient to provide incentives for investors to build new power plants with adequate capacity and characteristics to meet the demand trends. It is suspected that the market structure has been the cause for the shortages as discussed in some of the literatures [1, 2].

It has been shown in some studies [3-7] that deregulation of the ESI causes bust and boom cycles of generation capacity due to investment uncertainties. Initially power generators are uncertain as to 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 [8]. This bust and boom pattern has been observed to happen in the United States [3, 5] and European countries [6, 7]. Fig. 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 [9], indicating bust and boom patterns in the generation capacity.

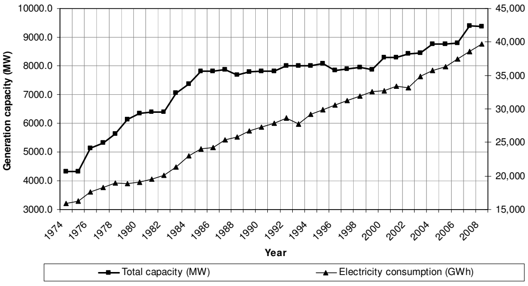

Fig. 1. Installed generation capacity in New Zealand from 1974-2008

Hydro has remained the dominant electricity resource in New Zealand for many years. However, hydro storage here is only up to six weeks [10]. For this reasons, the market is at the peril of weather patterns. Past dry winters have called for both conservation and high spot market prices [11].

II. Background and Objectives

Under part F of the Electricity Governance Rules 2003, the Statement of Opportunity (SOO) is published periodically by the New Zealand Electricity Commission. The purpose of the SOO is "to enable the identification of potential opportunities for efficient management of the grid, including investment in upgrades and transmission alternatives" [12]. The Statement of Opportunity 2008 (SOO2008) considers five different future scenarios as elaborated in Table 1. Under the various scenarios, the document provides electricity demand forecasts up to the year 2050 and tentative schedules of power plants up to the year 2040. However, the dry-year dispatch is not explicitly addressed in the document "as it is expected that market participants would effectively manage hydro storage using the capability of the grid to transfer power from North to South during periods of low demand" [12].

The SOO2008 uses a model known as the Generation Expansion Model (GEM) for its analyses. The model is formulated as a mixed integer programming (MIP) problem, written using the GAMS [13] optimisation software with a CPLEX solver. The model takes into account cost minimisation, future demand and HVDC link energy transfer between the North and South Islands in formulating the build schedules. However, the model does not include the effects of market supply and demand interaction in developing the schedules.

Table 1: SOO2008 Generation and Demand Assumptions for Five Different Future Scenarios [12]

Scenario	Generation assumptions
Sustainable Path (MDS1)	High renewable energy penetration backed by thermal peakers . New energy sources are commissioned in the late 2020s and 2030s
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 and supplemented by thermal peakers
Medium Renewables (MDS3)	Geothermal is the main resource and supplemented by thermal plants. The coal-fired units at Huntly transition through dry-year reserve to total closure
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
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 authors have developed an SD model to study the electricity generation expansion issue in New Zealand and made projections to investigate whether capacity cycles will happen in the future. The results show that capacity cycles will continue to occur due to the current market structure. Comparisons of the resulting capacity cycles against the steady capacity growth shown in SOO2008 has been made [14, 15]. The model is then extended to evaluate whether the cycles will cause energy shortages during future dry years. The evaluation takes into account the nature of hydro resources in New Zealand. The SD model takes seasonal hydro inflow variations and dry years into consideration for each scenario to identify if future energy shortages will occur.

III. Evaluation Methods

The model used in the evaluation is discussed in this section.

A. Model features

SD is a type of behavioural simulation model. It is a descriptive modeling method based on explicit recognition of feedback and time lags [16, 17]. Rather than model the electricity supply and demand using the concept of cause and effect, SD captures a more realistic dynamic relationship between them by incorporating feedbacks. The main interacting loops in the SD model are shown in Fig. 2. The components in the loops interact dynamically and influence each other's behaviour. The spot market price influences the investment decisions as what happens in the NZEM. The price is determined by the SD model from the difference between the supply and demand.

