Market Influence on Energy Use and Carbon Dioxide Emission Patterns

C. -Y. Hung and P. S. Bodger

***Abstract*--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 consumption, and the carbon dioxide emission from each form of electricity generation was also analysed from historical data.**

***Index Terms*-- Carbon Dioxide Emission, Deregulation, Energy Measurement, Energy Conversion, Energy Consumption, Energy Market Share, Forecasting.**

I. Introduction

ENERGY market is an interplay between various forms of non-renewable fossil fuels and renewable energies. The energy market share is the percentage or proportion of the total available market. For example, New Zealand's energy market is made up by coal, oil, natural gas, hydro, geothermal, wind, biomass and solar. The only energy source not available is nuclear. The 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. 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.

Public awareness on environmental issues has increased in the last decade. Greenhouse policies, such as Kyoto protocol, have played an important role in the development and designs of power plants and may have influences on the energy market patterns. The most commonly known greenhouse gas is carbon dioxide (CO_2), where the atmospheric concentration has increased by about 35% since the beginning of the age of industrialization. Major sources of CO_2 emission include home heating and cooling, electricity consumption, and transportation. To determine how human activities and economic growth have contributed to the change of CO_2 emissions, we can look at the CO_2 emissions from the generation of electricity by fuel type.

This paper is a continuation from The Substitution of Different Forms in New Zealand's Energy Market [1], which showed historical data for primary energy supplied, and energy consumed by fuel and by sector was analyzed to observe the changes in the energy market patterns. Predictions were then made for the future, using linear models and by observation. World energy consumption was also analyzed to forecast world energy trends and determine how New Zealand's energy market is related to these.

Further work focused on the electricity generation from each fuel type and the amount of CO_2 each generation emits. By comparing the primary energy supplied, energy consumed and the electricity generation by fuel, we can discuss and see how the reformations of the energy sector in the 1980s and 1990s have influenced the energy market and carbon emissions in New Zealand.

II. 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 [2]. 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 [3].

III. Historical Data

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,

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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.

The energy supply and consumption data from the previous work were collected from Ministry of Economic and Development [4] and Statistics New Zealand [5]. New data were collected to calculate the amount of carbon emissions each form of electricity generation was producing. Net electricity generation by fuel type and the heat value data for New Zealand was available from Ministry of Economic and Development [4].

All the data were converted to petajoules in order to compare different types of energy on the same scale. To compare carbon emission, all heat values from electricity generation were converted into carbon equivalents in ktonnes.

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.

IV. New Zealand Example

A. 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). Fig. 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.

Fig. 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 [4]. 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.

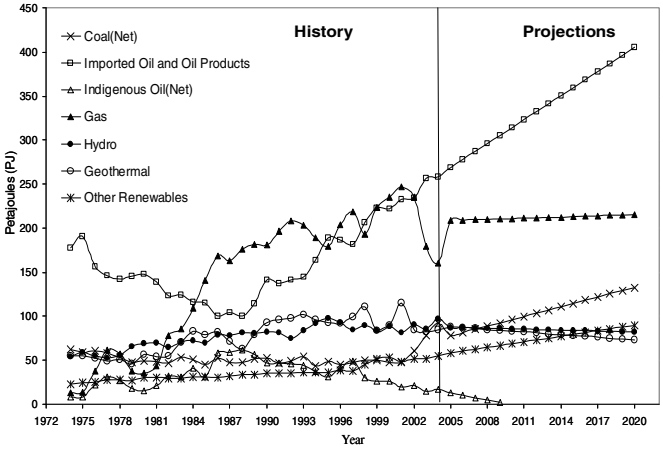

Fig. 1. New Zealand Primary Energy Supply by Fuel Forecast to 2020.

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.

