The Substitution of Different Forms in New Zealand's Energy Market

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Abstract
New Zealand's energy market is an interplay between various forms of non-renewable fossil fuels and renewable energies. Market share patterns before and after deregulation are observed to ascertain any changes in behaviour over this period of political and economic development of society. Forecasts were made for each form of energy, and showed primary energy supply for other renewable energies to surpass hydroelectricity and geothermal by 2020. World energy data were also collected to show how New Zealand's energy market is related to the more global situation. The forecasts show hydroelectricity and nuclear energy only increases in a small share by 2020.

1. Introduction

New Zealand's energy sector has experienced a period of significant change and reform over the past two decades. In the 1980s and 1990s, successive governments deregulated the economy and the energy sector. This provided challenges and opportunities for existing and new energy sector participants [1]. Energy patterns during the deregulation period are of interest to see how people and politics have controlled and influenced the energy market. Historical events, the Kyoto protocol, world events (e.g. oil crises), and greenhouse policies may also have influence on the energy market patterns.

Previous research [2] investigated the patterns of actual energy consumption in New Zealand. However, such analysis does not provide an insight to the interplay of the various forms of energy that make up the market which supplies the economy. Consequently, in this paper, historical data for primary energy supplied, and energy consumed by fuel and by sector is analyzed to observe the changes in the energy market patterns. Predictions are then made for the future, using mathematical models and by observation. World energy consumption is also analyzed to forecast world energy trends and determine how New Zealand's energy market is related to these.

2. Deregulation

In the 1980s, the Labour government instigated deregulation for the electricity sector. The deregulation process removed restrictions on business and was thought of as a way to encourage the efficient operation of markets, providing challenges and opportunities for existing and new energy sector participants. The major goal of deregulation should be to ensure that appropriate incentives are provided for good capital decisions as well as good operating decisions [3]. Fewer regulations lead to a raised level of competitiveness, therefore higher productivity would increase efficiency and lower prices overall.

The energy sector reformations were seen as a good basis for encouraging renewable energy developments. Enhancements of the opportunities for the cost-effective application of renewable energy were announced, including work on identification of the barriers to renewable energy [4].

3. Historical Data

3.1 Data Collection

The form of energy supplied to the New Zealand economy can be viewed from two perspectives, primary and secondary. Primary energies are those embodied in natural resources that have not undergone any technological conversion or transformation. These include coal, oil, natural gas, hydro, geothermal, wind, biomass and solar. Secondary energy is derived from any of the primary energies, such as electricity from coal, oil and natural gas, and gas from coal. Secondary energy is energy consumed.

Energy consumption data was collected from various government publications. Ministry of Economic and Development (MED) [5] and Statistics New Zealand [6] were the main sources for energy consumption by fuel and by sector and primary energy supply data. The available energy consumption by fuel data ranged from 1924-2004 with data from 1924 to 1974

shown in steps of 10 years. The energy consumption by sector found in the Energy Data Files (EDF) [5] were divided into Agriculture, Commercial, Residential, Industrial and Transport. The accessible data was from 1982-2004. Primary energy supply data from 1974-2004 was found in the Energy Data Files July 2005 [5].

3.2 Data Conversion

All the data were converted to petajoules in order to compare different types of energy on the same scale. Gigawatt -hour (GWh) were converted into petajoules (PJ) using (1).

$$1PJ = 277.778GWh \qquad (1)$$

The market share for each data set was calculated by dividing the absolute supplied or consumed energy by the total supplied or consumed energy, i.e. the market share is the percentage or proportion of the total available market.

3.3 Forecasting Model

One method to determine if a curve is linear, exponential, or logistic is to take a moving average of five years, calculate the difference in ordinate between successive points, and plot these differences against time [7]. Only an exponential curve will have an exponential differential curve. A constant differential indicates linear growth, while a declining, but still positive, differential suggests that saturation may be occurring.