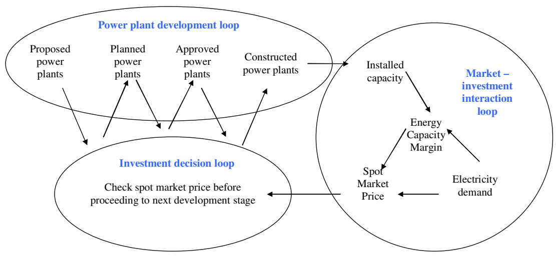

Fig. 2. The three main loops in the SD model that captures market interaction with power plant development

In the power plant development loop, before allowing the power plants to proceed into different development phases, their Long Range Marginal Cost (LRMC) is compared against the 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. This investment decision process is summarized in Fig. 3.

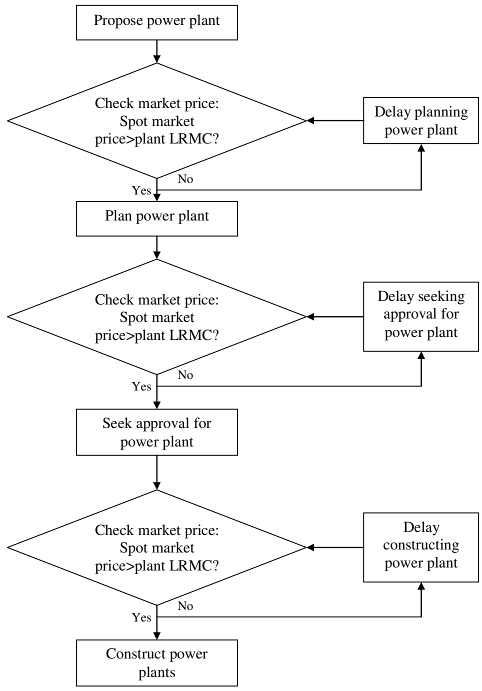

Fig. 3. Investment decisions based on the NZEM model

When a new capacity gets commissioned, the installed capacity increases. Depending on the gap between the supply and demand, the spot market price is adjusted accordingly. A big gap pushes up the price and vice versa. The adjusted price will then influence when a new plant comes in as it is only allowed to go through a development stage when its LRMC is exceeded by the price.

B. Model inputs

The SD simulations are run from 2010 till 2040, similar to the GEM model simulations for the SOO2008. To provide a fair comparison, the SD model uses the same inputs and assumptions as the GEM model for the SOO2008. These inputs are the plants' LRMC and plant availability factors (Table 2 and 3). The LRMC for thermal plants are higher due to higher gas prices and carbon tax.

Table 2: LRMC and Plant Availability Factors for Non Thermal Plants [12]

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

Table 3: LRMC and Plant Availability Factors for Thermal Plants [12]

Plant types	Plant availability 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
Integrated Gasification Combined Cycle (IGCC) with Carbon Capture Storage (CCS)	90	119	123

Other inputs that are the same as the SOO2008's inputs are the demand forecasts for each scenario until 2050, illustrated in Fig. 4. The figure shows the annual total demand, but the model takes the data monthly to include seasonal demand variation. The demand growth for MDS1 and MDS4 are higher due to the assumption of an active uptake of electric vehicles. MDS2 and MDS5 assume more active demand side participation. MDS3 assumes that the Tiwai aluminium smelter will decommission in the mid 2020s.

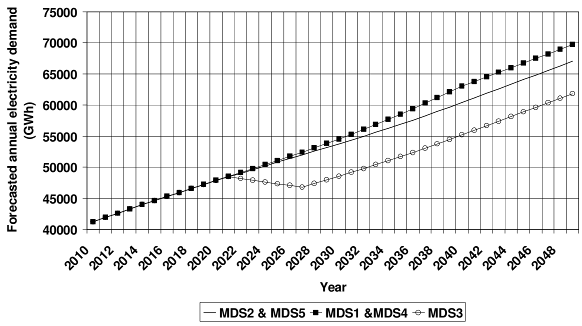

Fig. 4. Demand input data for the different projected scenarios [12]

The model also uses the power plant schedules proposed by the SOO2008 as inputs to the power plant development loop. The scheduled plants are given a certain lead time and allocated different development phase durations depending on the plant type, as shown in Table 4.

