Nation Energy System Patterns and Forecasting

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ABSTRACT

This thesis investigates the patterns of each type of energy consumption for fourteen countries, to study the link between energy consumption, economics and population. It was found that for all the countries studied, there is a decrease in energy consumption relative to economic growth. This shows that the world has become less energy based, and is more efficient in using energy to produce economic wealth.

The carbon dioxide (CO_2) emissions for each fossil fuel type used for electricity generation in New Zealand: coal, gas and oil was also calculated. Gas is the main contributor of CO_2 by electricity generation for New Zealand. New Zealand's CO_2 emissions from electricity generation have nearly tripled in the last 12 years. Despite the environmental concerns of global warming and the Kyoto protocol, there has been a large increase in total CO_2 emitted. This increase has seen a replacement of gas by coal in order to continue to meet the electricity demand of the nation.

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

Of the renewable energy supply fuels, both hydro and geothermal have been in decline, from before deregulation. This trend will continue in the future if left to market forces. Although renewable energy may be a solution to New Zealand's energy supply, the increase in market share of other renewable energies to date is limited. They are unlikely to be sufficient to cover New Zealand's energy demand in the near future. With New Zealand being dependent on the world supply of oil, the expected 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.

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LIST OF PUBLICATIONS

The following papers have been presented or accepted for presentation during the course of the research described in this thesis:

1. C.-Y Hung and P.S. Bodger, The Substitution of Different Forms in New Zealand's Energy Market, Proceedings of the Australasian Universities Power Engineering Conference (AUPEC) 2007, Perth, 9-12 December 2007.

2. C.-Y Hung and P.S. Bodger, Market Influence on Energy Use and Carbon Dioxide Emission Patterns, Proceedings of the IEEE PES Power Systems Conference & Exhibition (PSCE) 2009, Seattle, 15-18 March 2009.

3. C.-Y Hung and P.S. Bodger, CO_2 Emission Market Share and Electricity Generation Patterns in New Zealand, Electricity Engineers' Association (EEA) Conference & Exhibition 2009, Christchurch, 19-20 June 2009.

LIST OF ABBREVIATIONS

CO_2	-	Carbon Dioxide
EI	-	Energy Intensity
EIA	-	Energy Information Administration
EIC	-	Energy Intensity Curves
EIF	-	Energy Intensity Factors
GDP	-	Gross Domestic Product
GJ	-	Gigajoules, 10^9 Joules
GWe	-	Gigawatt Electric Power, 10^9 Electric Power
GWh	-	Gigawatt Hour, 10^9 Watt Hours
HHV	-	Higher Heat Value
kJ	-	Kilojoules, 10^3 Joules
kt	-	Kilotonnes, 10^3 tonnes, 10^6 kg
LCA	-	Life Cycle Analysis
LHV	-	Lower Heat Value
LNG	-	Liquefied Natural Gas
MED	-	Ministry of Economic Development
MER	-	Market Exchange Rate
MJ	-	Megajoules, 10^6 Joules
MOX	-	Mixed Oxide
MTOE	-	Million Tonnes of Oil Equivalent, 41.89 PJ
MW	-	Megawatt, 10^6 Watt
NZD	-	New Zealand Dollar

OECD	-	Organization for Economic Cooperation and Development
PJ	-	Petajoules, 10^{15} Joules
PPP	-	Purchasing Power Parity
PV	-	Photovoltaics
TWh	-	Terawatt Hour, Billion Kilowatt hours, 10^{12} Watt Hours
USD or US$	-	United States Dollar
WEO	-	World Economic Outlook

KEYS FOR COUNTRIES

– △ –	Australia
– ⧫ –	Brazil
– □ –	Canada
– ▲ –	China
– × –	France
– ○ –	Germany
· – · –	India
– + –	Indonesia
– ◊ –	Japan
– ∗ –	New Zealand
– ▽ –	Russia
– · –	Taiwan
– – –	United Kingdom
——	United States

KEYS FOR FUEL TYPES

– △ –	Coal
– ⧫ –	Electricity
– – –	Gas
– □ –	Geothermal
– ◊ –	Hydro
– × –	Imported Oil
– ∘ –	Indigenous Oil
– + –	Nuclear
– ∗ –	Oil
· – · –	Other Renewable (Wind, Biogas, Waste and Wood, Solar)
– ▲ –	Solid (Coal, Wood, Renewable Fuel)
– • –	Total
– ■ –	Wind

Estimated Values

··· △ ···	Coal
·········	Gas
··· ∗ ···	Oil
··· • ···	Total

Net Value

– ∘ –	Net Electricity Generation

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Chapter 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. Commercial energy is clearly tied to population growth and to overall economic performance [1] [2]. During the period of exponential growth in energy consumption in the 1960s and early 1970s, the rate of energy growth and GDP growth was highly correlated [3]. 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. This provided challenges and opportunities for existing and new energy sector participants [4]. 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 an influence on energy market patterns [5].

1.1 THESIS OBJECTIVE

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 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) [6]. Secondary energy is derived from any of the primary energies, such as electricity from coal, oil and natural gas, and gas from coal [5]. Secondary energy is energy consumed. Primary and secondary energies are just different technologies competing for a market and should behave accordingly [7].

The history of energy substitutions for the world were been studied [8] and it was found that these transitions are remarkably in order. Every given technology undergoes three distinct substitution phases : growth, saturation and decline. It is assumed that one and only one technology is in the saturation phase at any given time [9]. The substitution process is very slow, with every new source taking about a century to penetrate half of the market share. Normally it is higher quality fuels substituting lower quality fuels [10]. Despite many possible perturbations, the penetration rates remain constant over long periods of time [1]. As coal displaced wood and oil displaced coal, so will economic and technical imperatives ensure that natural gas, nuclear, and solar energies will displace oil [1].

New Zealand's energy supply and consumption data is usually shown as a pie chart for a particular year or shown as a stacked area graph [6]. This does not provide an insight to the interplay of the various forms of energy that make up the market which supplies the economy. Data for the primary energy substitution market for New Zealand studied during 1900 to 1980 [9] [11], shows that the sequence of substitution is similar to that of the world primary energy data: wood-coal-oil-gas, with the addition of electricity between oil and gas. The same sequence of energy substitution usage can also be observed using secondary energy consumptions. However, by considering primary energy forms, more direct physical explanation of the patterns was more possible. This research aims to extend the work already done by [9] [11] [12] [13] and include historical data from 1980 onwards for primary energy supplied and energy consumed by fuel, and observe the changes in New Zealand's energy market substitutions patterns after 1980 and see if the predictions made back then for the primary energy market for New Zealand from 1980 to 2006 [9] [12] [14] were correct.

The observed patterns in New Zealand were then compared to other countries. The different forms of data compared includes: energy supplied and energy consumed by fuel, Gross Domestic Product (GDP), and population. Various combinations of this data are formed and their patterns over time are analyzed to ascertain how national societies have changed their energy use and to predict where they are likely to go in the future.

Relationships between the patterns of electricity consumption, GDP and population were previously studied for 12 countries, including New Zealand [15]. The link between economic growth and electricity consumption is stronger in developing countries than those for industrialized countries [16]. The GDP data for showing the total primary energy intensity, used the Market Exchange Rates (MER) method [17]. The thesis will firstly compare the MER and Purchasing Power Parity (PPP) method for converting GDP between different countries.

This research aims to add to current literature on different fuel consumptions, GDP and population by proposing and comparing various fuels for the selected countries. Countries chosen will be following the same methodology as [15] in order to compare and justify the different findings when using MER and PPP for GDP data. The countries are chosen based on their high rankings in different categories, namely energy consumption, industrial production, and population. The proposed fuel types are: coal, oil, natural gas, hydro, geothermal, wind, nuclear and total electricity.

Energy consumption, GDP and population can be combined to show the energy intensity (EI), energy intensity curves (EIC) and energy intensity factors (EIF) [18] [19]. It can reflect changes in energy consumption over time in the production of an economy, and also measure the energy efficiency of a nation's economy [15]. Energy efficiency refers to using less energy to produce the same amount of services or getting more service from the same energy amount [10]. It is an important component in New Zealand's environmental management programme. EI, EIC and EIF for each fuel will be calculated, since there is relatively little known about how New Zealand's energy efficiency has changed and how it compares to other countries [10]. This value varies widely between countries, depending on their level of industrialization, the mix of services and manufacturing in their economies, and the attention they pay to energy efficiency. Since the 1980s, the relationship between GDP growth and growth in energy consumption has not been one-to-one. The increase in energy efficiency has enabled economic growth over the past two decades without concomitant growth in energy consumption [3].

The mix of primary fuels used to generate electricity has changed a great deal over the past two decades on a worldwide scale [20]. New Zealand's society is small compared to the world, but there are strong similarities in this country's patterns to those of the global scale [14]. However, there were also some significant historical differences, namely that oil's primary supply market share peaked in 1972, well before the rest of the world; hydro/geothermal electricity is a significant energy source, but doesn't capture even 1% of the world's resources, and natural gas was a late starter in the field [14]. Availability and accessability explain the early peak, in 1972, of oil penetration in the New Zealand market, compared to the world peak after 1980 [21].

Coal has continued to be the fuel most widely used for electricity generation around the world, although generation from nuclear power increased rapidly from the 1970s through to the mid 1980s, and natural gas fired generation grew rapidly from the 1980s to 1990s. The use of oil for electricity generation has been declining since the mid 1970s, when the oil embargo by Arab producers in 1973 to 1974 and the Iranian Revolution in 1979, produced an oil price shock [20].

A long-term look at CO_2 emissions from fossil fuel combustion and their role in future global warming, was published in 1974, when few people were interested in such topics [1]. Energy consumption is directly related to the production of electricity, which 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. Another aim of this thesis is to illustrate how much CO_2 is emitted from each source of fossil fuel, and show their market shares in New Zealand. This 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 [22].

1.2 THESIS OUTLINE

Chapter 2 finds the top five countries with high rankings in four categories, namely electricity consumption, population, GDP and GDP per capita using both MER and PPP. The final fourteen countries found included nine industrialized countries: Australia, Canada, France, Germany, Japan, New Zealand, Taiwan, the United Kingdom and the United States. There are five developing countries: Brazil, China, India, Indonesia and Russia.

Chapter 3 discusses and compares the two methods of converting GDP between countries: MER and PPP. The final method chosen for this research was PPP.

Chapter 4 describes how to find and calculate the EI, EIC and EIF.

Chapter 5 initially compares the difference between higher and lower heating values (LHV) of various fuels. This thesis uses higher heating value (HHV).The chapter then illustrates how to calculate the CO_2 conversion factor for coal, oil, gas and other renewable energies.

Chapter 6 shows the relationship between coal consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity,

intensity curves, and intensity factors are studied. Heat values, net values, efficiency, and CO_2 emitted from coal use in electricity generation for New Zealand are shown.

Chapter 7 shows the relationship between oil consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Estimated heating values, net values, estimated CO_2 emitted from oil use in electricity generation for New Zealand are shown.

Chapter 8 shows the relationship between gas consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat values, net values, efficiency, and CO_2 emitted from gas use in electricity generation for New Zealand are shown.

Chapter 9 shows the relationship between hydroelectricity consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat values, net values and efficiency from hydro use in electricity generation for New Zealand are shown.

Chapter 10 shows the relationship between the consumption of other renewables (geothermal, solar, wind, and wood and waste electric power consumption), GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat values, net values and efficiency from geothermal and wind use in electricity generation for New Zealand are shown.

Chapter 11 shows the relationship between nuclear electric power consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied.

Chapter 12 shows the relationship between net electricity consumption, GDP and population of the selected countries. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Net values and CO_2 emitted from electricity generation for New Zealand are also shown.

Chapter 13 shows graphs of the primary energy supply, energy consumption by fuel and by sector, and their market shares and forecasts until 2020 for New Zealand and the world. A summary of all the EIC, EIF, net electricity generation and its market share from each fuel type are plotted on the same graph for comparison. CO_2 emissions from net electricity generation and its market share are also shown.

Chapter 14 gives an overall comparison of all fuels shown across the selected countries. This chapter also summarizes the major findings of each chapter.

Chapter 15 summarizes the main conclusions and findings of the research and recommends directions for future research and development in energy forecasting for any country.

Accompanied CD links all the raw data and conversion factors used to obtain all the graphs for this thesis. The trend lines are in colour which allows easier identification, and the reader can change the ranges to get a closer view of a particular line. Extra summary of energy by country is also included.

Chapter 2

SELECTION OF FOURTEEN COUNTRIES

The countries are chosen following the same methodology as [15] in order to compare and justify the different findings when using MER and PPP for the GDP data chosen based on the high rankings in different categories, namely energy consumption, industrial production, and population. Firstly, the five countries which consumed the highest amounts of electricity in 2004 were selected as shown in Table 2.1 [23]. They are the United States, China, Japan, Russia and India. Secondly, the five countries with the largest population in 2003 were selected and shown in Table 2.2 [24]. They are the China, India, the United States, Indonesia and Brazil in order of decreasing population. Some of these countries are the same as those on the electricity consumption list.

Table 2.1 Top Five Countries for Electricity Consumption

United States	3717 TWh
China	1927 TWh
Japan	906 TWh
Russia	804 TWh
India	588 TWh

Table 2.2 Top Five Countries by Population

China	1291.49 Million
India	1049.70 Million
United States	290.34 Million
Indonesia	234.89 Million
Brazil	182.03 Million

Finally, the five countries that account for the highest GDP and GDP per capita in 2003 using both PPP and MER were selected. These are shown in Table 2.3 [24] and Table 2.4 [25].

France, New Zealand and Taiwan were also included. France was included, as it ranked

Table 2.3 Top Five Countries for GDP in 2003

PPP	International$	MER	2000 US$
United States	10817.21 Billion	United States	10381.30 Billion
China	7392.20 Billion	Japan	4869.10 Billion
Japan	3549.52 Billion	Germany	1887.56 Billion
India	3003.97 Billion	United Kingdom	1530.32 Billion
Germany	2339.95 Billion	China	1371.00 Billion

Table 2.4 Top Five Countries for GDP per Capita in 2003

PPP	International$	MER	2000 US$
United States	37.17 Thousand	Japan	38.14 Thousand
Canada	31.35 Thousand	United States	35.70 Thousand
Australia	28.51 Thousand	United Kingdom	25.83 Thousand
Germany	28.36 Thousand	Canada	23.96 Thousand
Japan	27.81 Thousand	Germany	22.89 Thousand

sixth for GDP(PPP), GDP (MER) and GDP per Capita (MER). New Zealand's geographic isolation makes it important to study the country's use of its renewable energy and imported resources. During the 1970s other factors such as the oil crises undermined the viability of the New Zealand economy; which for periods before 1973 had achieved levels of living standards exceeding both Australia and Western Europe [26]. Australia is the closest neighbour to New Zealand. Australia is rich in natural resources with significant petroleum, natural gas and coal reserves. Australia's energy consumption is dominated by coal, which fuels most of the country's power generation [27].

Taiwan was also included as it has experienced rapid economic growth and industrialization during the latter half of the twentieth century. It's geographic isolation is similar to that of New Zealand. Taiwan's GDP (PPP) per capita is equal to the average of the EU Countries [25]. Taiwan represents a relatively small industrialized economy. The author was born in Taiwan.

The fourteen countries selected can also be divided into two groups, industrialized and developing [28]. The nine industrialized countries are Australia, Canada, France, Germany, Japan, New Zealand, Taiwan, the United Kingdom and the United States. The five developing countries are Brazil, China, India, Indonesia and Russia. Relationships between the patterns of energy consumption, GDP and population are studied over the period 1980-2004. The data for Russia prior to 1992 was not used due to inconsistencies observed while trying to incorporate the data of the former USSR from 1980 to 1991. The data for Germany prior to 1991 was not used, as the reunification of West and East Germany took place in 1990.

Chapter 3

GROSS DOMESTIC PRODUCT (GDP)

Estimates of global economic growth are key factors of global energy forecasts. There are two techniques for converting and comparing the GDP between countries; MER and PPP. The relative ranking of countries may differ dramatically between the two approaches. Definitions and outcomes of these techniques are discussed in this chapter.

3.1 MARKET EXCHANGE RATES (MER)

GDP is one of the ways of determining the size of a region's economy. A country's GDP is defined as the market value of all goods and services produced within a country in a given period of time.

A MER between two currencies will fluctuate over time. Each country's national currency is usually presented by the amount it is equal to one United States dollar (USD/US$), which is the most widely traded currency in the world. The MER method converts the value of goods and services using global currency exchange rates. A country's GDP can either be expressed as Nominal GDP or Real GDP. The Nominal GDP measures the value of all goods and services produced, expressed in current prices. On the other hand, Real GDP is expressed in the price of some base year.

The data which [15] used for GDP per capita from the Energy Information Administration (EIA) [23] is no longer available. Due to a lack of resources, EIA no longer provides its own estimates of GDP using market exchange rates. The most recent GDP data was from the International Energy Annual 2003 [24].

The real GDP data [24], expressed in billions of USD, are at year 2000 market prices. The population data used throughout this research, was obtained from the EIA [24]. Figure 3.1 shows the GDP per capita for the 14 countries. The results show Japan has the highest GDP per capita, while the United States is second. Canada, the United Kingdom, France and Germany have very similar GDP per capita throughout this period. Australia has a higher GDP per capita trend than New Zealand. Taiwan's GDP per capita has increased linearly from the level of a developing country to being at the same level as New Zealand.

The developing countries have very low GDP per capita compared to the industrialized countries. Brazil has the largest, almost constant, GDP per capita compared to the other four developing countries. Russia had a slight decrease from 1992, with the lowest level occurring in 1997. However, it has increased slightly in the last six years and is now back to the same GDP per capita as it was in 1992. China, India and Indonesia have had a very slow growth rate in GDP per capita since the 1980s. These three countries have the lowest GDP per capita out of all the 14 countries.

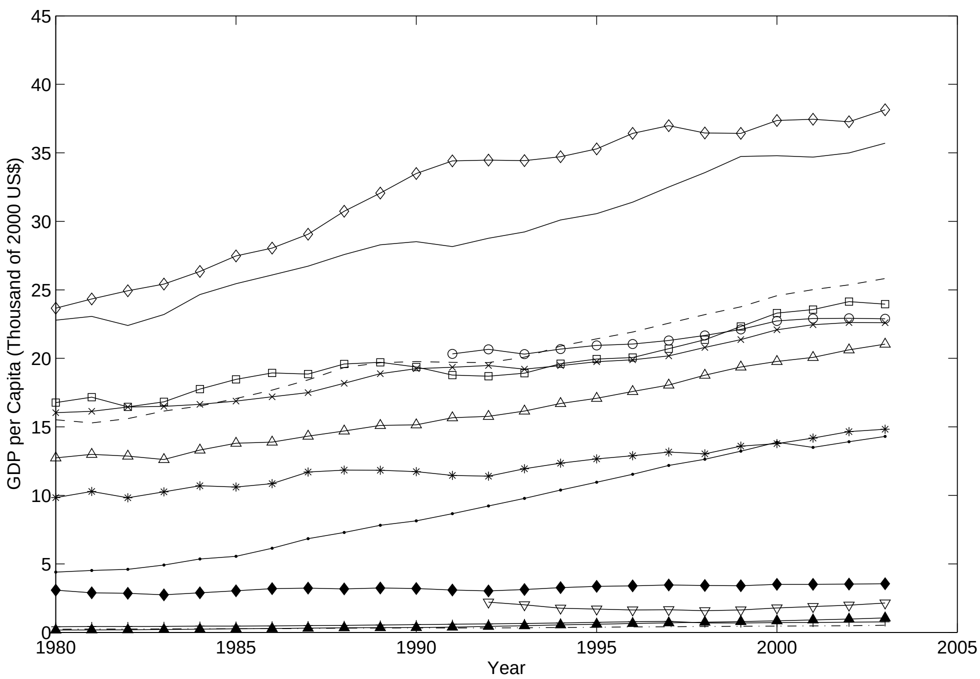

Figure 3.1 GDP per Capita for the 14 Countries using 2000 Market Exchange Rate

When MER is used to compare the standard of living or per capita GDP, it can give a very misleading picture. For example, if the New Zealand dollar (NZD) falls to 80% of its value, the GDP expressed in USD will also drop to 80%. This does not accurately reflect the standard of living in New Zealand, because the devaluation of the NZD is most likely due to international trade issues that will not yet have had an effect on the average New Zealander [29]. Currencies are traded for purposes other than trade in goods and services, e.g. to buy capital assets whose prices vary more than those of physical goods. Also, different interest rates, speculation, hedging or interventions by central banks can influence the foreign exchange market.

MER fluctuates widely and cause distortions because prices of non-trade goods and services are usually lower in poorer economies. For example, an USD exchanged and spent in the People's Republic of China will buy much more than a dollar spent in the United States.

3.2 PURCHASING POWER PARITY (PPP)

The PPP theory was developed by Swedish economist Gustav Cassel in 1920 [30]. It is used when attempting to determine the relative values of different currencies. The basis for PPP is the "law of one price", where in an efficient market, identical goods must have only one price. Purchasing power parity uses long-run equilibrium exchange rates which equalizes the purchasing power of different currencies in their own country for a given basket of goods. These special exchange rates are often used to compare the standards of living in two or more countries.

By using PPP, temporary devaluation of the NZD in relation to the USD is not misleading. The use of PPP is meant to lessen the effects of shifts in a national currency. This type of adjustment to an exchange rate is controversial because of the difficulties of finding comparable baskets of goods to compare purchasing power across countries. This effect is lessened by looking at a large sample of commodities, rather than finding one or two, however, this simply minimizes the problem, but it does not eliminate it entirely. PPP lumps items together into broad classes, not taking into account things such as quality; a hat is a hat, and its value in the index remains static, even though a shoddy hat's value on the international market would be much lower than a well made hat's value.

PPP exchange rates are especially useful when official exchange rates are artificially manipulated by governments. Countries with strong government control of the economy sometimes enforce official exchange rates that make their own currency artificially strong. By contrast, the currency's black market exchange rate is artificially weak. In such cases a PPP exchange rate is likely to be the most realistic basis for economic comparison. The World Economic Outlook (WEO) and Organization for Economic Cooperation and Development (OECD) and a number of private sector organizations, use PPP exchange rates. By contrast, the World Bank and other groups in the private sector use market prices. There are still others which use hybrids between these two main alternatives [31].

The relative ranking of a country's GDP per capita differ between the two approaches. The GDP data, obtained from the International Monetary Fund [25], are expressed in

Current International Dollars, based on the PPP valuations as shown in Figure 3.2 for the 14 countries. The GDP by PPP data for Germany was available from 1980 to 2005. The International Monetary Fund combined the West and East Germany's GDP by PPP. The result shows that the United States has the highest GDP per capita using PPP while Canada is second. The industrialized countries show very close and similar trends. Taiwan's GDP per capita initially started at the lower end of the scale, but has made a dramatic entrance into the higher end of the scale and has overtaken New Zealand.

The GDP using PPP per capita for the 5 developing countries are the lowest on the graph. Following the break up of the USSR, a downturn occurred from 1992 to 1998. Russia then increased linearly from 1998 and has the highest GDP per capita of the developing countries. Brazil started at the same value as Taiwan, in 1980, but did not have as steep of a growth rate compared to Taiwan. Indonesia had a higher GDP per capita compared to China up till 1997. India started off in the early 1980s with a slightly higher GDP per capita than China, but by the late 1990s they were on the same scale. China has since surpassed India and also exceeded Indonesia in 1998. Compared to Figure 3.1, all countries have higher growth rates when considering GDP using PPP.

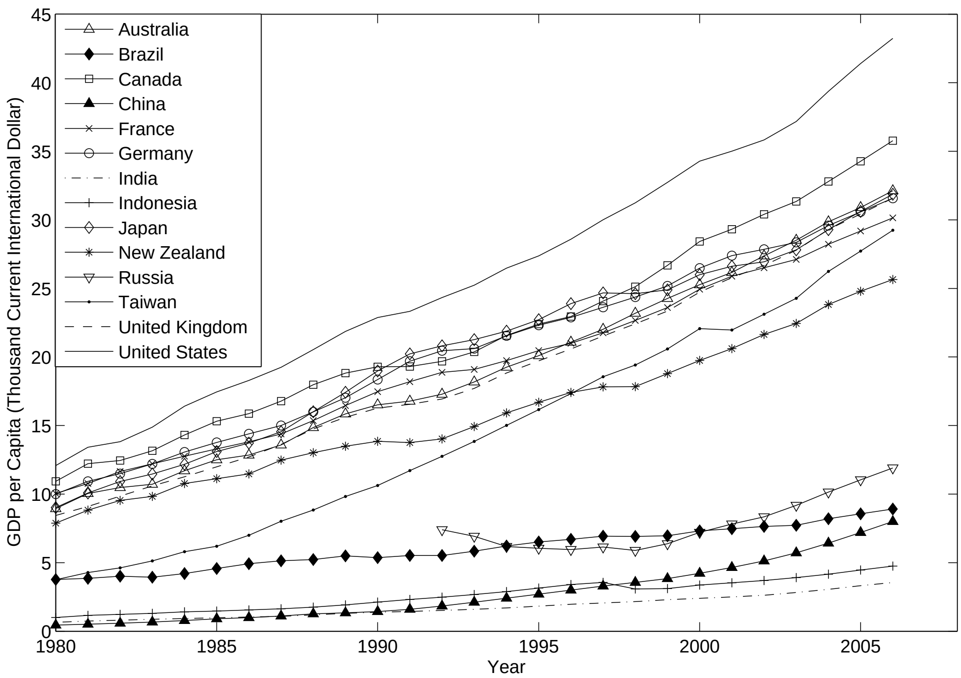

Figure 3.2 GDP per Capita for the 14 Countries using Purchasing Power Parity

Chapter 4

ENERGY INTENSITY (EI)

EI is defined as the relationship between a form of energy consumption and GDP, it measures the amount of energy it takes to produce a dollar's worth of economic output. This is expressed as

$$\text{Energy Intensity} = \frac{\text{Consumption}}{\text{GDP}} \tag{4.1}$$

EI is important as it can reflect changes in energy consumption over time, in the production of an economy, and also measure the energy efficiency of a nation's economy [15]. This value varies widely between countries depending on their level of industrialization, the mix of services and manufacturing in their economies, and the attention they pay to energy efficiency.

The EIA provides total primary energy consumption per GDP using both PPP and MER [17]. However, for this research, raw data of each fuel's energy consumption are used and all converted into Petajoules (PJ). The GDP data, obtained from the International Monetary Fund [25], are expressed in Current International Dollars.

4.1 ENERGY INTENSITY CURVE (EIC)

EIC shows the stage of development of energy in the process of GDP output [18]. The EIC presents the relationship between the EI and the level of wealth of a country, measured by GDP per capita [15]. By graphing the above relationship, EI against GDP per capita, an EIC is obtained and assists in determining whether that energy industry is in a growth, mature or aging phase [18].

A typical EIC of an output to industry is shown in Figure 4.1 [19]. The growth period indicates rapid expansion of the input to industry either due to new industrial growth or substitution of other products [18]. The mature phase represents a saturation of market penetration of that input to industry. Finally, the ageing phase represents a decline in intensity. This implies a substitution of the input to industry by some new inputs. The mature and ageing phase do not necessarily imply a decline in the absolute consumption [18].

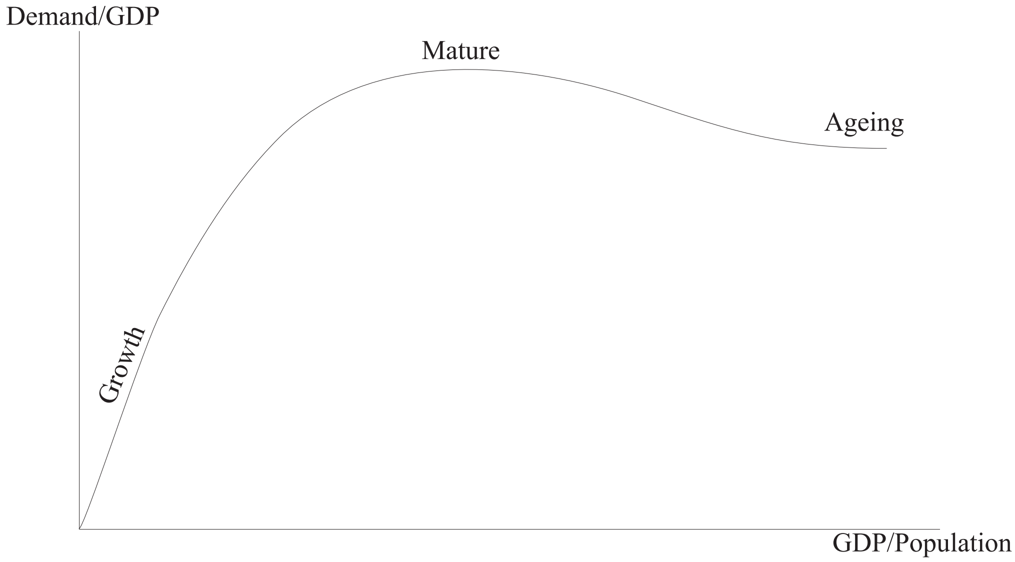

Figure 4.1 Typical Intensity Curve of an Input to Industry Showing the Stages of Development

4.2 ENERGY INTENSITY FACTOR (EIF)

The original EIC is not time based. Each point on an EIC curve represents a combination of consumption, GDP and population for a particular year [19]. However, the above information can be rearranged and represented by a point in time called the EIF. The EIF is defined as [18]

$$\begin{aligned}\text{EIF} &= \frac{\text{Consumption/GDP}}{\text{GDP/Population}} \\ &= \frac{\text{Consumption} \times \text{Population}}{\text{GDP}^2}\end{aligned} \tag{4.2}$$

The EIF can be graphed against time to show the historical evaluation of an energy output [19]. A peak in an EIF curve can be a predictor of the transition from the growth to the maturing phase of the EIC.

Chapter 5

CARBON DIOXIDE (CO_2) EMISSION CONVERSION FACTORS

Public awareness on environmental issues has increased in the last decade. Greenhouse policies, such as the Kyoto protocol, have played an important role in the development and designs of power plants and may have influences on energy market patterns.

The most commonly known greenhouse gas is CO_2, where the atmospheric concentration has increased by about 35% since the beginning of the industrialization age [32]. Major sources of CO_2 emission include home heating and cooling, electricity generation, and transportation.

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, where air is the usual source of oxygen [2]:

$$C + O_2 \rightarrow CO_2 \tag{5.1}$$

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.

To determine how human activities and economic growth have contributed to the change of CO_2 emissions, the CO_2 emissions from the electricity generation by fuel type is investigated. While the CO_2 formation from each fossil fuel electricity generator is similar, an important difference in the burning of coal, oil, and natural gas is the quantity of CO_2 formed *per unit of energy released* [2].

5.1 HEATING VALUE

The heating value is the amount of heat released during the combustion of a specified amount of fuel. It is measured in units of energy per unit of the substance, usually mass, such as: kJ/kg or kJ/mol. There are two different definitions of heating value in use: the HHV and the LHV. These two measures reflect different assumptions about whether energy can be recovered from water vapor formed during combustion [2].

If the vapor is cooled and condensed into a liquid, additional useful energy (equal to the heat of vaporization) can be extracted. This is the HHV and is the prevailing measure used in the United States, the United Kingdom and Japan. In most of Europe and many other parts of the world the LHV is used to quantify fuel energy content. The LHV reflects the fact that existing combustion systems do not recover the heat vaporization because it is not economical to do so with current technology. This treats any H_2O formed as a vapor. The energy required to vaporize the water therefore is not realized as heat. This makes fuel-using technologies appear more efficient [2].

The numerical difference between HHV and LHV ranges from about 2% to 10%, depending on the specific fuel. The difference is greatest for natural gas, whose combustion produces more water vapor per unit of fuel than oil or coal. Manufacturers of gas-using equipment (such as gas turbines) thus favour the use of LHV [2]. Many sources do not clearly state whether HHV or LHV is being used. This research uses HHV.

5.2 COAL

For this research, the use of bituminous coal is assumed, 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 [2]

$$(\mathrm{CO_2})_{\mathrm{coal}} = (0.67\mathrm{kg\,C})(\frac{44\mathrm{kg\,CO_2}}{12\mathrm{kg\,C}}) = 2.46\mathrm{kg\,CO_2/kg\,coal\,burned}$$

The amount of CO_2 per unit of fuel energy is

$$\begin{aligned}(\mathrm{CO_2})_{\mathrm{coal}} = \frac{2.46\mathrm{kg\,CO_2/kg\,coal}}{28,400\mathrm{kJ/kg\,coal}} &= 86.5 \times 10^{-6}\mathrm{kg\,CO_2/kJ\,of\,fuel\,energy} \\ &= 86.5\mathrm{kt\,CO_2/PJ} \qquad (5.2)\end{aligned}$$

The CO_2 emission factors published for bituminous coal in New Zealand is 88.8 kt CO_2/PJ [33], which is very close to the calculated 86.5 kt CO_2/PJ [2]. This thesis uses the 86.5 kt CO_2/PJ value.

5.3 OIL

For this research, the use of distillate oil is assumed, which has 87% carbon by weight with a heating value of 45,200kJ/kg [2]. Hence in 1kg of oil there is 0.87kg of C. This produces

$$(CO_2)_{\text{oil}} = (0.87\text{kg C})(\frac{44\text{kg CO}_2}{12\text{kg C}}) = 3.19\text{kg CO}_2/\text{kg oil burned}$$

The amount of CO_2 per unit of fuel energy is

$$\begin{aligned}(CO_2)_{\text{oil}} = \frac{3.19\text{kg CO}_2/\text{kg oil}}{45,200\text{kJ/kg oil}} &= 70.6 \times 10^{-6}\text{kg CO}_2/\text{kJ of fuel energy} \\ &= 70.6\text{kt CO}_2/\text{PJ} \qquad (5.3)\end{aligned}$$

The CO_2 emission factors published for distillate oil in New Zealand is 72 kt CO_2/PJ [33], which is very close to the calculated 70.6 kt CO_2/PJ [2]. This thesis uses the 70.6 kt CO_2/PJ value.

5.4 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 [2]

$$(CO_2)_{\text{gas}} = (0.74\text{kg C})(\frac{44\text{kg CO}_2}{12\text{kg C}}) = 2.71\text{kg CO}_2/\text{kg gas burned}$$

The amount of CO_2 per unit of fuel energy is

$$\begin{aligned}(CO_2)_{\text{gas}} = \frac{2.71\text{kg CO}_2/\text{kg gas}}{54,400\text{kJ/kg gas}} &= 49.9 \times 10^{-6}\text{kg CO}_2/\text{kJ of fuel energy} \\ &= 49.9\text{kt CO}_2/\text{PJ} \qquad (5.4)\end{aligned}$$

The CO_2 emission factors published for distributed gas streams in New Zealand range from 51.9-53.1 kt CO_2/PJ [33], which is very close to the calculated 49.9 kt CO_2/PJ [2]. This thesis uses the 49.9 kt CO_2/PJ value.

The ratio of CO_2 emissions from natural gas to that of coal is thus

$$\frac{(\mathrm{CO_2})_{\mathrm{gas}}}{(\mathrm{CO_2})_{\mathrm{coal}}} = \frac{49.9}{86.5} = 0.58$$

5.5 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 [34]. 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 [34]. Their evaluation is known as life cycle analysis (LCA) [35].

LCA is out of the scope of this thesis. This thesis focuses on the CO_2 emitted during the process of transforming the primary energy into electricity generation. Hence, the conversion factor used for hydro, wind and geothermal for New Zealand are 0 kg/CO_2 [34].

Chapter 6

COAL

In this chapter, the relationship between coal consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat value, net value, efficiency, and CO_2 emitted from coal use in electricity generation for New Zealand are also shown.

6.1 COMPARISON BETWEEN FOURTEEN COUNTRIES

Figure 6.1 shows the total coal consumption for the 14 countries from 1980 to 2004. Coal includes anthracite, subanthracite, bituminous, subbituminous, lignite, brown coal [23]. Countries apart from China, India and the United States had a fairly constant consumption throughout this period. China's coal consumption surpassed the United States in 1986, and it became the highest coal consumping country in the world. China's consumption has been relatively linear from 1980 to 2002, followed by a steep increase to 2004. India's coal consumption has also increased linearly, from 1980 to 2004. Coal consumption of the other 12 countries is low compared to the United States and China. New Zealand is the lowest coal consumer.

Figure 6.2 shows the coal consumption per capita for the 14 countries. Australia has the highest coal consumed per capita, increasing from 77 (GJ/person) in 1980 to 124.45 (GJ/person) in 2004. The United States is the second highest, increasing at a fairly constant rate. Taiwan's rate of increase is the highest out of the 14 countries, from 8.68 (GJ/person) in 1980 to 72.32 (GJ/person) in 2004. Taiwan surpassed Germany in 2001, and now has the third highest coal consumption per capita of the 14 countries. New Zealand, despite being the lowest in total coal consumption, is above France, India, Indonesia, and Brazil for coal consumed per capita. New Zealand's trend was decreasing from 1980 to 1998, but has since increased from 13.1 (GJ/person) in 1998 to 23.86 (GJ/person) in 2004. This increasing trend in coal reflects the run-down of the

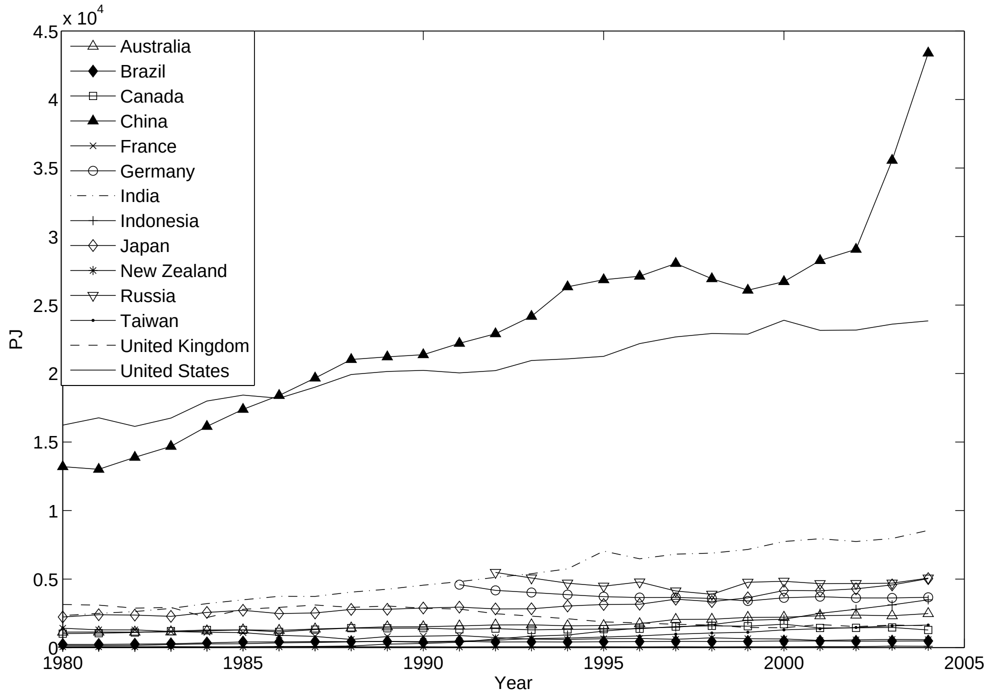

Figure 6.1 Coal Consumption for the 14 Countries

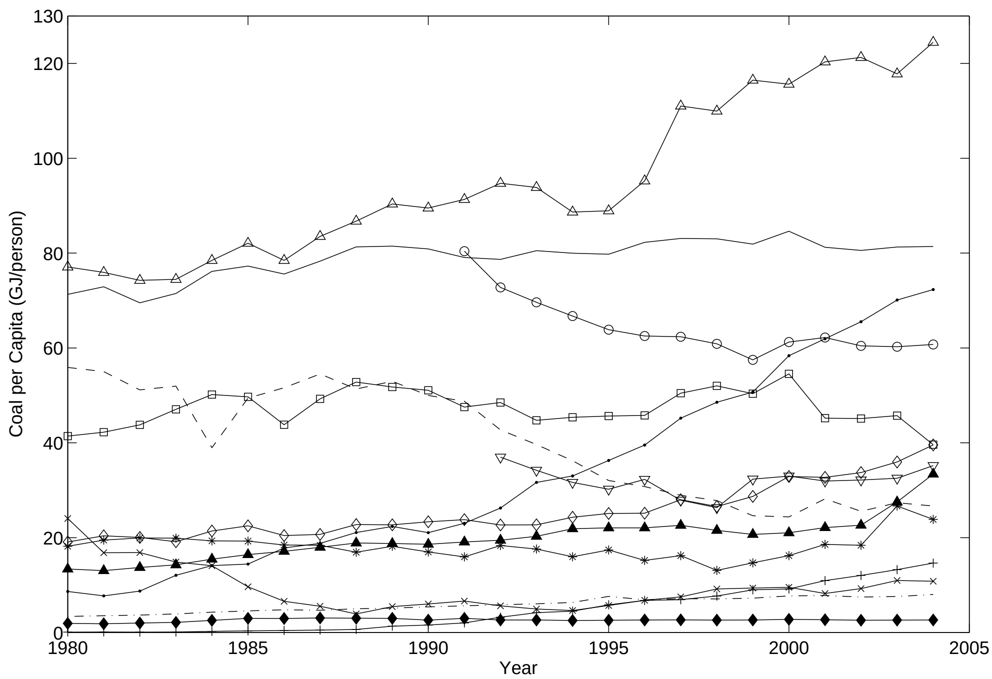

Figure 6.2 Coal Consumption per Capita for the 14 Countries

Maui gas field, making coal a replacement, particularly in some of the thermal power stations, which were originally run on coal before being converted to run on natural gas.