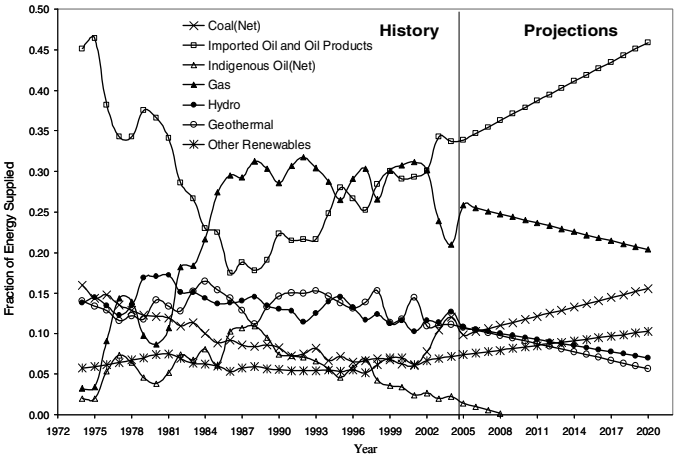

Fig. 2. New Zealand Primary Energy Supply by Fuel Market Share Forecast to 2020.

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.

B. 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. Fig. 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.

The market shares of energy consumed by fuel are shown in Fig. 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.

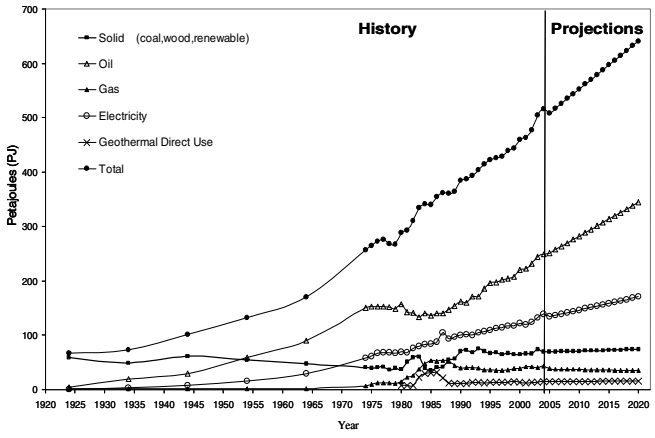

Fig. 3. New Zealand Energy Consumption by Fuel Forecast from 2004 to 2020.

The significant increase in gas consumption and market share was due to the discovery of the major Maui offshore field in 1969 and 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 [6] predicts that gas will run out by 2011 at today's consumption.

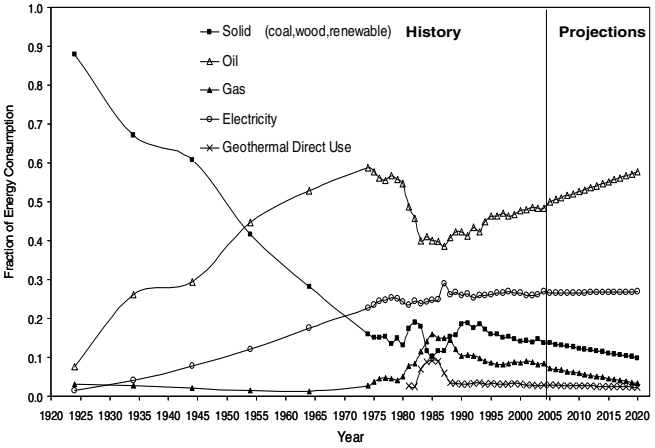

Fig. 4. New Zealand Primary Energy Consumption by Fuel Market Share Forecast to 2020.

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 [7]. The overestimate would give slightly higher market shares for the other fuels.

C. Energy Consumption 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.

Fig. 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 Fig. 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 Fig. 4.

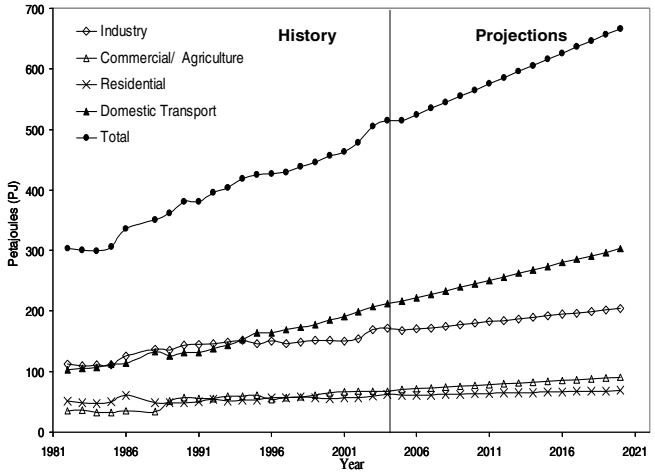

Fig. 5. New Zealand Energy Consumption by Sector Forecast to 2020.