The differential curves for each fuel consumed were calculated and plotted. The curves were found to be neither linear nor exponential over the entire data series. This reflects the impact of deregulation. The timeline for energy consumption can be divided into three main periods, during regulation, after the oil crisis and after deregulation. Using data from 1988 to 2004, the trends after deregulation can be fitted with a linear line. The assumption for this model is "business as usual" over this period. Forecasted values to 2020 were then found.

4. Results

4.1 New Zealand Primary Energy Supply

Primary energy supply by fuel includes net coal, imported oil and oil products, net indigenous oil, natural gas, hydro, geothermal and other renewable (includes electricity generation from wind, biogas, industrial waste, wood and solar water heating). Figure 1 shows the primary energy supplied by fuel since 1974 to 2004 and forecasted values from 2005 to 2020, using linear extrapolation models.

There has been a dramatic turn around in imported oil since 1988. Showing a 50% decrease from 1974, imported oil supply has reached more than two and a half times its low point in just 16 years. The prediction is for this increase to continue. Coal supply has also increased. In contrast, there appears to be a stagnation for gas, slight declines for hydro and geothermal and a significant decline in indigenous oil (itself a by product of gas production). The trend of increasing renewables appears more certain.

Figure 2 shows the primary energy supply by fuel market share. The imported oil market share was 46% in 1975. It dropped significantly after the oil crisis in 1973, decreasing linearly to 17.5% in 1986. There was a substitution of indigenous oil and oil products for imported oil after 1973 to just before deregulation in 1986. However, deregulation removed price control, government involvement in the refinery, licensing of wholesalers and retailers and restriction on imports refined products [10]. As a result, the market share of imported oil has been increasing linearly since. This is predicted to continue to not only meet demand but to replace gas following the exhaustion of Maui. Imported oil is predicted to take up 46% of the market share by 2020, back to its pre energy crisis level. Indigenous oil is predicted to run out by 2008.

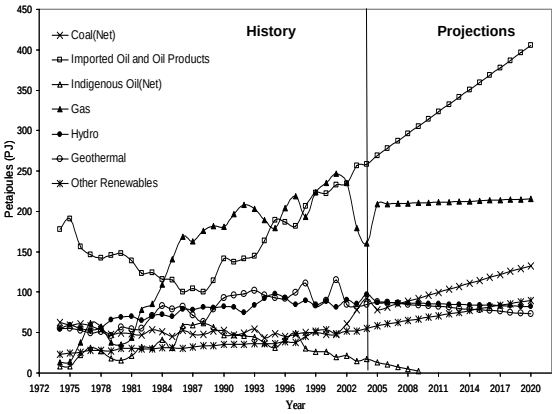

Figure 1 New Zealand Primary Energy Supply by Fuel Forecast to 2020

The supply of natural gas has increased by 20% since full commissioning of the Maui field in 1979. It peaked in 1988 and remained stagnant until 2001. Gas supply has since dropped by 10% in 4 years. Its future is one of decline.

After a long and continuous decline, coal has had a considerable resurgence in production since 2000. Virtually all of that increased output is being exported. The run-down of Maui gas in New Zealand may mean coal is required here as a replacement, particularly in our thermal power stations, which were originally run on this fuel.

Of the renewable energy supply fuels, both hydro and geothermal have been in decline, from before deregulation. Their future appears to continue this trend if left to market forces. Although renewable energy may be considered to be a solution to New Zealand's energy supply, the increase in market share of other renewables to date is limited. They are unlikely to be sufficient to cover New Zealand's energy demand in the near future.

