CO_2 Emission Market Share and Electricity Generation Patterns in New Zealand

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EEA Conference & Exhibition 2009, 19-20 June 2009, Christchurch

1. Introduction

Energy is the most important entity which allows a society to function. Energy use underpins every physical action taken and every item that is made. One particular energy form, electricity, has reached immense dimensions in its use, due to its versatility in generation, transmission, distribution and utilization. Electricity as a secondary energy form has utilized increasingly scarce primary energy fossil fuels which contribute to the greenhouse effect and global warming. 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 energy sector. Energy patterns during the deregulation period are of interest to see how people and politics have controlled and influenced the energy market.

New Zealand total net electricity is generated from the fuel types: hydro, gas, geothermal, coal, wind, wood, biogas, waste heat and oil, in descending order. Electricity generation has long been identified as one of the major sources of air pollutants (e.g. SO_2, CO_2, NO_x) into the atmosphere. The total electricity consumption pattern can reflect the results of energy savings and improved fuel efficiency standards.

This paper firstly illustrates how each fuel has substituted one another and their market shares in electricity generation. The conversion factors for the amount of kg of CO_2 emitted for each petajoule (PJ) used is calculated. By studying how much CO_2 is emitted from each source of fossil fuel, and showing their market shares, it will show whether New Zealand is heading towards the commitment with the Kyoto protocol's target of reducing CO_2 emissions back to the level in 1990 [1].

2. Net Electricity Generation by Fuel

Figure 1 shows net electricity generated from each fuel from 1974 to 2006. Hydro use is the main source for electricity generation in New Zealand. The variations in patterns of hydro and gas use are almost a mirror image of each other. This reflects dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations. Negative generation by oil fired plants implies a net import into the station to maintain station viability and system voltage stability [2], this occurred in 1980, 1981, 1989, and 1997. Coal surpassed geothermal in 2003. The total net electricity generation has increased linearly with small variations about this trend. The total electricity generation has doubled in the last 33 years, from 19868 GWh in 1974 to 41396 GWh in 2006.

Figure 2 shows net electricity generated by fuel market share from 1974 to 2006. Hydro's market share declined from a high of 86% in 1980 to 56% in 2006. Gas's market share lies within a 20% margin. Coal's market share increased from 4.5% in 2002 to 12.4% in 2006. Geothermal has a fairly constant market share of around 7%. Wind's market share increased from 0.002% in 1992 to 1.5% in 2006. Due to the impacts of the 1973 and 1979 oil crises, oil's market share dropped from 9.8% in 1974 to 0.05% in 2006. The increase in market share of other renewables to date is limited and is unlikely to be sufficient to cover New Zealand's energy demand in the near future. The rate of growth in fossil fuel use overwrites the small increases in renewable use in electricity generation. It will take more time before New Zealand can commit to 90% renewable electricity by 2025 [1].