6.1.1 Energy Intensity

Figure 6.3 shows the coal intensity for these countries. The coal intensities for all the countries have been in decline or stagnant from 1980 to 2004. However, China's coal intensity has increased since 2002. China had a very high coal intensity compared to all the other 13 countries in the 1980s, but this has dropped dramatically from 29.67 (MJ/International Dollar) in 1980 to 4.41 (MJ/International Dollar) in 2002. The decreasing trends reflects more efficient use of coal in the production of GDP, and substitution of coal by higher quality fuels.

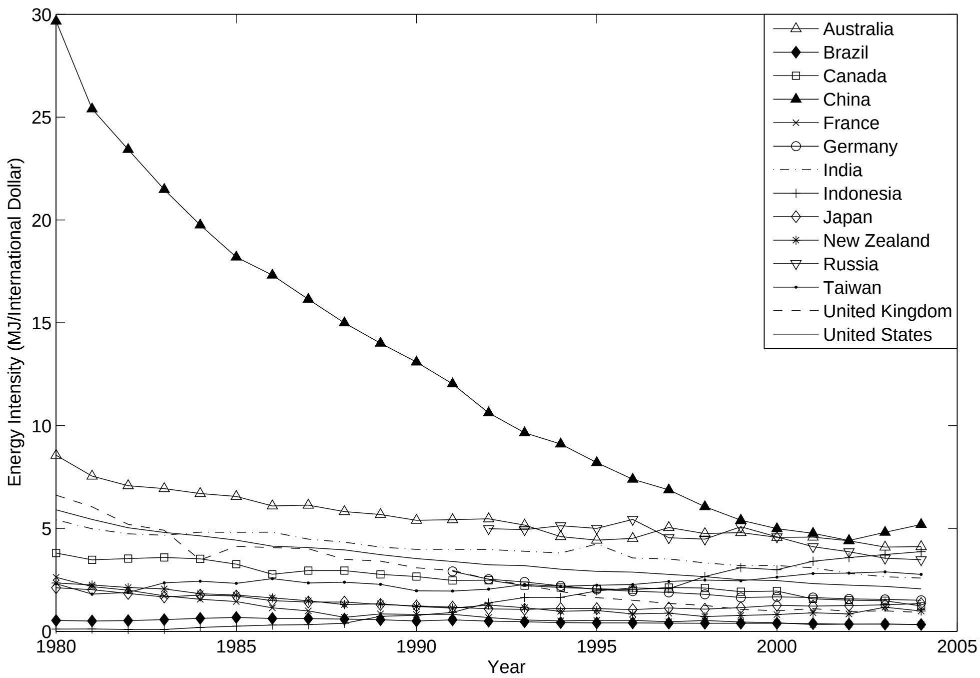

Figure 6.3 Coal Intensity for the 14 Countries Using PPP

6.1.2 Energy Intensity Curves

The coal intensity curves for the 14 countries are shown in Figure 6.4. The industrialized countries have higher incomes per capita. Therefore these plots are towards the right portion of Figure 6.4. The developing countries with lower income per capita are in the left portion of Figure 6.4. Figure 6.5 and Figure 6.6 show the coal intensity curves for the industrialized countries and developing countries respectively.

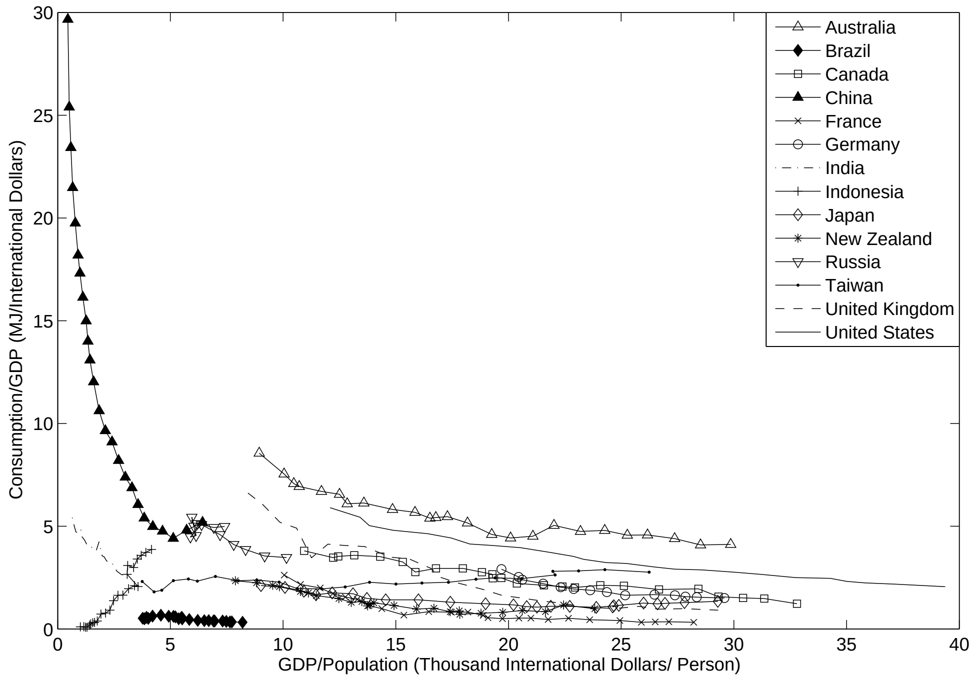

Figure 6.4 Coal Intensity Curve for the 14 Countries Using PPP

For all industrialized countries apart from Taiwan and New Zealand, as GDP per capita increases, consumption of coal in producing that GDP decreases. Thus, the coal intensity for all of the industrialized countries, except Taiwan and New Zealand, have declined relative to economic growth. Taiwan's coal intensity has increased as the economy grew. New Zealand's coal consumption has been in decline to one point, but has then increased relative to economic growth.

For the developing countries, Indonesia's coal intensity had a large incline, while China, India, Russia and Brazil declined relative to economic growth. In Russia, the coal intensity has been stagnant as the economic growth rate decreases to one point, then the coal intensity started decreasing relative to the increase in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has increased with lower coal intensity.

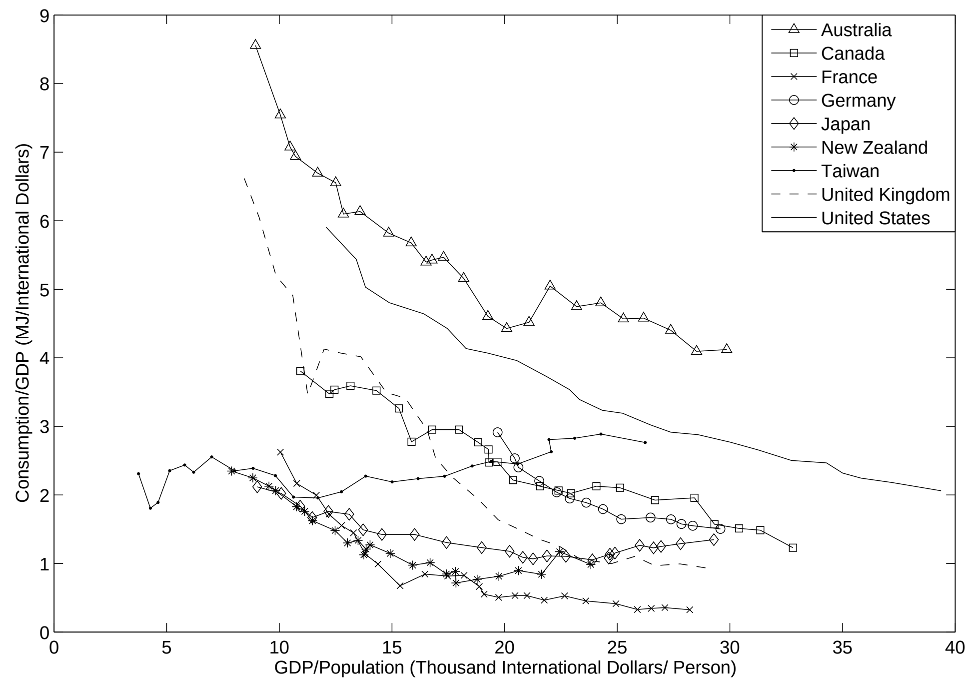

Figure 6.5 Coal Intensity Curve for Industrialized Countries Using PPP

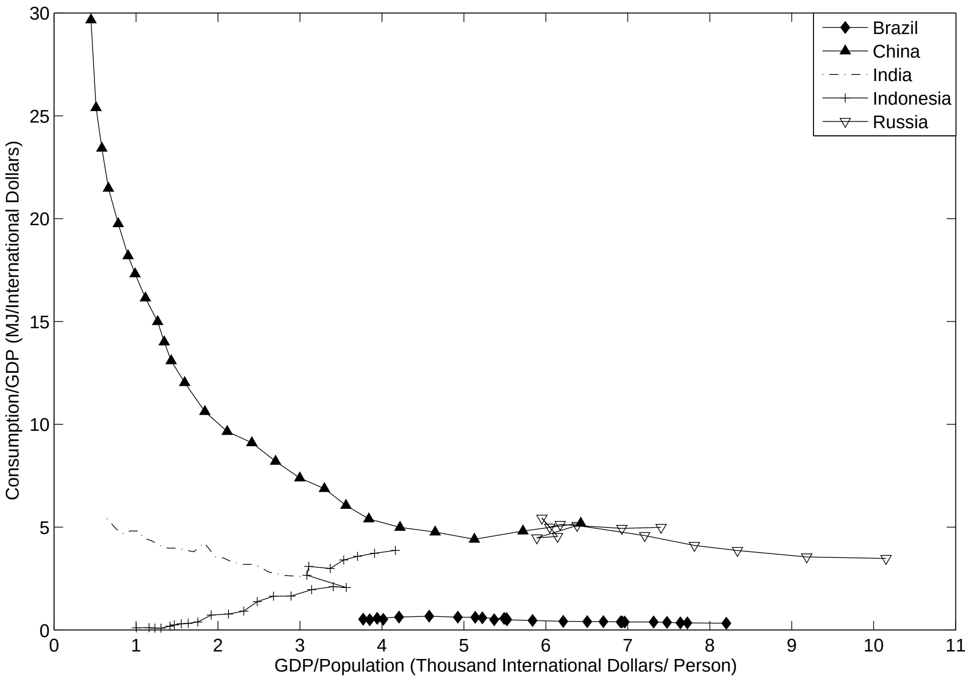

Figure 6.6 Coal Intensity Curve for Developing Countries Using PPP

6.1.3 Energy Intensity Factor

The coal intensity factors for the 14 countries are shown in Figure 6.7. China had the highest coal intensity factor from 1980 to 2004, followed by India. These two countries are at a much higher scale compared to the other 12 countries. China started off at a high value, but has decreased rapidly and converged with the other 13 countries. From 1999 to 2004, the differences in coal intensity factor over all the countries are small when compared to the previous period.

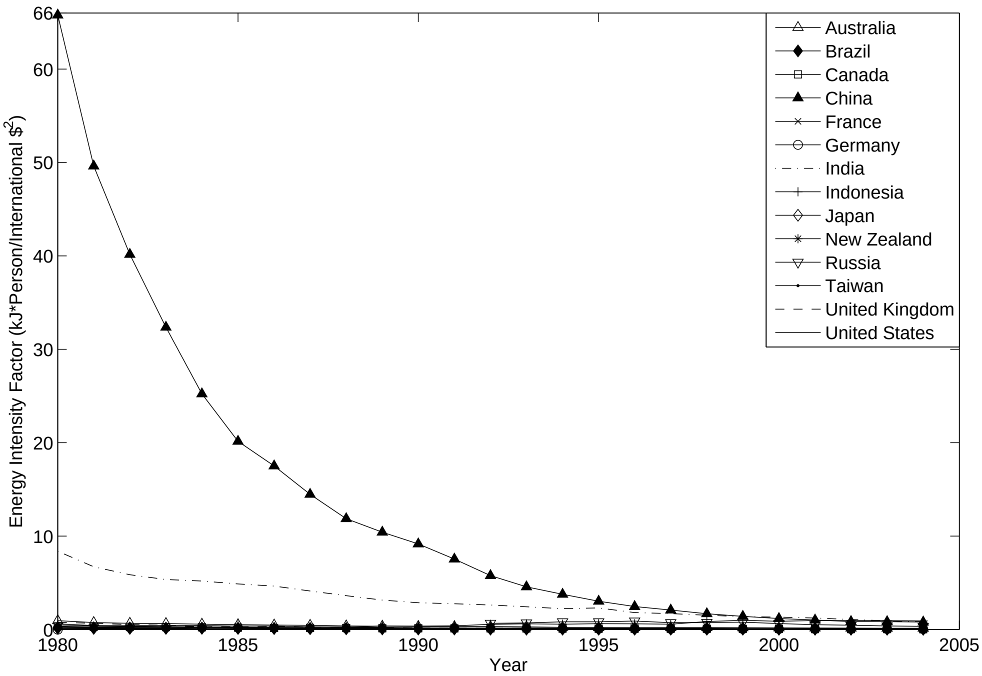

Figure 6.7 Coal Intensity Factor for the 14 Countries Using PPP

The small variations in the pattern of coal intensity factor for these countries are shown in Figure 6.8 and Figure 6.9 for the industrialized and developing countries respectively. In general, the coal intensity factors for the industrialized countries have decreased over the years and converged.

For the developing countries, China's coal intensity factor had the largest drop from 65.77 (kJ/International $\$^2$) in 1980 to 0.81 (kJ/International $\$^2$) in 2004. By contrast, Brazil had the most steady coal intensity factor. Overall, the coal intensity factors have converged in a similar manner to those for the industrialized countries.

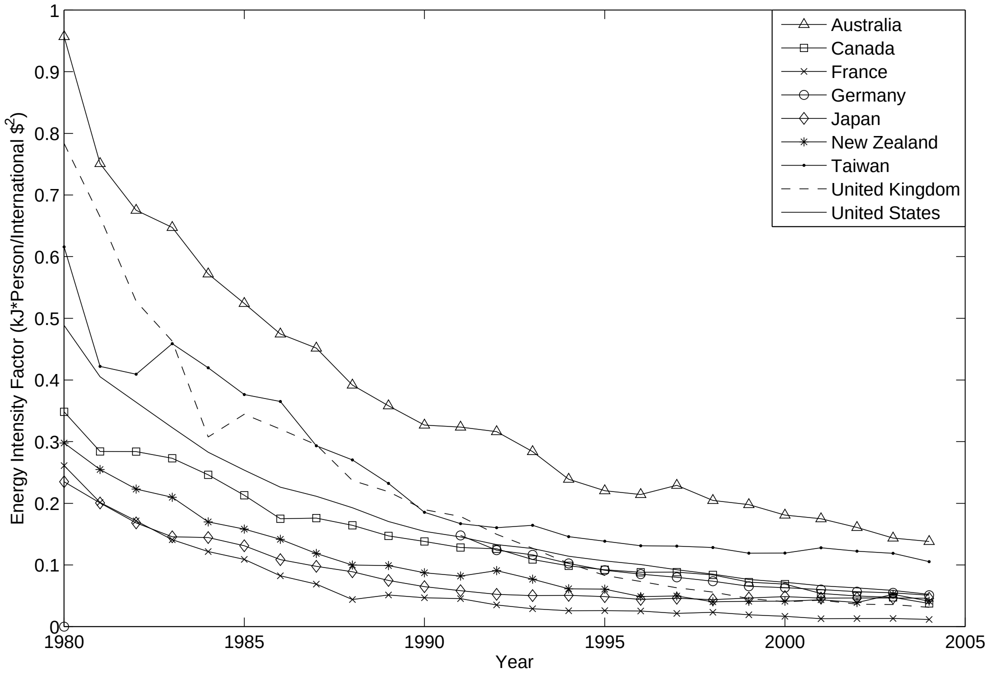

Figure 6.8 Coal Intensity Factor for Industrialized Countries Using PPP

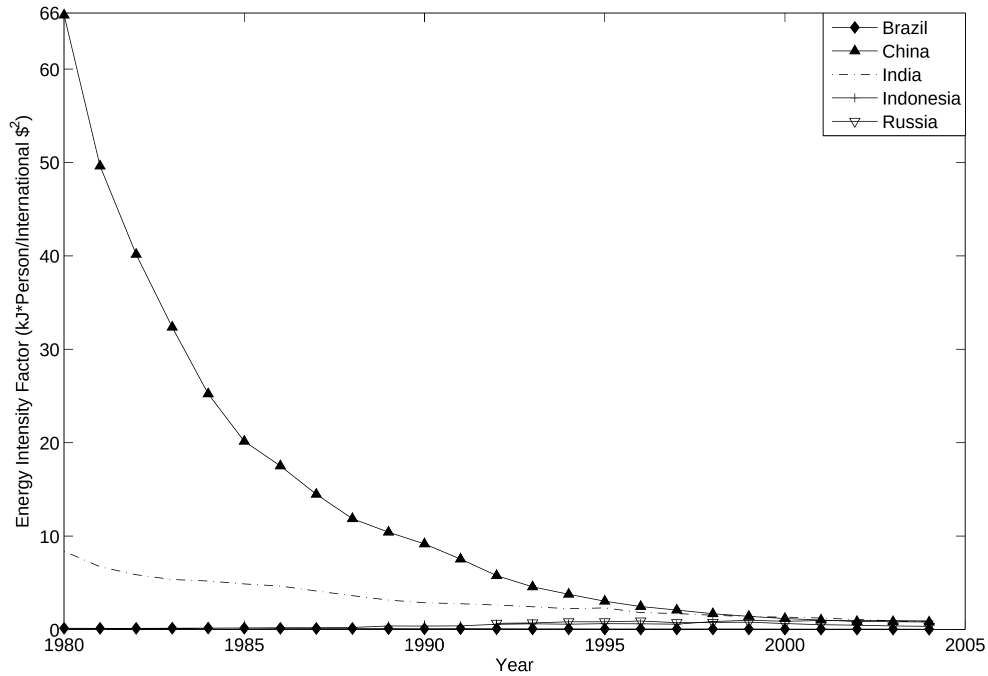

Figure 6.9 Coal Intensity Factor for Developing Countries Using PPP

6.2 COAL USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

Coal is used for base load electricity generation. Data for net electricity generation by fuel type came from the New Zealand Ministry of Economic Development (MED) [36]. This data also includes generation from cogeneration plants. Cogeneration combines the process of producing heat and power on site, from a single primary energy source, instead of importing power from the national grid. The data is available in both GWh and PJ for the period 1974 to 2006. The heat value for coal in electricity generation was only available from 1995 to 2006 in the Energy Supply and Demand Balance Tables [37]. The weighted average efficiency worldwide for coal generation is 35% [38], and the average efficiency for New Zealand found from the heat and net values from 1995 to 2006 was 36%.

6.2.1 Heat Values and Net Values

Figure 6.10 shows the net electricity generated using coal from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. Coal use in electricity generation has been relatively constant until 1995, then increased linearly with slight variations till 2002. The dramatic increase from 1744 GWh in 2000 to 5120 GWh in 2006 reflects the use of coal in thermal plants due to the depletion of gas in the Maui fields. The smaller peaks from Figure 6.10 correlate to dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations. The driest years are 1976, 1992, 2001, and 2003 [39]. These occurred at different stages of development of the New Zealand Electricity Market, from basically central control in 1992 to an uncapped spot market with no central control in 2001 and 2003 [39].

Figure 6.11 shows the real heat, estimated heat and net values in PJ for coal use in electricity for comparison. The heat value is available from 1995 to 2006, where as the net value is from 1974 to 2006 and the estimated heat value is determine by dividing the net values by 36%. The heat value is at a much higher scale compared to the net value from 2002 to 2006.

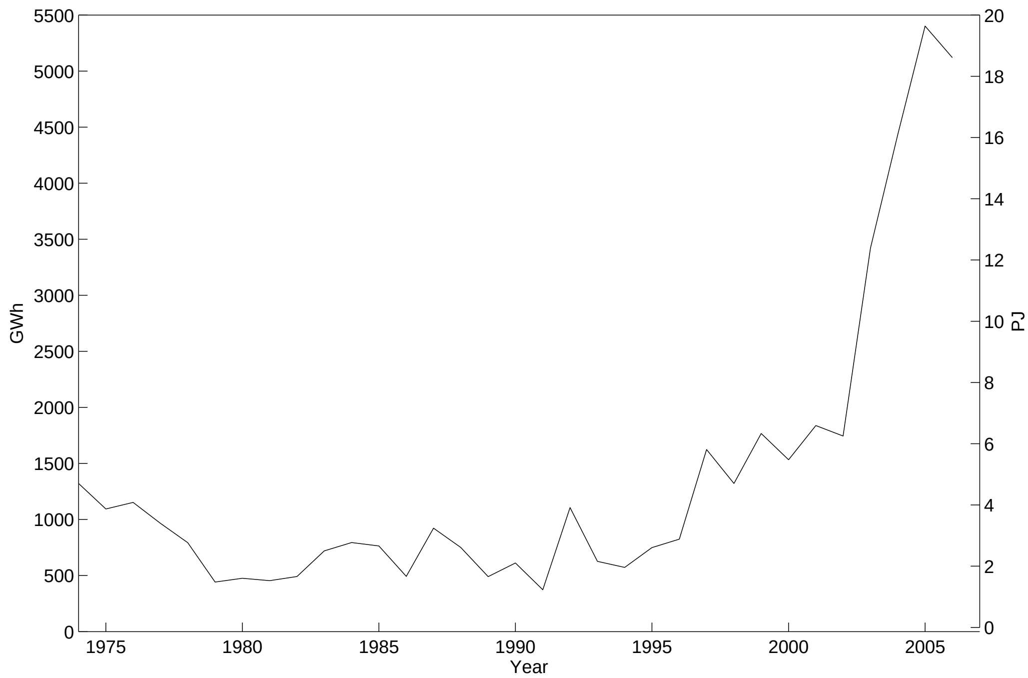

Figure 6.10 Net Electricity Generated from Coal in New Zealand

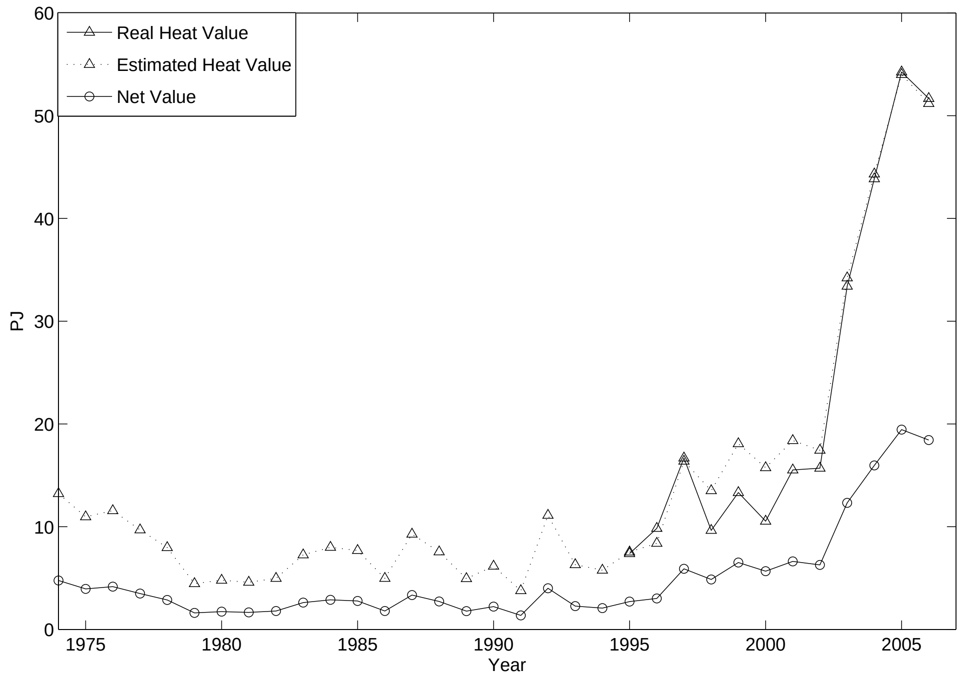

Figure 6.11 Comparison Between Heat and Net Value for Coal

6.2.2 Efficiency

The efficiency of coal use in electricity generation in New Zealand plants from 1995 to 2006 is shown in Figure 6.12. This is the ratio of the net to heat values of Figure 6.11. The efficiency peaked at 53.8% in 2000 and dropped to 35.6% in 2006. This may be due to the run down of the coal-fired plants, or an error in the published data. The weighted average efficiency worldwide for coal generation is 35%, and highest is 42% in Japan [38]. New Zealand once had a higher efficiency compared to Australia, China, France, Germany, India, Japan, Nordic countries (Denmark, Finland, Sweden and Norway aggregated), South Korea, the United Kingdom and Ireland, and the United States [38]. Together these countries generate 65% of worldwide fossil fuel power generation.

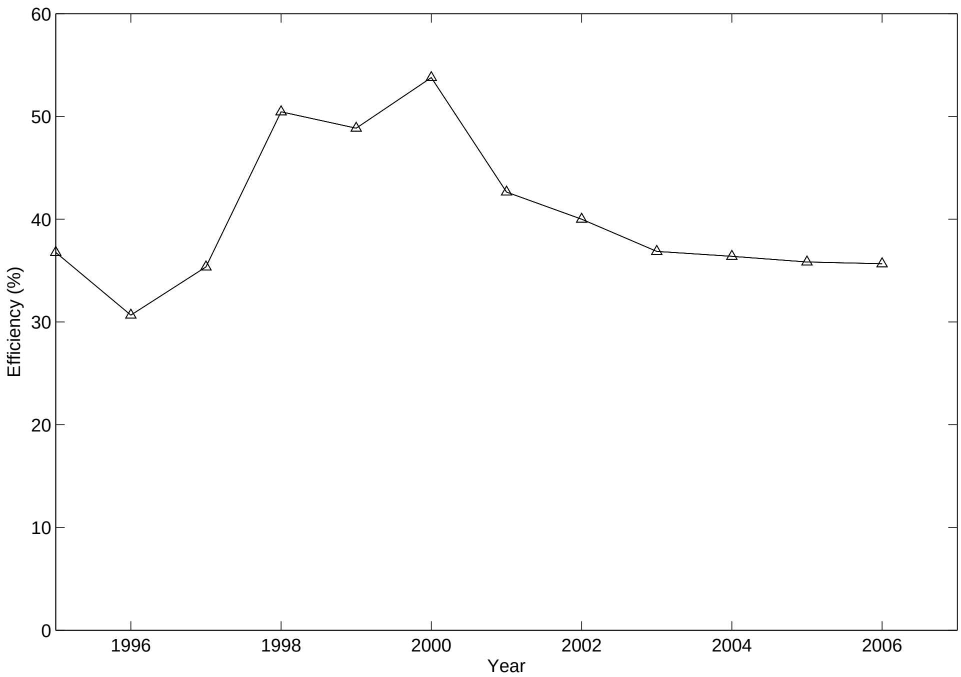

Figure 6.12 Coal Efficiency in Electricity Generation

6.2.3 CO_2 Emitted

Equation 5.2 showed that each PJ of coal used in electricity generation will produce 86.5 kt of CO_2. Using Equation 5.2 to convert the heat values from 1995 to 2006 and estimated heat values from 1974 to 2006, the CO_2 emitted from coal use in electricity generation is shown in Figure 6.13. Despite the environmental concerns of global warming and the targets set for Kyoto protocol, there has been a large increase in CO_2 emissions. This significant increase was due to the replacement of gas by coal in order to continue to meet the electricity demand of the nation.

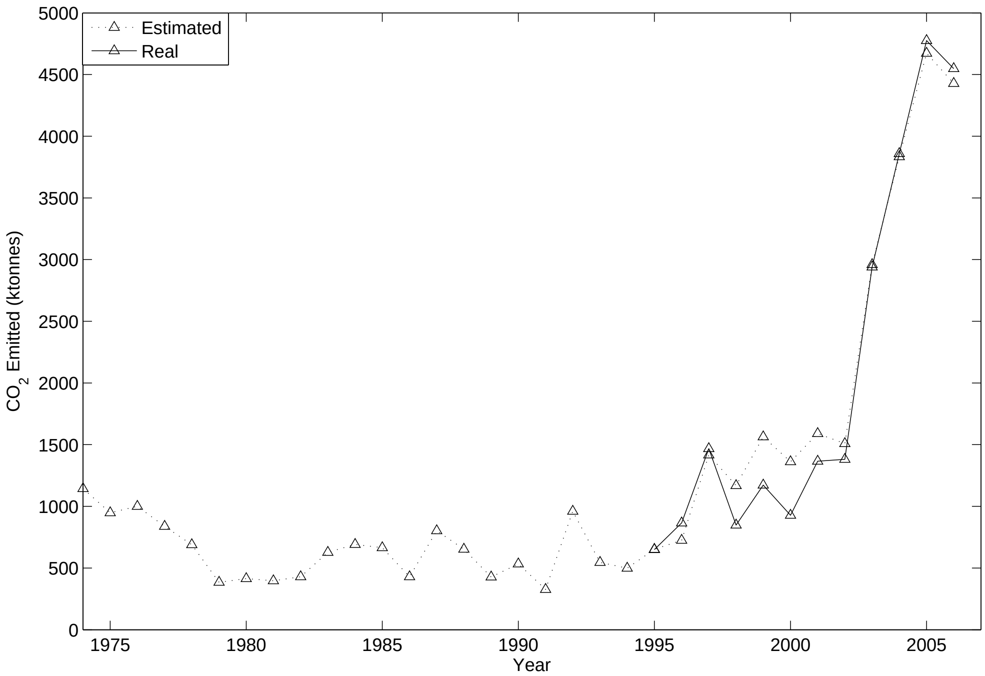

Figure 6.13 CO_2 Emissions from Electricity Generation Using Coal

Chapter 7

OIL

7.1 COMPARISON BETWEEN FOURTEEN COUNTRIES

In this chapter, the relationship between oil consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Oil use in electricity generation for New Zealand is also shown.

Figure 7.1 shows the total oil consumption for the 14 countries from 1980 to 2004. A general decline in oil consumption for all countries from 1980 to 1983 can be seen. These declines are due to the oil crises in 1973 and 1979. The total oil consumption was highest in the United States while Japan was second up till 2003. China surpassed Japan in 2004 and became the second largest oil consumer in the world. Oil consumption of the other 11 countries is low compared to the United States, Japan and China. New Zealand has the lowest oil consumption.

Figure 7.2 shows the oil consumption per capita for the 14 countries. Canada had the highest oil consumption per capita in 1980, but dropped below the United States, and became the second highest up till 2002. Since 2003, Canada has regained its place as the highest oil consumer per capita. The two countries have very similar patterns reflecting their free trade economies. Germany, Australia and Japan are very similar and are the next highest. New Zealand, despite being the lowest in total oil consumption, is higher than all the five developing countries, on a per capita basis. Taiwan surpassed France in 1985, and the United Kingdom, New Zealand and Russia in 1994. Taiwan in now on the same scale as Japan, Germany, and Australia. While all the industrialized countries have gradually recovered from the 1979 oil crisis, and started to increase in oil consumption per capita after 1984, France had a big drop in 1985. This reflects the lack of indigenous oil resources and their reliance on imported fuel. France remained on the lower scale up till 1994, but has since increased linearly, surpassing the United Kingdom in 2000, and New Zealand in 2004. Apart from Russia, the other four developing countries are the lowest.

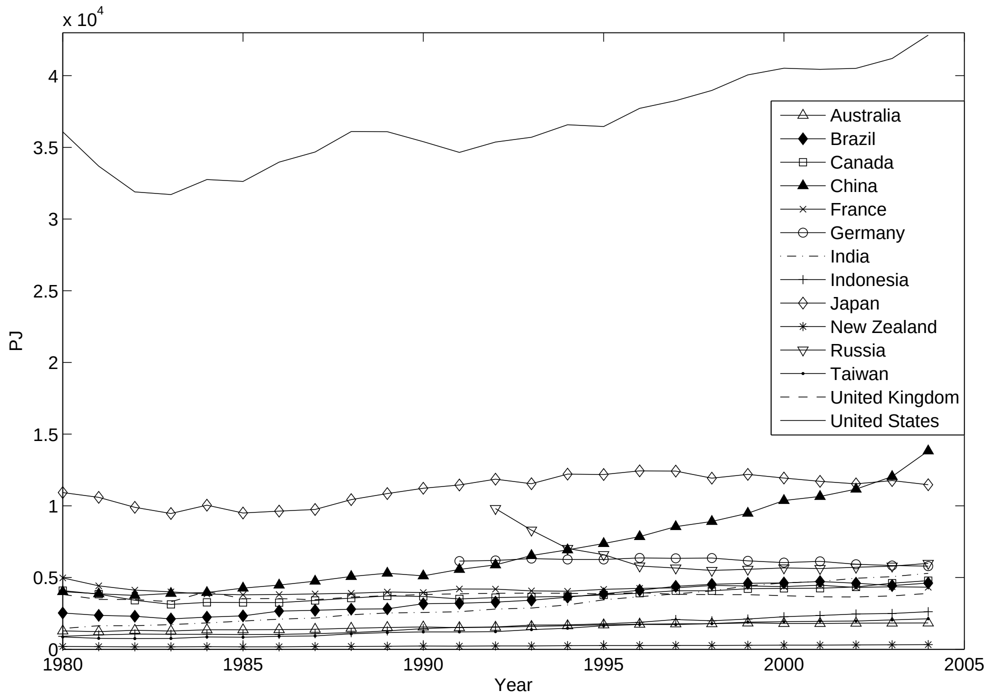

Figure 7.1 Oil Consumption for the 14 Countries

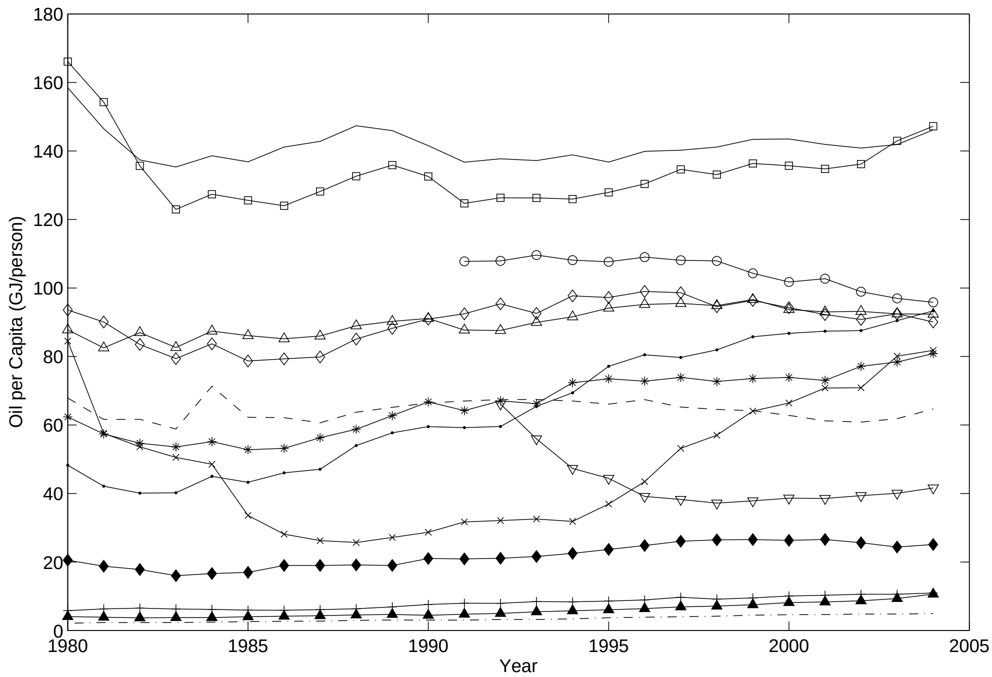

Figure 7.2 Oil Consumption per Capita for the 14 Countries

7.1.1 Energy Intensity

Figure 7.3 shows the oil intensities for all the countries had a steep decrease from 1980 to 1985. From 1986 to 2004, the trends were still decreasing, but at slower rates. The decreasing trends reflects more efficient use of oil in the production of GDP, and a substitution of oil by natural gas, a higher quality fuel.

From 1992 to 2002, Russia had the highest oil intensity. It had the most rapid decrease in its trend, and from 2003 to 2004 the oil intensity became lower than that for Canada. India has the lowest oil intensity, the decreasing trend is also fairly slow compared to the other countries. China's decreasing trend has dropped to the same oil intensity as India in 2004.

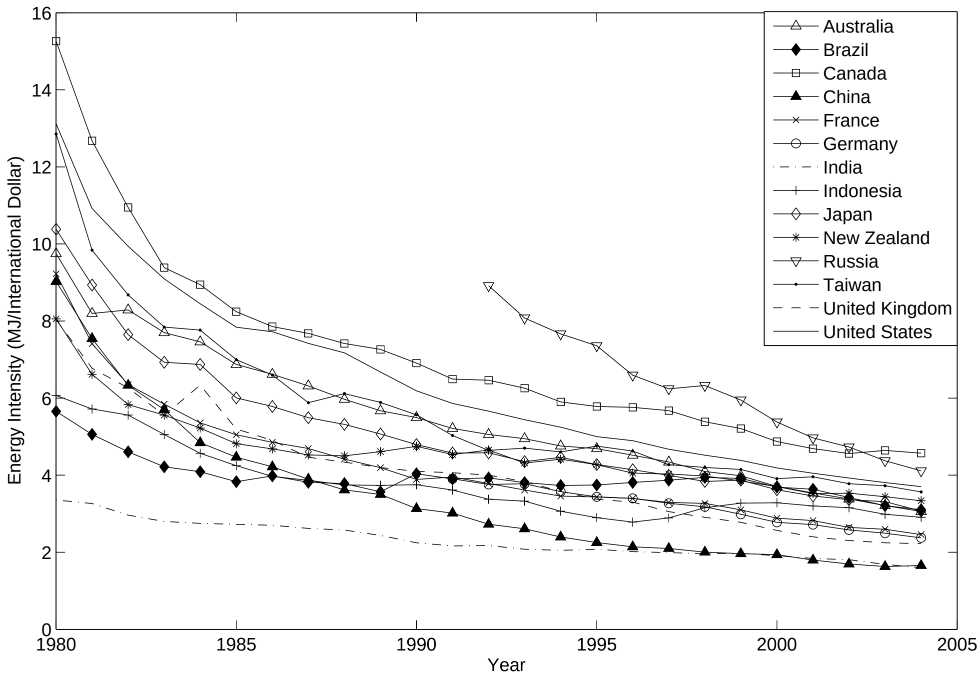

Figure 7.3 Oil Intensity for the 14 Countries Using PPP

7.1.2 Energy Intensity Curves

The oil intensity curves for the 14 countries are shown in Figure 7.4. The industrialized countries have higher incomes per capita. Therefore these plots are towards the right portion of Figure 7.4. The developing countries with lower income per capita are in the left portion of Figure 7.4.