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.

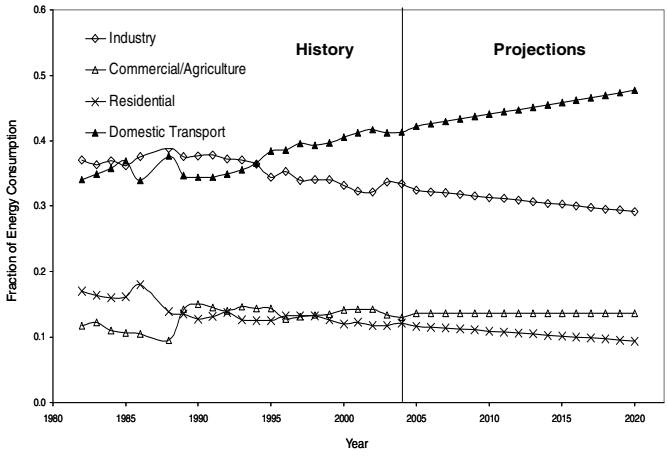

Fig. 6. New Zealand Energy Consumption by Sector Market Share Forecast to 2020.

D. Carbon Emission from Electricity by Fuel

New Zealand's electricity is generated from the following primary energy; Hydro, Geothermal, Oil, Coal and Gas, Wind. Biogas, wood and waste heat are also used as well, but on a very small scale. The net electricity generation by fuel data was collected from MED initially given in GWh. Data for geothermal, coal and gas include generation from cogeneration plants. Hydro, geothermal and coal are the base load power plants where gas and oil are the peak power plants which are run when the demand is high. Fig. 7 shows a mirror image between hydro and gas, where gas is the used to meet the demands in the dry years. Coal has tripled from 6 PJ in 2002 to 19 PJ in 2006. Negative generation by oil-fired plants implies a net import into the station to maintain station viability and system voltage stability. The total electricity generated has increased linearly and doubled from 75 PJ in 1974 to 155 PJ in 2006.

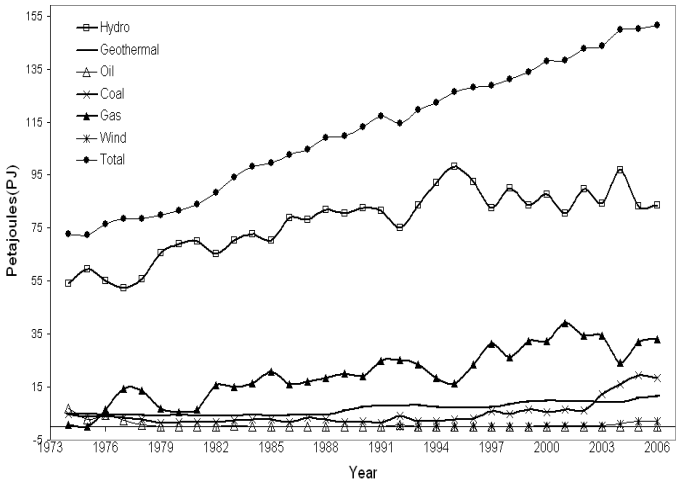

Fig. 7. New Zealand Net Electricity Generation by Fuel Type.

Fig. 8. shows the market share for the net electricity generation by fuel. Hydro generation contributed to 80% of the market share in the 1970s but has been decreasing steadily to now only 55% in 2006. Coal has increased by 10% since 2004. Gas has taken up approximately 20% of the market share.

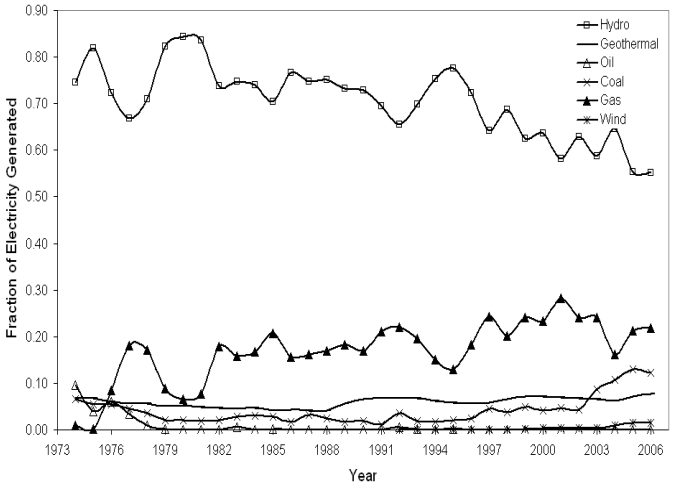

Fig. 8. New Zealand Net Electricity Generation by Fuel Market Share.