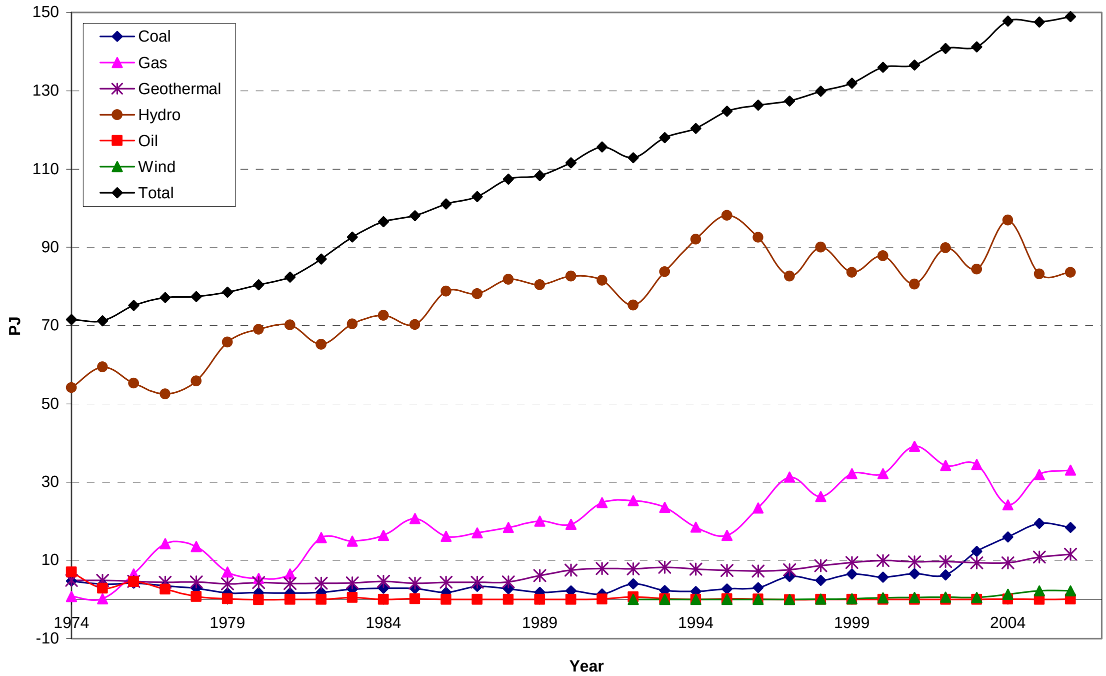

Figure 1. Net Electricity Generation by Fuel

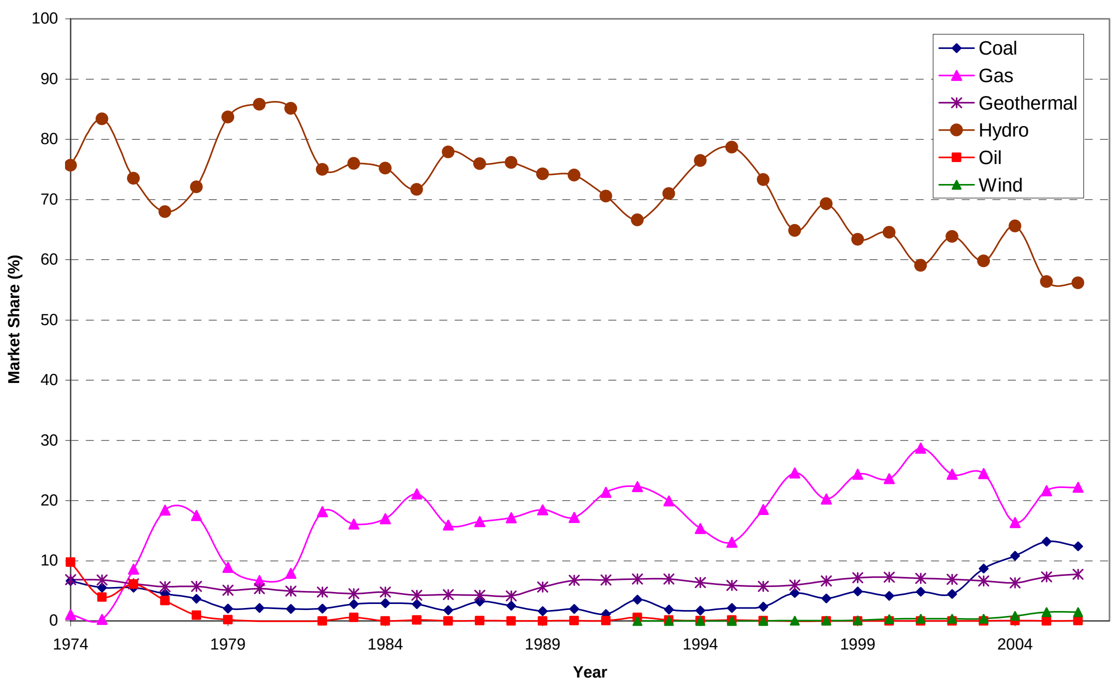

Figure 2. Net Electricity Generation by Fuel Market Share

3. Efficiency in Electricity Generation by Fuel

Heating value is the amount of heat released during the combustion of a specified amount of fuel. The efficiency is the ratio of the net to heat values of each fuel used from 1995 to 2006, as shown in Figure 3. The heat values for oil in electricity generation were not available, so the efficiency of oil in electricity generation could not be determined. This paper uses 38% [4] as the efficiency for estimating the heat value from net value. Wind and hydro have nearly 100% efficiency, and gas has about 40%. Coal's efficiency peaked at 54% in 2000 and dropped to 36% in 2006. Geothermal has the lowest efficiency of 15%.