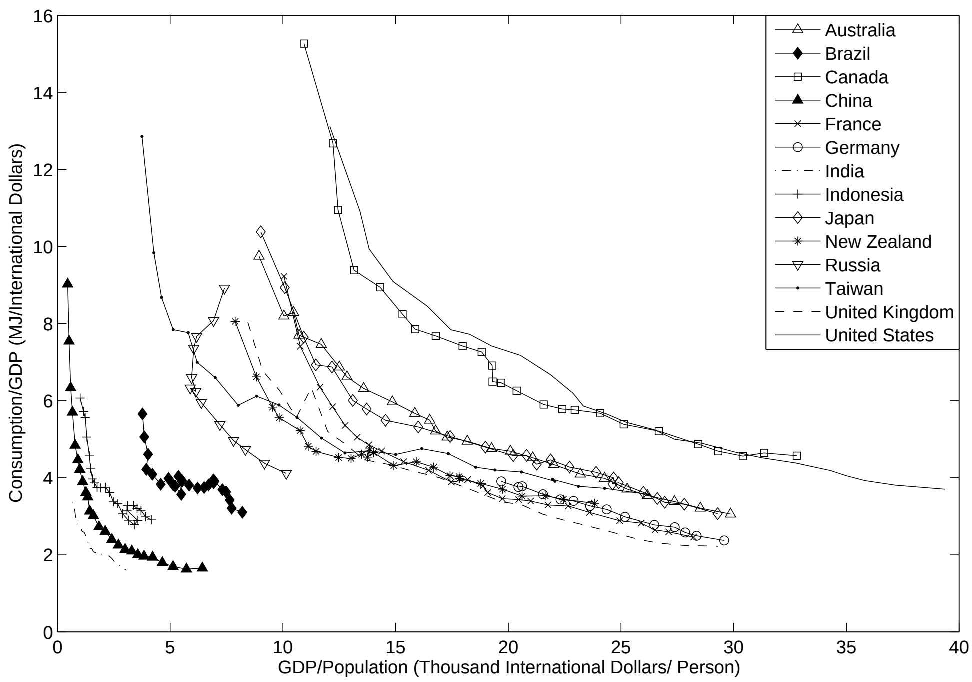

Figure 7.4 Oil Intensity Curve for the 14 Countries Using PPP

Figure 7.5 and Figure 7.6 show the oil intensity curves for the industrialized countries and developing countries respectively. For all industrialized countries, as GDP per capita increases, consumption of oil in producing that GDP decreases. Thus, the oil intensities for all of the industrialized countries have declined relative to economic growth.

For the developing countries, China, India, Brazil and Indonesia, oil intensity has also declined relative to economic growth. In Russia, the oil intensity initially decreased with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has since increased, with lower oil intensity.

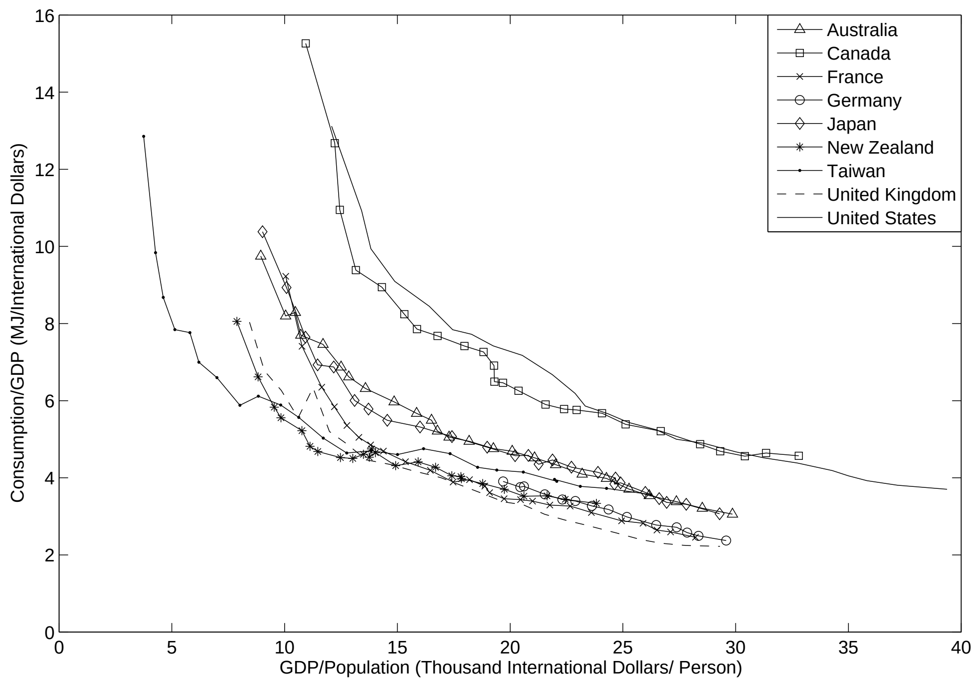

Figure 7.5 Oil Intensity Curve for Industrialized Countries Using PPP

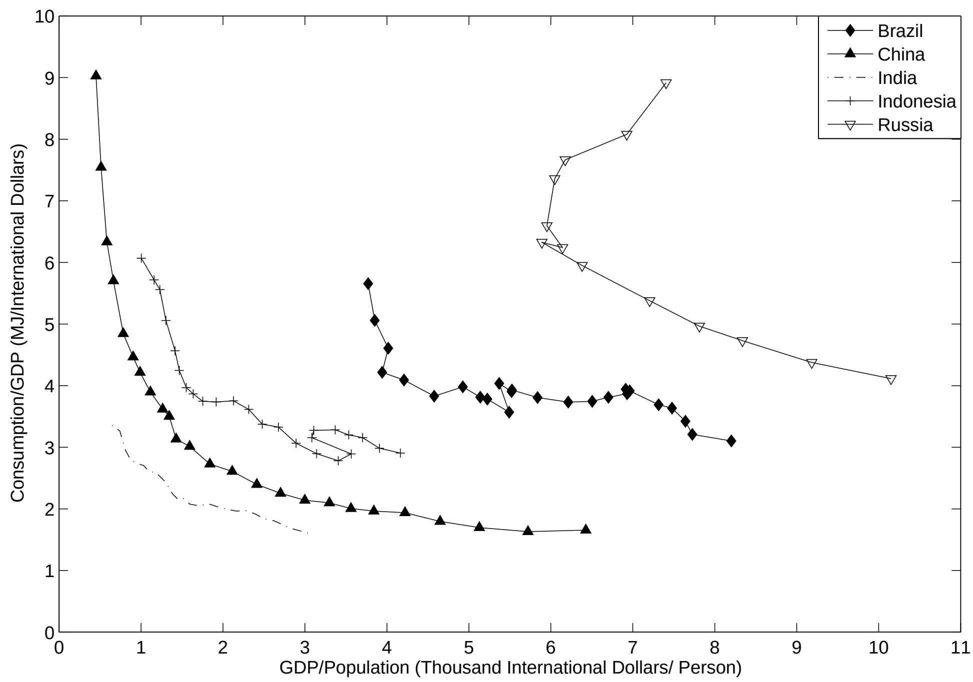

Figure 7.6 Oil Intensity Curve for Developing Countries Using PPP

7.1.3 Energy Intensity Factor

The oil intensity factors for the 14 countries are shown in Figure 7.7. These are relatively smooth declining curves over time. China had the highest oil intensity factor from 1980 to 1991. Indonesia was the second highest, followed by India. From 1992 to 2004, the differences in oil intensity factor over all the countries is small when compared to the previous period.

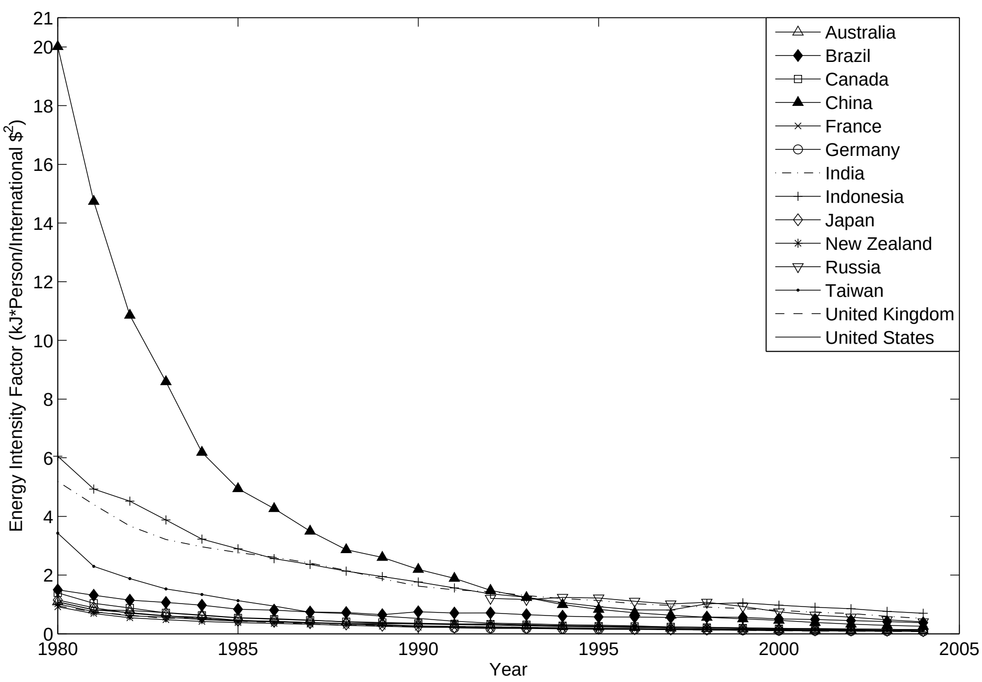

Figure 7.7 Oil Intensity Factor for the 14 Countries Using PPP

The small variations in the pattern of oil intensity factor for these countries are shown in Figure 7.8 and Figure 7.9 for the industrialized and developing countries respectively. Taiwan had the highest oil intensity factor, but this has decreased dramatically from 3.4 (kJ/International $\$^2$) in 1980 to 0.14 (kJ/International $\$^2$) in 2004. This reflects its transition to a fully industrialized country. In general, the oil intensity factors for the industrialized countries have decreased over the years and converged.

For the developing countries, China's oil intensity factor has dropped from 20 (kJ/International $\$^2$) in 1980 to to 0.14 (kJ/International $\$^2$) in 2004. By contrast, Brazil has had the most steady oil intensity factor. Overall, the oil intensity factors have converged in a similar manner to those for the industrialized countries.

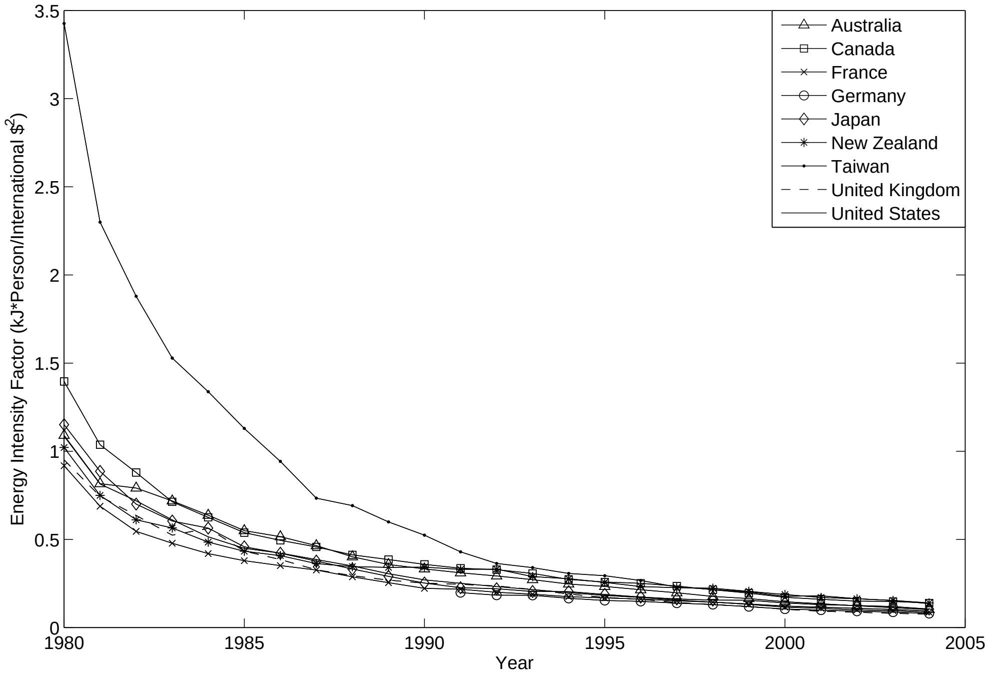

Figure 7.8 Oil Intensity Factor for Industrialized Countries Using PPP

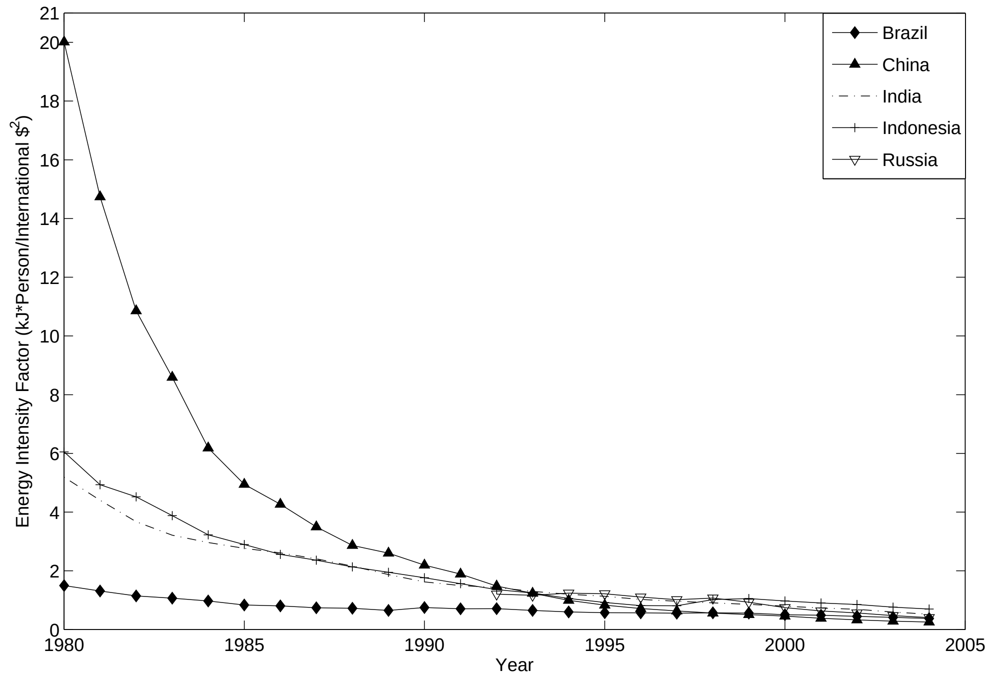

Figure 7.9 Oil Intensity Factor for Developing Countries Using PPP

7.2 OIL USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

Oil is used for electricity generation when the demand is high. Data for net electricity generation by fuel type came from the New Zealand MED [36]. This data also includes generation from cogeneration plants. The data is available in both GWh and PJ for the period 1974 to 2006.

Negative generation by oil-fired plants implies a net import into the station to maintain station viability and system voltage stability [36], this occurred in 1980, 1981, 1989, and 1997. The heat value for oil in electricity generation was not available in the Energy Supply and Demand Balance Tables [37]. However, the weighted average efficiency for oil-fired power generation is 38% [38], so the estimated heat value can be calculated by using the known net values and 38% efficiency. The CO_2 emission from oil-fired generation can then be determined from the estimated heat values.

7.2.1 Heat Values and Net Values

Figure 7.10 shows the net electricity generated using oil from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. The 1973 crisis resulted in the great drop in using oil in electricity generation from 1945 GWh in 1974 to 800 GWh in 1975. Since deregulation in the mid 1980s, oil has not been used very much in electricity generation.

Figure 7.11 shows the estimated heat and net values in PJ for oil use in electricity for comparison. The estimated heat value is calculated from the 1974 to 2006 net values dividing by 38% efficiency. The estimated heat value is at a much higher level compared to the net value from 1974 to 1977. The difference in the two values is very small from 1980 to 2006 as the net values were either negative or close to zero.

Nearly 70% of New Zealand's electricity generation is from hydroelectricity. The water resource is susceptible to, in particular, the rainfall in the catchment areas of the lake that feed the river systems across which the dams have been built. The driest years for hydro were 1976, 1992, 2001, and 2003 [39]. These occurred at different stages of development of the New Zealand Electricity Market, from basically central control in 1992 to an uncapped spot market with no central control in 2001 and 2003 [39]. Some of the peaks from Figure 7.10 correlate to dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations. The smaller peak during in 2003, shows that the market period has seen a dampening of the use of oil during the dry years.

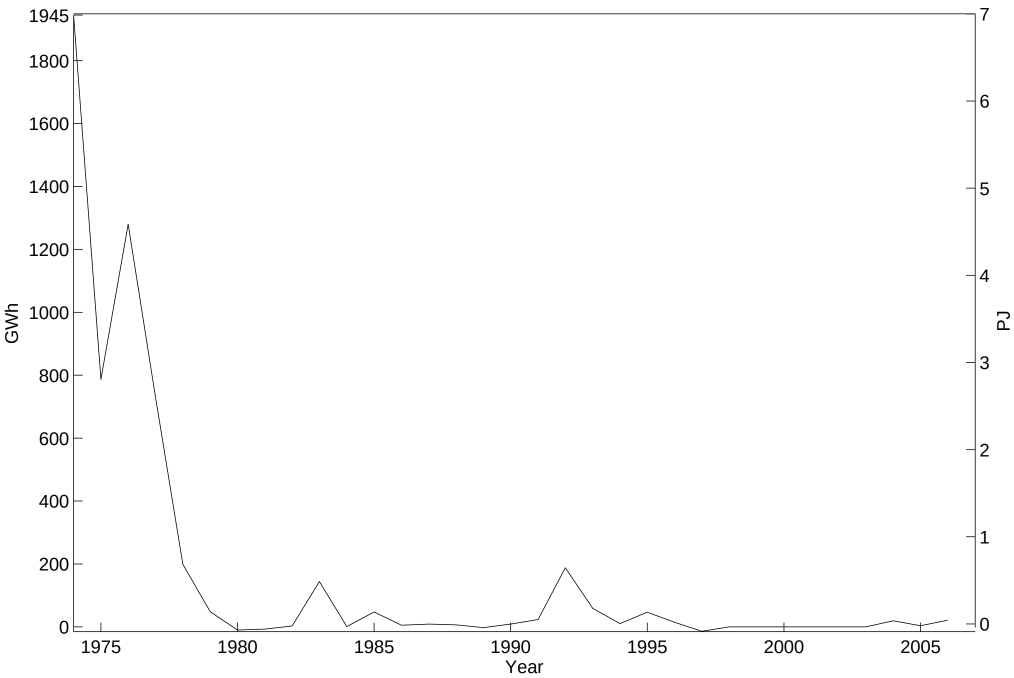

Figure 7.10 Net Electricity Generated from Oil in New Zealand

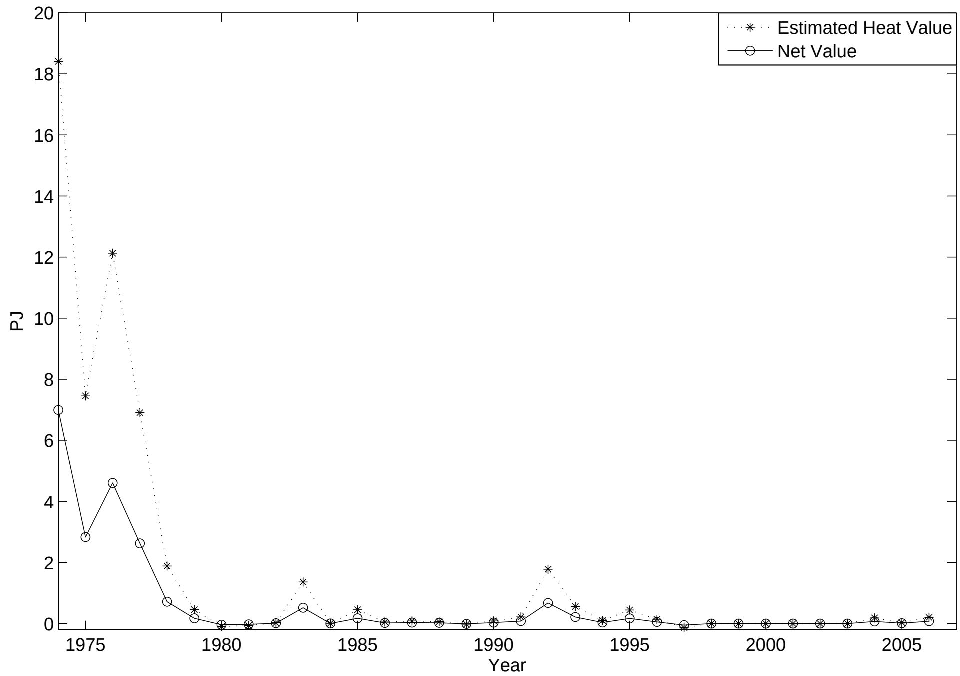

Figure 7.11 Comparison Between Estimated Heat and Net Value for Oil

7.2.2 CO_2 Emitted

Equation 5.3 showed that each PJ of oil used in electricity generation will produce 70.6 kt of CO_2. Using Equation 5.3 to convert the estimated heat values from 1974 to 2005, the estimated CO_2 emitted from oil use in electricity generation is calculated and shown in Figure 7.12. Oil's estimated CO_2 emission has dropped significantly from 1300 kt in 1974 to -6.68 kt in 1980. Oil is no longer largely used in electricity generation, but rather used in transportation. From 1980 to 2006, oil was not a major contributor in CO_2 emission in electricity generation.

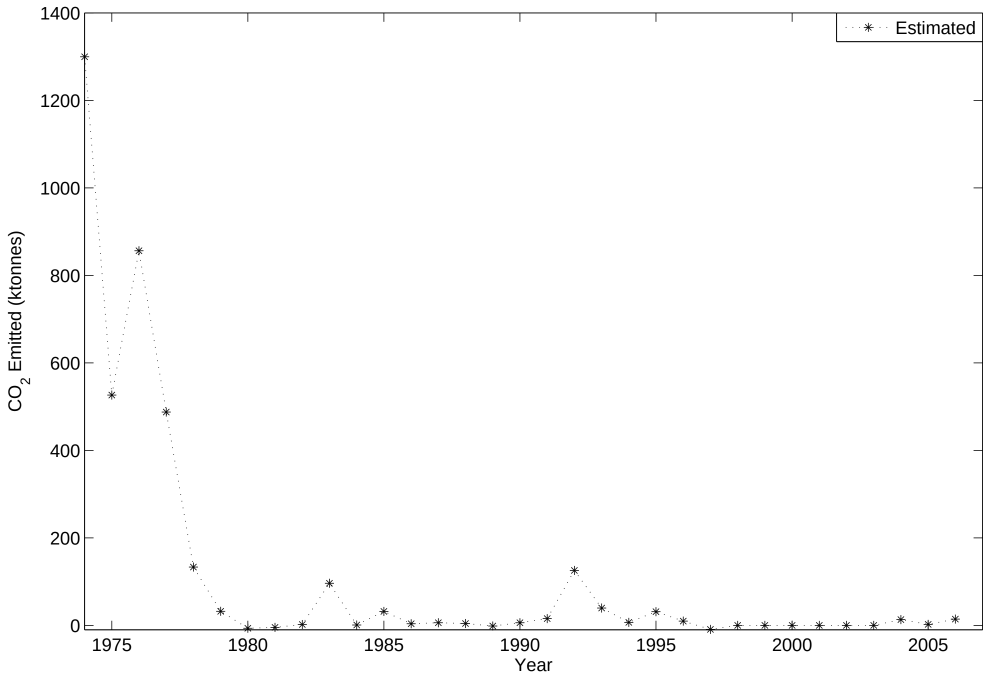

Figure 7.12 CO_2 Emissions from Electricity Generation Using Oil

Chapter 8

NATURAL GAS

In this chapter, the relationship between gas consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat value, net value, efficiency, and CO_2 emitted from gas use in electricity generation for New Zealand are also shown.

8.1 COMPARISON BETWEEN FOURTEEN COUNTRIES

Figure 8.1 shows the total gas consumption for the 14 countries from 1980 to 2004. A general increase in gas consumption for all countries from 1986 to 2004 can be seen. These increases reflect the impact from the oil crisis in 1973 and 1979, and the substitution of oil and coal by natural gas, a higher quality fuel. The total gas consumption is highest in the United States, while Russia has been the second highest consumer since 1992. The United Kingdom started off on the same scale as Canada, but surpassed it in 1995 and it became the third highest gas consumer in the world. Germany, Canada, Japan and Indonesia are very similar in gas consumption. Gas consumption of the other 12 countries is low compared to the United States and Russia. New Zealand was the third lowest in 1980, but has become the lowest gas consumer since 2002, due to the depletion in the Maui gas field, the main gas supply field.

Figure 8.2 shows the gas consumption per capita for the 14 countries. Russia and Canada were equally the highest gas consumers per capita from 1995 to 2003. The United States was the third highest. The United Kingdom, Germany, New Zealand and Australia were very similar and were the next highest. New Zealand, despite being the lowest in total gas consumption, was once the fourth highest gas consumer per capita. From 11.96 (GJ/person) in 1980 to a steep increase to 50.8 (GJ/person) in 1986, it peaked at 64.5 (GJ/person) in 2001, then sustained a large drop to 41 (GJ/person) by 2004. This pattern represents the time line from the full commissioning of the Maui

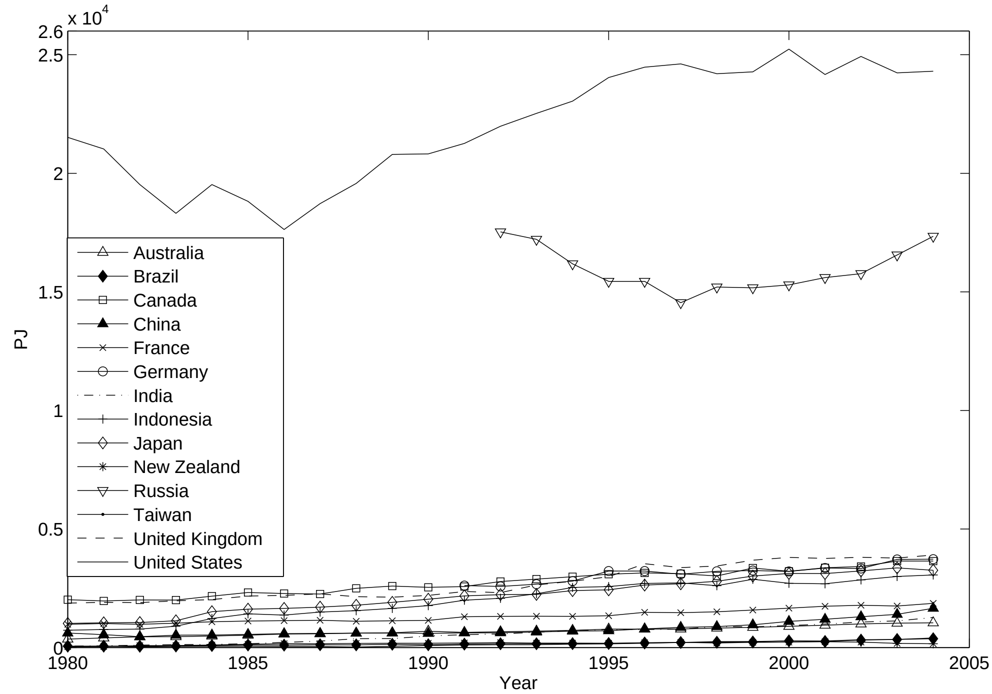

Figure 8.1 Gas Consumption for the 14 Countries

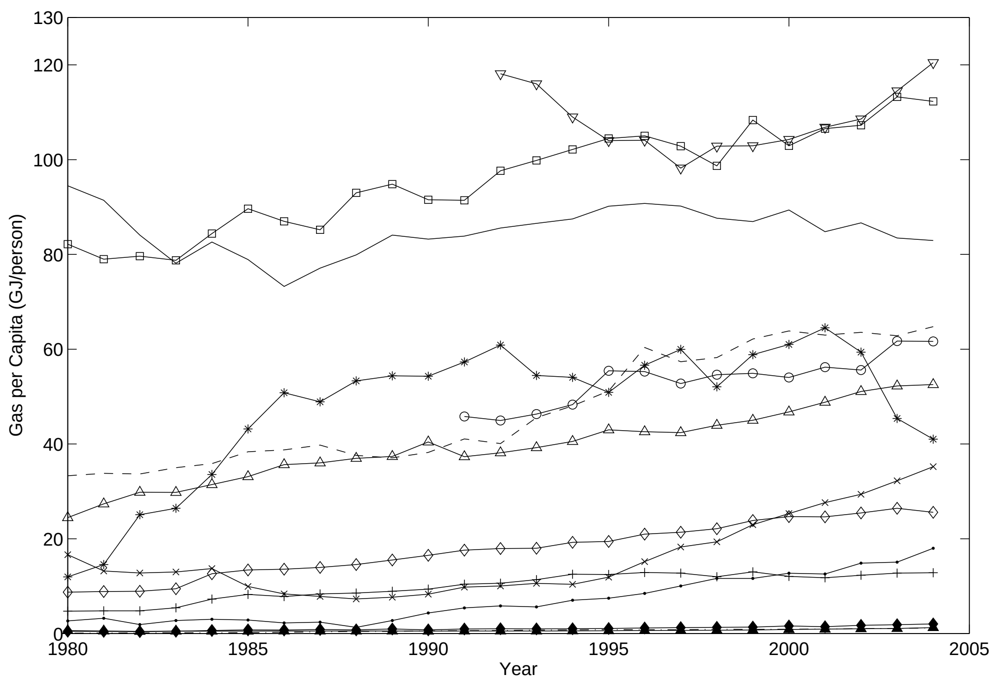

Figure 8.2 Gas Consumption per Capita for the 14 Countries

gas field in 1979, the growth and maturing stage to its peak in 2001 and subsequent decline due to the expected exhaustion of the field. Natural gas was used extensively for electricity generation during the growth and maturing stages. Apart from Russia, the other four developing countries are the lowest.

8.1.1 Energy Intensity

Figure 8.3 shows the gas intensity for the selected countries. The gas intensities for all the countries apart from Indonesia, New Zealand and Russia have been in decline or stagnant from 1980 to 2004. Indonesia and New Zealand's gas intensity peaked around 1985, but have since declined linearly. Russia has a very high gas intensity compared to all the other 13 countries. From the available data, Russia has peaked in 1994, but has dropped dramatically from 17.5 (MJ/International Dollar) in 1998 to 11.9 (MJ/International Dollar) in 2004. The decreasing trends reflects more efficient use of gas in the production of GDP. Brazil had a very constant gas intensity. It was the lowest from 1980 to 1998, but China's decreasing trend dropped below Brazil in 1999, making China now the lowest gas intensity country amongst the 14 countries.

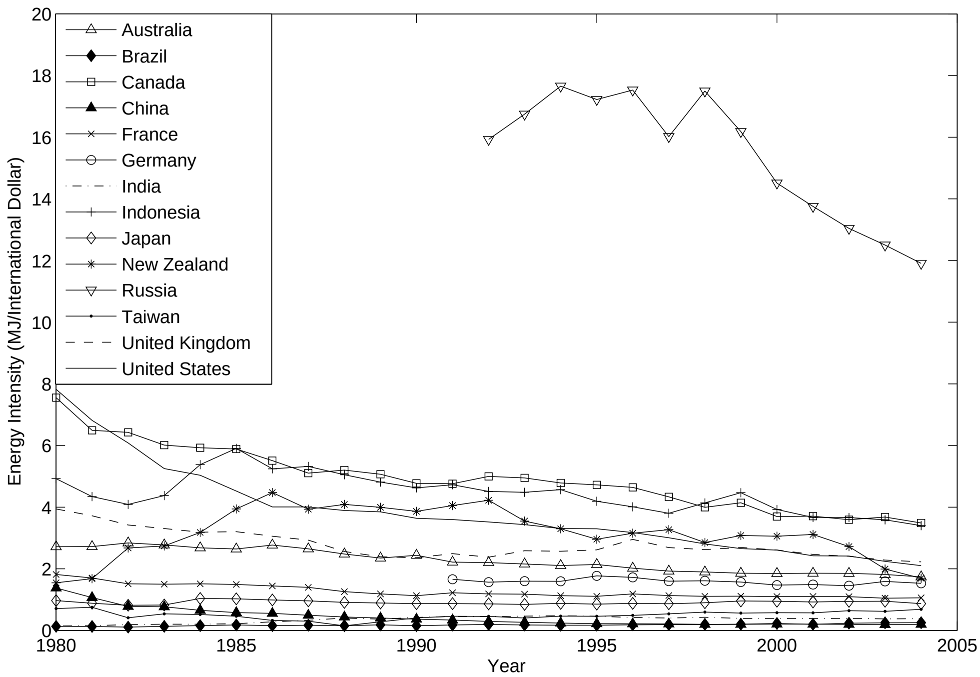

Figure 8.3 Gas Intensity for the 14 Countries Using PPP

8.1.2 Energy Intensity Curves

The gas intensity curves for the 14 countries are shown in Figure 8.4. The industrialized countries have higher incomes per capita. Therefore these plots are towards the right portion of Figure 8.4. The developing countries with lower income per capita are in the left portion of Figure 8.4.

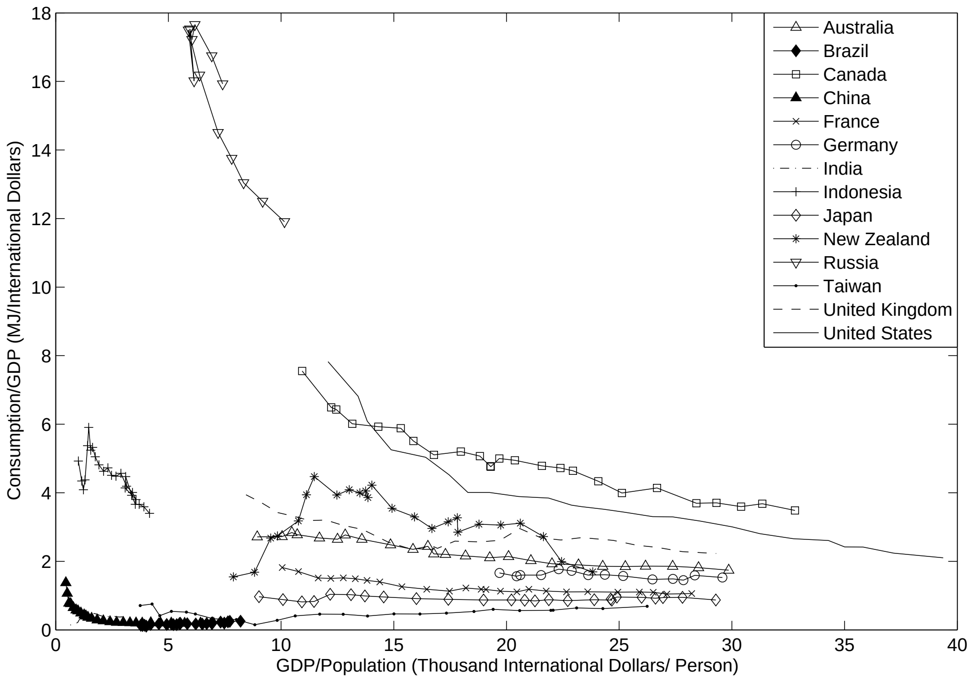

Figure 8.4 Gas Intensity Curve for the 14 Countries Using PPP

Figure 8.5 and Figure 8.6 show the gas intensity curves for the industrialized countries and developing countries respectively. For all industrialized countries apart from New Zealand's incline and peak, as GDP per capita increases, consumption of gas in producing that GDP decreases. Thus, the gas intensities for all of the industrialized countries have declined relative to economic growth.

For the developing countries, China, India, and Brazil, gas intensity has also declined relative to economic growth. Indonesia inclined and peaked, but then declined. In Russia, gas intensity initially increased with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has since increased with lower gas intensity.

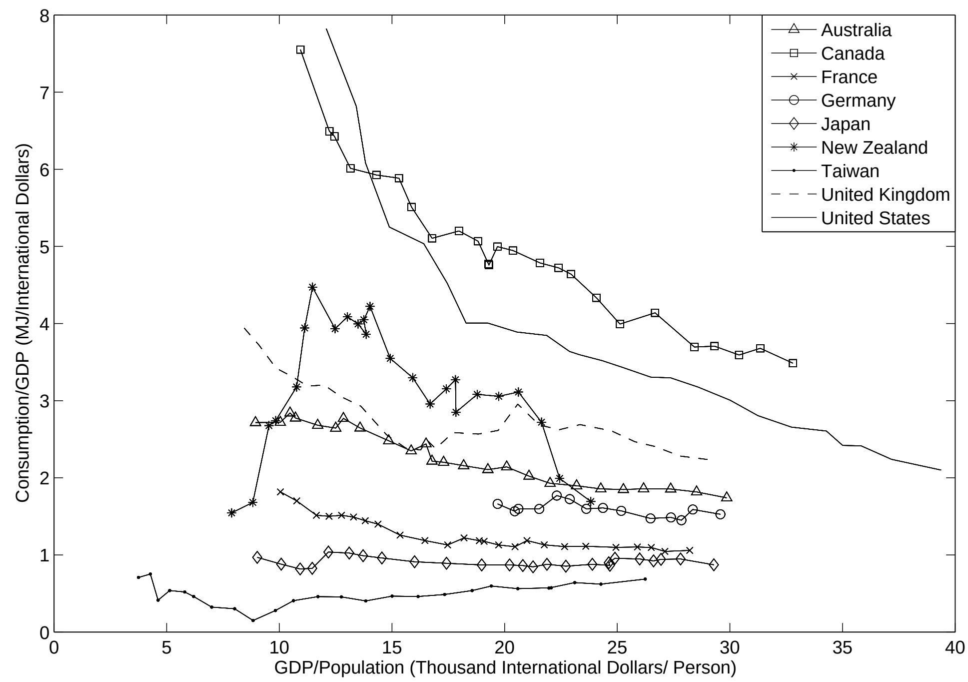

Figure 8.5 Gas Intensity Curve for Industrialized Countries Using PPP

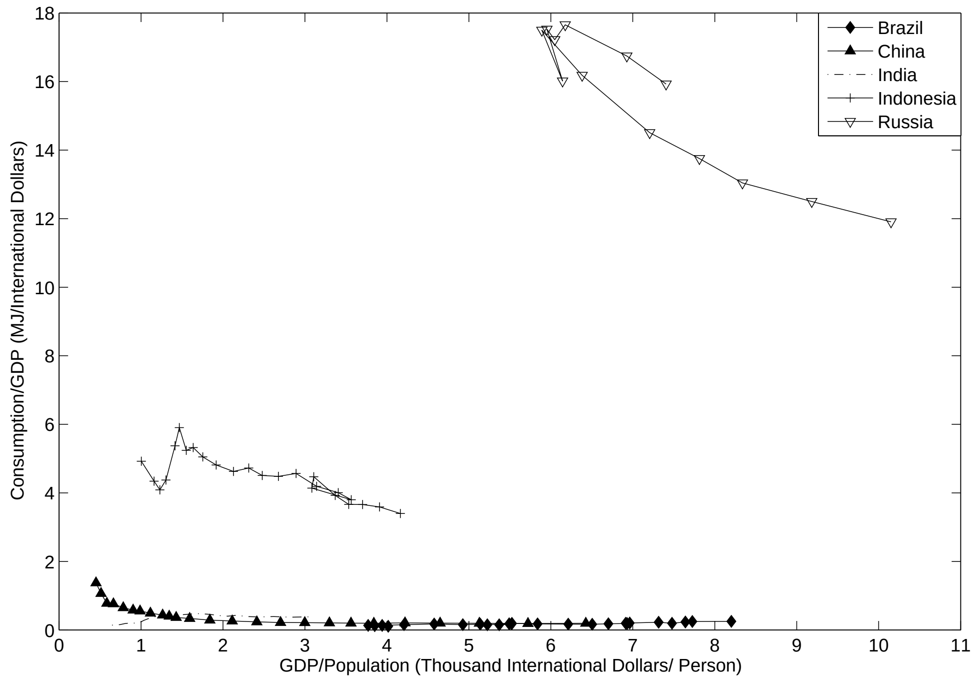

Figure 8.6 Gas Intensity Curve for Developing Countries Using PPP

8.1.3 Energy Intensity Factor

The gas intensity factors for the 14 countries are shown in Figure 8.7. These are relatively smooth declining trends over time, apart from Indonesia and Russia. Russia had the highest gas intensity factor from 1992 to 2004, followed by Indonesia. These two countries are at a much higher scale compared to the other 12 countries. China started off at a high value, but has decreased rapidly and converged with the other 11 countries. From 1992 to 2004, the differences in gas intensity factor over all the countries, except Indonesia and Russia, are small when compared to the previous period.