Table 4: Plant Lead Time and Development Phase Duration

Plant type	Plant lead time (year)	Planning duration (year)	Appro -val time (year)	Construc -tion duration (year)
Hydro	5	1	1	3
Coal / IGCC	4	1	1	2
CCGT	3	0.5	0.5	2
OCGT	2	0.5	0.5	1
Wind	3	1	1	1
Geother- mal	3	1	1	1
Cogenera- tion	3	1	1	1

C. Hydro Resources Considerations

The hydro inflows in New Zealand are highly dependent on the season. The natural lake cycles cause high lake level heading into summer (around December), reducing levels during summer and autumn and increasing levels during winter (around June) and spring [18]. Depending on the location, the inflows into storage lakes can also be affected by the El Niño-La Niña Southern Oscillation (ENSO). Monitoring of inflows to New Zealand's hydroelectric lakes stretches back to the 1920s. With the benefit of such a long time series, New Zealand's National Institute of Water and Atmospheric Research (NIWA) can show that the flow into South Island hydro lakes in La Niña years is considerably lower than the flow for other years [19].The schemes in the South Island accounts for 66% of the total installed hydro capacity in New Zealand [20]. This is almost twice the capacity of hydro schemes in the North Island. Hence, drought in South Island lakes causes a serious problem for hydro resources in New Zealand.

From Fig. 5, it can be observed that severe La Nina happens at least once in every seven years [19]. The y-axis represents the Southern Oscillation Index (SOI) which indicates the severity of the ENSO. For La Niña, the higher the SOI, the worse is its severity. The figure also shows that energy shortages in New Zealand in 2001, 2003 and 2008 coincided with severe La Niña occurrences.

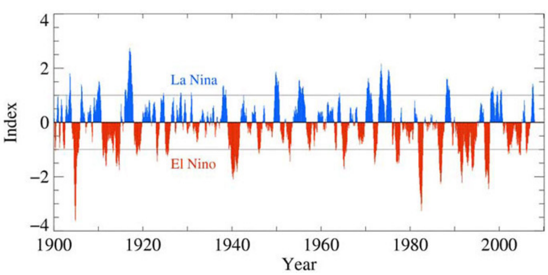

Fig. 5. Global ENSO occurrence in the last 110 years [19]

The GEM model used a constant plant availability factor for hydro plants. The SD model uses variable hydro plant availability factors for the different months of the year to take into account of the lake level cycles (see Fig. 6). The monthly average values are calculated from past hydrological data of the main hydro lakes in New Zealand. To include the impact of a severe La Niña on the hydro resources, the SD model includes its effects once every seven years with dry winter occurring in 2015, 2022, 2029, 2036 and 2043. This hydro model has been validated using data from 1996 to 2008 and the validation work will be published in other future publications. This model is deemed adequate since it is not the research objective to perform accurate forecasting of hydro data.

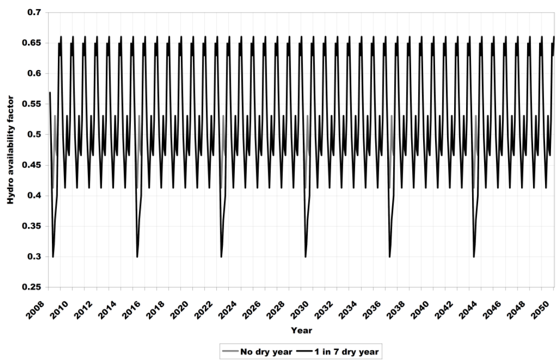

Fig. 6. Hydro availability factors used by the SD model

D. Energy Shortages Evaluation

In the last thirty years, New Zealand has been successful in meeting peak electricity demands (instantaneous power demand in MW) by having active demand side participation. However, the system has become energy constrained, especially during dry winter years where low hydro lake levels caused the supply to become insufficient to meet the energy demand (in GWh). To evaluate energy supply adequacy, a variable known as the energy capacity margin (ECM) is introduced. It is defined as:

$$\text{ECM} = \frac{\text{Available energy supply} - \text{Energy demand}}{\text{Energy demand}} \quad (1)$$

ECM is a ratio and hence it is dimensionless or can be written as a percentage. The available energy supply is calculated from the installed capacity and the plant availability factor where:

Available energy supply = Installed capacity x Plant availability factor

The energy demand is the load demand in GWh. The plant availability factors are as shown in Tables 2 and 3. The ECM is calculated on a monthly basis to take into account seasonal variations in electricity demand as winter consumptions in New Zealand are higher due to space heating.