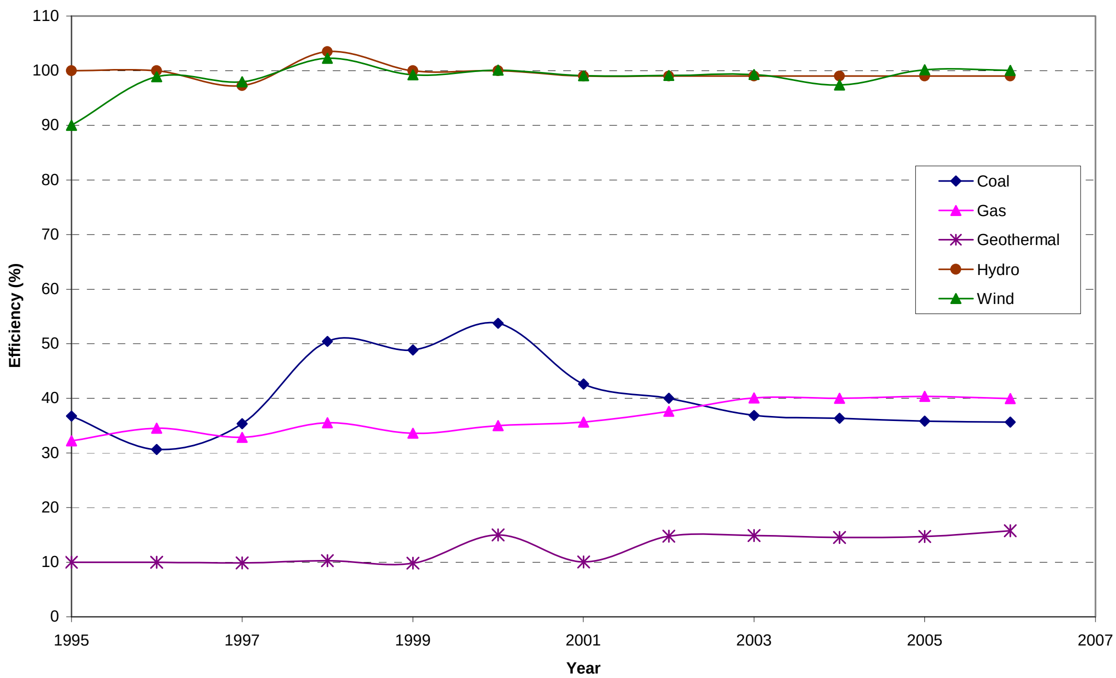

Figure 3. Efficiency of Electricity Generation by Fuel

4. CO_2 Conversion Factors

The carbon in fossil fuels is converted to CO_2 when it is completely combusted. CO_2 is a natural end product of fossil fuel combustion. The overall reaction is the oxidation of carbon to CO_2, here air is the usual source of oxygen [3]:

$$C + O_2 \rightarrow CO_2$$

The atomic weight of carbon is 12 and for oxygen it is 16, so the molecular weight of CO_2 is

$$12 + 2(16) = 44$$

Hence 12kg of C produces 44kg of CO_2.

4.1 Coal

This paper assumes the use of bituminous coal, which has 67% carbon by weight with a heating value of 28,400kJ/kg. Hence in 1kg of coal there is 0.67kg of C. This produces [3]

$$(CO_2)_{Coal} = (0.67kgC)(\frac{44kgCO_2}{12kgC}) = 2.46\,\text{kg CO}_2\text{/ kg Coal burned}$$

The amount of CO_2 per unit of fuel energy is

$$(CO_2)_{Coal} = (\frac{2.46kgCO_2 / kgCoal}{28{,}400kJ / kgCoal}) = 86.5x10^{-6}\ \text{kg CO}_2\text{/ kJ of fuel energy}$$

$$= 86.5\,\text{kt CO}_2\text{/PJ} \qquad (1)$$

The CO_2 emission factors published for bituminous coal in New Zealand is 88.8 kt CO_2/PJ [5], which is very close to the calculated 86.5 kt CO_2/PJ [3]. This paper uses the 86.5 5 kt CO_2/PJ value.