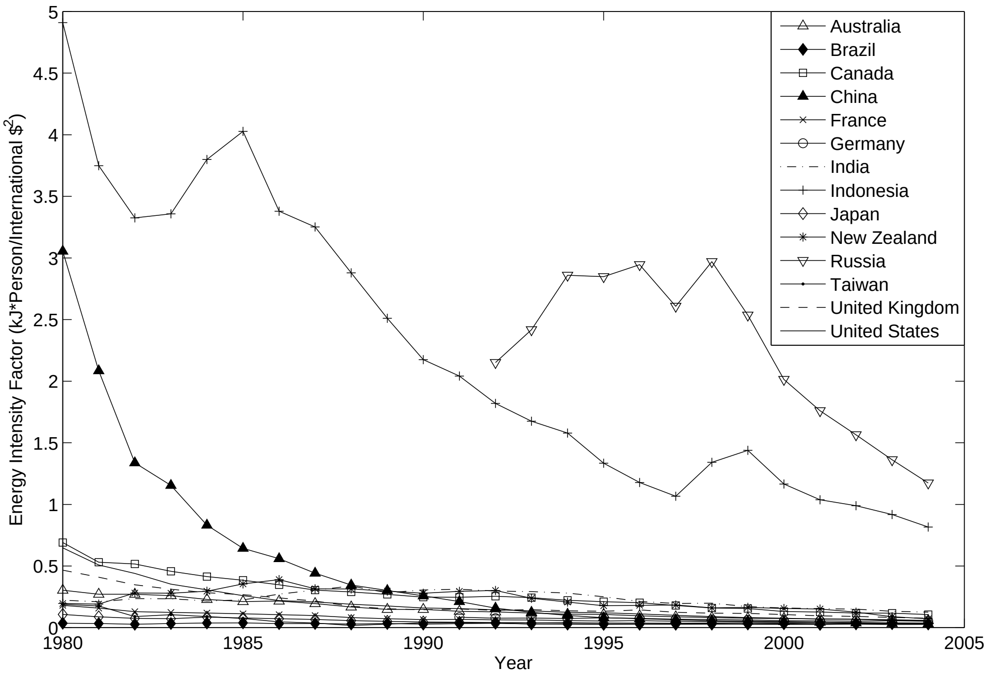

Figure 8.7 Gas Intensity Factor for the 14 Countries Using PPP

The small variations in the pattern of gas intensity factor for these countries are shown in Figure 8.8 and Figure 8.9 for the industrialized and developing countries respectively. All the industrialized countries were in decline except for New Zealand which increased from 1980 to 1986. New Zealand peaked in 1986, surpassed Canada and became the highest up till 1992. This peak in New Zealand's gas intensity factor is an indicator at that time, 1986, that gas's intensity curve and hence penetration into the New Zealand economy was making the transition from growth to a maturing phase. In this it has lagged all the other countries studied, except for Russia, which peaked in 1998. In general, the gas intensity factors for the industrialized countries have decreased over the years and converged.

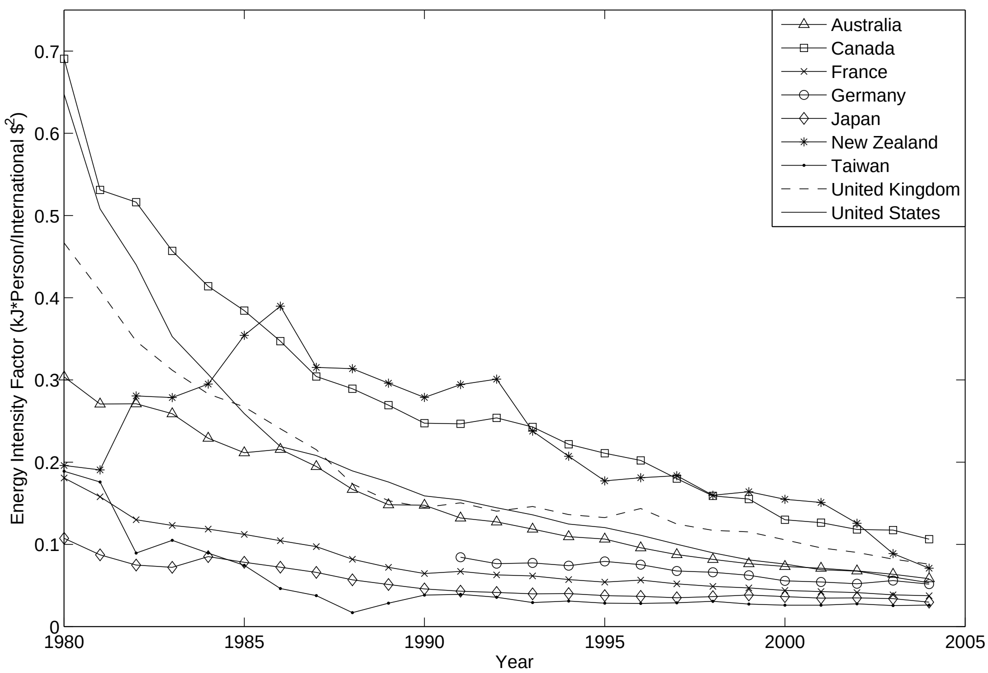

Figure 8.8 Gas Intensity Factor for Industrialized Countries Using PPP

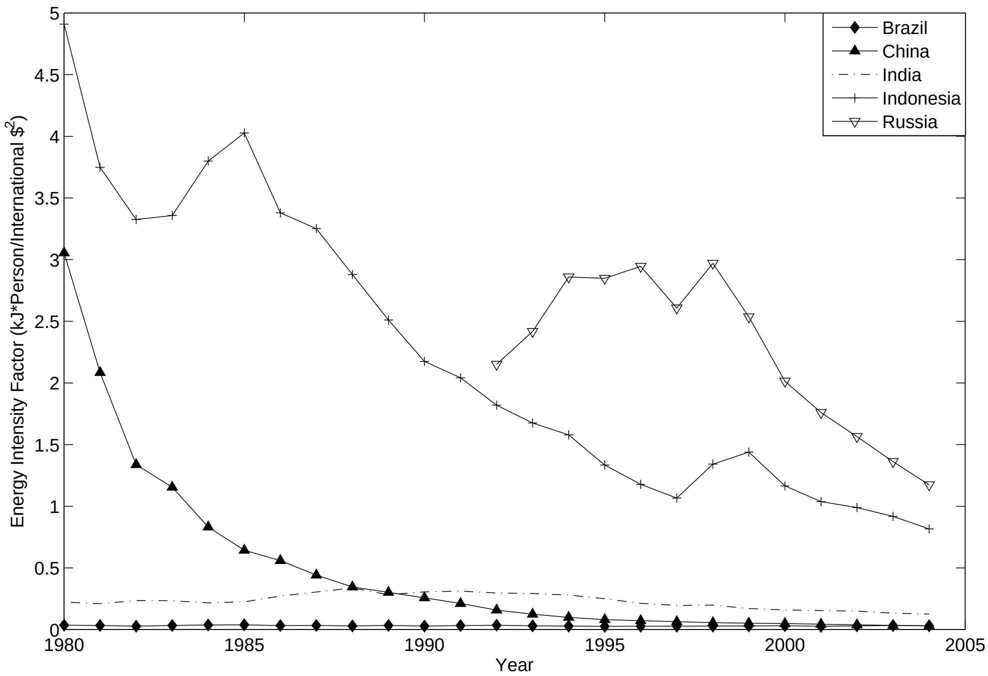

Figure 8.9 Gas Intensity Factor for Developing Countries Using PPP

For the developing countries, Indonesia's gas intensity factor had the largest drop from 4.9 (kJ/International $\$^2$) in 1980 to 0.82 (kJ/International $\$^2$) in 2004. Overall, the gas intensity factors for Brazil, China, and India have converged in a similar manner to those for the industrialized countries. Russia and Indonesia's gas intensity factors are in the process of getting closer to the other developing countries.

8.2 NATURAL GAS USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

Gas is used for base load electricity generation. Prior to 1970, all gas used in New Zealand was a secondary fuel derived from coal and oil [14]. Natural gas became available in 1971. Data for net electricity generation by fuel type came from the New Zealand MED [36]. The data is available in both GWh and PJ for the period 1974 to 2006. The heat value for gas in electricity generation was only available from 1995 to 2006 in the Energy Supply and Demand Balance Tables [37]. The weighted average efficiency worldwide for natural gas generation is 45% [38], and the average efficiency for New Zealand found from the heat and net values from 1995 to 2006 was 36%.

8.2.1 Heat Values and Net Values

Figure 8.10 shows the net electricity generated using gas from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. The gas use in electricity generation has increased linearly with variations about this trend. The peaks from Figure 7.10 generally correlate to dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations.

Figure 8.11 shows the real heat, estimated heat and net values in PJ for gas use in electricity for comparison. The real heat value is available from 1995 to 2006, where as the net value is from 1974 to 2006 and the estimated heat value is determine by dividing the net values by 36%. The heat value is at a much higher level compared to the net value.

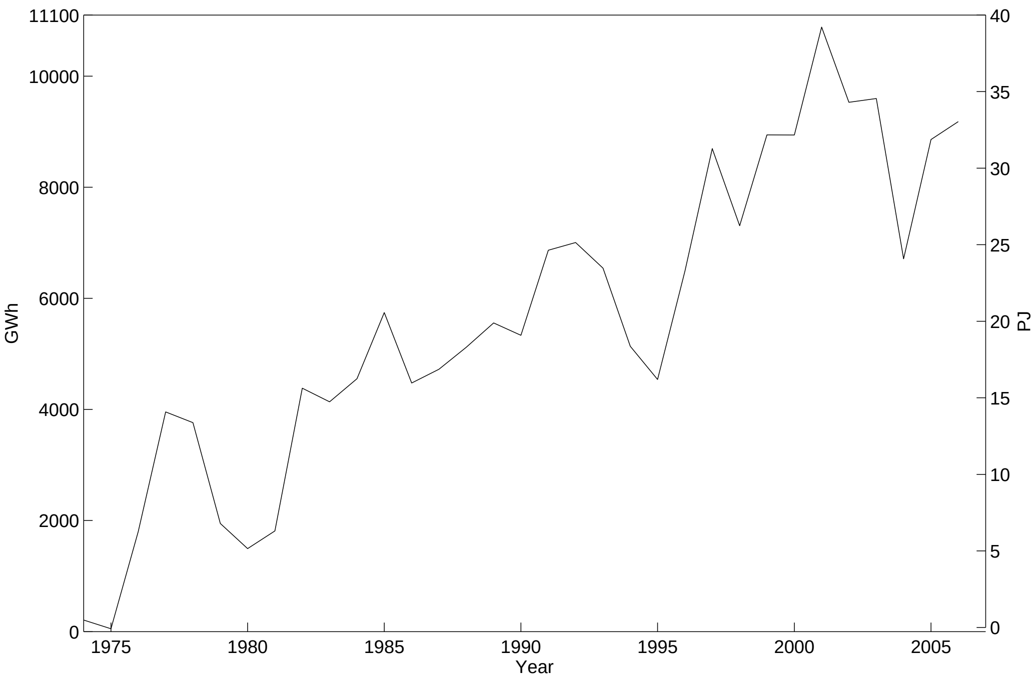

Figure 8.10 Net Electricity Generated from Gas in New Zealand

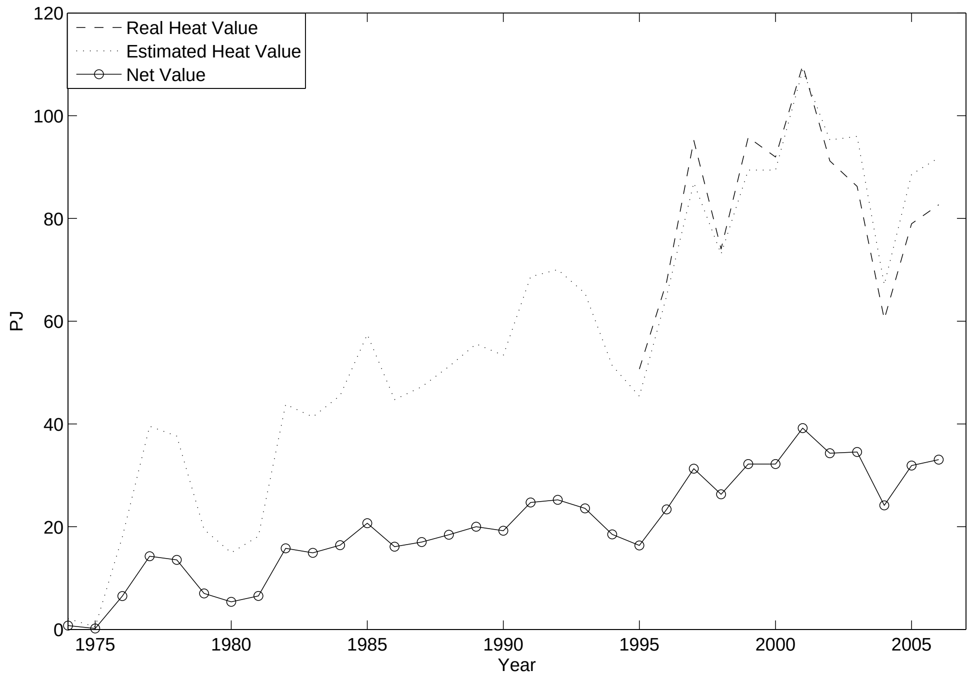

Figure 8.11 Comparison Between Heat and Net Value for Gas

8.2.2 Efficiency

The efficiency of gas use in electricity generation in New Zealand plants from 1995 to 2006 is shown in Figure 8.12. This is the ratio of the net to heat values of Figure 8.11. The average efficiency for New Zealand from 1995 to 2006 was 36%. The efficiency has increased from 32.2% in 1995 to 40.4% in 2005. The weighted average efficiency worldwide for natural gas generation is 45% [38].

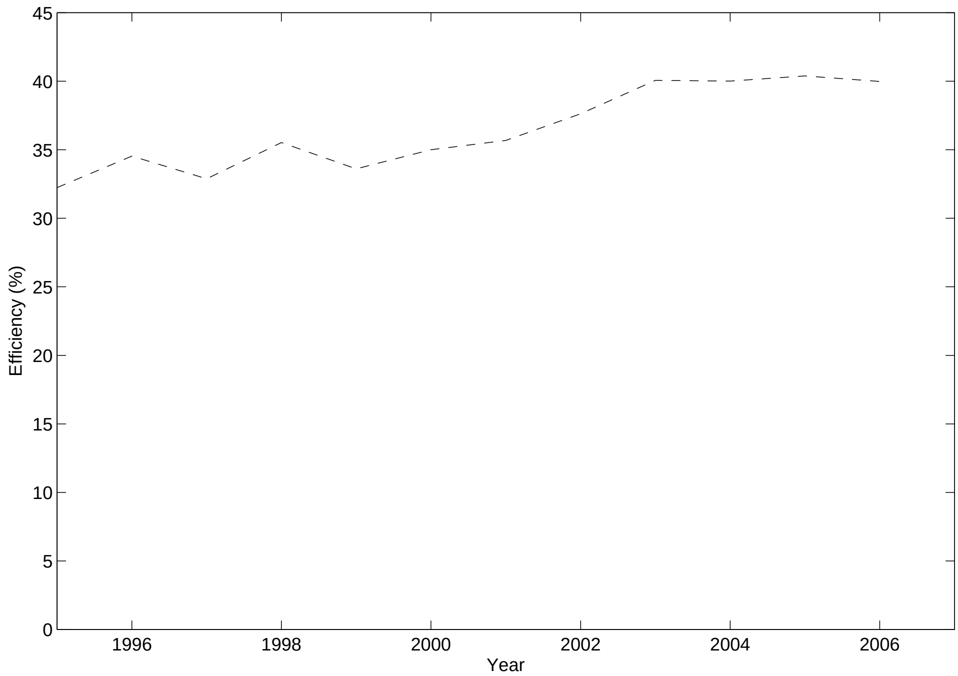

Figure 8.12 Gas Efficiency in Electricity Generation

8.2.3 CO_2 Emitted

Equation 5.4 showed that each PJ of gas used in electricity generation will produce 49.9 kt of CO_2. Using Equation 5.4 to convert the heat values from 1995 to 2006 and estimated heat values from 1974 to 2006, the CO_2 emitted from gas use in electricity generation is shown in Figure 8.13. Despite the environmental concerns of global warming and the Kyoto protocol, there is no significant reduction in emission of CO_2 from gas use in electricity generation.

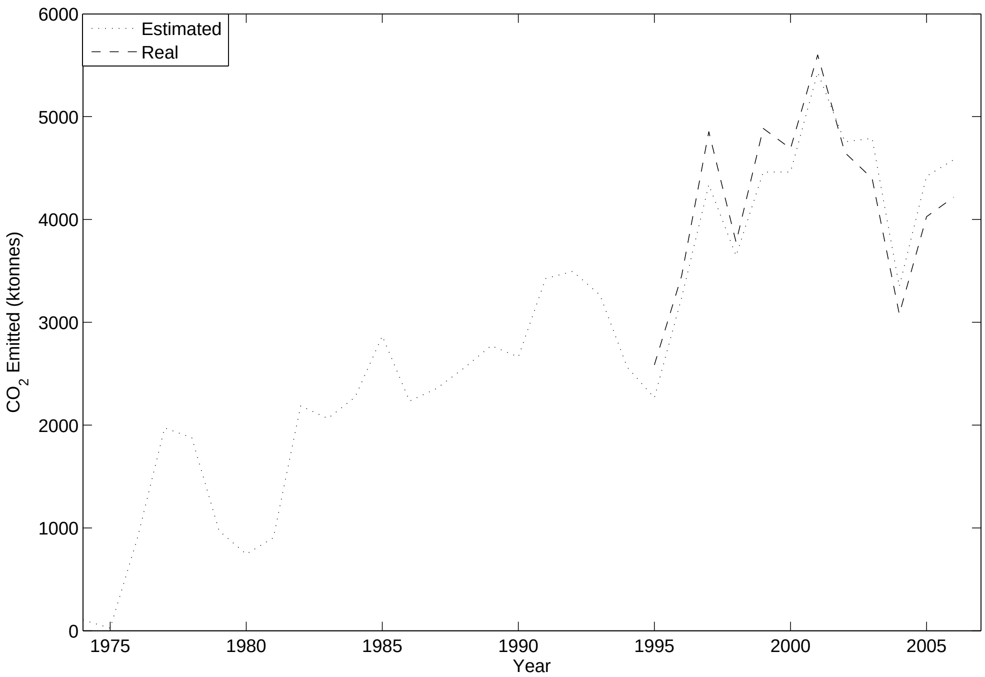

Figure 8.13 CO_2 Emissions from Electricity Generation Using Gas

Chapter 9

NET HYDROELECTRICITY

In this chapter, the relationship between hydro consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat values, net values and efficiency from hydro use in electricity generation for New Zealand are also shown.

9.1 COMPARISON BETWEEN FOURTEEN COUNTRIES

Figure 9.1 shows the net hydroelectric power consumption for the 14 countries from 1980 to 2004. Net consumption excludes the energy consumed by the generating units and also excludes generation from hydroelectric pumped storage [23]. Canada has the highest hydro consumption. Countries apart from China and Brazil had a fairly constant consumption with some variation throughout this period. China's rapid increase in hydro consumption surpassed Brazil in 2004, and became the second highest hydro consuming country in the world. Brazil's consumption has been relatively linear from 1980 to 2000 with a drop in 2001, but increased linearly again till 2004. The United States was once the highest hydro consuming country before Canada surpassed it in 1985. The pattern had a big variation and was second highest from 1985 to 1996. With a drop in 1999, and growth of hydro in Brazil and China, the United States became fourth largest hydro consumer in the world.

Figure 9.2 shows the hydro consumption per capita for the 14 countries. Canada had the highest hydro consumption per capita from 1980 to 2004. New Zealand had the second highest. Hydro consumption in the other 12 countries has been low and constant compared to Canada and New Zealand.

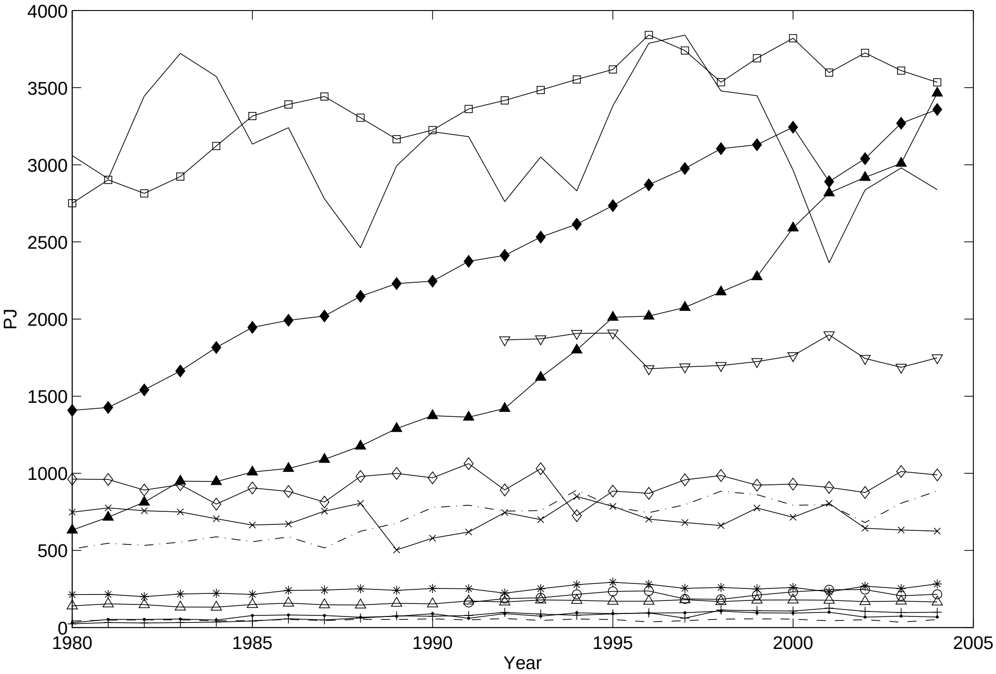

Figure 9.1 Hydro Consumption for the 14 Countries

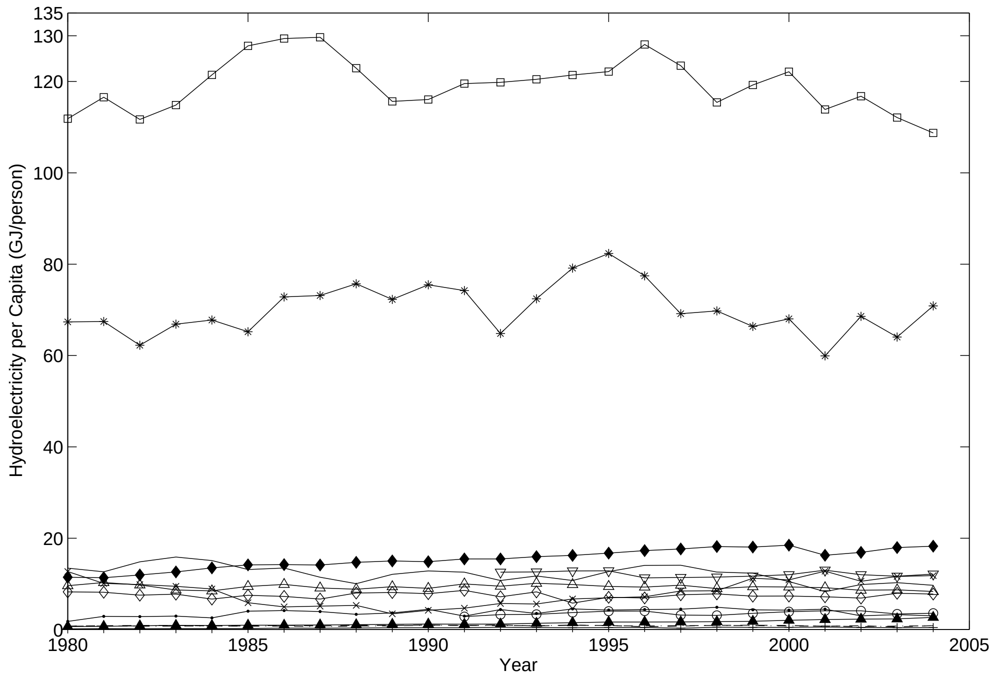

Figure 9.2 Hydro Consumption per Capita for the 14 Countries

9.1.1 Energy Intensity

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. Figure 9.3 shows the hydro intensity for these countries. The hydro intensities for all the countries have been in decline or stagnant from 1980 to 2004. Canada and New Zealand have had a very high hydro intensity compared to all other 12 countries. Brazil has the third highest hydro intensity in the world.

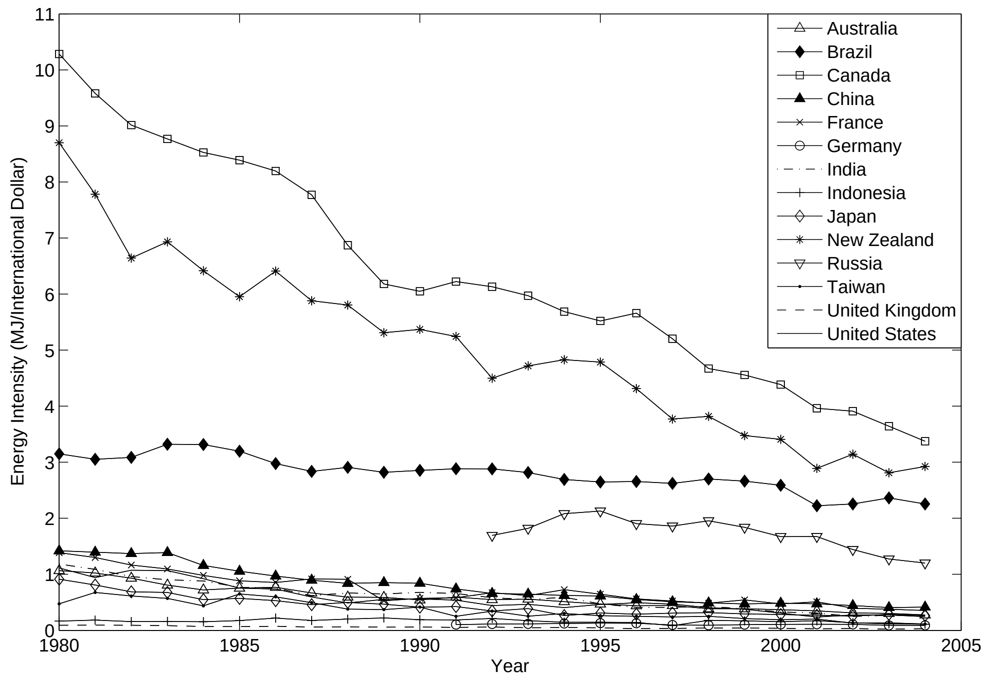

Figure 9.3 Hydro Intensity for the 14 Countries Using PPP

9.1.2 Energy Intensity Curves

The hydro intensity curves for the 14 countries are shown in Figure 9.4. The industrialized countries have higher incomes per capita. Therefore these plots are towards the right portion of Figure 9.4. The developing countries with lower income per capita are in the left portion of Figure 9.4.

Figure 9.5 and Figure 9.6 show the hydro intensity curves for the industrialized countries and developing countries respectively. For all industrialized countries apart from Canada and New Zealand, as GDP per capita increases, consumption of hydro in producing that GDP decreases. Canada and New Zealand have been in decline, but at a higher level compared to the other 12 countries. Thus, the hydro intensities for all of the industrialized countries have declined relative to economic growth.

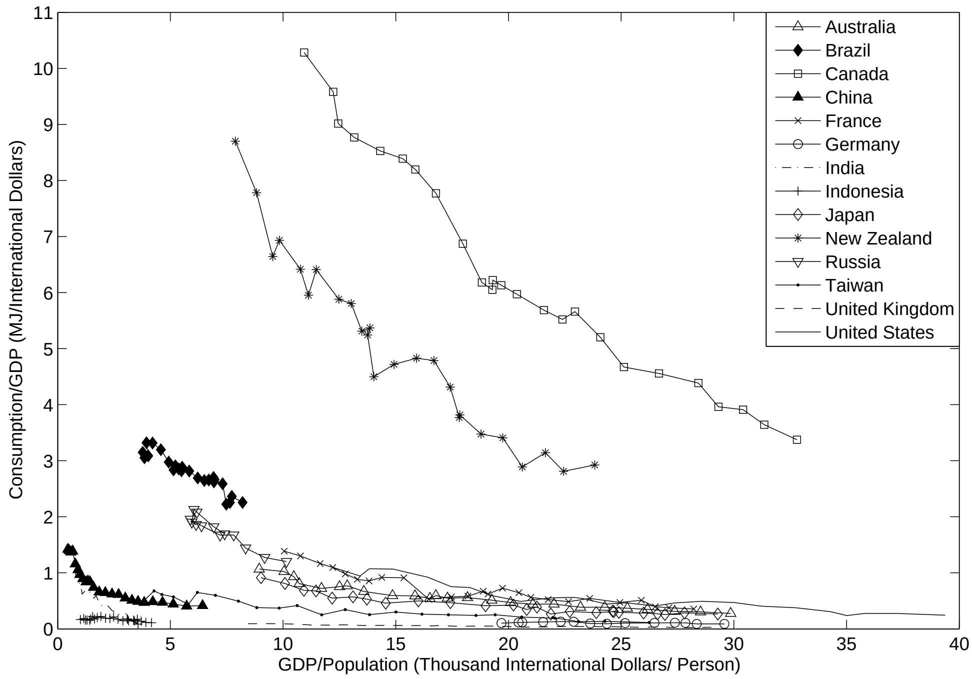

Figure 9.4 Hydro Intensity Curve for the 14 Countries Using PPP

For the developing countries, Indonesia's hydro consumption has been constant, while Brazil, China and India's have declined relative to economic growth. In Russia, the hydro intensity has initially increased with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has since increased with lower hydro intensity.

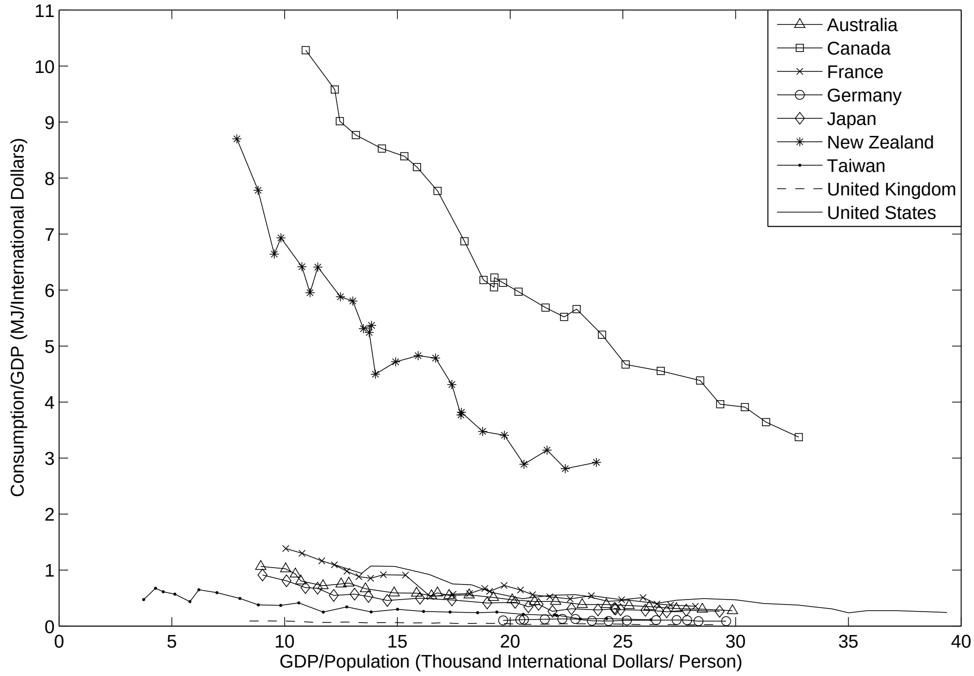

Figure 9.5 Hydro Intensity Curve for Industrialized Countries Using PPP

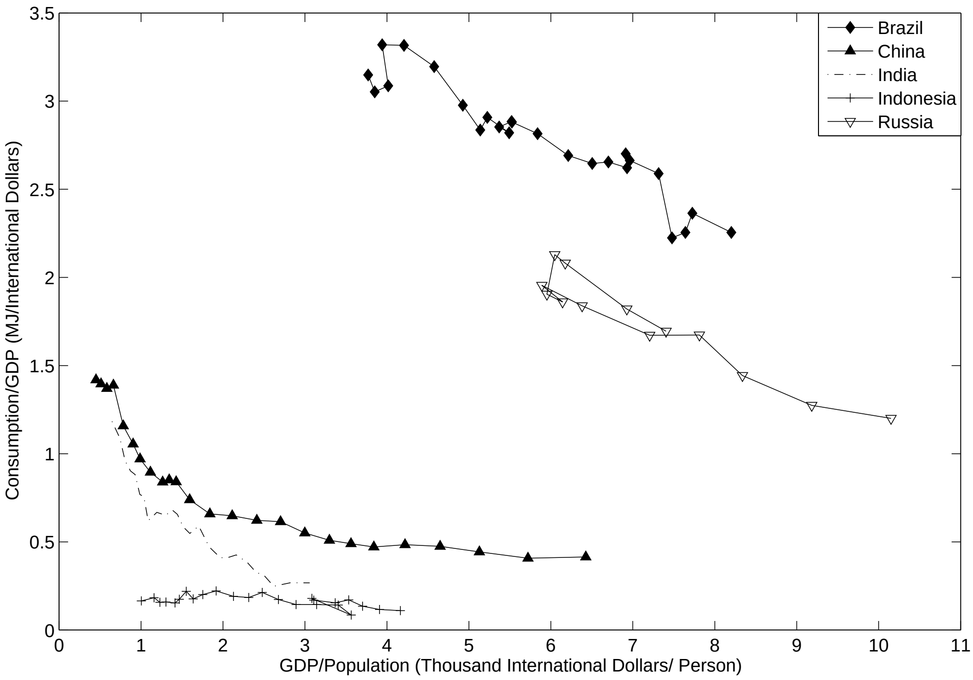

Figure 9.6 Hydro Intensity Curve for Developing Countries Using PPP

9.1.3 Energy Intensity Factor

The hydro intensity factors for the 14 countries are shown in Figure 9.7. These are relatively smooth declining trends over time, apart from China and India. China had the highest hydro intensity factor from 1980 to 1990, followed by India. These two countries are at a much higher scale compared to the other 12 countries. China's hydro intensity factor has decreased rapidly and converged with the other 13 countries.

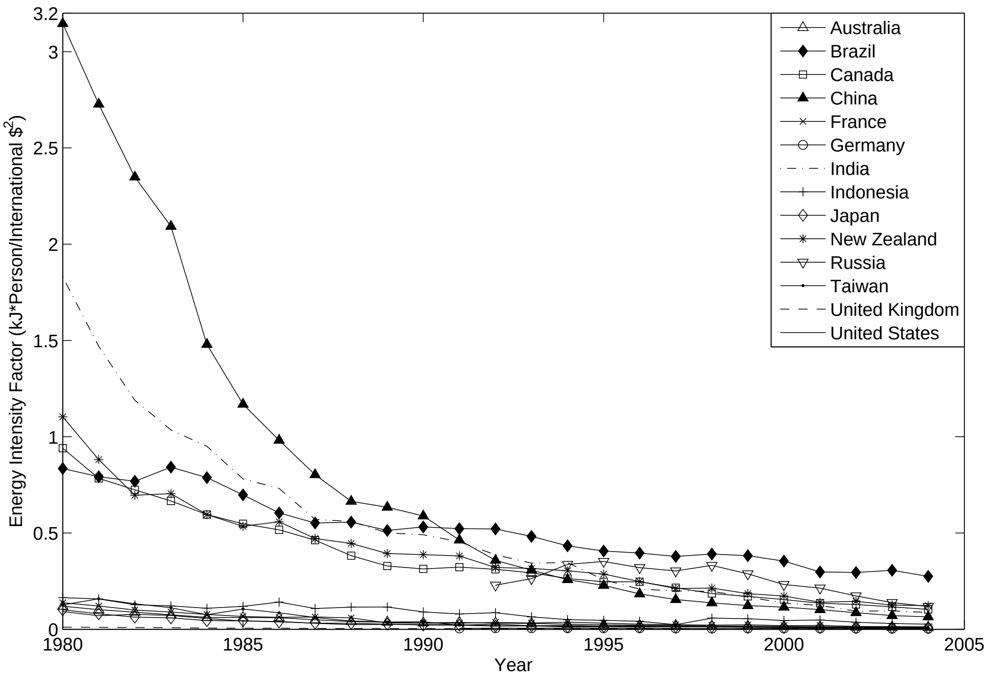

Figure 9.7 Hydro Intensity Factor for the 14 Countries Using PPP

The small variations in the pattern of hydro intensity factors for these countries are shown in Figure 9.8 and Figure 9.9 for the industrialized and developing countries respectively. All the industrialized countries were in decline from 1980 to 2004. New Zealand and Canada are highest equal and decrease from a higher starting value. In general, the hydro intensity factors for the industrialized countries have decreased over the years and converged.

For the developing countries, China had the largest decrease from 3.15 (kJ/International $\$^2$) to 0.065 (kJ/International $\$^2$) from 1980 to 2004. Indonesia's hydro intensity factor was the lowest from 1980 to 2004. Overall, the hydro intensity factors have converged in a similar manner to those for the industrialized countries.