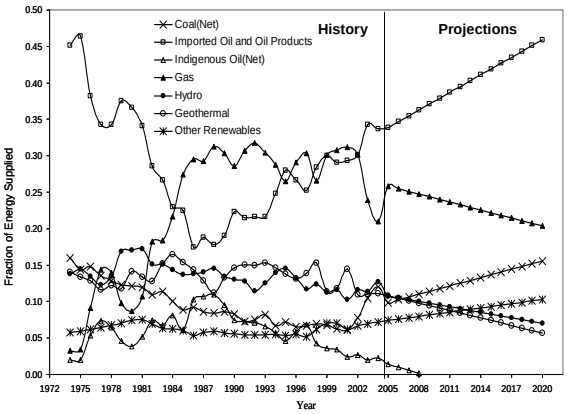

Figure 2 New Zealand Primary Energy Supply by Fuel Market Share Forecast to 2020

4.2 New Zealand Consumer Energy by Fuel

The energy consumed is what society uses rather than what is supplied. It includes solid energy (coal, wood and renewable fuel), oil, gas, electricity and direct use of geothermal. The projected values were forecasted using a linear continuation of the past 16 years of data. Figure 3 shows the patterns for each fuel type consumed in New Zealand from 1924 to 2004 and forecasted values from 2005 to 2020. While the total energy use has followed a relatively uninterrupted trend, the various fuel types show dynamic changes during the 1980s, with a down turn in oil and the rise of gas. Subsequently, only oil and electricity are seen to increase, with the other energy forms maintaining a relatively constant contribution level.

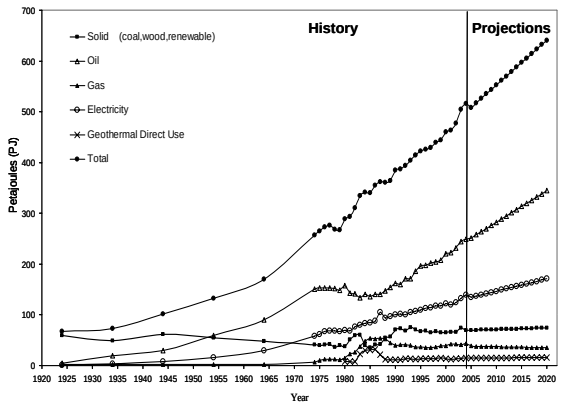

Figure 3 New Zealand Energy Consumption by Fuel Forecast from 2004 to 2020

The market shares of energy consumed by fuel are shown in Figure 4. The substitution of oil for coal dominated the early energy market with a change over in 1955. There has been a penetration of electricity, surpassing coal in 1970. The impacts of the 1973 and 1979 oil crises show as a dramatic drop in oil consumption market share. Just as the oil market share was about to rise again after the 1973 oil crisis, the 1979 oil crisis made a greater impact and caused the market share to drop from 59% in 1979 to 38% in 1987. Oil's market share has risen since. Assuming that oil continues to be available, its share is predicted to rise to 58% of the market by 2020. Electricity's market share appeared to level out in the 1980s and hence is predicted to remain at this level for the near future.

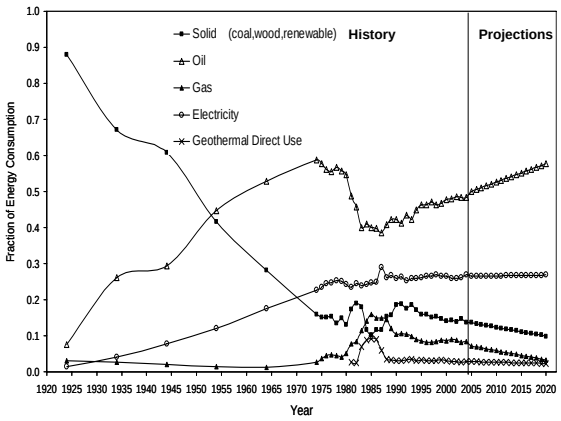

Figure 4 New Zealand Energy Consumption by Fuel Market Share Forecast to 2020

The significant increase in gas consumption and market share was due to the discovery of the major Maui offshore field in 1969. It was fully commissioned by 1979. Gas surpassed coal in 1984, peaked in 1985 and then declined, with the market share of coal re-substituting gas in 1988. However, both are predicted to decline, with the gas market share at around 3% by 2020. The Canterbury Manufacturers Association [8] predicts that gas will run out by 2011 at today's consumption.