4.2 Oil

This paper assumes the use of distillate oil, which has 87% carbon by weight with a heating value of 45,200kJ/kg [3]. Hence in 1kg of oil there is 0.87kg of C. This produces

$$(CO_2)_{Oil} = (0.87kgC)(\frac{44kgCO_2}{12kgC}) = 3.19\,\text{kg CO}_2\text{/ kg Oil burned}$$

The amount of CO_2 per unit of fuel energy is

$$(CO_2)_{Oil} = (\frac{3.19kgCO_2 / kgOil}{45{,}200kJ / kgOil}) = 70.6x10^{-6}\ \text{kg CO}_2\text{/ kJ of fuel energy}$$

$$= 70.6\,\text{kt CO}_2\text{/PJ} \qquad (2)$$

The CO_2 emission factors published for distillate oil in New Zealand is 72 kt CO_2/PJ [5], which is very close to the calculated 70.6 kt CO_2/PJ [3]. This paper uses the 70.6 kt CO_2/PJ value.

4.3 Gas

Natural gas has 74.1% carbon by weight with a heating value of 54,400kJ/kg. Hence in 1kg of gas there is 0.74kg of C and this produces [3]

$$(CO_2)_{Gas} = (0.74kgC)(\frac{44kgCO_2}{12kgC}) = 2.71\,\text{kg CO}_2\text{/ kg oil burned}$$

The amount of CO_2 per unit of fuel energy is

$$(CO_2)_{Gas} = (\frac{2.71 kgCO_2 / kgGas}{54{,}400 kJ / kgGas}) = 49.9x10^{-6} \text{ kg } CO_2\text{/ kJ of fuel energy}$$

$$= 49.9 \text{ kt } CO_2\text{/PJ} \quad (3)$$

The CO_2 emission factors published for distillate oil in New Zealand is 51.9-53.1 kt CO_2/PJ [5], which is very close to the calculated 49.9 kt CO_2/PJ [3]. This paper uses the 49.9 kt CO_2/PJ value.

4.4 Renewables

Non-fossil fuel based technologies such as wind, photovoltaics (PV), hydro, biomass, wave/tidal and nuclear are often referred to as “low carbon” or “carbon neutral” because they do not emit CO_2 during their operation [6]. However, they are not “carbon free” as CO_2 emissions do arise in other phases of their life cycle such as during extraction, construction, maintenance and decommissioning [6]. Their evaluation is known as life cycle analysis (LCA) [7]. LCA is out of the scope of this paper. This paper focuses on the CO_2 emitted during the process of transforming the primary energy into electricity generation. Hence, the conversion factors used for hydro, wind and geothermal for New Zealand are 0 kg/ CO_2 [6].

5. CO_2 Emission from Electricity Generation

Net values were available from 1974 to 2006 and heat values only from 1995 to 2006, so the heat values from 1974 to 1994 were estimated by dividing the net values with the fuel efficiency, and then using Equations 1-3 to convert into CO_2 emissions. Figure 4 shows the real and estimated CO_2 emissions from coal, oil and gas. The difference between the real and estimated values for coal, gas and total is very small from 1995 to 2006. So the estimated CO_2 emission value from oil generation should not be too far from the real values.

CO_2 emissions from electricity generation in New Zealand have nearly tripled in the last 12 years, from 3235 kt in 1995 to 8764 kt in 2006. Up until 2003, gas use in electricity generation emitted more CO_2 than coal and oil use. The general public targets coal and oil as being the main source of CO_2 emissions, however burning gas produces significant amounts of CO_2. Despite the environmental concerns of global warming and the Kyoto protocol, there has been a large increase in total CO_2 emissions. This increase has seen a replacement of gas by coal in order to continue to meet the electricity demand of the nation.

The market share of CO_2 emitted in electricity generation is shown in Figure 5, made up by coal, oil and gas use. Oil and coal both had around 50% of the market in 1974. Gas substituted both coal and oil in 1977 and from 1995 to 2002, gas had an 80% market share in emissions, while coal was around 20%. Oil’s market share was insignificant after 1980. The depletion of the Maui gas field made gas’s market share declined to 44% in 2004. It then increased to 48% in 2006, due to the findings of smaller gas fields. On the other hand, coal increased its market share of emissions from 23% in 2002 to 52% in 2006.