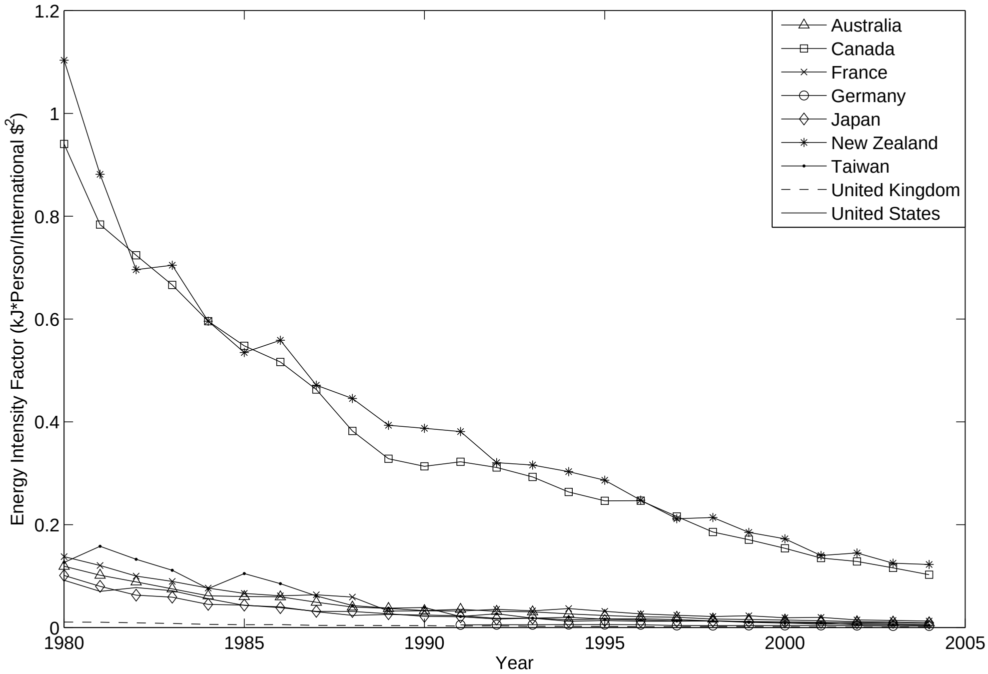

Figure 9.8 Hydro Intensity Factor for Industrialized Countries Using PPP

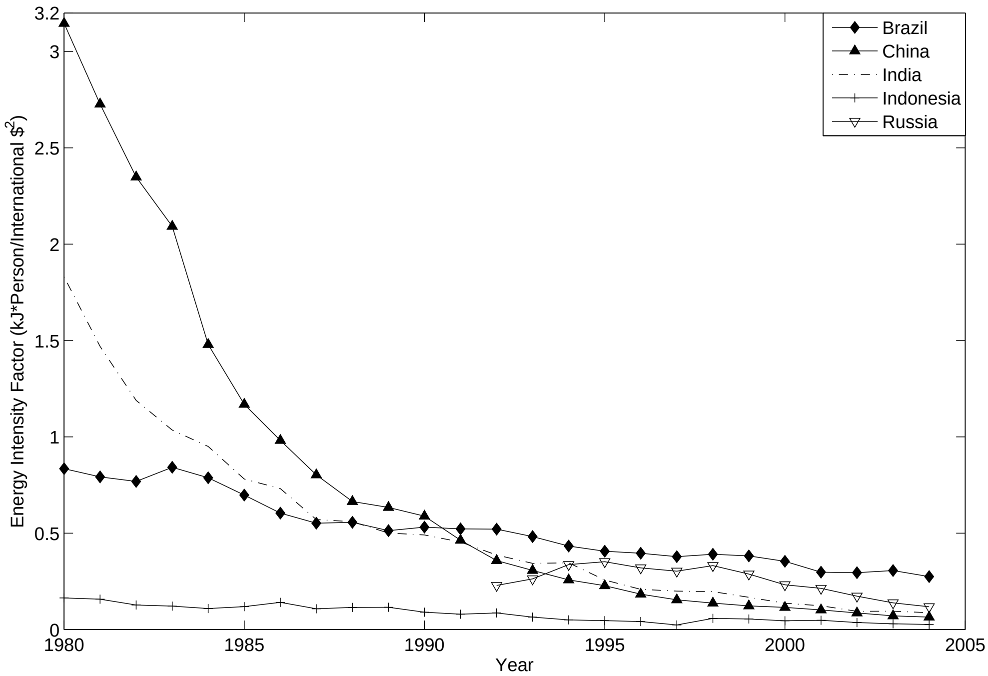

Figure 9.9 Hydro Intensity Factor for Developing Countries Using PPP

9.2 HYDRO USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

Hydro is used for base load electricity generation. 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. The driest years for hydro were 1976, 1992, 2001, and 2003 [39]. Data for net electricity generation by fuel type came from the New Zealand MED [36]. The data is available in both GWh and PJ for the period 1974 to 2006. The supply for hydro in electricity generation was only available from 1995 to 2006 in the Energy Supply and Demand Balance Tables [37].

No CO_2 emissions are calculated for hydro, as only the energy conversion process is considered, not the full life cycle.

9.2.1 Supply Values and Net Values

Figure 9.10 shows the net electricity generated using hydro from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. The hydro use in electricity generation has increased linearly with variations about this trend up to about 1995. It has been relatively constant since then. The troughs from Figure 9.10 generally correlate to dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations.

Figure 9.11 shows the supply and net values in PJ for hydro use in electricity for comparison. The supply values are available from 1995 to 2006, whereas the net values are from 1974 to 2006. The supply values are similar to the net values.

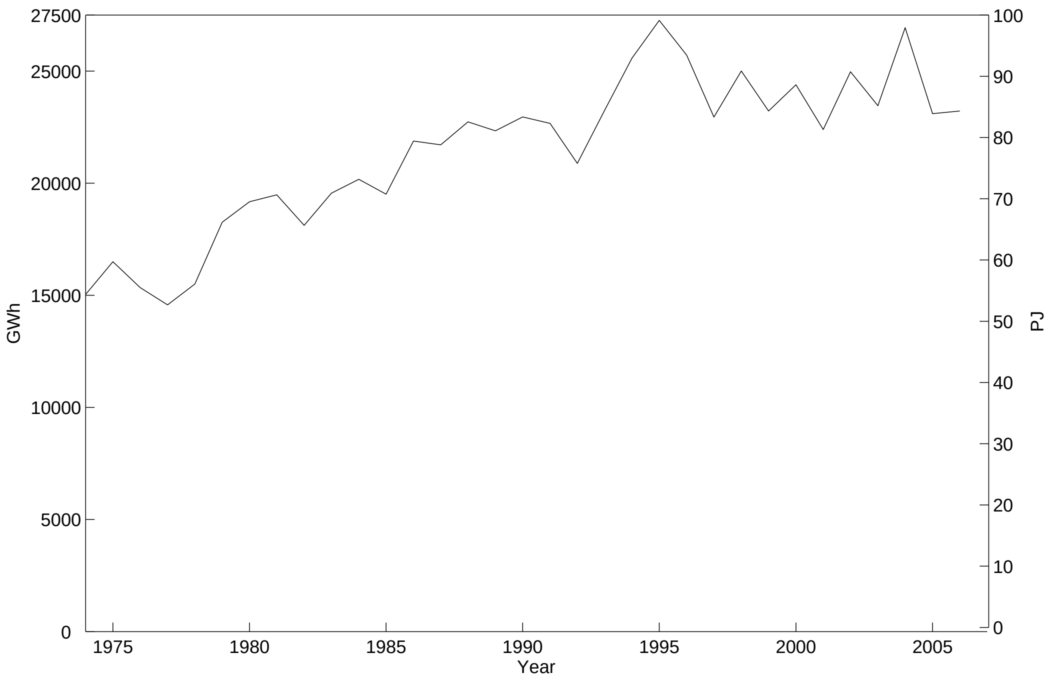

Figure 9.10 Net Electricity Generated from Hydro in New Zealand

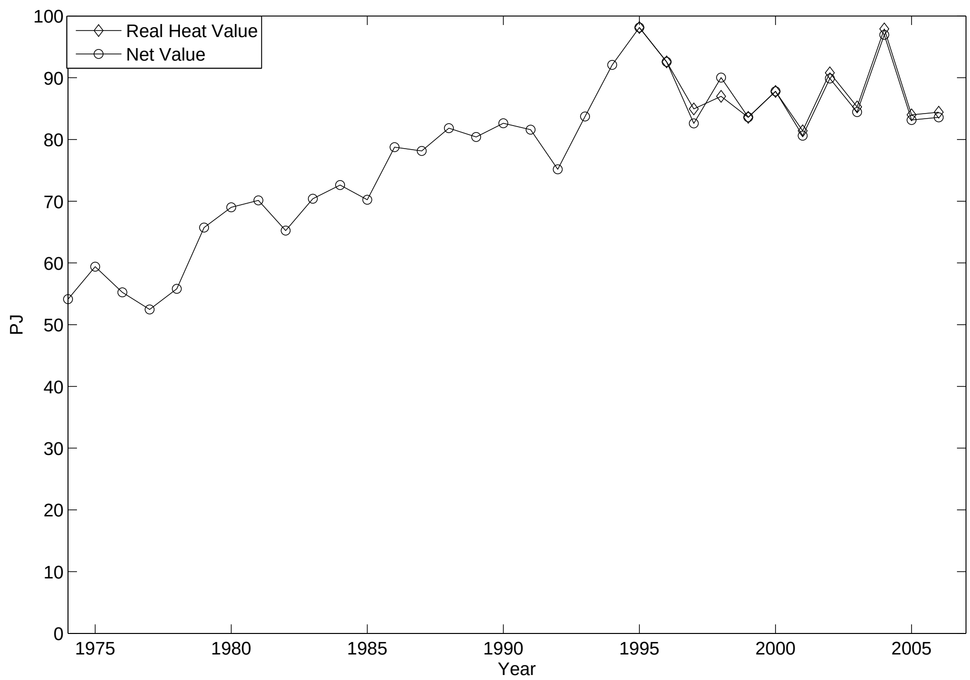

Figure 9.11 Comparison Between Supply and Net Value for Hydro

9.2.2 Efficiency

The efficiency of hydro use in electricity generation in New Zealand plants from 1995 to 2006 is shown in Figure 9.12. This is the ratio of the net to supply values of Figure 9.11. Apart from the two values 97.26% and 103.5% in 1997 and 1998 respectively, the efficiency throughout this period is fairly constant around 99% to 100%. The anomaly of 103.5% in 1998 maybe due to errors in the data collected by the New Zealand MED [37].

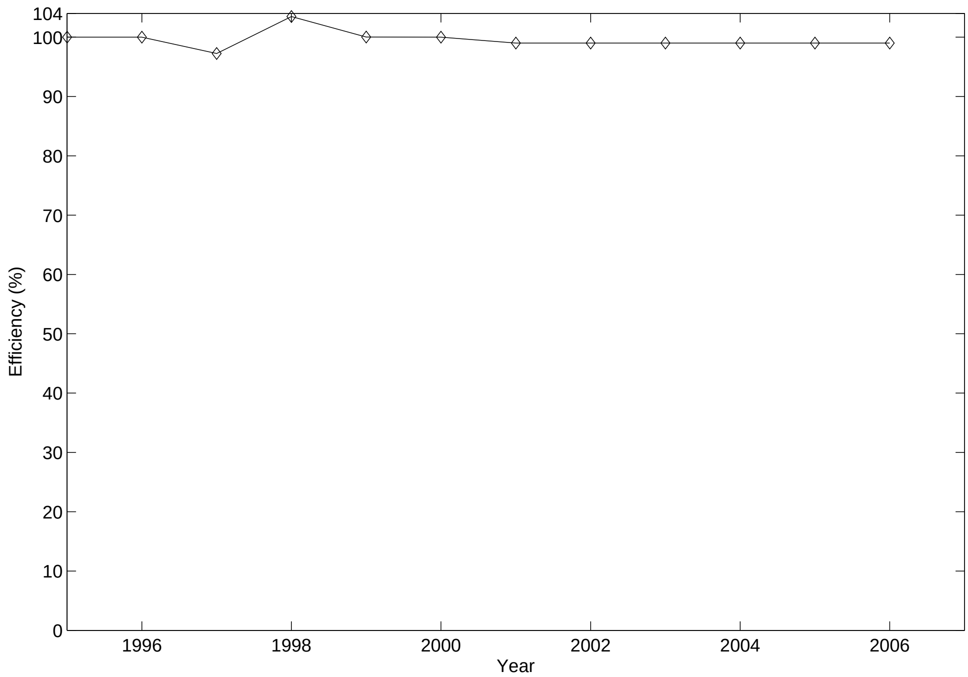

Figure 9.12 Hydro Efficiency in Electricity Generation

Chapter 10

NET OTHER RENEWABLE

In this chapter, the relationship between the consumption of other renewables, GDP and population of the selected countries is analyzed. EIA [23] includes geothermal, solar, wind, and wood and waste electric power consumption as other renewables. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Heat value, net value and efficiency from geothermal and wind use in electricity generation for New Zealand are also shown.

10.1 COMPARISON BETWEEN THIRTEEN COUNTRIES

There is no data available for Taiwan's other renewable consumption. Figure 10.1 shows the net other renewable consumption for the 13 countries from 1980 to 2004. Net consumption excludes the energy consumed by the generating units [23]. China's data was only available from 1994 to 2004, India's data was only available from 1986 to 2004 and the United Kingdom's data was only available from 1984 to 2004.

The United States has the highest other renewable consumption. After 1980, it experienced phenomenal growth in the water-dominated segment of the geothermal industry [40]. The sharp increase in the number of new water-dominated plants in 1988 and 1989 resulted from developers rushing to complete projects before expiration of SO-4 contracts and available tax credits [40]. This reflects the dramatic step increase in other renewable consumption in 1989.

Japan's consumption had a smaller step increase in 1982 and continued increasing up to 2003, and then dropped in 2004. Germany has increased and surpassed Japan in 2001, making it the second highest geothermal consuming country in the world. Countries apart from the United States, Germany and Japan had a small increase in other renewable consumption throughout this period. Overall, the 13 country's other renewable consumptions are in a growth phase.

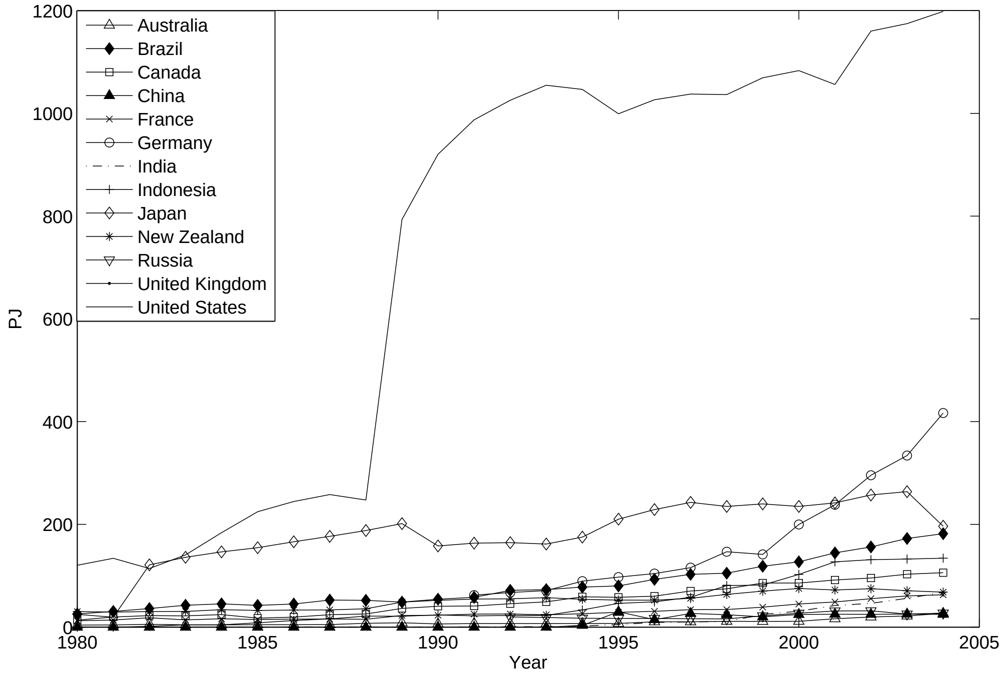

Figure 10.1 Other Renewable Consumption for the 13 Countries

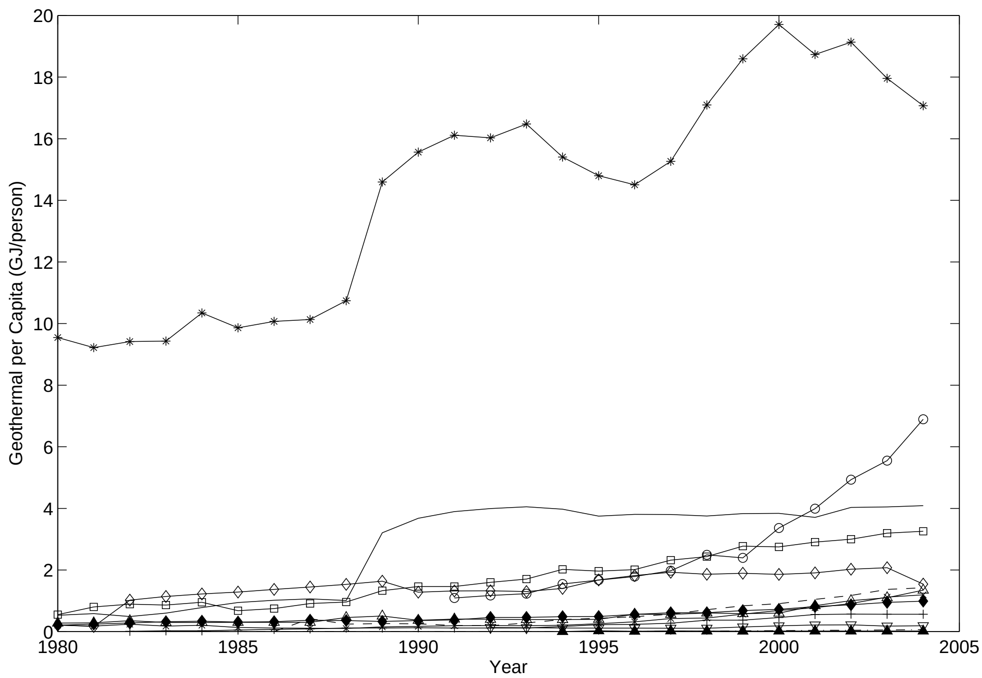

Figure 10.2 Other Renewable Consumption per Capita for the 13 Countries

Figure 10.2 shows the other renewable consumption per capita for the 13 countries. New Zealand had the highest other renewable consumed per capita, increasing from 9.5 (GJ/person) in 1980 to 19.7 (GJ/person) in 2000. The United States was the second highest from 1989 to 2000, increasing at a fairly constant rate. Germany surpassed the United States in 2001, and is now the second highest other renewable consumer per capita in the world.

10.1.1 Energy Intensity

Figure 10.3 shows the other renewable intensity for these countries. The other renewable intensities for the 13 countries have been generally in decline or stagnant from 1980 to 2004. However, Germany's other renewable intensity has increased since 2000. New Zealand had a very high other renewable intensity compared to all the other 12 countries. This trend shows two full typical EI curves from growth to maturity and then ageing. The points that growth started reflect the commissioning of two new geothermal power stations, Ohaaki in 1989 and Poihipi Road in 1996 [41].

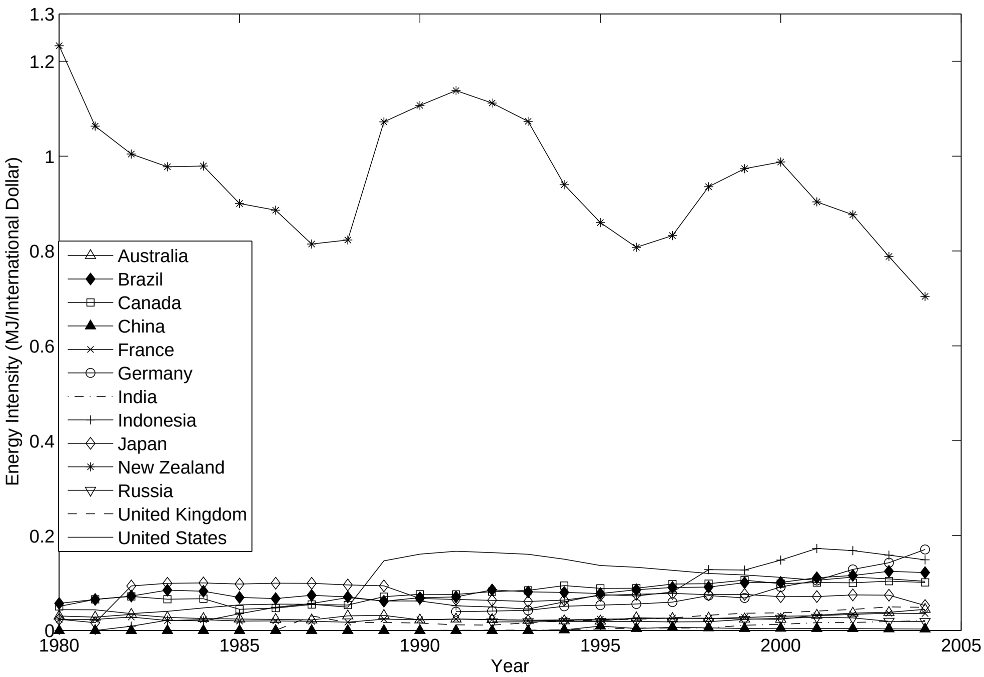

Figure 10.3 Other Renewable Intensity for the 13 Countries Using PPP

10.1.2 Energy Intensity Curves

The other renewable intensity curves for the 13 countries are shown in Figure 10.4. The industrialized countries have higher incomes per capita. Therefore these plots are towards the right portion of Figure 10.4. The developing countries with lower income per capita are in the left portion of Figure 10.4.

Figure 10.5 and Figure 10.6 show the other renewable intensity curves for the industrialized countries and developing countries respectively. For all industrialized countries apart from Germany and New Zealand, as GDP per capita increases, consumption of other renewable in producing that GDP decreases. New Zealand has been in decline but at a higher level compared to the other 12 countries. Germany has been slightly increasing relative to economic growth. Thus, the other renewable intensities for all of the industrialized countries, except for Germany have declined relative to economic growth.

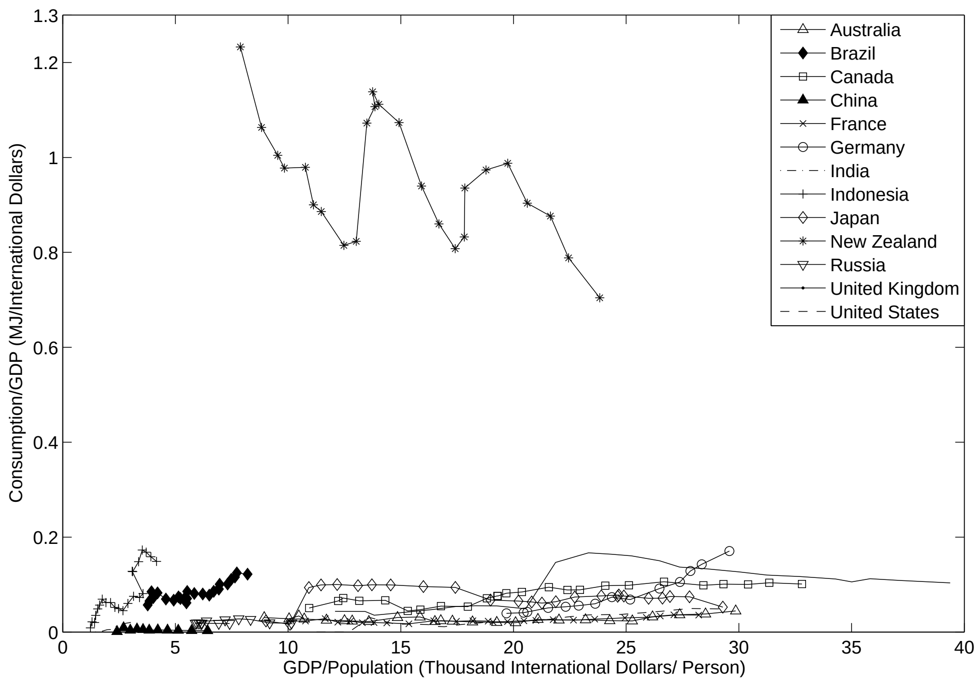

Figure 10.4 Other Renewable Intensity Curve for the 13 Countries Using PPP

For all developing countries, Indonesia and Brazil's other renewable intensity has increased rapidly relative to economic growth. India's has increased as well, but at a smaller rate. Russia's other renewable intensity was initially constant with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. Russia's economic wealth then in-

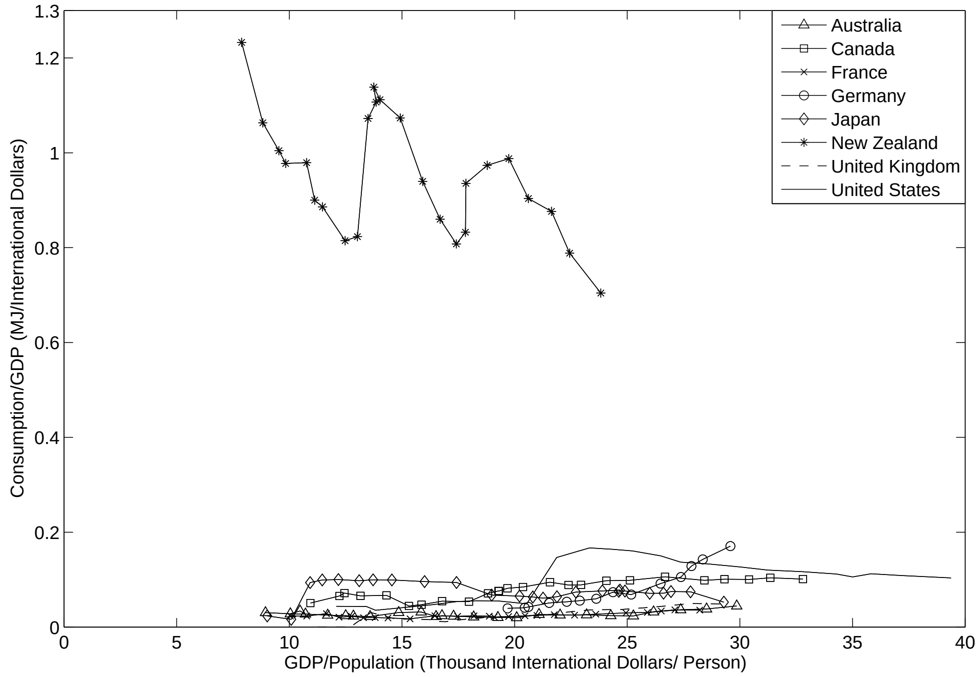

Figure 10.5 Other Renewable Intensity Curve for Industrialized Countries Using PPP

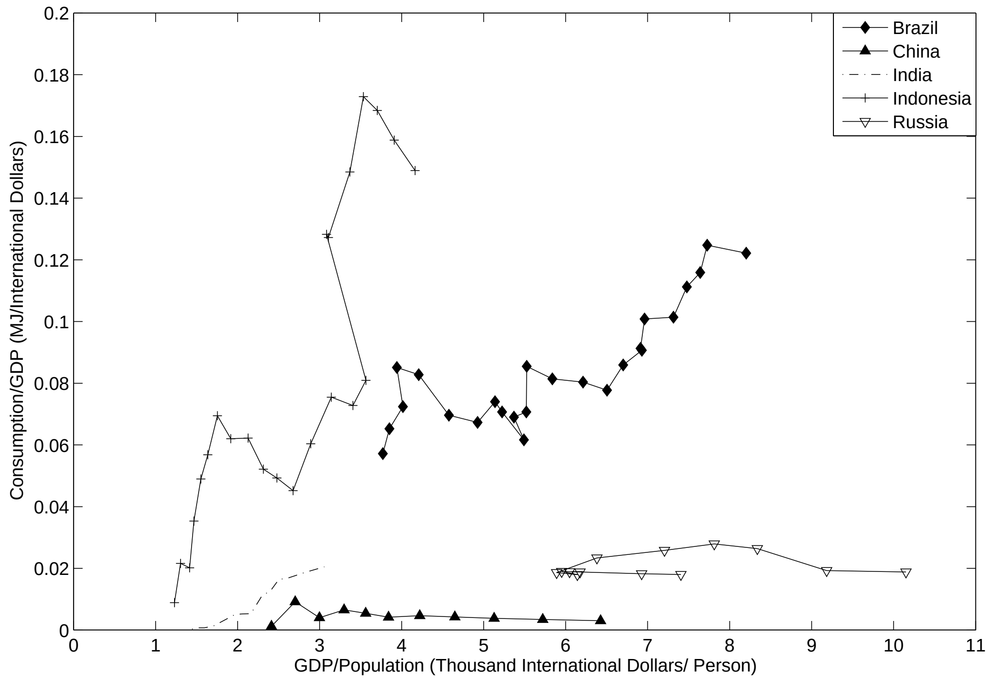

Figure 10.6 Other Renewable Intensity Curve for Developing Countries Using PPP

creased with a decrease in other renewable intensity. China's other renewable intensity has decreased as its economic wealth has increased.

10.1.3 Energy Intensity Factor

The other renewable intensity factors for the 13 countries are shown in Figure 10.7. New Zealand had the highest other renewable intensity factor from 1980 to 2000, followed by Indonesia which surpassed New Zealand in 2001. While New Zealand had essentially been decreasing throughout this period, Indonesia's intensity factor had generally been increasing. These two countries are at a much higher scale compared to the other 11 countries.

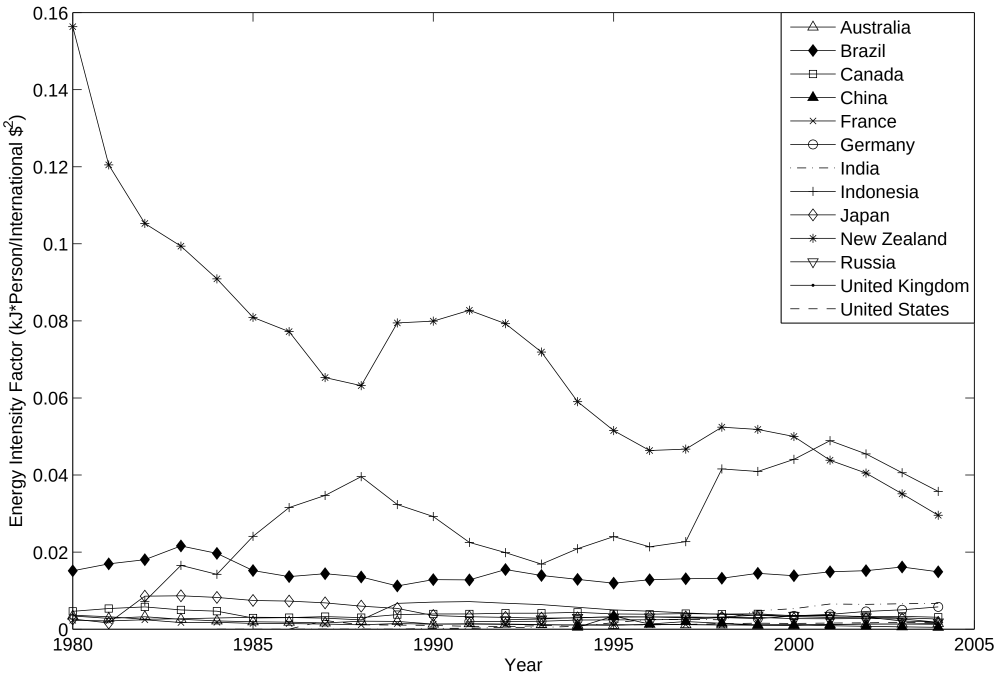

Figure 10.7 Other Renewable Intensity Factor for the 13 Countries Using PPP

The small variations in the pattern of other renewable intensity factors for these countries are shown in Figure 10.8 and Figure 10.9 for the industrialized and developing countries respectively. New Zealand's other renewable intensity factor had the largest drop from 0.156 (kJ/International $\$^2$) in 1980 to 0.03 (kJ/International $\$^2$) in 2004. In general, the other renewable intensity factors for the industrialized countries have decreased over the years and converged. For the developing countries, Indonesia's other renewable intensity factor had the largest increase from 0.007 (kJ/International $\$^2$) in 1982 to 0.036 (kJ/International $\$^2$) in 2004. This includes two typical EIF curves, which peaked in 1988 and 2001. India has also been increasing, while Brazil, China and Russia have been in decline.

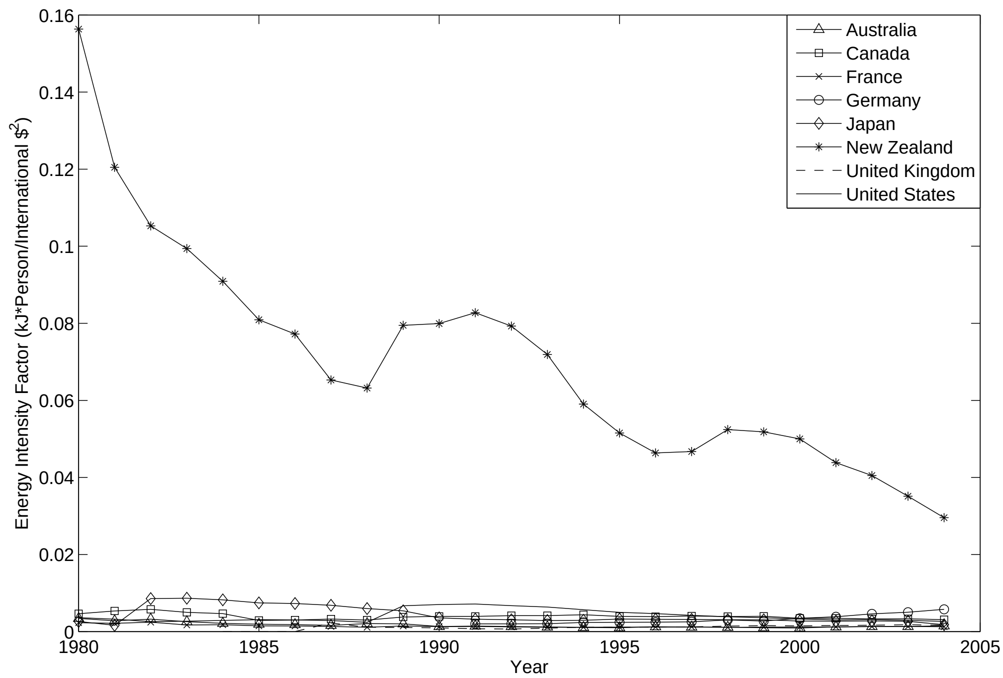

Figure 10.8 Other Renewable Intensity Factor for Industrialized Countries Using PPP

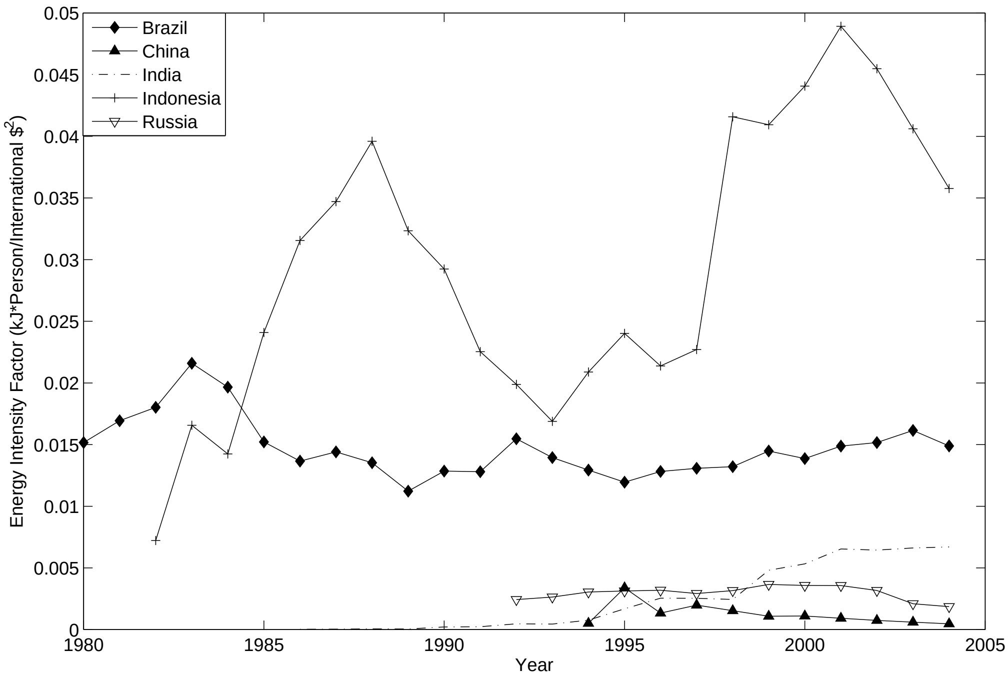

Figure 10.9 Other Renewable Intensity Factor for Developing Countries Using PPP

10.2 GEOTHERMAL USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

Wairakei Power Station was commissioned in 1958 as the first geothermal plant of its kind anywhere in the world. It has become an iconic symbol of New Zealand's electricity generation system [41].

Geothermal is used for base load electricity generation. Data for net electricity generation by fuel type came from the New Zealand MED [36]. This data also includes generation from cogeneration plants. The data is available in both GWh and PJ for the period 1974 to 2006. The heat value for geothermal in electricity generation was only available from 1995 to 2006 in the Energy Supply and Demand Balance Tables [37].

No CO_2 emissions are calculated for geothermal, as only the energy conversion process is considered, not the full life cycle.

10.2.1 Heat Values and Net Values

Figure 10.10 shows the net electricity generated using geothermal from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. Geothermal use in electricity generation has been relatively constant to 1988, then increased with a peak in 1993 and slight decrease to 1996, before another increase and peak in 2000. Growth started again in 2004. These first two growth trends reflect the commissioning of the Ohaaki Power Station in 1989, and the Poihipi Road Power Station in 1996 [41]. In 2005, Contact Energy opened a 16 MW binary plant on the Wairakei site where there was enough new generation to increase Wairakei's total output by 10%. However, recently Ohaaki has been operating at less than capacity due to a shortage of geothermal steam.

Figure 10.11 shows the heat and net values in PJ for geothermal use in electricity for comparison. The heat value is available from 1995 to 2006, where as the net value is from 1974 to 2006. The heat value is at a much higher scale compared to the net value from 1995 to 2006.