IV. Results and conclusions

The following sections show the resultant installed capacities and ECM for the five scenarios. The installed capacities are compared with the scheduled capacities of SOO2008. The ECM graphs show that the values change monthly with seasonal variation. Since the SD model looks at the input demand data with a monthly resolution, lower ECMs are observed in winter when the demands are high due to space heating.

A. *Sustainable Path (MDS1)*

Fig. 7 shows that the SD model results lag behind the SOO2008 proposed schedule. This is due to investors waiting for the right spot market price before investing to allow for maximum profit. Capacity cycles are not obvious as the capacity dips are only for several months. The corresponding ECM (Fig. 8) became negative during every modeled dry winter, indicating the predicted occurrences of energy shortages.

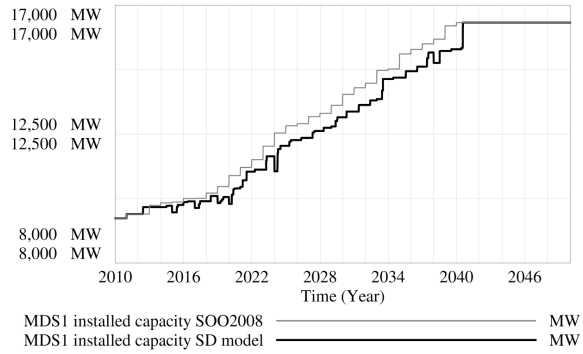

Fig. 7. Comparison of the SD model installed capacities with the SOO2008 for MDS1

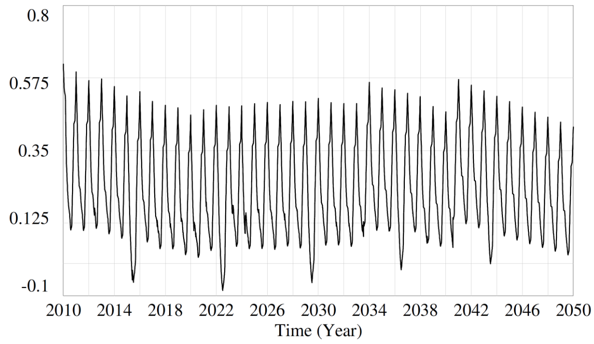

Fig. 8. Forecasted ECM for MDS1

B. *South Island Surplus (MDS2)*

Under MDS2, the differences between the SD model and SOO2008 results widen throughout the years (Fig. 9). The gap between the two results for MDS2 is bigger than for MDS1 since the demand grows at a slower pace after 2022 (see Fig. 4). The corresponding ECM (Fig. 10) became negative during every modeled dry winter, indicating the predicted energy shortages.

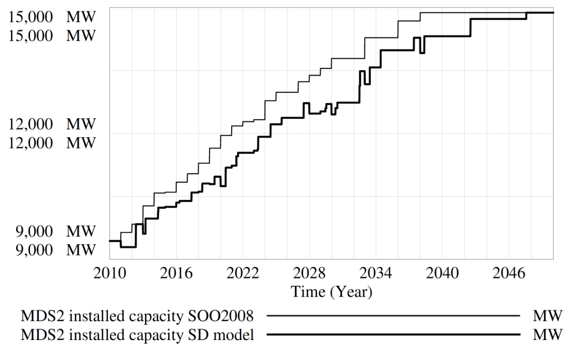

Fig. 9. Comparison of the SD model installed capacities with the SOO2008 for MDS2