The heat value is the actual amount of fuel inputted into the system to produce electricity, shown in Fig. 9. The shapes of the curves for each fuel type is nearly identical to Fig. 7, but with higher values in the y-axis scale. Knowing the input and output for each electricity generation fuel, the thermal efficiency of each fuel type is calculated by dividing the net electricity output by the fuel input and shown in Fig. 10.

Hydro and wind show nearly 100% efficiency, with coal and gas around 50% and geothermal the lowest, with 10-15% efficiency.

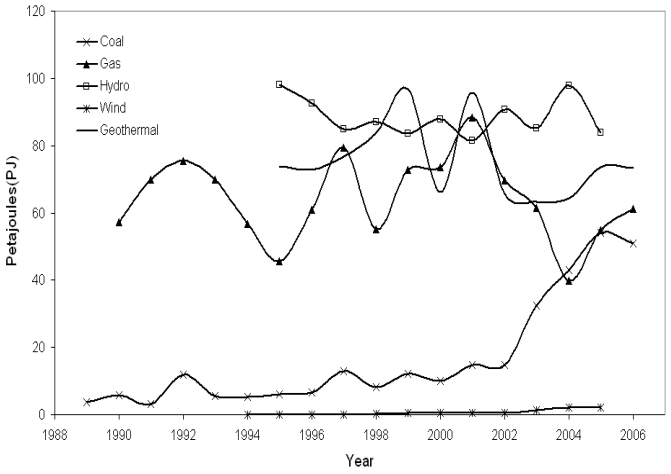

Fig. 9. New Zealand Electricity Generation Heat Value by Fuel.

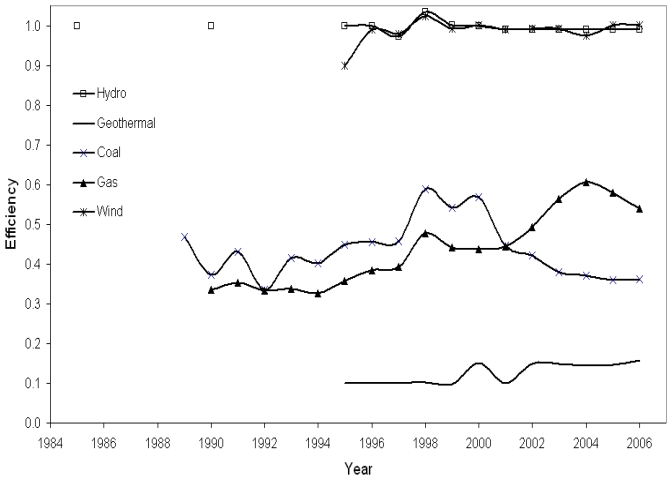

Fig. 10. New Zealand Electricity Generation Efficiency by Fuel.

The heat value for electricity generation's market share is shown in Fig.11. Coal has had a significant increase in market share of 15% in four years since 2002. Coal substituted gas in 2004. This is expected as we saw in Section A, the run-down of Maui gas meant coal is required as a replacement. Hydro and geothermal have a market share around 30-35%, and show a slight decline trend. Wind generation plays a very minor role of 1% in electricity generation due to its availability.

Conversion factors for PJ and kWh to carbon equivalent kg are shown below [8]:

Coal: $1kJ=88x10^{-6}kg$

Gas: $1kJ=51x10^{-6}kg$

Hydro and Wind: $1kWh=9x10^{-3}kg$

Factors which effect the CO_2 emissions from electricity generation throughout these periods are the increase demand for electricity, the available type of fuel or energy source used for generation, and the thermal efficiencies of the plants.