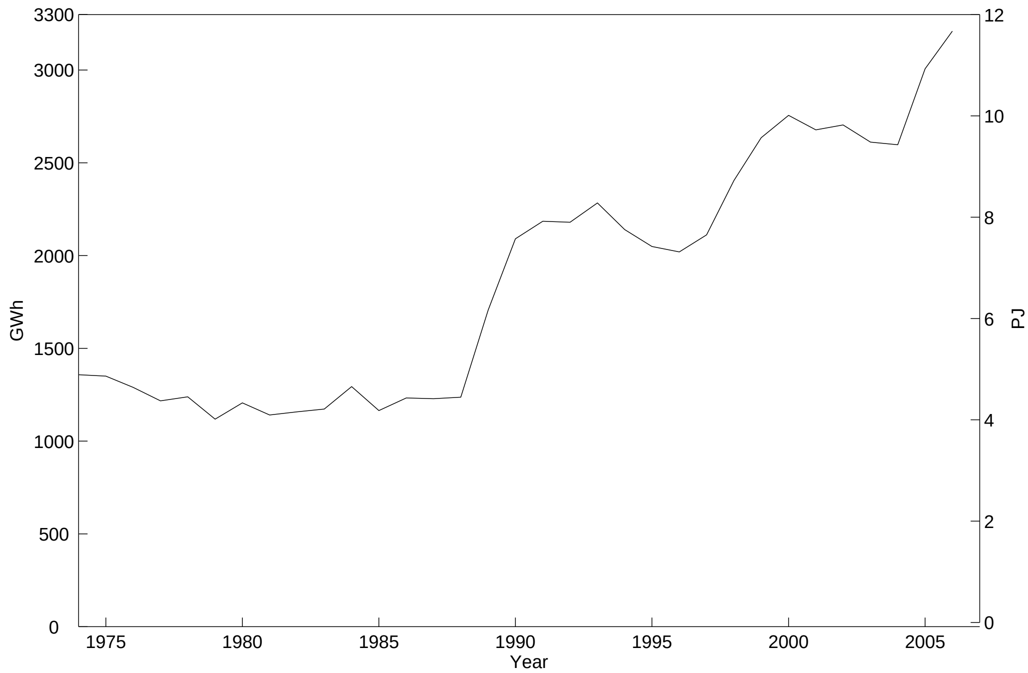

Figure 10.10 Net Electricity Generated from Geothermal in New Zealand

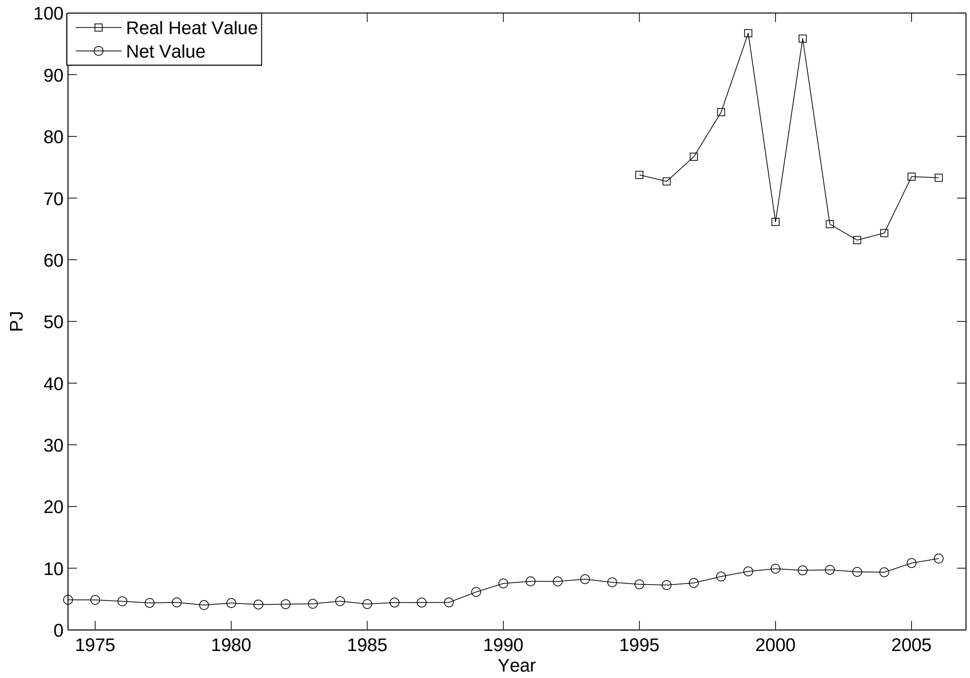

Figure 10.11 Comparison Between Heat and Net Value for Geothermal

10.2.2 Efficiency

The efficiency of geothermal use in electricity generation in New Zealand plants from 1995 to 2006 is shown in Figure 10.12. This is the ratio of the net to heat values of Figure 10.11. From an initial level of 10%, the efficiency increased to 15% in 2000, dropped back down to 10% in 2001, increased back to 14.8% in 2002, and stayed fairly constant with little increase to 15.8% in 2006.

The geothermal power station at Poihipi Road is an efficient plant, converting 60% of the energy in geothermal steam into electricity [41]. Contact's plans for three new geothermal power stations are progressing rapidly. The plans involve replacing the 50 year old Wairakei Power Station with a new power station at Te Mihi, which will be powered with steam from the Wairakei steam field. The Te Mihi power station will produce up to 220 MW of electricity, and will gradually replace the Wairakei Power Station which will be phased out of production [42]. Other geothermal plans have also been developed by Mighty River Power [43]. These new plans and upgrades should increase the efficiency and net generation of geothermal use in electricity generation.

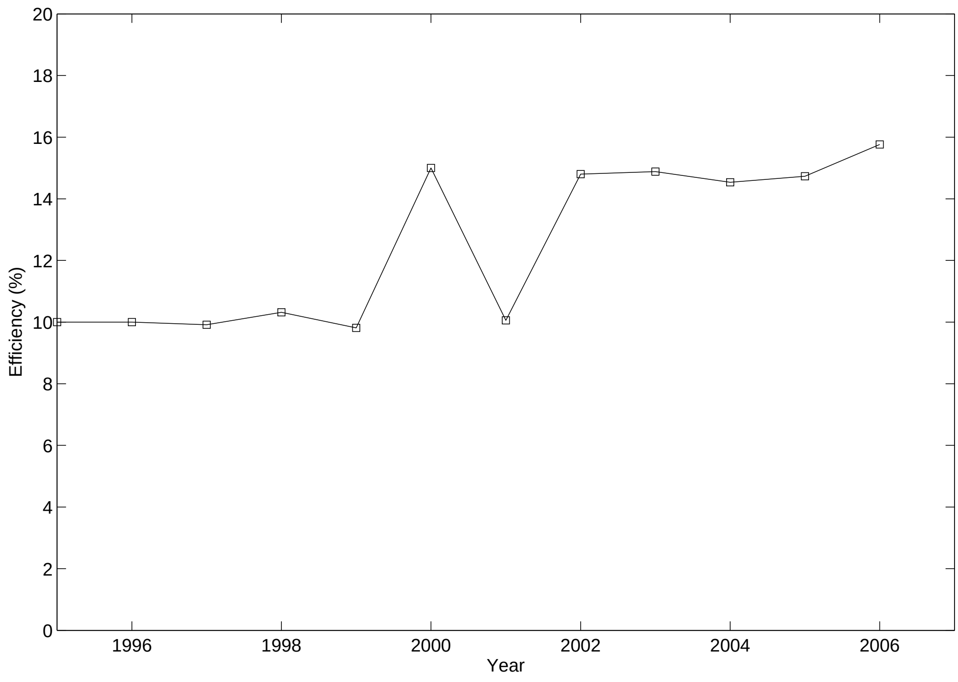

Figure 10.12 Geothermal Efficiency in Electricity Generation

10.3 WIND USE IN ELECTRICITY GENERATION FOR NEW ZEALAND

New Zealand has eight wind farms which have a combined installed capacity of 321 MW in 2008. Brooklyn was the first commissioned wind turbine in 1993, with 0.225 MW capacity [44].

Wind is used for base load electricity generation. Data for net electricity generation by fuel type came from the New Zealand MED [36]. The data is available in both GWh and PJ for the period 1992 to 2006. The supply value for wind in electricity generation was only available from 1995 to 2006 in the Energy Supply and Demand Balance Tables [37].

No CO_2 emissions are calculated for wind, as only the energy conversion process is considered, not the full life cycle.

10.3.1 Supply Values and Net Values

Figure 10.13 shows the net electricity generated using wind from 1992 to 2006. The left axis is in GWh, while the right axis is in PJ. Wind use in electricity generation has had a dramatic increase from 146.2 GWh in 2003 to 609.3 GWh in 2005. The years which generation growth started reflects the new commissioned wind farms. Each new generation of turbine installed has a greater capacity than the previous. In particular, the Te Apiti wind farm, commissioned in 2004, had a 1.65 MW turbine capacity and 90.8 MW wind farm capacity [44].

Figure 10.14 shows the supply and net values in PJ for wind use in electricity for comparison. The supply value is available from 1995 to 2006, where as the net value is from 1992 to 2006. The supply values are similar to the net values.

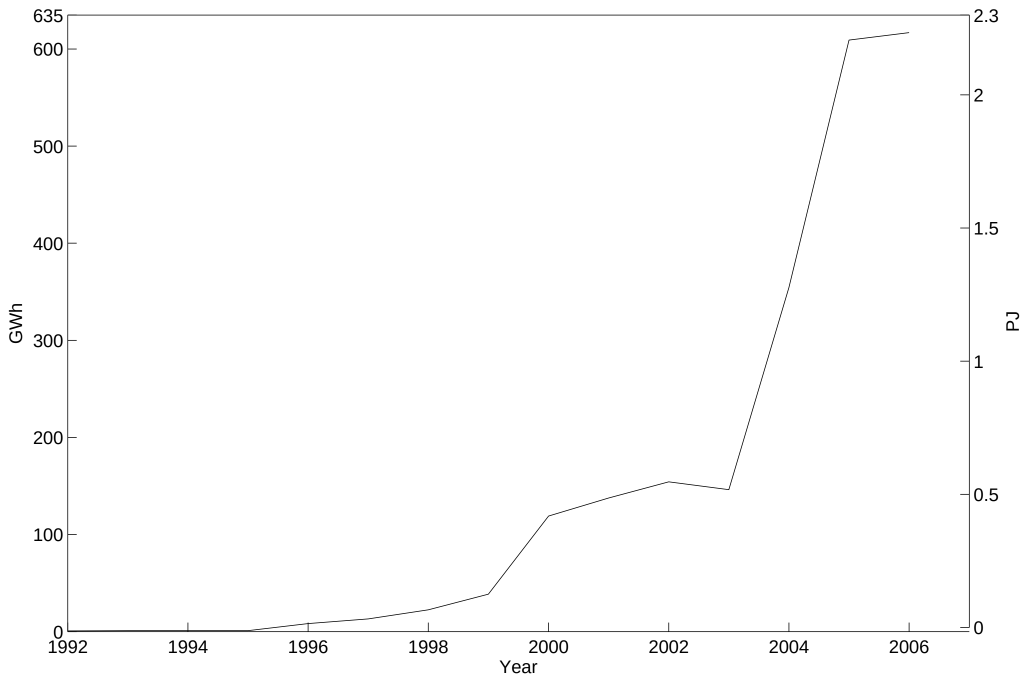

Figure 10.13 Net Electricity Generated from Wind in New Zealand

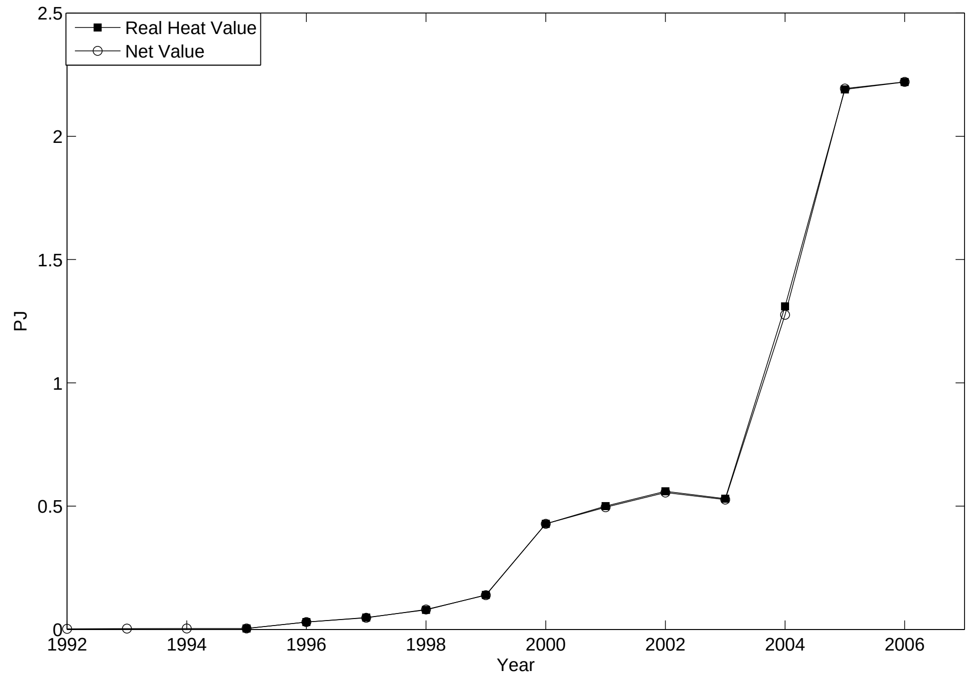

Figure 10.14 Comparison Between Supply and Net Value for Wind

10.3.2 Efficiency

The efficiency of wind use in electricity generation in New Zealand plants from 1995 to 2006 is shown in Figure 10.15. This is the ratio of the net to heat values of Figure 10.14. Apart from the two values, 90% in 1995 and 102.3% in 1998, the efficiency throughout this period is fairly constant at around 97% to 100.2%. The anomaly, 102.3% in 1998, maybe due to errors in data collected by the New Zealand MED [37].

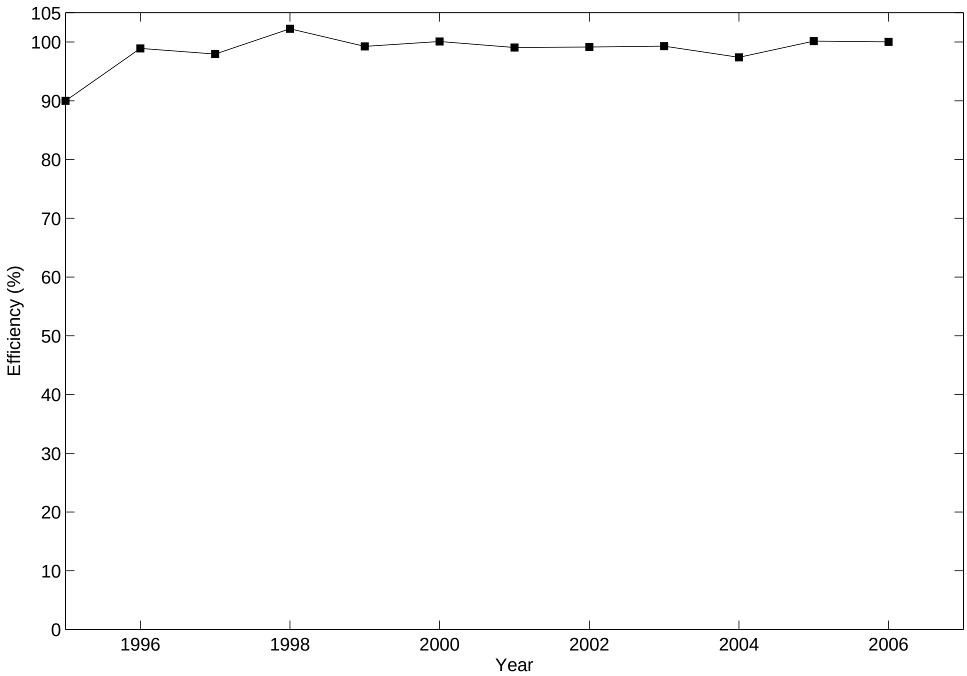

Figure 10.15 Wind Efficiency in Electricity Generation

Chapter 11

NET NUCLEAR ELECTRIC POWER

In this chapter, the relationship between nuclear electric power consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied.

11.1 COMPARISON BETWEEN ELEVEN COUNTRIES

There is no nuclear power plants in Australia, Indonesia and New Zealand. Figure 11.1 shows the net nuclear electric power consumption for the 11 countries from 1980 to 2004. Net consumption excludes the energy consumed by the generating units [23].

Currently, Australia has no commercially operating or planned nuclear power reactors. As a nation well endowed with low-cost reserves of coal [20], this position would have been unlikely to change in the foreseeable future were it not for the threat of an impending global environmental crisis arising from the combustion of fossil fuels and a government commitment to a solution based upon a 'technology fix' through its international Climate Action Partnerships [45]. In 2005, there were rising expectations for nuclear power. High rates of economic growth and energy demand, particularly from China and India, combined with environmental constraints, energy security concerns, and ongoing energy poverty in the developing world raised the possibility of a nuclear revival [45].

In 2005, Indonesia, the world's largest producer of natural gas and long an oil exporter, announced that it was proceeding with the construction of the country's first nuclear power plant. The project was originally announced in 1995, but was later shelved due to public opposition, the effects of the Asian financial crisis of 1997-98 and discovery of the Natuna gas field. The project involves construction of four 1,000 MW plants, down from the 12 originally planned. Construction is to begin in 2010 with completion slated for 2017 [46]. The introduction of nuclear power plants to Indonesia is not only to reach an optimum energy mix considering costs and the environment, but also to relieve the pressure arising from increasing domestic demand for oil and gas (so that oil and gas could be used for export) [47].

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 utilized. 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 [48]. 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). Concern about global warming due to CO_2 emissions from burning fossil fuels, especially coal, coupled with impending electricity shortages in Auckland, has put nuclear energy back on the agenda in New Zealand [48].

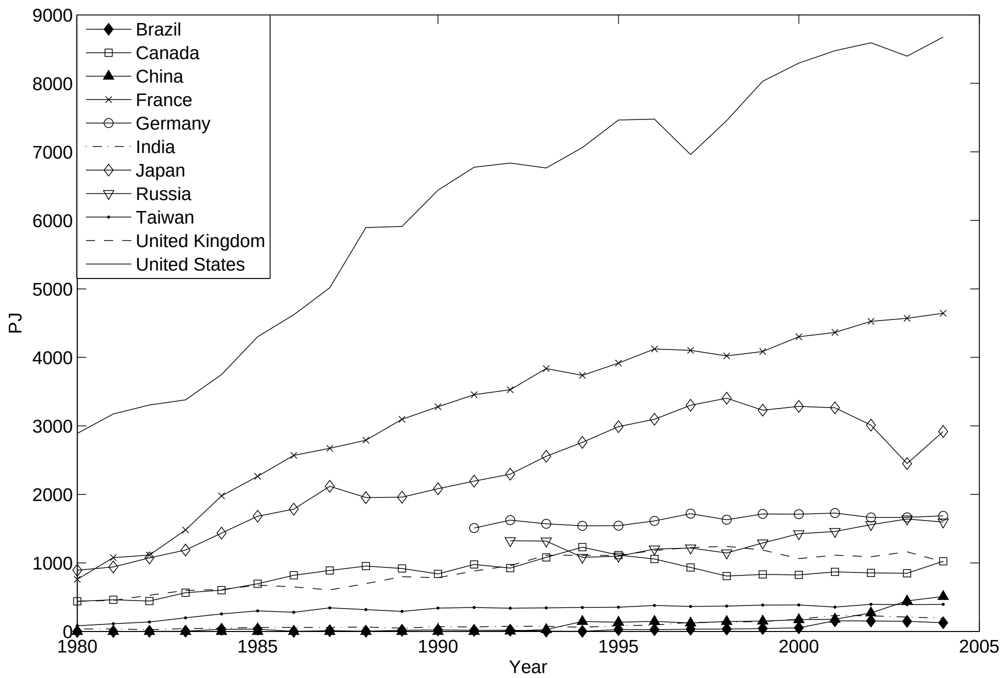

Figure 11.1 Nuclear Consumption for the 11 Countries

The United States has the highest nuclear consumption and had a dramatic increase from 1980 to 2004. One reason for nuclear generation to meet the growing demand, is that the existing plants may now have a higher plant factor, as there has been no new nuclear construction since the 1970s [49]. Its industry seems to have little interest in nuclear power generation except for maintaining existing plants. The United States's energy supply is shifting more towards natural gas.

France, Japan and Russia have had a small increase in nuclear consumption throughout this period. It is the nations of East Asia, including Japan, that are planning to construct nuclear power as a necessity for the future [49].

France has the second highest nuclear consumption, and has been increasing since 1980. It is the world's largest net exporter of electric power, exporting 18% of its total production (about 100 TWh 360 PJ) to Italy, the Netherlands, Britain, and Germany, and its electricity cost is amongst the lowest in Europe [50]. The present situation in France is due to their government's decision, just after the first oil shock in 1973, to rapidly expand the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous energy resources. Nuclear energy, with the fuel cost being a relatively small part of the overall cost, made good sense in minimizing imports and achieving greater energy security [50]. As a result of the 1974 decision, France now claims a substantial level of energy independence and almost the lowest electricity cost in Europe. It also has an extremely low level of CO_2 emissions per capita from electricity generation, since over 90% of its electricity is nuclear or hydro [50].

Japan's nuclear consumption increased from 1980 to 1998, dropped from 1998 to 2003 and started to increase again in 2004. The dip in 2003 was caused by Japanese nuclear power plants being shut down due to maintenance concerns. These have since been bought back online [50]. In March 2002 the Japanese government announced that it would rely heavily on nuclear energy to achieve greenhouse gas emission reduction goals set by the Kyoto Protocol. A 10 year energy plan, submitted in July 2001 to the Minister of Economy, Trade & Industry, was endorsed by cabinet. It called for an increase in nuclear power generation by about 30% (13,000 MWe), with the expectation that power utilities would have 9 to 12 new nuclear plants operating by 2011 [50]. In countries like France or Japan, the nuclear fuel is processed in a fuel cycle. Reprocessing is the basic strategy to increase the efficiency of uranium, as wastes can be contained, managed and reused. The reuse of plutonium as a mixed oxide (MOX) fuel for light water reactors also ensures the nonproliferation of weapons using plutonium. Reprocessing reduces the volume of high-level radioactive waste and costs associated with its disposal [49].

Germany's support for nuclear energy was very strong in the mid to late 1970s, following the oil price shock of 1974 [50]. There was a perception of vulnerability regarding energy supplies. The Social Democratic Party affirmed nuclear power in 1979, but this policy faltered after the Chernobyl incident in April 1986. In August 1986 a resolution was passed to abandon nuclear power within ten years. When Germany was reunited in 1990, all the Soviet-designed reactors in the east were shut down for safety reasons and are being decommissioned.

Russia's nuclear consumption increased from 1994 to 2005. Nuclear electricity output is rising strongly due to better performance of nuclear power plants, with capacity factors leaping from 56% in 1998 to 76% in 2003. Several more reactors have been under construction [50].

China has been in growth since 2001. Additional nuclear reactors are planned, including some of the world's most advanced, to give a sixfold increase in output capacity to around 60 GWe (0.22 PJ) by 2020 and then a further increase to 120-160 GWe (0.43-0.58 PJ) by 2030 [50]. Apart from France, China, the United States, Russia and Japan, the production of electricity from nuclear has been declining.

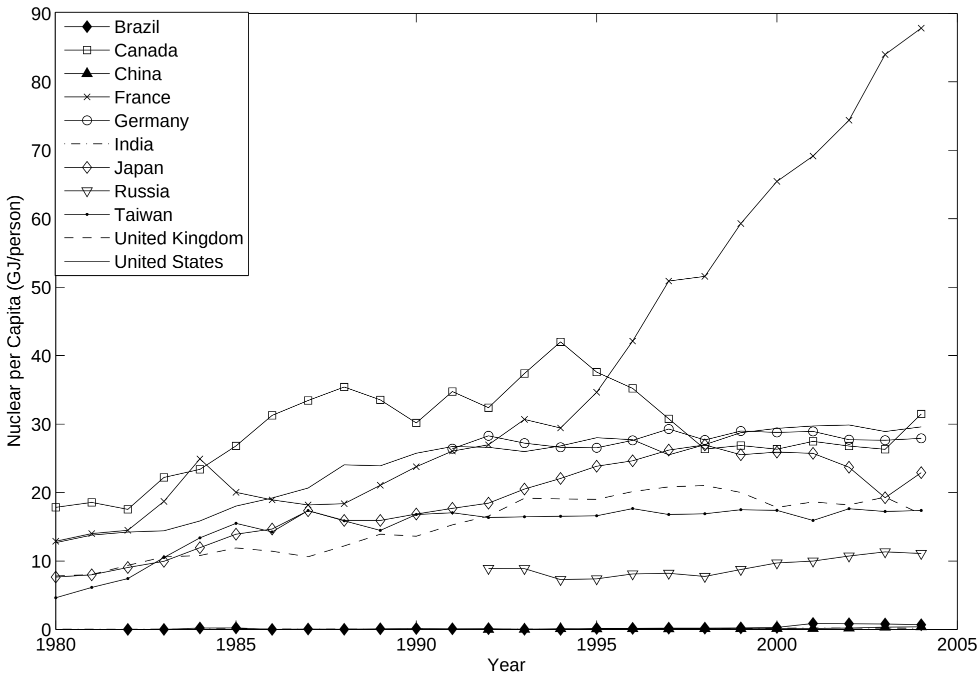

Figure 11.2 Nuclear Consumption per Capita for the 11 Countries

Figure 11.2 shows the net nuclear consumption per capita for the 11 countries. Canada had the highest nuclear electricity consumed per capita from 1980 to 1995, but has since declined. France has increased linearly, surpassing Canada in 1996 and became the largest nuclear electric power consumer per capita in the world.

11.1.1 Energy Intensity

Figure 11.3 shows the nuclear intensity for these countries. The nuclear intensities for all the countries, apart from Taiwan, France and Canada, have been fairly constant or stagnant from 1980 to 2004. France's nuclear intensity has dropped owing to structural changes in the economy, i.e. reduction in the share of energy intensive industries in total GDP, and to a lesser extent, due to efficiency improvements [47]. Taiwan's nuclear intensity levels compared to other developed countries tend to be relatively high. This is due primarily to the country's heavy concentration of energy-intensive manufacturing industries [27]. The ageing in Taiwan's nuclear intensity may also reflect factory closures due to the shift of production to China, where costs are lower.

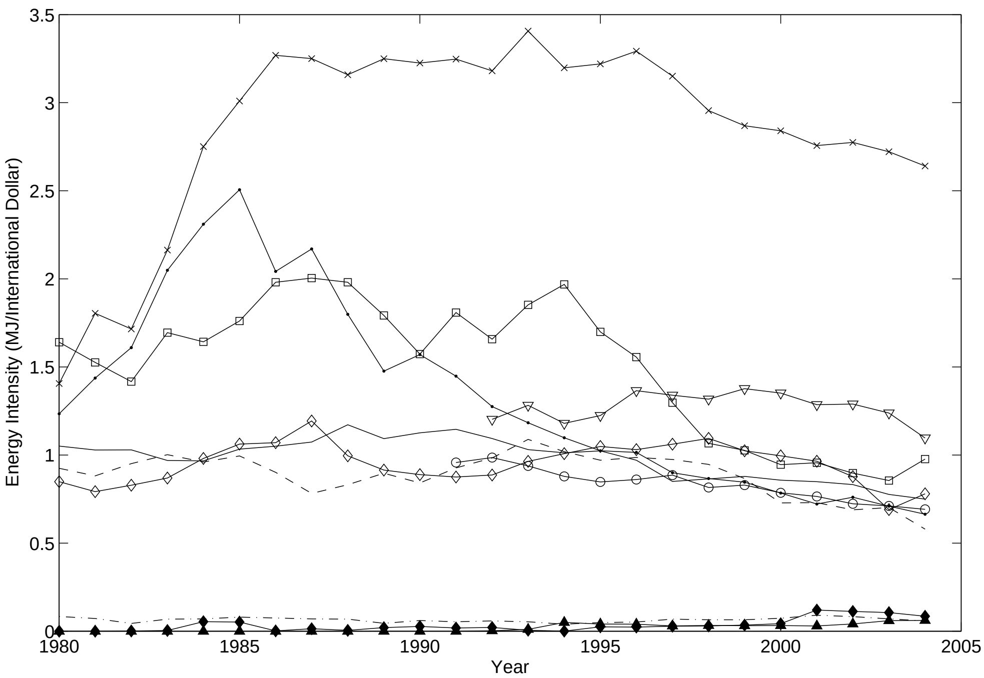

Figure 11.3 Nuclear Intensity for the 11 Countries Using PPP

11.1.2 Energy Intensity Curves

The nuclear intensity curves for the 11 countries are shown in Figure 11.4. The industrialized countries have higher incomes per capita, therefore these plots are towards the right portion of Figure 11.4. The developing countries with lower income per capita are in the left portion of Figure 11.4.

Figure 11.5 and Figure 11.6 show the nuclear intensity curves for the industrialized countries and developing countries respectively. For all industrialized countries apart from Taiwan, Canada and France, while the GDP per capita increases, the consumption of nuclear in producing that GDP decreases. Thus, the nuclear intensity for all of the industrialized countries, except Taiwan, Canada and France, have declined relative to economic growth. Taiwan, Canada and France all show the typical EI curve, with growth, maturity and ageing phases throughout this period.

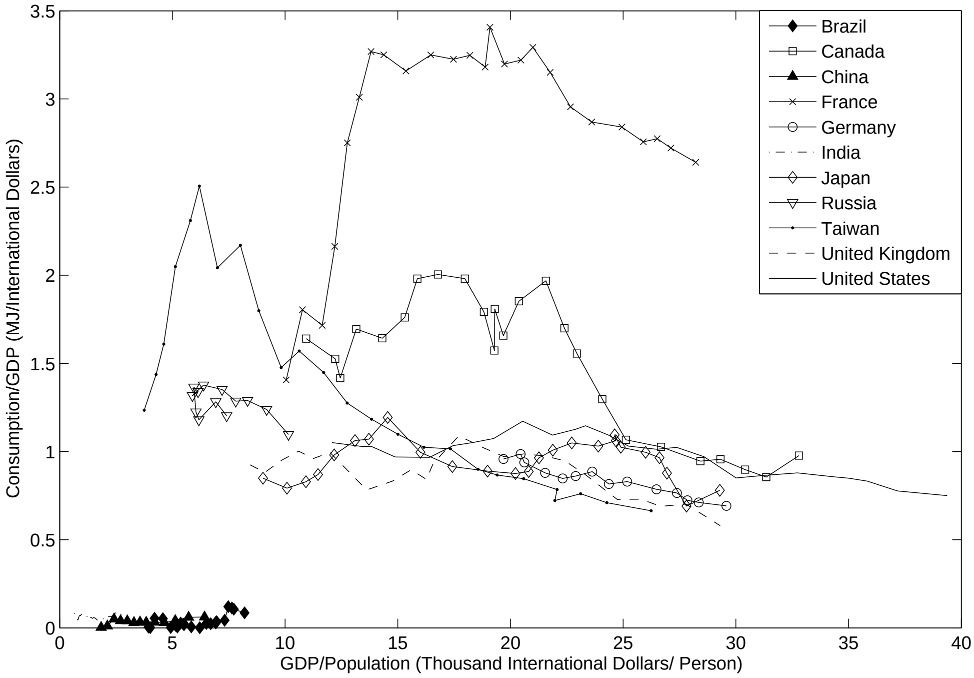

Figure 11.4 Nuclear Intensity Curve for the 11 Countries Using PPP

For the developing countries, the nuclear intensity of India has declined, while China and Brazil have been increasing relative to economic growth. In Russia, nuclear intensity has been stagnant as the economic growth rate decreases to one point, then the nuclear intensity started decreasing relative to the increase in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage.

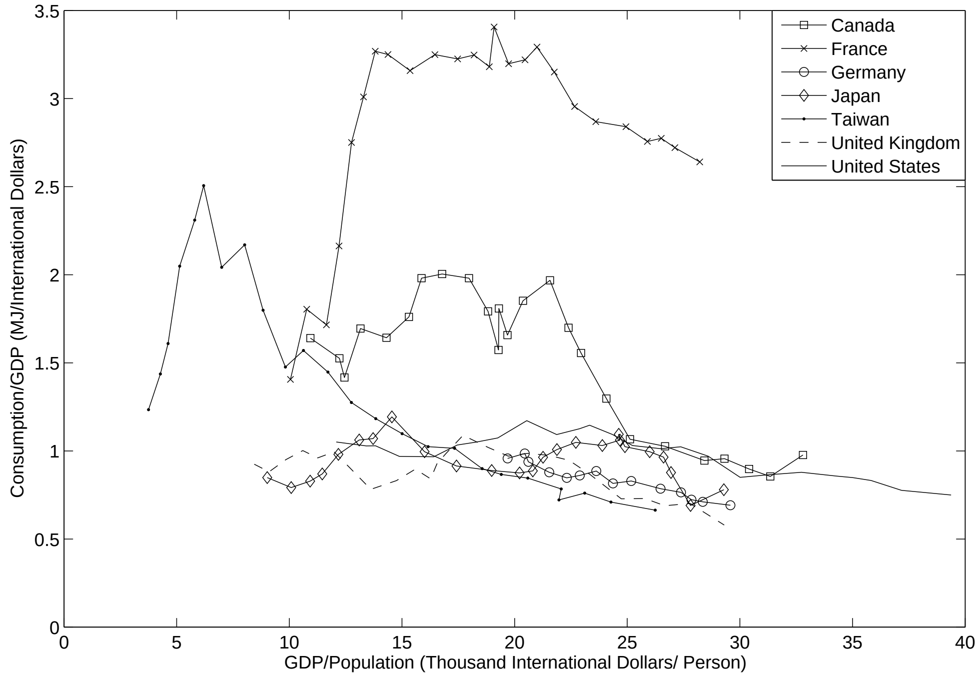

Figure 11.5 Nuclear Intensity Curve for Industrialized Countries Using PPP

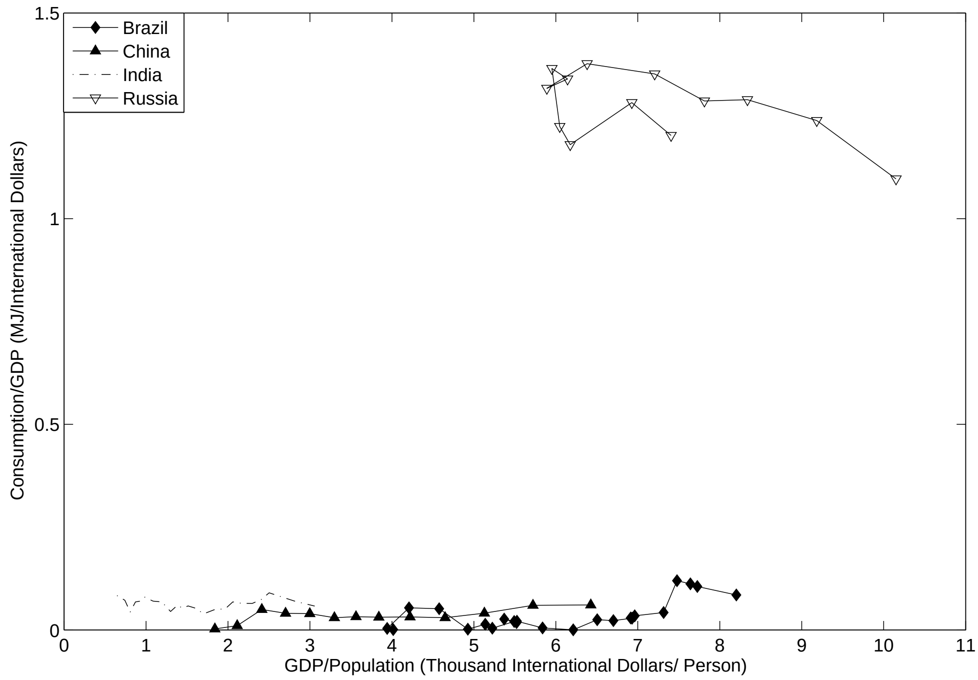

Figure 11.6 Nuclear Intensity Curve for Developing Countries Using PPP

11.1.3 Energy Intensity Factor

The nuclear intensity factors for the 11 countries are shown in Figure 11.7. These are relatively smooth declining trends over time, apart from Taiwan, France and Russia. Taiwan had the highest nuclear intensity factor from 1980 to 1987, peaked in 1985 and has since declined rapidly and converged with those the other 8 countries. France was in growth from 1980 to 1986, it peaked in 1986 and has since declined, but at a slower rate compared to Taiwan. France was the second highest from 1980 to 1987 and 1993 to 2004. From the available data for Russia, growth occurred from 1992 to 1996, and has since declined to the same level as France. Russia and France's nuclear intensity factor are at a much higher scale compared to the other 9 countries.

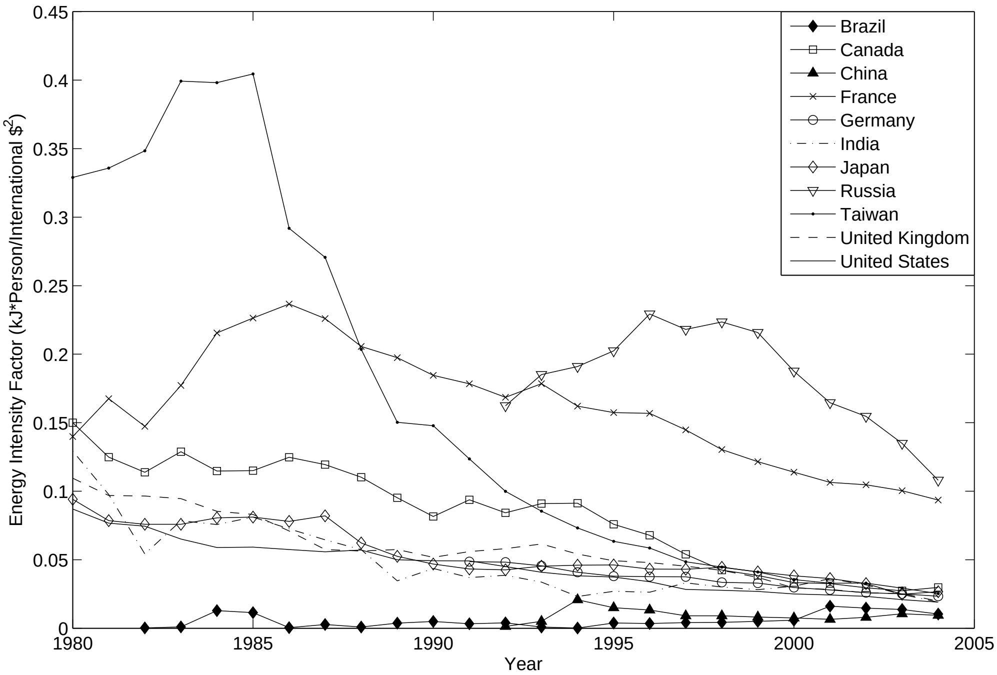

Figure 11.7 Nuclear Intensity Factor for the 11 Countries Using PPP

The small variations in the pattern of nuclear intensity factors for these countries are shown in Figure 11.8 and Figure 11.9 for the industrialized and developing countries respectively. Taiwan and France were in growth from 1980 to 1985. In general, the nuclear intensity factors for the industrialized countries have decreased over the years and converged. For the developing countries, apart from Russia, India had the largest decrease from 0.129 (kJ/International $\$^2$) to 0.019 (kJ/International $\$^2$) from 1980 to 2004. Brazil's nuclear intensity factor was the lowest from 1982 to 2000, while China has been decreasing since 1994 and had the lowest nuclear intensity factor from 2001 to 2004. Overall, the nuclear intensity factors have decreased and converged in a similar manner to those for the industrialized countries.