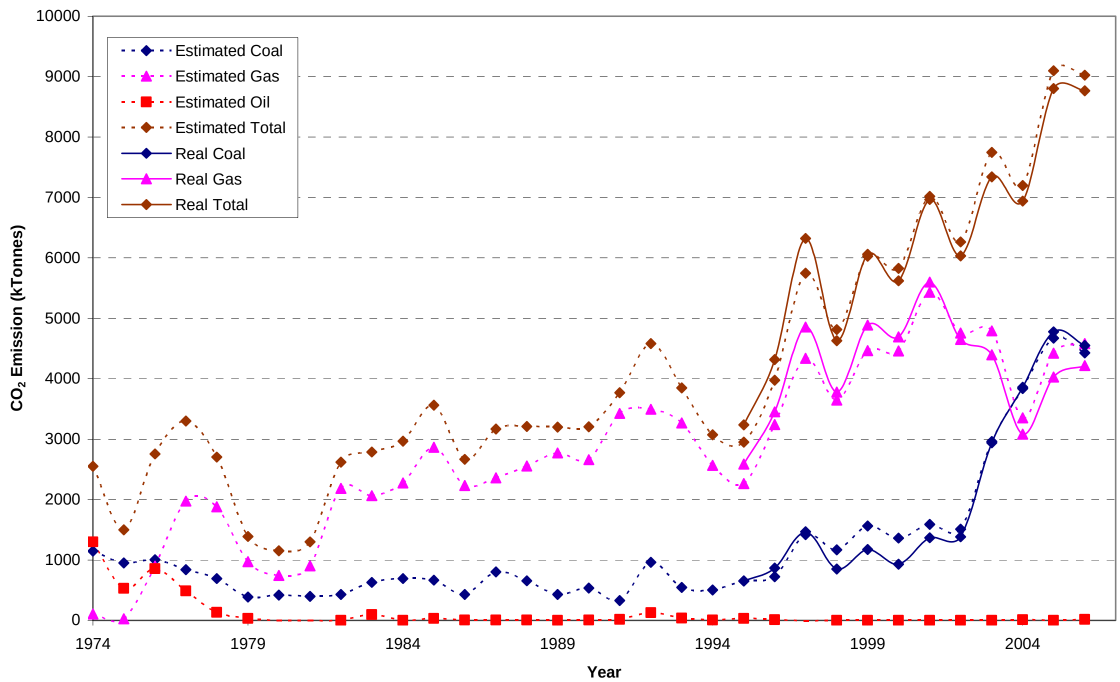

Figure 4. CO_2 Emission from Electricity Generation by Fuel

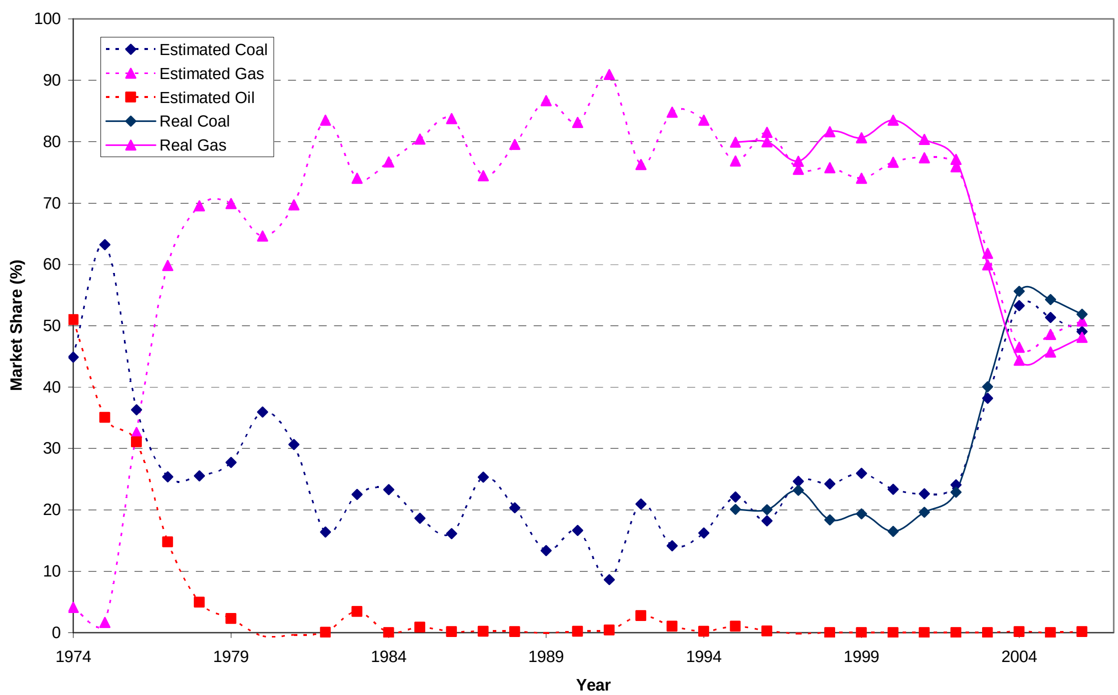

Figure 5. CO_2 Emission from Electricity Generation by Fuel Market Share

6. Conclusion

New Zealand total net electricity is generated from the fuel types: hydro, gas, geothermal, coal, wind, wood, biogas, waste heat and oil, in descending order. Wind overtook wood in 2005. Net values were available from 1974 to 2006 and heat values from 1995 to 2006. Heating value is the amount of heat released during the combustion of a specified amount of fuel. The heat values from 1974 to 1995 were estimated by dividing the net values with the fuel efficiency, and then converted into CO_2 emissions.

The total net electricity generation has doubled in the last 33 years. Hydro use is the main source for electricity generation in New Zealand. Its market share has declined from a high of 86% in 1980 to 56% in 2006. Gas's market share lies within the 20% margin. Coal's market share has increased from 4.5% in 2002 to 12.4% in 2006. Geothermal has a fairly constant market share of around 7%. Wind's market share has increased from 0.002% in 1992 to 1.5% in 2006. Oil has dropped from 9.8% in 1974 to 0.05% in 2006.

The heat value for oil in electricity generation was not available. However, the efficiency of oil fired plant's weighted average is 38% [4]. Wind and hydro have nearly 100% efficiency, gas has 40%, coal's efficiency peaked at 54% in 2000 and dropped to 36% in 2006, and geothermal has the lowest efficiency of 15%.

Since the paper focuses on the CO_2 emitted during the process of transforming the primary energy into electricity generation, the conversion factors used for hydro, wind and geothermal for New Zealand are 0 kg/ CO_2. For each PJ used in electricity generation, coal produces 86.5 kt/ CO_2, oil produces 70.6 kt/ CO_2, and gas produces 49.9 kt/ CO_2.