The geothermal direct use increase in 1982-1988 was found to be an overestimate of data. The current geothermal direct use was reported by the New Zealand Geothermal Association to be 9.5 PJ instead of the published 14.5 PJ in EDF [9]. The overestimate would give slightly higher market shares for the other fuels.

4.3 New Zealand Consumer Energy by Sector

Energy consumption in the economy has been named and divided into different sectors at various stages. From 1982 to 1989, there were four sectors: industry, commercial/agriculture, domestic and transport. From 1990 to 1994, the commercial and agriculture sectors were separated. From 1995 to 2004, there

were five sectors: industry, commercial, agriculture, residential and domestic transport. Since the data prior to 1989 for commercial/agriculture could not be separated, the data for commercial and agriculture after 1990 were combined together. Hence, for this research, four main sectors were investigated: industry, commercial/agriculture, residential and domestic transport.

Figure 5 shows the energy consumed by sector for New Zealand from 1982 to 2004, and projected values from 2005 to 2020. All data is remarkably smooth and continuous over the time spans. Domestic transport and industry dominate energy use, while commercial/agriculture and residential use show modest growth. The market share of the energy consumed by sector is shown in Figure 6. The energy consumed by domestic transport surpassed the industry sector in 1994. This substitution indicates that people in New Zealand have more access to personal transportation. This explains the increase in oil market share of Figure 4.

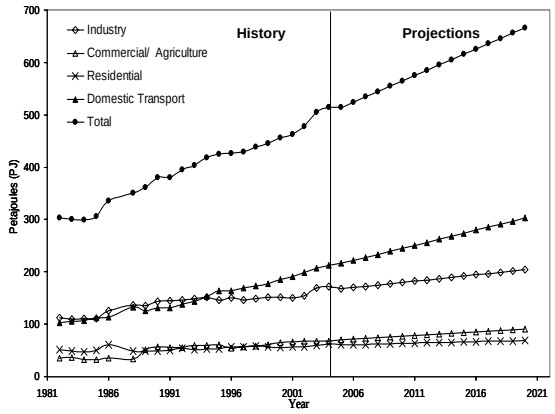

Figure 5 New Zealand Energy Consumption by Sector Forecast to 2020

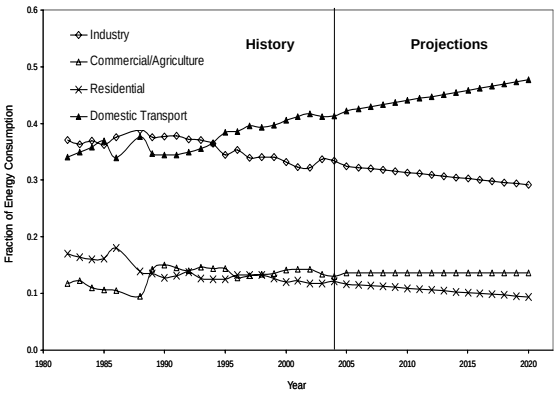

Figure 6 New Zealand Energy Consumption by Sector Market Share Forecast to 2020

Industry's market share has steadily declined since deregulation. There was an abrupt 5% increase in the energy used by the commercial/agriculture sector after deregulation. It has remained relatively constant since. The residential sector has used a decreasing portion of the total energy market in New Zealand.

The projected values to 2020 show that the domestic transport sector market share increases to 48% while the industry sector market share drops to 29%. This may indicate that we are importing more of our goods from overseas and producing less local products, as well as the effect of increased tourism and its transport requirements. The commercial/agriculture and residential sectors take up 14% and 9% of the market share, respectively.

4.4 World Consumer Energy by Fuel

World energy consumption is measured in tonnes, where one tonne is equivalent to 8.99×10^{19} J. The available total energy consumption by fuel from 1965 to 2005 was obtained from the BP Statistical Review of World Energy June 2006 [10]. This is shown in Figure 7 along with predicted values from 2006 to 2020.

The impact of the 1973 and 1979 oil crises are temporary dips in the relatively smooth increasing trends. There is no obvious down turn in any energy form over the historical data. Consequently, all energy forms are predicted to increase in consumption.