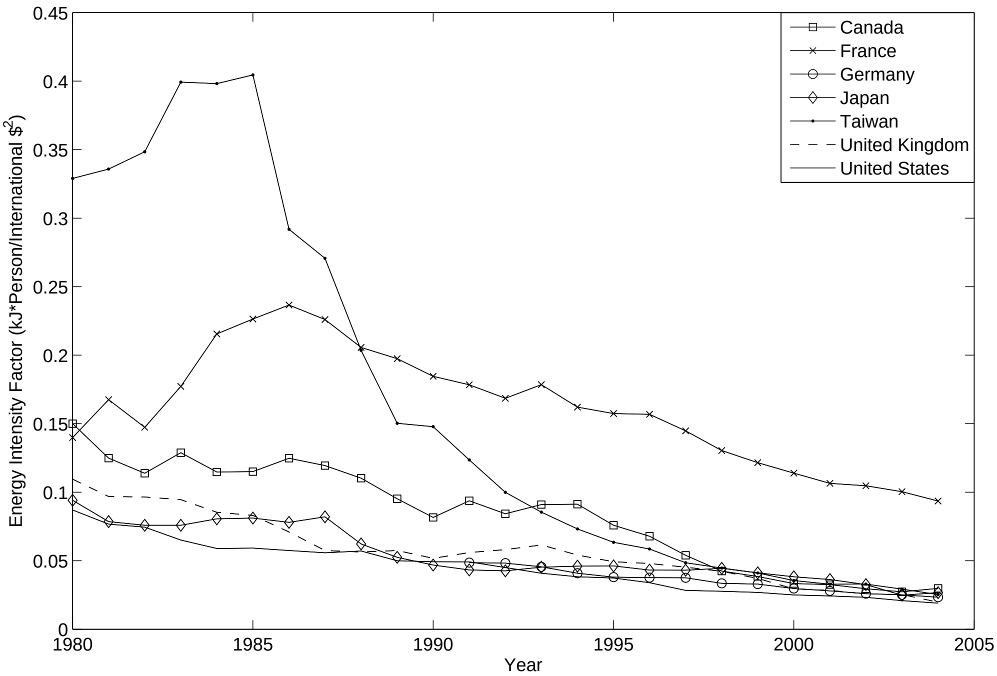

Figure 11.8 Nuclear Intensity Factor for Industrialized Countries Using PPP

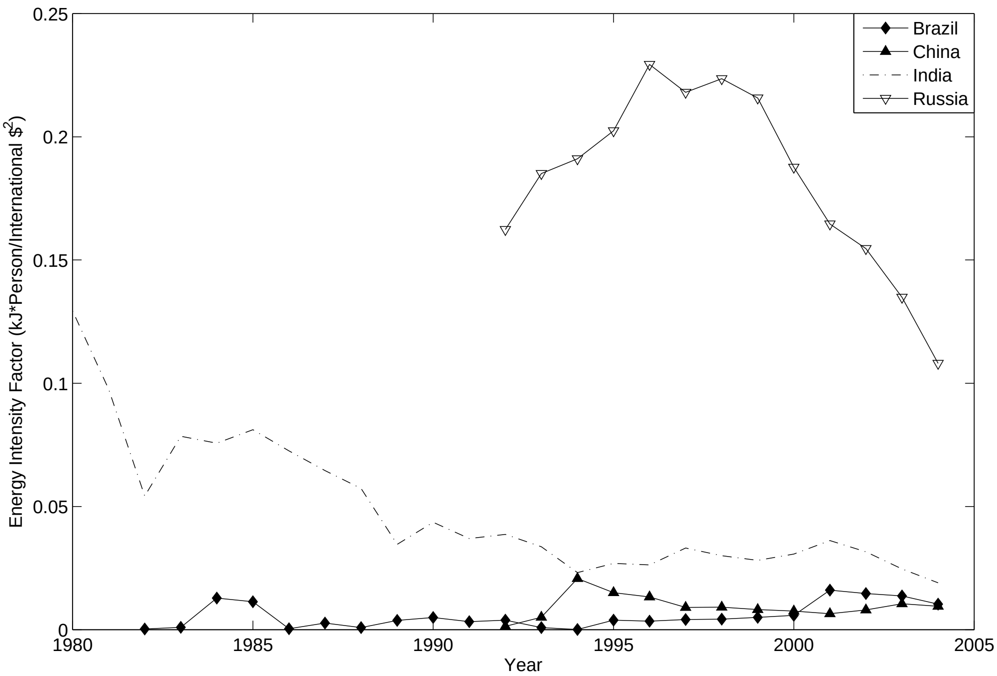

Figure 11.9 Nuclear Intensity Factor for Developing Countries Using PPP

Chapter 12

TOTAL NET ELECTRICITY

In this chapter, the relationship between net electricity consumption, GDP and population of the selected countries is analyzed. Graphs of total consumption, consumption per capita, intensity, intensity curves, and intensity factors are studied. Net value and CO_2 emitted from electricity generation for New Zealand are also shown.

12.1 COMPARISON BETWEEN FOURTEEN COUNTRIES

Figure 12.1 shows the total net electricity consumption for the 14 countries from 1980 to 2004. For the United States, the total net electricity consumption is equal to the end use. For the other countries, the total net electricity consumption is calculated from summing the total net electricity generation, electricity imports and then subtracting the electricity exports and electricity distribution losses. Net consumption excludes the energy consumed by the generating units [23].

The United States has the highest net electricity consumption. China's rapid rate of increase in electricity consumption surpassed Japan in 1998, and became the second highest electricity consuming country in the world. Net electricity consumption of the other 13 countries is low and at a fairly constant value compared to the United States and China.

Figure 12.2 shows the electricity consumption per capita for the 14 countries. Canada had the highest electricity consumption per capita from 1980 to 2004. The United States had the second highest. France shows a decrease between 1985 and 1994 but a subsequent increase from 1995 to 2004. All other 13 countries show an increase in electricity consumption per capita.

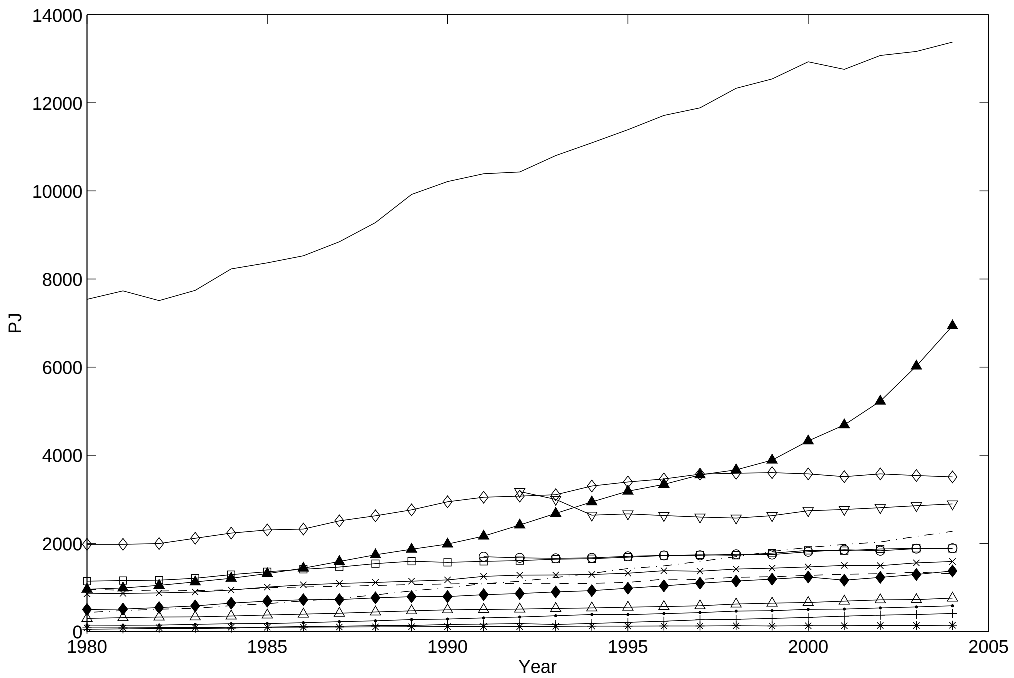

Figure 12.1 Electricity Consumption for the 14 Countries

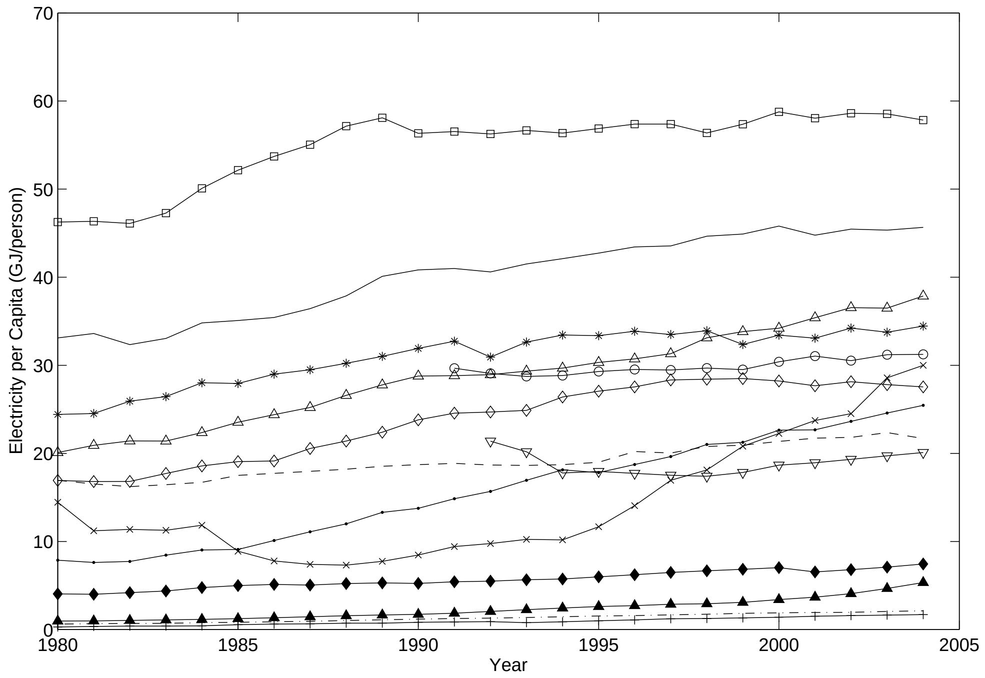

Figure 12.2 Electricity Consumption per Capita for the 14 countries

12.1.1 Energy Intensity

Figure 12.3 shows the electricity intensity for these countries. The electricity intensities for all the countries except Indonesia have been in decline or stagnant from 1980 to 2004. Russia was stagnant from 1992 to 1998, and decreased from 1999 to 2004. Canada had the second largest electricity intensity, followed by New Zealand.

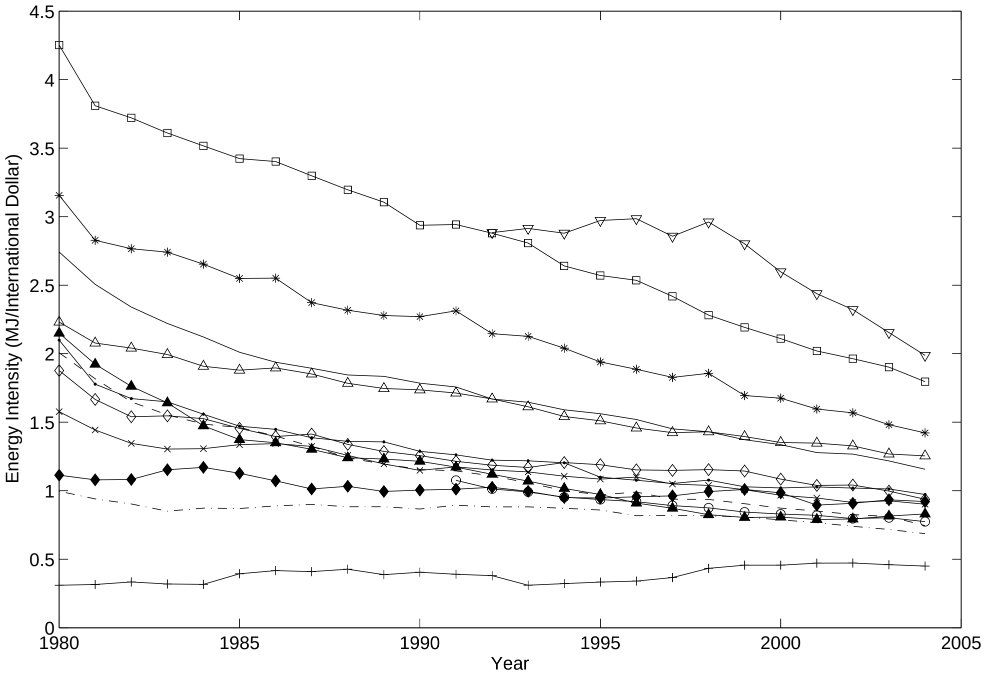

Figure 12.3 Electricity Intensity for the 14 Countries Using PPP

12.1.2 Energy Intensity Curves

The electricity intensity curves for the 14 countries are shown in Figure 12.4. The industrialized countries have higher incomes per capita, therefore these plots are towards the right portion of Figure 12.4. The developing countries with lower income per capita are in the left portion of Figure 12.4.

Figure 12.5 and Figure 12.6 show the electricity intensity curves for the industrialized countries and developing countries respectively. For all the industrialized countries, as GDP per capita increases, consumption of electricity in producing that GDP decreases. Thus, the electricity intensities for all of the industrialized countries have declined relative to economic growth.

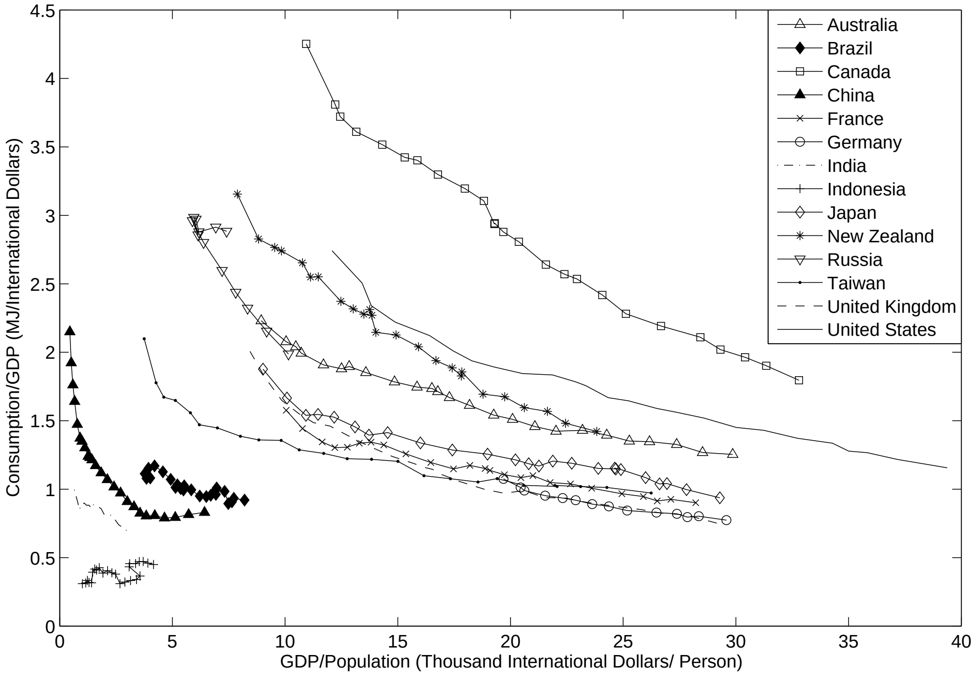

Figure 12.4 Electricity Intensity Curve for the 14 Countries Using PPP

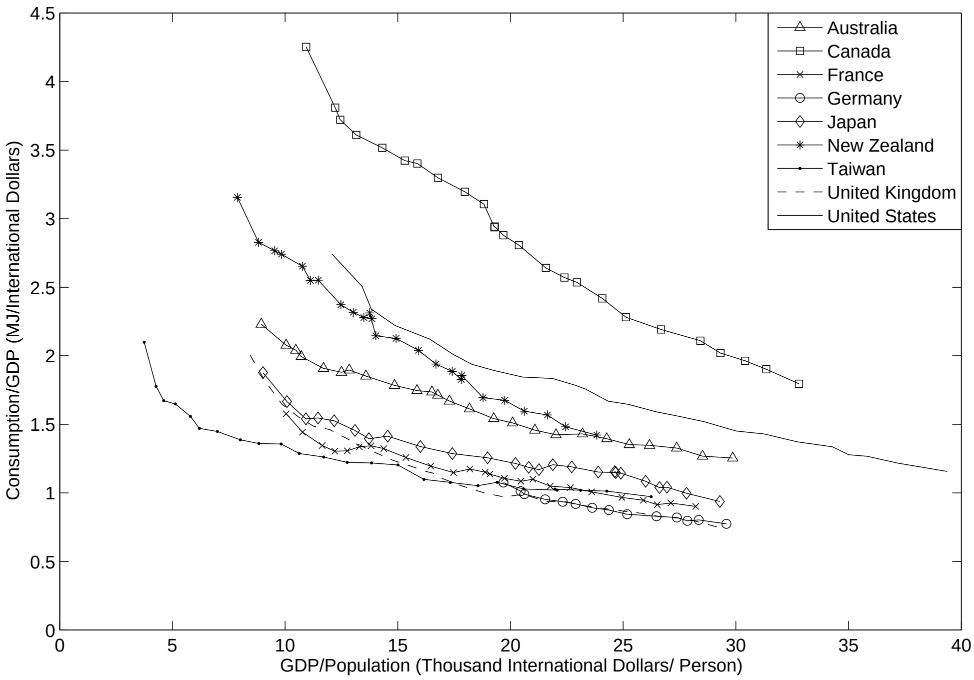

Figure 12.5 Electricity Intensity Curve for Industrialized Countries Using PPP

For the developing countries, except for Indonesia, electricity intensity has also declined relative to economic growth. Indonesia's electricity consumption has been approximately constant. In Russia, the electricity intensity has initially increased with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has since increased with lower electricity intensity.

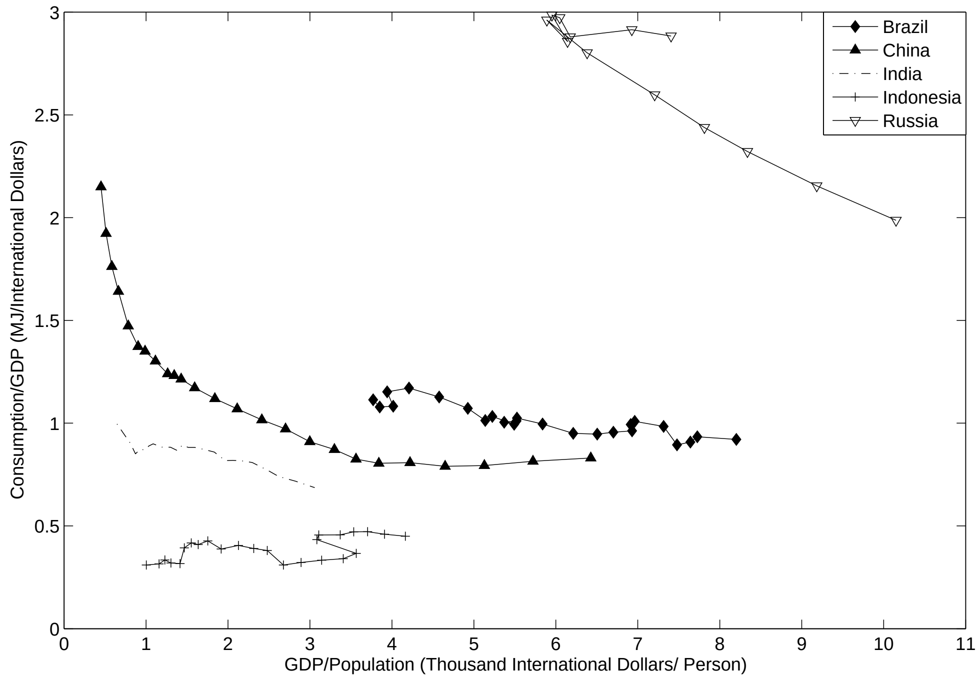

Figure 12.6 Electricity Intensity Curve for Developing Countries Using PPP

12.1.3 Energy Intensity Factor

The electricity intensity factors for the 14 countries are shown in Figure 12.7. These are relatively smooth declining trends over time. China had the highest electricity intensity factor from 1980 to 1991, followed by India. China started off at a higher value, but decreased rapidly and converged with the other 13 countries. Russia surpassed China and Japan in 1995, but has since decreased and converged with the other 13 countries.

The small variations in the pattern of electricity intensity factors for these countries are shown in Figure 12.8 and Figure 12.9 for the industrialized and developing countries respectively. In general, the electricity intensity factors for the industrialized countries have decreased over the years and converged. Taiwan was the highest from 1980 to 1985. New Zealand and Canada have been highest equal and decrease from a higher starting value from 1986 to 2004.

For the developing countries, China had the largest decrease from 4.76 (kJ/International $\$^2$) to 0.13 (kJ/International $\$^2$) from 1980 to 2004. Indonesia and Brazil have the lowest electricity intensity factor from 1980 to 2004. Overall, the electricity intensity factors have converged in a similar manner to those for the industrialized countries.

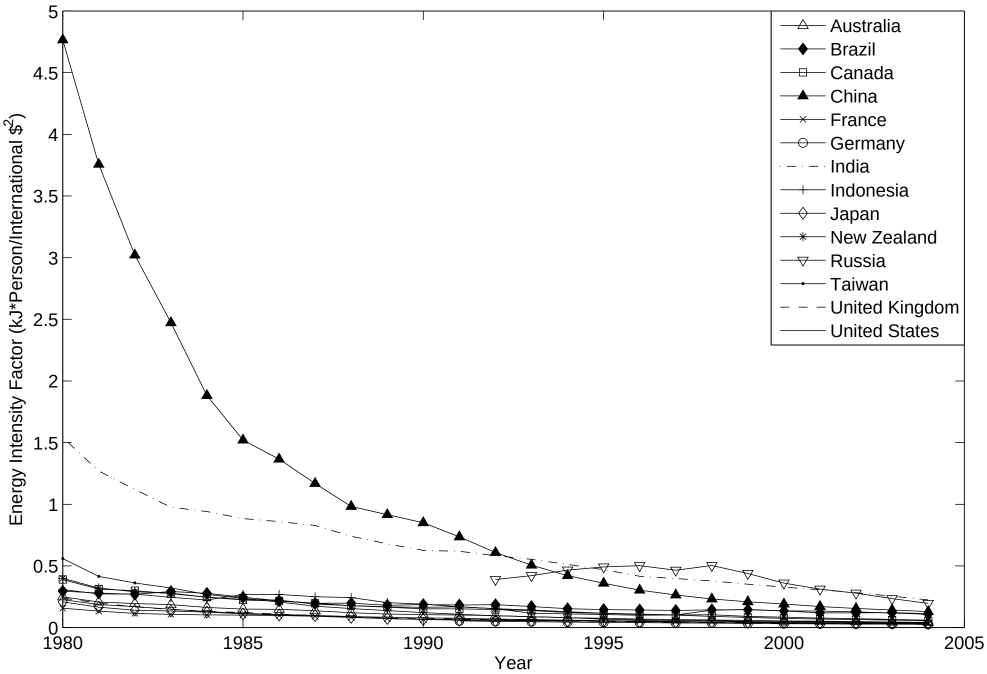

Figure 12.7 Electricity Intensity Factor for the 14 Countries Using PPP

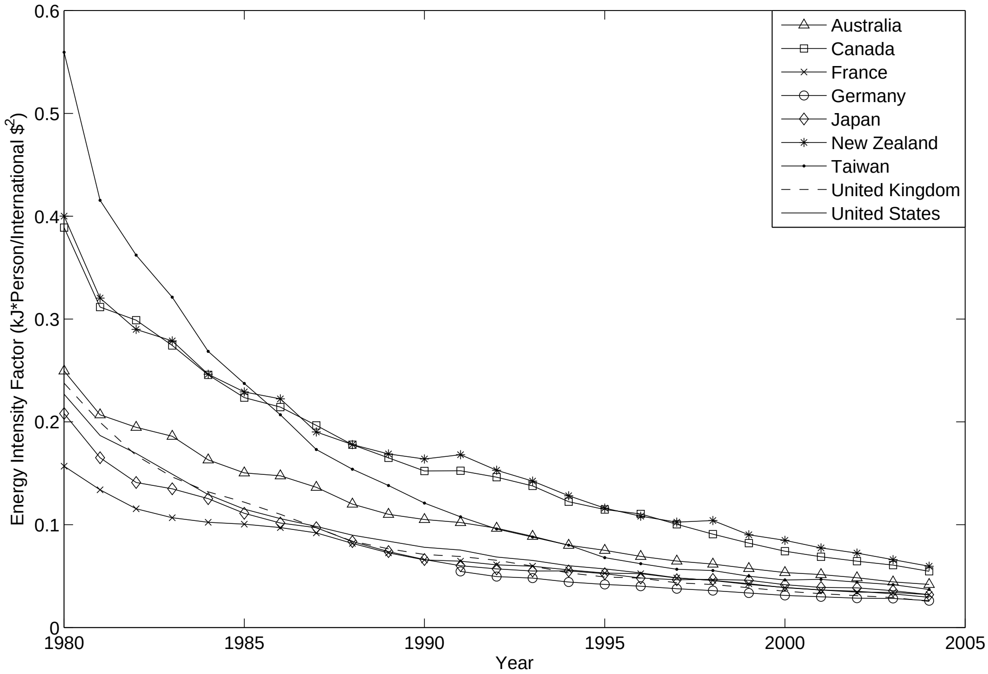

Figure 12.8 Electricity Intensity Factor for Industrialized Countries Using PPP

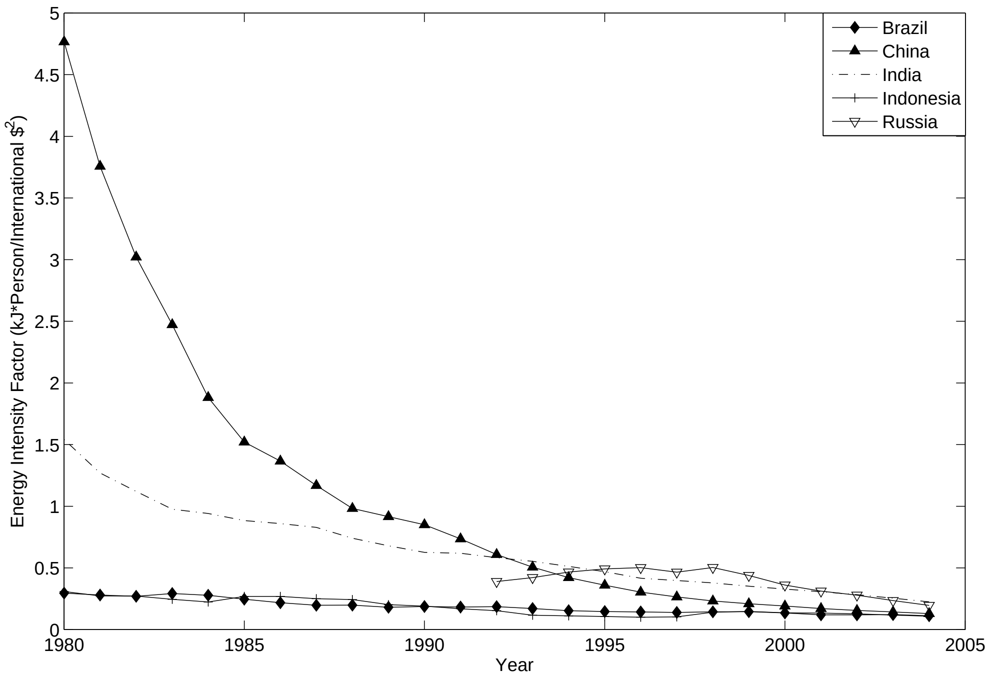

Figure 12.9 Electricity Intensity Factor for Developing Countries Using PPP

12.2 TOTAL ELECTRICITY GENERATED FOR NEW ZEALAND

New Zealand's total net electricity is generated from these fuel types, in descending order: hydro, gas, geothermal, coal, wind, wood, biogas, waste heat and oil. Wind overtook wood in 2005. Data for net electricity generation by fuel type came from the New Zealand MED [36]. The data is available in both GWh and PJ for the period 1974 to 2006.

12.2.1 Net Values

Figure 12.10 shows the total net electricity generated from 1974 to 2006. The left axis is in GWh, while the right axis is in PJ. 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.

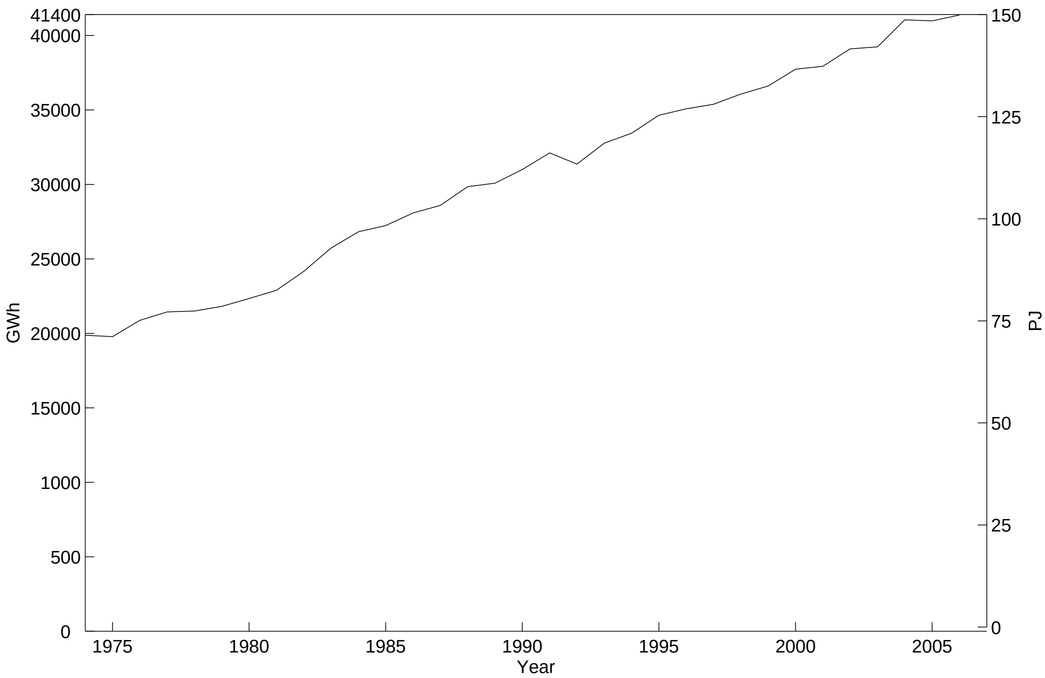

Figure 12.10 Total Net Electricity Generated in New Zealand

12.2.2 CO_2 Emitted

The real total CO_2 emitted from net electricity generation is calculated by adding the values from Figure 6.13 and Figure 8.13, which are the CO_2 emitted from using coal and gas in electricity generation, as shown in Figure 12.11. The estimated CO_2 emitted is including the estimated oil in electricity generation. The CO_2 emitted from wood use is neglected in this research, as it is insignificant compared to coal and gas use. CO_2 emissions from electricity generation in New Zealand has nearly tripled in the last 12 years, from 3235 kt in 1995 to 8764 kt in 2006.

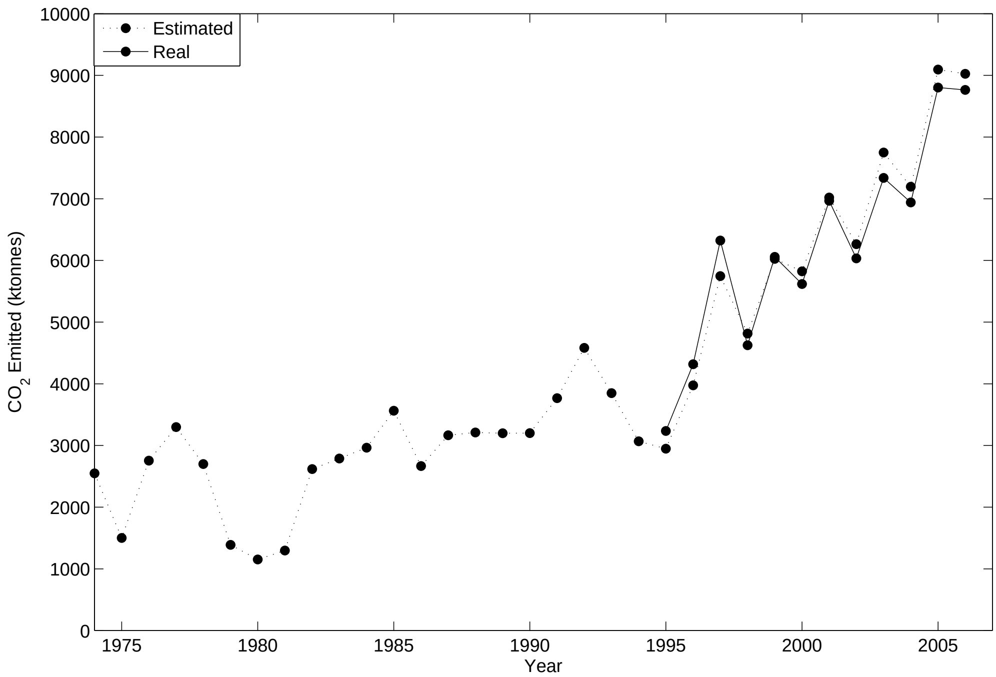

Figure 12.11 CO_2 Emission from Total Electricity Generation

Chapter 13

SUMMARY FOR NEW ZEALAND

In this chapter, graphs of the primary energy supply by fuel, energy consumption by fuel, and their market shares are shown. A summary of all the EIC, EIF, net electricity generation and its market share from each fuel type are plotted on the same graph for comparison. CO_2 emissions from net electricity generation and its market share are also shown.

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.

13.1 PRIMARY ENERGY SUPPLY BY FUEL FORECAST TO 2020

Primary energy supply data from 1974-2004 was found from the MED [6]. 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 13.1 shows the primary energy supplied by fuel since 1974 to 2004 and forecasted values from 2005 to 2020, using a linear extrapolation model. These forecasts use 1994-2004 data and assume that there is no structural change in the economy as that which occurred with deregulation in 1986, and no major gas field is found.

Imported oil supply showed a 50% decrease from 1974 to 1988, there was then a dramatic turn around and increased to 2.5 times its lowest value by 2004. The prediction is for this increase to continue. Coal supply has also increased. In contrast, there appears

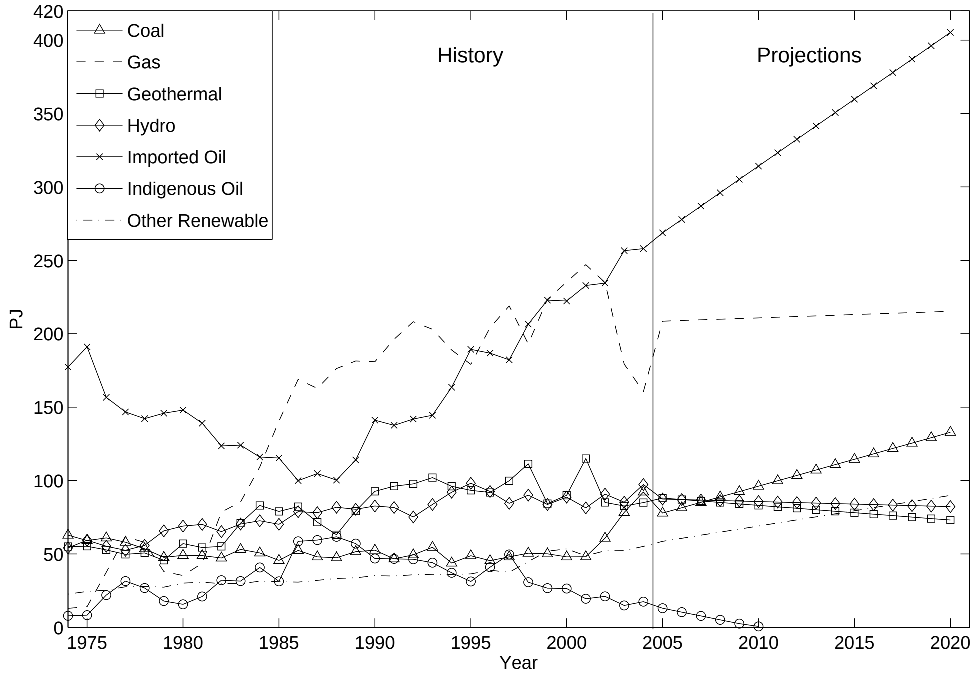

Figure 13.1 Primary Energy Supply by Fuel for New Zealand Forecast to 2020

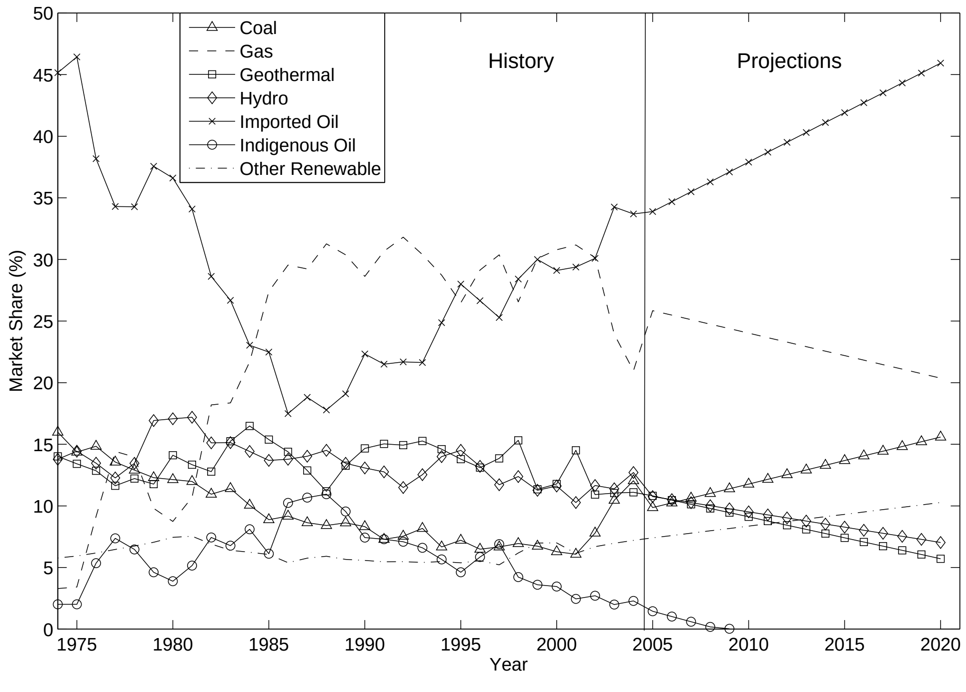

Figure 13.2 Primary Energy Supply by Fuel Market Share for New Zealand Forecast to 2020

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 renewable energy appears more certain.

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 [61].

Figure 13.2 shows the primary energy supply by fuel market share. The imported oil market share was 46% in 1975, then decreased linearly after the oil crisis, in 1973, 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 in the oil industry removed price control, government involvement in the refinery, licensing of wholesalers and retailers and restriction on imported refined products [6] [51]. 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 expected exhaustion of the Maui gas field. Imported oil is predicted to take up 46% of the market share by 2020, back to its pre energy crisis level. Indigenous oil's market share is predicted to be insignificant by 2009.

The supply of natural gas has increased by 20% since full commissioning of the Maui gas 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 had a considerable resurgence in production since 2000. Approximately half of New Zealand's current annual coal production is exported [51]. Quantities of coal are imported due to local producers being unable to meet shortfalls in supply to the Huntly power station which has been modified in the past two years to burn coal rather than gas [51]. The run-down of the Maui gas field in New Zealand means coal is required as a replacement.

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 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.

13.2 ENERGY CONSUMPTION BY FUEL FORECAST TO 2020

Energy consumption includes solid energy (coal, wood and renewable fuel), oil, gas, electricity and direct use of geothermal. The energy consumption data from 1974-2000 was found from Statistics New Zealand [52], with data from 1924 to 1974 shown in steps of 10 years. Energy consumption from 2001 to 2004 was from the New Zealand MED [6]. Figure 13.3 shows the patterns for each fuel type consumed in New Zealand from 1924 to 2004 and forecasted values from 2005 to 2020. Figure 13.3 can be divided into three main periods, before the oil crisis (1924-1979), after the oil crisis (1980-1987), and after deregulation (1987). The projected values were forecasted using a linear continuation of the past 17 years of data, after deregulation, from 1988 to 2004.