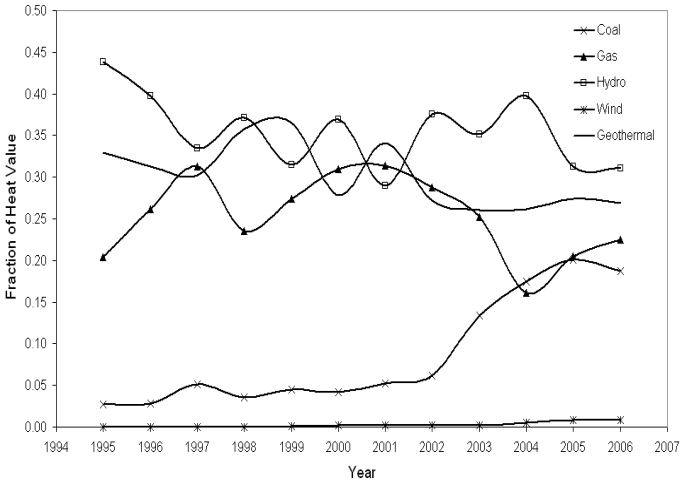

Fig. 11. New Zealand Electricity Generation Heat Value by Fuel Market Share.

Coal produces approximately 70% more CO_2 than gas. Fig.12 shows the CO_2 emission in ktonnes by fuel type. Conversion factors for geothermal were not available, so it is not being presented here. Coal electricity generation has increased from 1000 ktonnes in 2002 to 4700 ktonnes in 2006, surpassing the CO_2 emitted by gas generations. Hydro generation emits CO_2 at a steady rate of around 230 ktonnes. Wind generation has increased from 0.01 ktonnes in 1995 to 5.55 ktonnes in 2006.

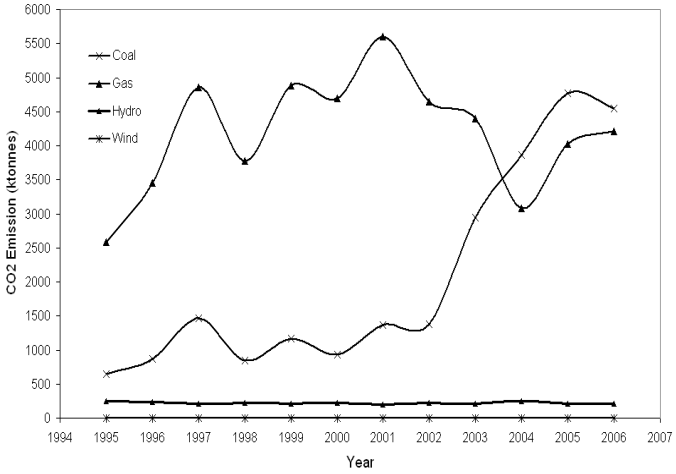

Fig. 12. New Zealand Carbon Emission from Each Electricity Generation.

The CO_2 emission from electricity generation market share is shown in Fig.13. Gas has contributes to 80% of the total CO_2 emissions up till 2002 and has dropped to 45% in two years. Coal has preformed the exact opposite of gas and has increased from 20% to 50% which makes up the loss from gas generations. Hydro has dropped from 7% to 2% since 1995 to 2006. Coal has being the replacement for gas after the depletion of Maui gas field, despite the concerns of CO_2 emissions from coal-fired power plants.

The reason for New Zealand's CO_2 emission change is due weather for hydro and the depletion of gas. The increasing demand in electricity has enhanced the use of coal in

electricity generation and increased the CO_2 emission by 5 times in just four years.

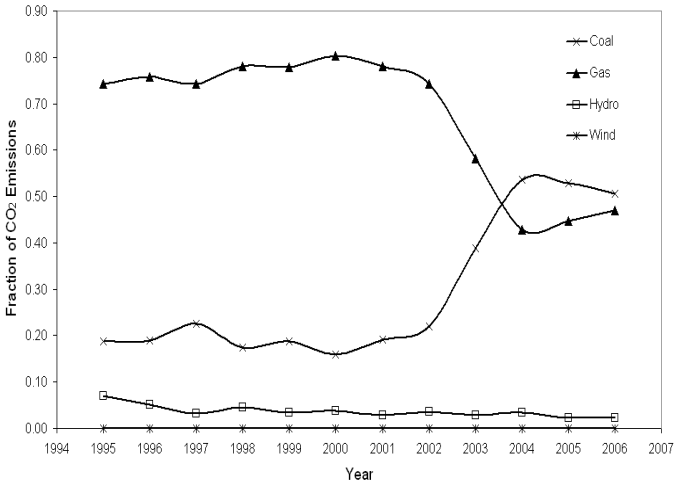

Fig. 13. New Zealand Carbon Emission from Each Electricity Generation Market Share.