Figure 8 shows the world energy consumption market shares. The substitution of oil for coal was at the start of the data near 1965, which was about 10 years after New Zealand's substitution. Oil's market share peaked in 1973 (the same as for New Zealand) and has been declining since. There has been no resurgence in oil's market share on the world scale, despite most developed countries, which consume the bulk of the world's oil, moving to more open markets. The New Zealand move from a controlled to a free market has created an anomaly.

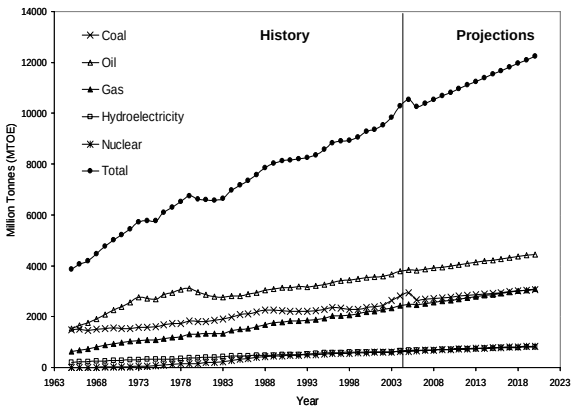

Figure 7 World Energy Consumption by Fuel Forecast to 2020

Gas consumption market share rises throughout the period and is predicted to surpass coal by 2012. These are also in contrast to that for New Zealand.

Hydroelectricity only represents a steady 7% of the market share whereas for New Zealand, hydro plays a major role in supplying the country's electricity needs.

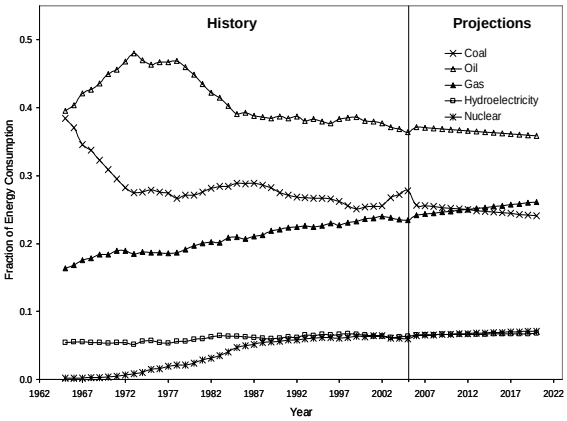

Figure 8 World Energy Consumption by Fuel Market Share Forecast to 2020

The other energy source with a significant global market share is nuclear. There is a gradual rise until the late 1980s. It has been static since, so the projected nuclear consumption market share stays at 7% of the total energy consumption. Although nuclear power has been considered as the cleanest energy source compared to other fuels, the incidents at Three Mile Island and Chernobyl have caused public concerns as to the dangers of nuclear power plants.

In the United States, which has the largest nuclear power generation, energy supply is shifting more towards natural gas. There has been no new nuclear construction since the 1970s; the industry seems to have little interest in nuclear power generation except for maintaining existing plants. It is the nations of East Asia, including Japan, that are planning to construct nuclear power as a necessity for the future [11]. At this stage New Zealand does not have a nuclear future.

5. Discussion

Coal was the main energy form at the start of the last century in New Zealand. Other forms of energy entered the market to substitute it. Substitutions include oil dominating coal in 1955 and then gas dominating coal in 1970. Oil is currently the major primary energy supply.

The rising demand for oil has always been met by increased supply. However, most fields outside the Middle East are already past their peak output. Oil production is thought of as a bell shape, as proposed by M. King Hubbert in 1956. With the easy half of the world's oil extracted, world oil production reaches its 'peak' and then declines. The peak does not signal the "end of oil". It will be around for at least another 50 years. The decline leads to shortages with much higher prices and growing international tension over the remaining oil stocks. We are facing the end of cheap and abundant oil.