The total CO_2 emission from electricity generation has nearly tripled in the last 12 years. This increase has seemed a replacement of gas by coal in order to continue to meet the electricity demand of the nation. Up till 2003, gas emitted more carbon dioxide than coal use and oil use. Oil and coal both made around 50% of the market in 1974. Gas substituted both coal and oil in 1977 and from 1995 to 2002, gas had a 80% market share in emissions, while coal was around 20%. Oil's market share has been insignificant after 1980. Gas's market share was 48% in 2006. Coal has increased its market share of emissions from 23% in 2002 to 52% in 2006.

New Zealand's deregulation and discovery of Maui gas field and coal reserves lead to nuclear power plans being abandoned. Now that the Maui gas field is being depleted, and that the newly discovered gas fields will not be able to replace Maui in the long run, a resurgence of coal has been seen in electricity generation. The future use of coal is constrained by the need to limit CO_2 emissions, or pay substantially for them according to the Kyoto protocol. With New Zealand being dependent on the world supply of oil, the depletion of the Maui gas field, the low market share for renewable energy and rising concerns about pollution, the green house effects and global warming, nuclear power is considered an option in New Zealand.

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. The rate of growth in fossil fuel use overwrites the small increases in renewable use in electricity generation. It will take some time before New Zealand can reach its commitment to 90% renewable electricity [1].

References

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