V. 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 [9]. This is shown in Fig. 14 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.

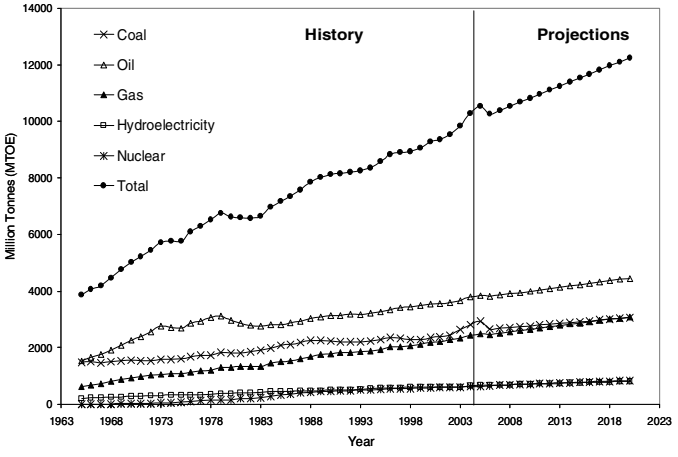

Fig. 14. World Energy Consumption by Fuel Forecast to 2020.

Fig. 15 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.

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.

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.

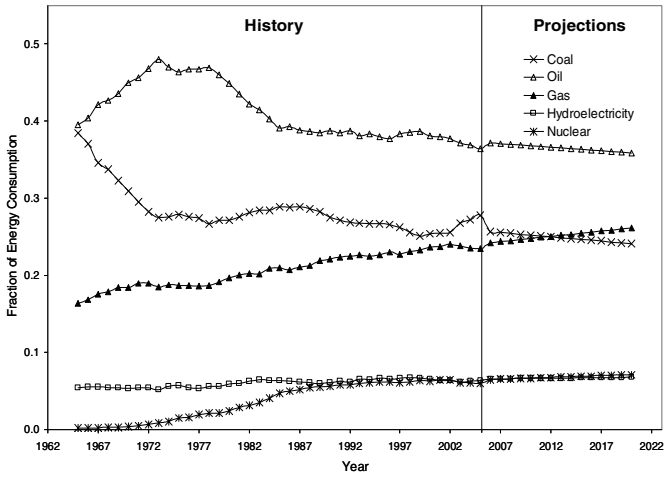

Fig. 15. World Energy Consumption by Fuel Market Share Forecast to 2020.

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 [10]. At this stage New Zealand does not have a nuclear future.

VI. 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 [11]. 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 [11]. However, given the history of the lack of oil discoveries in New Zealand, we are likely to remain a significant importer of oil [12].

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 [13].

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 [14]. 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) [15].

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 [10]. Overall, it may yet be a relatively sustainable and plausible option for further base-load capacity in New Zealand.

VII. 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.

The CO_2 emission market share from electricity generation for coal has increased from 20% to 50% in 2002 to 2006. The future use of coal is constrained by the need to limit carbon dioxide emissions. With the other fuels and sources for electricity generation reaching saturation, nuclear power may yet be a relatively sustainable and plausible option for further base-load capacity in New Zealand.

Gas has contributes to 80% of the total CO_2 emissions up till 2002 and has dropped to 45% in two years. Coal has preformed the exact opposite of gas and has increased from 20% to 50%

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.

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IX. Biographies

Ching-Yi Emily Hung completed her BE (Hons) in electrical engineering from the University of Canterbury in 2006 and is continuing her studies towards a ME in electrical engineering. She is aiming to complete her thesis by the end of 2008. Her current research topic is National Energy System Modelling and Forecasting.

Pat Bodger completed his BE (Hons) and PhD degrees in electrical engineering from the University of Canterbury in 1972 and 1977 respectively. From 1977-1981 he worked for the Electricity Division, Ministry of Energy, New Zealand. He was appointed as Lecturer in the Department of Electrical Engineering, University of Canterbury in 1982. He is Professor of Electric Power Engineering and also Director of the Electric Power Engineering Centre.