With the oil crisis in the 1970s, we perceived ourselves to be very vulnerable in New Zealand, with little indigenous supply to fall back on [12]. This predicament sparked off a programme to become 50% self-sufficient in transport fuels by 1985. We became 60% self-sufficient through the conversion of natural gas from Kapuni and Maui into petrol at the synthetic fuels plant at Motunui [12]. However, given the history of the lack of oil discoveries in New Zealand, we are likely to remain a significant importer of oil [13].

The Maui gas field has been responsible for up to 25% of New Zealand's electricity generation. While the Maui gas field is depleting, there are several smaller fields that have been proven. Unfortunately, the rate of discovery of new gas fields within New Zealand in recent years does not give much confidence that these new fields will be able to replace Maui in the longer term. Furthermore, these new fields will not have the capability of Maui to "turn the tap on and off" to help cope with a dry year electricity situation [14].

In New Zealand, most gas is distributed by pipeline from producing fields. In Liquefied Natural Gas (LNG) facilities, the gas is liquefied and then transported to markets. As a significant portion of natural gas growth is driven by the increasing use of gas in electricity generation, power generators are looking to LNG and coal to replace local gas.

While known global oil and gas reserves are likely to be largely exhausted within the next 50 years, abundant and accessible coal reserves will last much longer. New Zealand's coal reserves are estimated to represent 1000 years of supply at the current rate of coal use in the country's primary energy production [15]. Reserves have been estimated to be equivalent to about 30 times that of the original Maui gas field.

The future use of coal is constrained by the need to limit carbon dioxide emissions, or pay substantially for them according to the Kyoto protocol. There is an effort to develop new coal based power generation technologies with reduced environmental impact, often referred to as "clean coal technologies." Coal gasification may be an important enabling technology in the transition towards a hydrogen energy economy where currently an increase in domestic transportation and oil consumption is concurrent with an increase in carbon dioxide emissions.
Hydroelectricity is by far the largest renewable resource used for electricity generation worldwide. The economic potential of hydroelectricity is often

considered to be many times the current global installed capacity. New Zealand has a high proportion of hydroelectricity, largely based on plants built from the 1930s to the 1980s. New developments have run into substantial public opposition because of some of the environmental and land use issues involved. The generation of hydroelectricity is highly dependent on weather and rainfalls. 1992, 2001, and 2003 were dry years where hydro generators experienced shortages of water. Electricity generation had to rely more on thermal power stations.

New Zealand's national power plan first looked into the likely need for nuclear power in 1968, since readily-developed hydro-electric sites had been utilised. A site at Oyster Point on the Kaipara harbour near Auckland was reserved for the first plant. Four 250 MWe reactors were envisaged, to supply 80% of Auckland's needs by 1990. However, the Maui gas field was discovered, along with coal reserves near Huntly, and the project was abandoned in 1972. In 1987, New Zealand passed a Nuclear-Free Zone, Disarmament and Arms Control Act. This was largely a symbolic statement of opposition to nuclear war and weapons testing. It prevented visits by nuclear-propelled or nuclear-armed vessels (primarily US ones) [16].

With New Zealand being dependent on the world supply of oil, the production of Maui gas field depleting, the low market share for renewable energy and rising concerns about pollution, green house effects and global warming, nuclear power is once again being considered as an option for New Zealand. Nuclear fuel is abundant and involves no opportunity cost, having virtually no other peaceful use. Also, wastes can be contained and managed where it is reused to increase the efficiency of the use of uranium. Reuse of plutonium as mixed oxide (MOX) fuel for light water reactors also ensures the non-proliferation of weapons using plutonium. Reprocessing also reduces the volume of high-level radioactive waste and cost of its disposal [11]. Overall, it may yet be a relatively sustainable and plausible option for further base-load capacity in New Zealand.

6. Conclusion

It is the mix of energy, both supplied and used, that has been discussed in this paper, along with predictions of what this mix might be in the future.