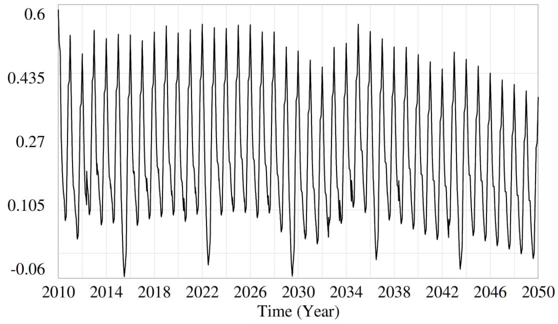

Fig. 10. Forecasted ECM for MDS2

C. Medium Renewables (MDS3)

The SD model predicts capacity cycles with a bust period of at least 6 years after 2026 (Fig. 11). This is because of the reduced demand due to the Tiwai aluminum smelter being decommissioned after mid 2020 (see Table 1 and Fig. 4). The reduced demand makes the spot market price low and not conducive for new investments. The bust period results in low ECM around 2031 (Fig. 12). A rapid boom follows afterward when investors try to maximize profits when the spot market price is encouraging again after a long period. The ECM is increased by the new capacities before it starts to decline again in 2041.

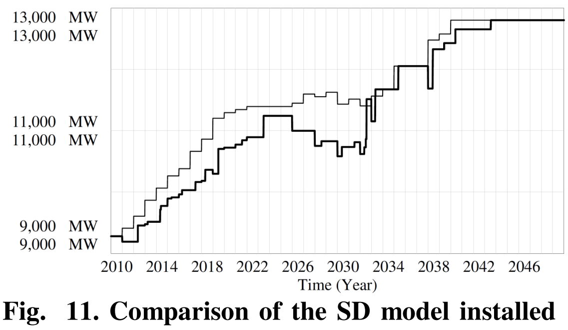

Fig. 11. Comparison of the SD model installed capacities with the SOO2008 for MDS3

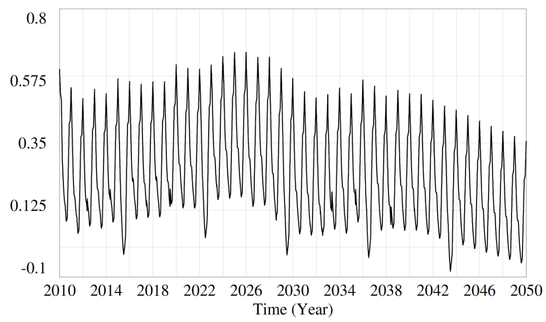

Fig. 12. Forecasted ECM for MDS3

D. Demand-side Participation (MDS4)

Under MDS4, the SD model predicts several cycles of boom and bust trends in the installed capacity (Fig. 13). The boom periods are in 2012-2022, 2030-2032 and 2035-2038 whereas the bust periods are in 2026-2028, 2032-2034 and 2038-2042. The booms after 2030 are steeper due to large capacity lignite and coal plants coming on line. The steady increase in demand causes the ECM to also become cyclic (Fig. 14). Shortages are predicted between 2015 and 2029.

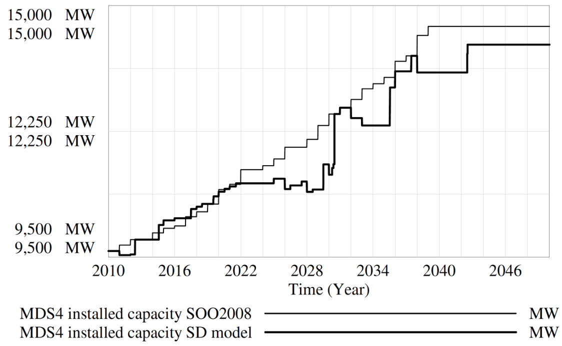

Fig. 13. Comparison of the SD model installed capacities with the SOO2008 for MDS4

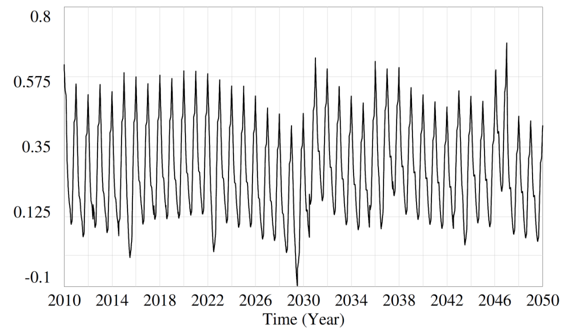

Fig. 14. Forecasted ECM for MDS4

E. High Gas Recovery (MDS5)

Under MDS5, a capacity dip is predicted in 2015. Since it coincides with a dry year, the ECM became very low for that year indicating a severe shortage. The SD model results do not differ much from the SOO2008 results from 2016 up to the year 2028, as shown in Fig. 15. A large disparity is observed between 2028 and 2040. This is because most of the scheduled plants around that time are thermal plants of large capacity and high LRMC. Investors would wait longer for the right market condition before proceeding with the plants. Negative ECMs are observed every modeled dry winter years, as shown in Fig. 16.