Oil's market share dropped dramatically after the two oil crises of 1973 and 1979. The energy reforms in New Zealand during the 1980s have proved to change energy market shares, with imported oil increasing linearly since deregulation in 1987. It now makes up 50% of the energy consumed. The deregulation of the oil industry in the late 1980s removed price control, and government involvement in the refinery, licensing of wholesalers and retailers and restriction on imported refined products. The projected market shares to 2020 show that it continues to increase to 56% for the energy consumption and 46% for primary energy supply.

Using linear models and assuming business as usual, the results showed that as the Maui gas field is depleting and no other larger scale fields have been discovered, the market share for gas declines to 3% for energy consumption and 20% for primary energy supply by 2020. The resurgence in coal may replace this depletion of Maui gas field to operate the largest thermal power stations. The forecasted primary energy supply market share for coal will increase by 5% by 2020.

Hydro power station outputs peaked in 1981 and have been declining ever since. The forecast hydroelectric primary energy supply market share is predicted to decrease from 10% to 7% by 2020. Primary energy supply for other renewable energies is projected to substitute hydro and geothermal by 2020 but will not have a substantial effect in the overall market. Only through government intervention and a move away from market forces are we likely to see renewables add significantly to the overall energy supply in New Zealand.

New Zealand is a small energy market relative to the global system. World energy market patterns show a recent history of oil declining, coal declining, gas increasing and the significant presence of nuclear. These are marked contrasts to the New Zealand scene. Renewables are insignificant on the world scene.

7. References

[1] Taylor, M., and Eng, G.: *New Zealand Energy Outlook to 2020*, Ministry of Commerce, Crown Copyright, Wellington, Feb 2000.

[2] Mohamed, Z.: *Forecasting electricity consumption: a comparison of growth curves, econometric and ARIMA models for selected countries and world regions*, PhD Theses, University of Canterbury, Christchurch, New Zealand, Nov 2004.

[3] Zaccour, G.: *Deregulation of Electric Utilities*, Kluwer Academic, Boston, Mass., c1998, p.2.

[4] Electricity Group: *Chronology of New Zealand Electricity Reform*, Ministry of Economic Development, New Zealand, April 2005.

[5] Ministry of Economic Development: *New Zealand Energy Data File*, Crown Copyright, July 2005. http:// www.med.govt.co.nz

[6] Statistics New Zealand: New Zealand Official Year Book, Wellington, N.Z. Govt. Printer, 1982-2004 editions.

[7] Diesendorf, M.O.: *Energy and people: social implications of different energy futures*, Society for Social Responsibility in Science, Canberra, 1979.

[8] Guy, P., Young, A., and Walley, J.: *Will it take more Blackouts before we see the Light?: A Systems Approach to the New Zealand Electricity Industry Issues*, Canterbury Manufactures' Association, Aug 2006.

[9] White, B.: An *assessment of Geothermal direct use in NZ*, New Zealand Geothermal Association, July 2006. http:// www.nzgeothermal.org.nz

[10] BP: *BP Statistical Review of World Energy June 2006*. http:// www.bp.com/statisticalreview

[11] Ichihara, Y.: A Perspective on Nuclear Power Generation in the Future Electric Power Industry-For Nonspecialists in the Electric Power Related Industries, Proceedings of the IEEE, vol.89, No.12, Dec 2001.

[12] Makeig, Wayne.:*Our Country: Our Choices-Energy*", New Zealand Futures Trust, May 2006. http://www.futurestrust.org.nz/

[13] Watson, J.D.: *Science and technologies important to New Zealand's energy future*, The Royal Society of New Zealand, 2005. http:// www.rsnz.org/topics/energy/watson.php

[14] Blakeley, J.: *NZ Energy Conference in Retrospect*, Engineers for Social Responsibility Inc, May 2006. http://www.esr.org.nz

[15] Solid Energy New Zealand Ltd: *New Zealand Coal*, Solid Energy New Zealand Ltd, June 2006. http:// www.solidenergy.co.nz

[16] Uranium Information Centre: *Nuclear Energy Prospects in New Zealand*, Briefing Paper #97, Uranium Information Centre Ltd**,** April 2005. http://www.uic.com.au/nip97.htm