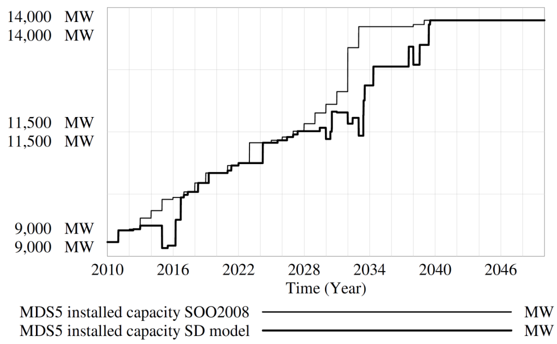

Fig. 15. Comparison of the SD model installed capacities with the SOO2008 for MDS5

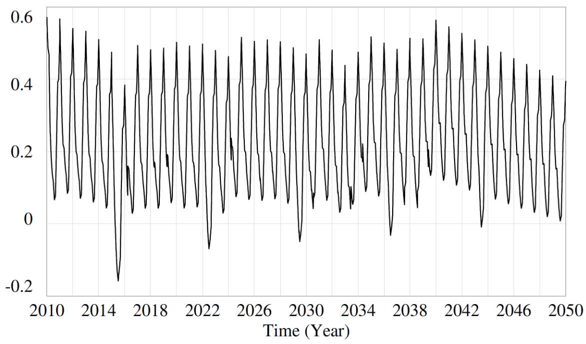

Fig. 16. Forecasted ECM for MDS5

V. Summary & Conclusions

Boom and bust cycles have been observed in other commodity markets such as real estates. However, the cycles in generation capacity are more pronounced because power plants are of large lumpy capacities, enormous capital investment and long lead time. It can be argued that capacity cycles are normal under a market environment to ensure that investments are made efficiently in meeting demands. However, a severe bust period in the generation capacity may cause severe electricity shortages that can be detrimental to the economy and cause inconvenience to consumers. In New Zealand, a bust period that is accompanied by a dry winter can be cause a serious energy shortage (like predicted for the year 2015 under MDS5)

Comparing the results for the different scenarios, the cyclic patterns in installed capacities are more obvious when the plants are large capacity thermal plants with high LRMCs (MDS3 and MDS4). Having more small renewable plants (like in MDS1 and MDS2) produces less cyclic patterns as the LRMCs are lower and hence the profit can be recovered easily with relatively lower spot market prices.

The variable ECM provides a good indicator in measuring a potential electricity shortage. The resultant ECMs for all five scenarios are summarised in Table 5. Comparing the ECMs for all five scenarios, dry winter shortages are identified for all scenarios. The least number of shortages are observed under MDS4. The severest shortage is predicted for the year 2015 under MDS5.

Table 5: Results Summary

Scena-rio	ECM statistics (%)			Shortage occurs?
	Min	Max	Mean	
Sustaina-ble Path (MDS1)	-8.39	61.75	23.66	Yes in every modelled dry winter
South Island Surplus (MDS2)	-5.57	58.69	23.25	Yes in every modelled dry winter, after 2049
Medium Renewa-bles (MDS3)	-8.03	65.43	25.09	Yes in every modelled dry winter, after 2045
Demand-side Participa-tion (MDS4)	-9.78	68.43	27.38	Yes in 2015 and 2029
High Gas Recove-ry (MDS5)	-15.84	57.06	22.71	Yes in every modelled dry winter

The SD model results from the dry year

analyses indicate the impact of generation mix onto New Zealand's energy security. High hydro penetration like in MDS1 and MDS2 can cause future energy shortages during dry years due to the high dependence upon hydro resources. However, under the current market structure, having more thermal plants aggravates the bust and boom patterns in the installed capacities. More severe shortages are observed if bust periods are accompanied with a dry winter year.

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