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 rise in 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 Figure 13.4. 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 since risen. Assuming that oil continues to be available, its share is predicted to rise back to pre energy crisis levels 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.

The significant increase in gas consumption and market share was due to the discovery of the major Maui gas 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 [53] 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 14.5 PJ as published by the New Zealand MED [54]. The overestimate would give other fuels a slightly higher market shares.

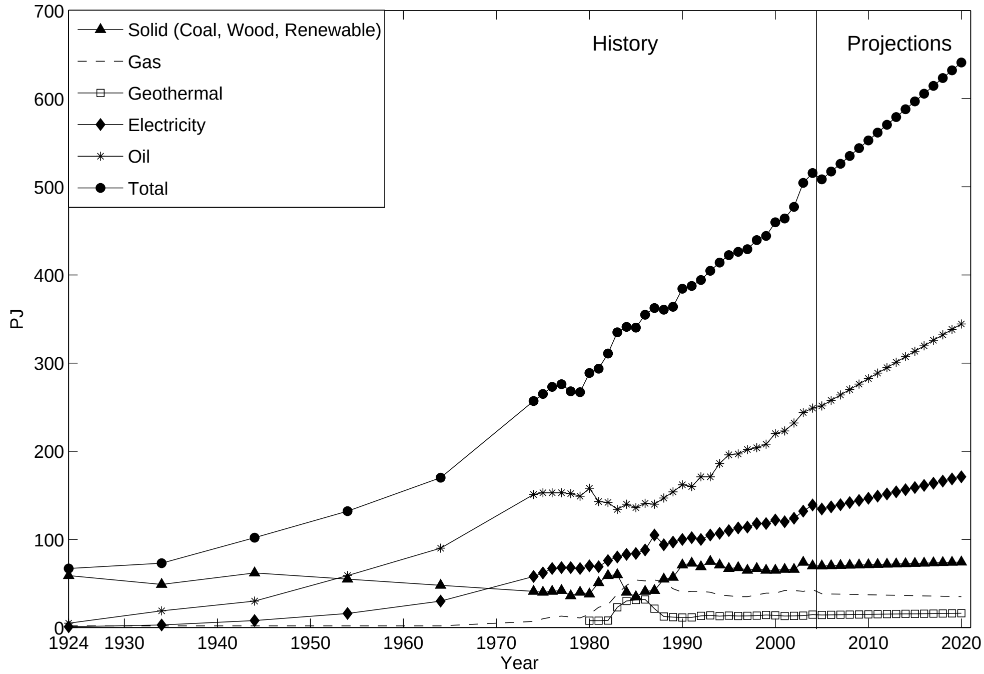

Figure 13.3 Energy Consumption by Fuel for New Zealand Forecast to 2020

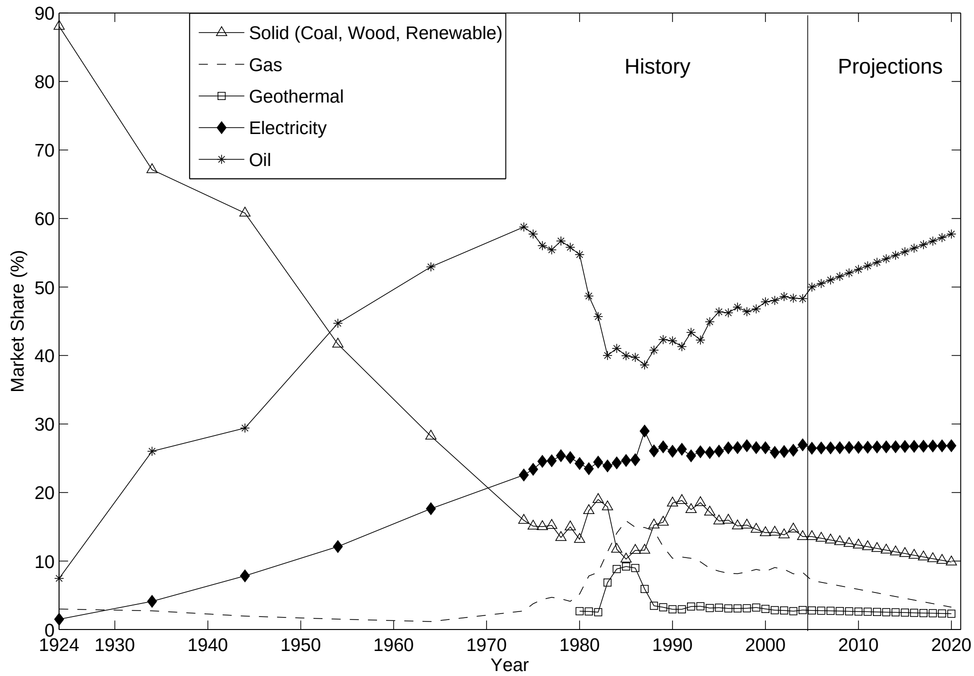

Figure 13.4 Energy Consumption by Fuel Market Share for New Zealand Forecast to 2020

World energy consumption is measured in million tonnes of oil equivalent (MTOE), instead of tonnes as stated previously in [5] [55]. Each MTOE is equal to 41.89 PJ. The available total energy consumption by fuel from 1965 to 2005 was obtained from [56]. This is shown in Figure 13.5 along with predicted values from 2006 to 2020, using linear regression and assuming business as usual.

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, consumption of all energy forms are predicted to increase.

Figure 13.6 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. New Zealand's move from a controlled to a free market is contrary to the world's market trend.

Gas consumption market share rises from 1965 to 2005 and is predicted to surpass coal by 2012. These trends are also in contrast to that for New Zealand. Hydroelectricity represents a steady 7% of the market share, whereas it plays a major role in supplying New Zealand's electricity needs. The other energy source with a significant global market share is nuclear. There is a gradual rise until the late 1980s and has been static since. The nuclear consumption market share is projected to stays at 7% of 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.

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

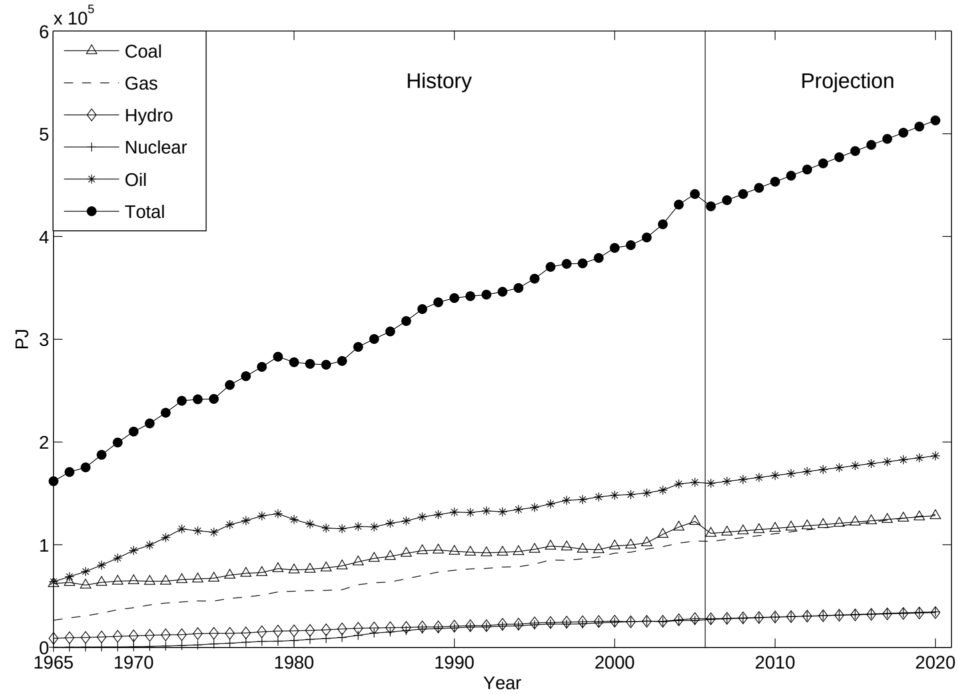

Figure 13.5 Energy Consumption by Fuel for the World Forecast to 2020

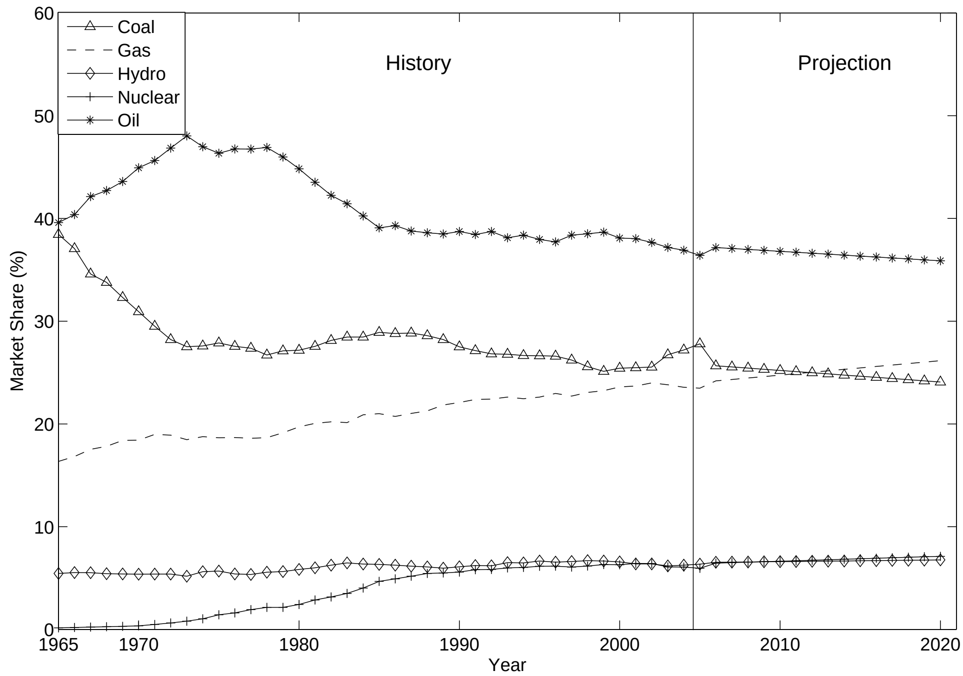

Figure 13.6 Energy Consumption by Fuel for the World Market Share Forecast to 2020

13.3 ENERGY CONSUMPTION BY SECTOR FORECAST TO 2020

Energy consumption in the economy has been named and divided into different sectors at various stages. From 1982 to 1989, there were four sectors: industrial, commercial/agriculture, domestic and transport. From 1990 to 1994, the commercial and agriculture sectors were separated. From 1995 to 2004, there were five sectors: industrial, 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 was combined. Hence, for this research, four main sectors were investigated: industrial, commercial/agriculture, residential and domestic transport.

Figure 13.7 shows the energy consumed by sector for New Zealand from 1982 to 2004 and projected values for 2005 to 2020. The data for 1987 was not available. All data is remarkably smooth and continuous over the time span. Domestic transport and industrial sectors dominate energy use, while commercial/agriculture and residential use show modest growth.

Market share of energy consumed by sector is shown in Figure 13.8. The energy consumed by domestic transport surpassed the industrial 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 after 1989, as shown in Figure 13.4.

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

The projected values show that the domestic transport sector market share increases to 48%, while the industrial sector market share drops to 29%. This may indicate that New Zealand will import more goods from overseas and will produce less local products, as well as an increase in tourism and its associated transportation requirements. The commercial/agriculture and residential sectors take up 14% and 9% of the market share, respectively.

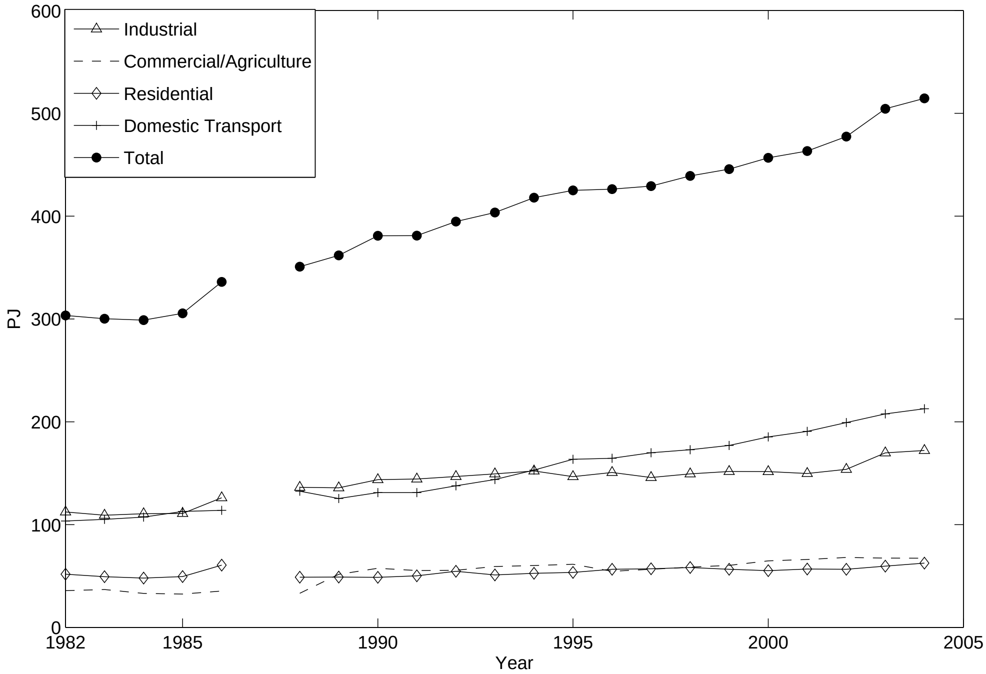

Figure 13.7 Energy Consumption by Sector for New Zealand Forecast to 2020

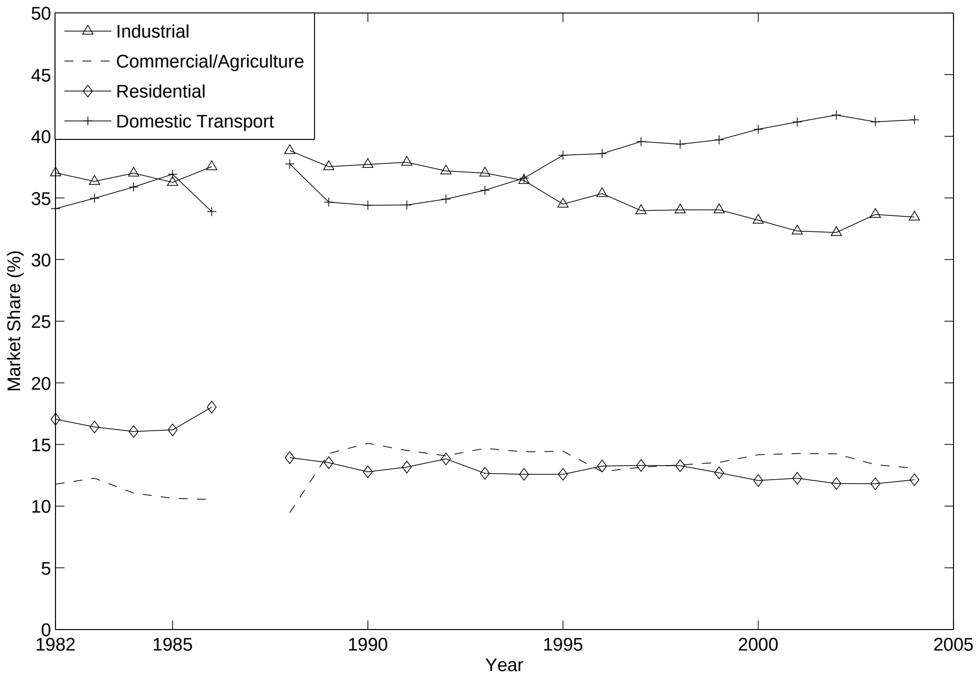

Figure 13.8 Energy Consumption by Sector Market Share for New Zealand Forecast to 2020

13.4 ENERGY INTENSITY CURVES FROM EACH FUEL TYPE

The EIC for New Zealand are shown in Figure 13.9. These curves were individually shown in previous chapters in comparison to the other 13 countries. These EIC include, coal, gas, geothermal, hydro and oil. For all EIC, apart from gas, as GDP per capita increases, consumption of energy in producing that GDP decreases. The gas intensity curve shows the growth, maturity and ageing stages. It has converged with the other EIC. Thus, the energy intensities for New Zealand have declined relative to economic growth.

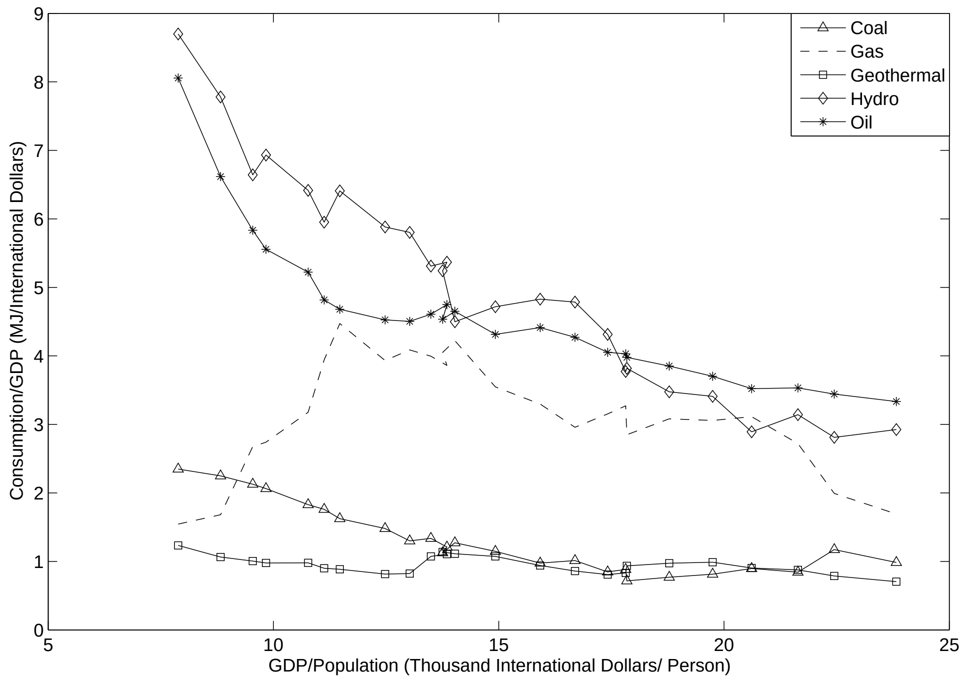

Figure 13.9 Energy Intensity Curve for New Zealand using PPP

13.5 ENERGY INTENSITY FACTOR FROM EACH FUEL TYPE

The EIF for New Zealand are shown in Figure 13.10. These have relatively smooth declining trends over time, apart from gas. Gas's intensity growth reflects the commissioning of the Maui gas field, while the decline represents ageing and the depletion of the field. Hydro had the highest EIF from 1980 to 1991, followed by oil. These two fuel types were at a much higher scale compared to other fuels, but have decreased rapidly and converged with the other fuels.

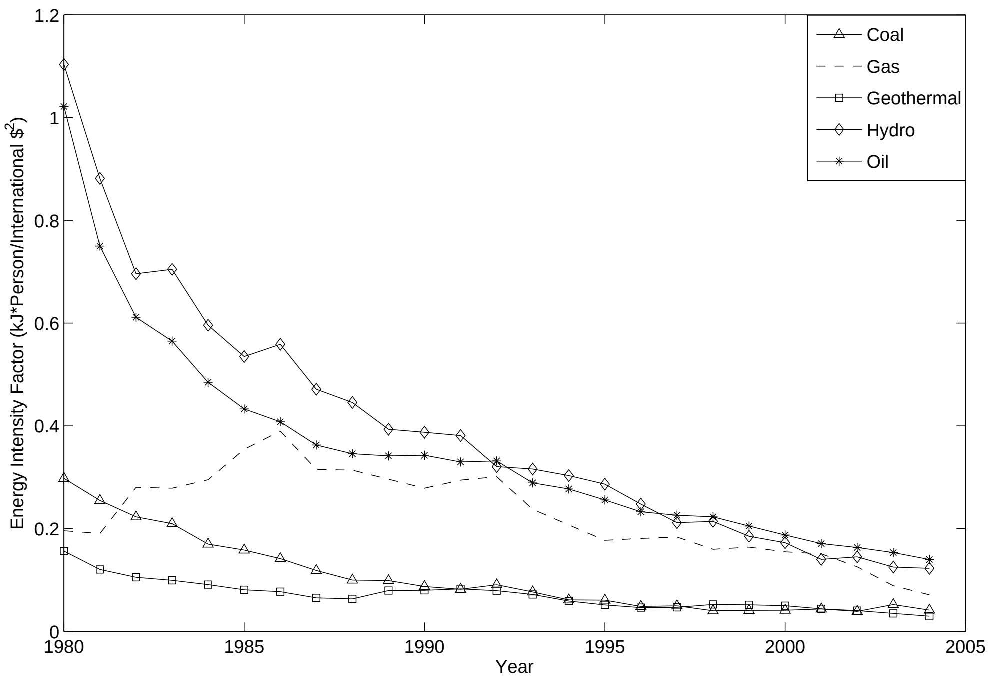

Figure 13.10 Energy Intensity Factor for New Zealand using PPP

13.6 NET ELECTRICITY GENERATION FROM EACH FUEL TYPE

Figure 13.11 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. Coal surpassed geothermal in 2003.

Figure 13.12 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. Oil 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 [22].

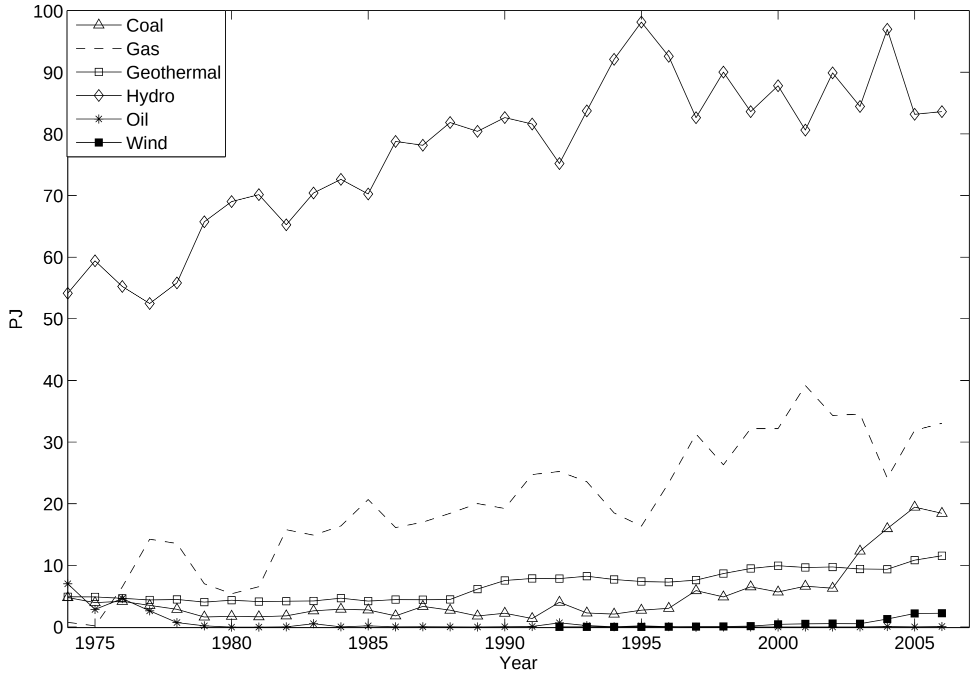

Figure 13.11 Net Electricity Generated by Fuel

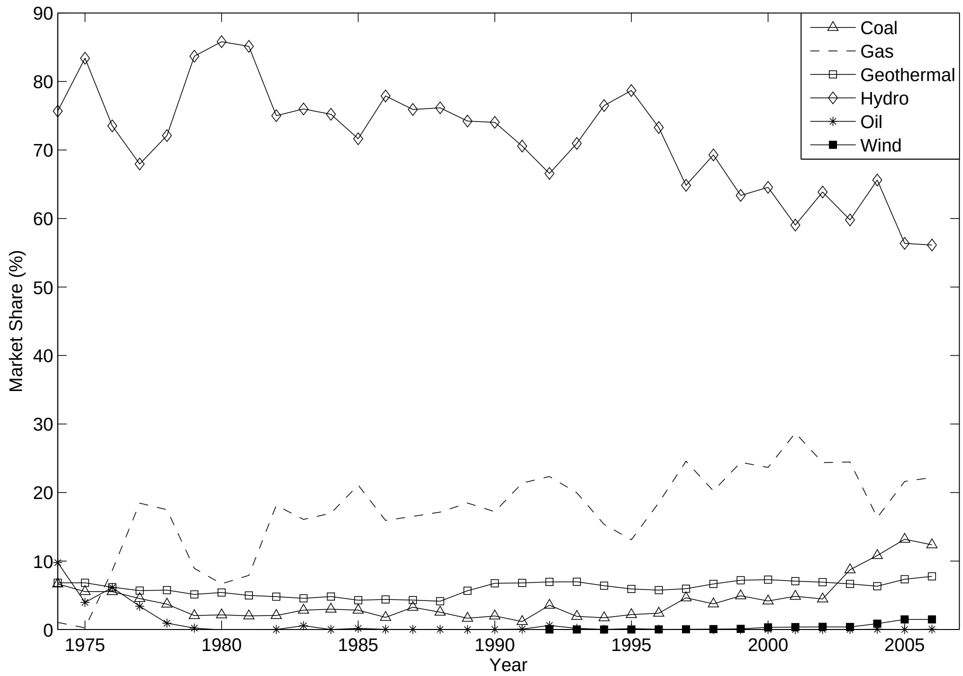

Figure 13.12 Net Electricity Generated by Fuel Market Share

13.7 CO_2 EMISSIONS FROM ELECTRICITY GENERATION

Figure 13.13 combines Figure 6.13, Figure 7.12, Figure 8.13 and Figure 12.11 for comparison. 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 has 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.

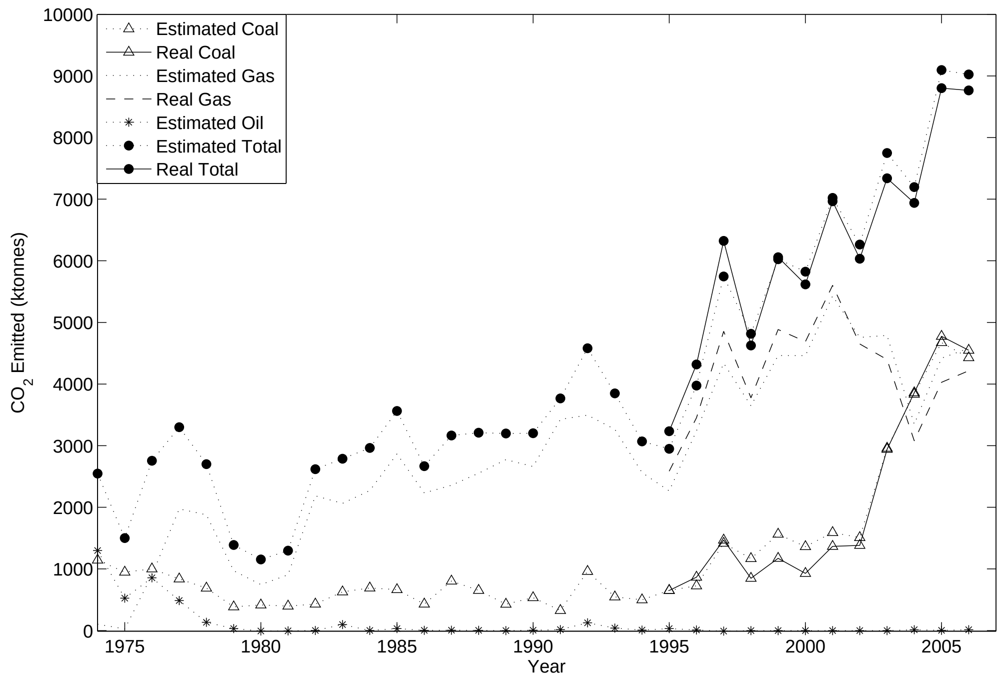

Figure 13.13 CO_2 Emission from Total Electricity Generation

The market share of CO_2 emitted in electricity generation is shown in Figure 13.14, 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. Gas's market share declined to 44% in 2004, then increased to 48% in 2006. On the other hand, coal increased its market share of emissions from 23% in 2002 to 52% in 2006.

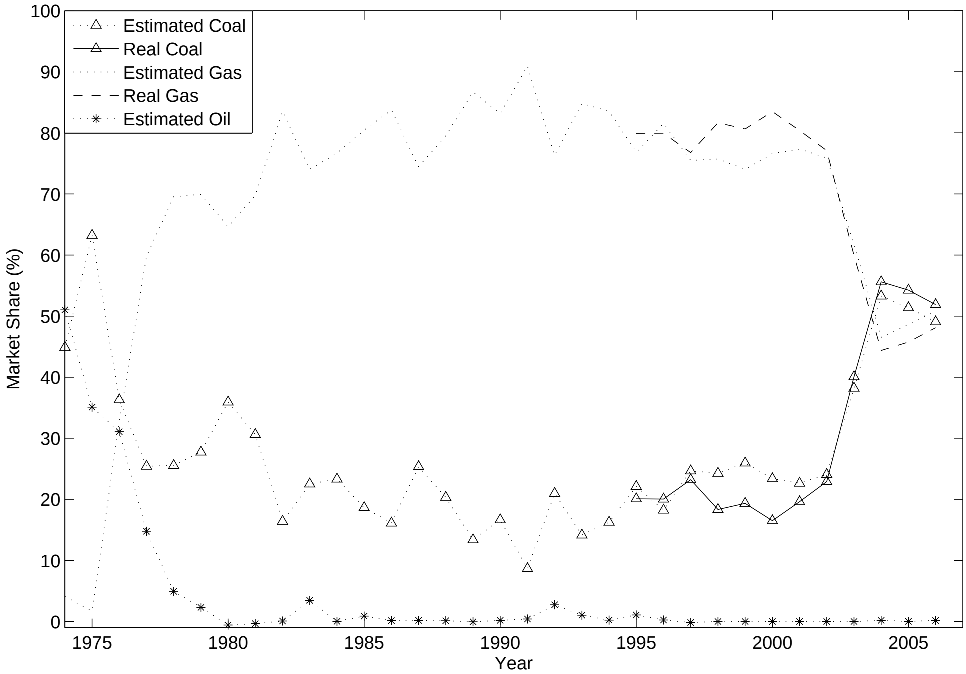

Figure 13.14 CO_2 Emission from Total Electricity Generation Market Share

13.8 EFFICIENCY IN ELECTRICITY GENERATION

The efficiency of each fuel used in New Zealand's electricity generation plants, from 1995 to 2006, are shown in Figure 13.15. The heat values for oil in electricity generation were not available and so the efficiency of oil in electricity generation could not be determined. This thesis uses 38% [38] 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%.

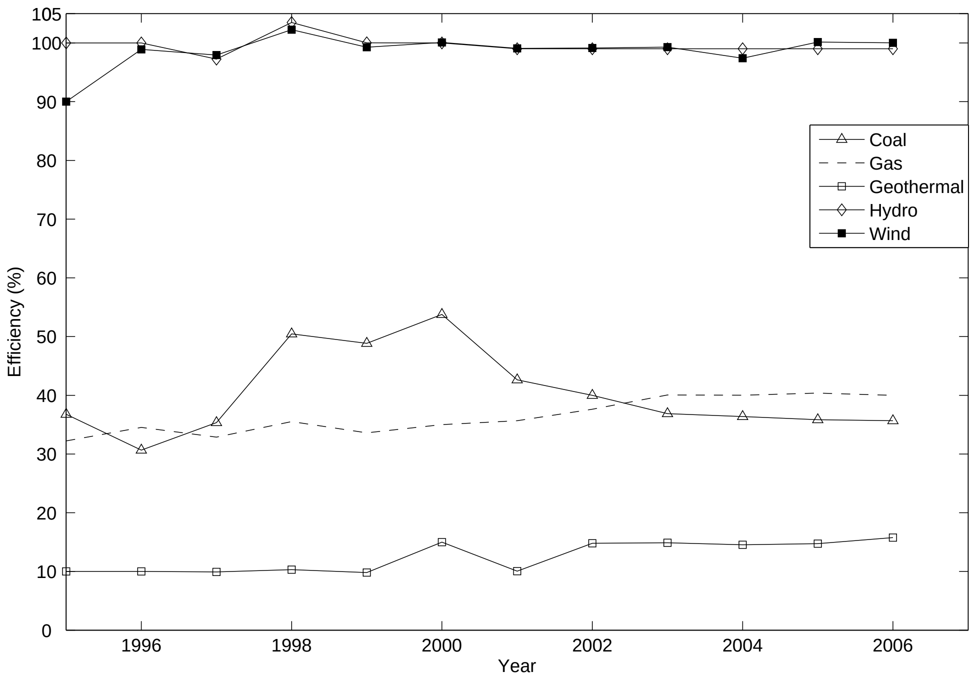

Figure 13.15 Efficiency for Each Fuel in Electricity Generation

Chapter 14

OVERALL COMPARISON

14.1 OVERVIEW

Fourteen countries were selected and divided into two groups, industrialized and developing. The nine industrialized countries are Australia, Canada, France, Germany, Japan, New Zealand, Taiwan, the United Kingdom and the United States. The five developing countries are Brazil, China, India, Indonesia and Russia. Data for each countries consumption of coal, oil, natural gas, hydro, other renewable, nuclear and total electricity were found, compared and analyzed. The population and GDP using PPP for the countries were used to find EI, the EIC and EIF.

New Zealand was further studied to find CO_2 values emitted from electricity generation. The efficiency of each fuel used in electricity generation was also determined.

This chapter shows many conclusions made from available data, which are extracted from the previous chapters. The last section also evaluates the forecasted results for New Zealand's primary energy supply and secondary energy consumption.

14.2 OVERALL CONSUMPTION OF COAL

Countries apart from China, India and the United States had a fairly constant consumption between 1980 to 2004. China's rapid increase in coal consumption surpassed the United States in 1986, and became the highest coal consuming country in the world. Coal consumption of the other 12 countries is relatively low compared to the United States and China. New Zealand is the lowest coal consumer.

Australia has the highest coal consumption per capita with the United States second. New Zealand's trend was decreasing from 1980 to 1998, but has since increased from 1998 to 2004. This increasing trend reflects the run-down of the Maui gas field, and coal's replacement for gas in some thermal power plant.

For all industrialized countries, apart from Taiwan and New Zealand, as GDP per capita increases, consumption of coal in producing that GDP decreases. For the developing countries, Indonesia had a large incline in coal intensity, while China, India, Russia and Brazil declined relative to economic growth.

China had the highest coal intensity factor from 1980 to 2004, followed by India. These two countries are at a much higher scale compared to the other selected countries. China started off at a high level, but decreased rapidly and converged with the other countries. Overall, the coal intensity factors have converged in a similar manner to those for the industrialized countries.

Coal is used in New Zealand for base load electricity generation. This use has been relatively constant to 1995, then increased linearly with slight variations until 2002. The dramatic increase from 1744 GWh in 2000 to 5120 GWh in 2006 reflects the use of coal in thermal plants due to the depletion of the Maui gas fields. The efficiency of conversion of coal to electricity peaked at 53.8% in 2000 and has dropped to 35.6% in 2006, maybe due to the run down of coal plants.

Each PJ of coal used in electricity generation will produce 86.5 kt of CO_2. Despite the environmental concerns of global warming and the targets set by the Kyoto protocol, there has been a large increase in CO_2 emissions. This significant increase was due to the replacement of gas by coal in order to continue to meet the electricity demand of New Zealand.

14.3 OVERALL CONSUMPTION OF OIL

There was a general decline in oil consumption for all countries from 1980 to 1983. These declines are due to the oil crises in 1973 and 1979. Total oil consumption was highest in the United States while Japan was the second highest up till 2003. China surpassed Japan in 2004 and became the second largest consumer of oil in the world. Oil consumption of the other 11 countries is low compared to the United States, Japan and China. New Zealand has the lowest oil consumption.

Canada had the highest oil consumption per capita in 1980, but dropped below the United States, and became the second highest up until 2003 when it regained its place as the highest oil consumer per capita. The United States and Canada have very similar patterns reflecting their free trade economies. New Zealand, despite being the lowest in total oil consumption, is higher than all the five developing countries, on a per capita basis. While all the industrialized countries have gradually recovered from the 1979 oil crisis, and started to increase in oil consumption per capita after 1984, France had a big drop in 1985. This reflects the lack of indigenous oil resources and their reliance on imported fuel.

Oil intensities for all 14 countries, had a steep decrease from 1980 to 1985. From 1986 to 2004, the trends were still decreasing, but at slower rates. The decreasing trends reflect more efficient use of oil in the production of GDP, and a substitution of oil by natural gas, higher quality fuel.

For all industrialized countries, as GDP per capita increases, consumption of oil in producing that GDP decreases. Thus, the oil intensities for all the industrialized countries have declined relative to economic growth. For the developing countries, China, India, Brazil and Indonesia, oil intensity has also declined relative to economic growth. In Russia, the oil intensity initially decreased with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. The economic wealth has since increased, with lower oil intensity.

The oil intensity factors for all 14 countries are relatively smooth declining curves over time. China had the highest oil intensity factor from 1980 to 1991. Indonesia was the second highest, followed by India. In general, the oil intensity factors for all countries have decreased over the years and converged.

In New Zealand, oil is used for electricity generation when demand is high. The 1973 crisis resulted in a drop in oil use for electricity generation from 1945 GWh in 1974 to 800 GWh in 1975. Since deregulation in the mid 1980s, oil has not been used much in electricity generation. Electricity generation had to rely more on coal and gas thermal power stations during the dry years for hydro. The smaller peak in 2003 shows that the market has seen a dampening of oil use during the dry years.

Each PJ of oil used in electricity generation will produce 70.6 kt of CO_2. The weighted average efficiency worldwide for oil-fired generation is 38% [38]. The estimated oil heat value is calculated by dividing the net values by efficiency. Negative generation by oil-fired plants implies a net import into the station to maintain station viability and system voltage stability [36]. Estimated CO_2 emissions have dropped significantly from 1300 kt in 1974 to -6.68 kt in 1980. Oil is no longer largely used in electricity generation, but rather used in transportation. From 1980 to 2006, oil was not a major contributor of CO_2 emissions in electricity generation.

14.4 OVERALL CONSUMPTION OF GAS

All countries had a general increase in gas consumption from 1986 to 2004. These increases reflect the impact of the oil crises in 1973 and 1979, and the substitution of oil and for a higher quality fuel, natural gas. Total gas consumption is highest in the United States, with Russia being the second highest consumer since 1992. Gas consumption of the other 12 countries is low compared to the United States and Russia. New Zealand had the third lowest consumption in 1980, but became the lowest gas consumer in 2002, due to the depletion in the Maui gas field.

Russia and Canada were, equally, the highest gas consumer per capita from 1995 to 2003. The United States was third highest. New Zealand, despite being the lowest in the total gas consumption, was once the fourth largest gas consumer per capita. This pattern also represents the time line since the full commissioning of the Maui gas field in 1979, the growth, maturing stage to its peak in 2001 and decline due to the expected exhaustion of the field. Apart from Russia, the other four developing countries are the lowest.

The gas intensities for all the countries apart from Indonesia, New Zealand and Russia were in decline or stagnant from 1980 to 2004. The decreasing trends reflects more efficient use of gas in the production of GDP, and a depletion in the gas fields. Indonesia and New Zealand's gas intensity peaked around 1985, but have since declined linearly. Russia has a very high gas intensity compared to all other countries.

For all industrialized countries, apart from New Zealand's incline and peak, as GDP per capita increases, consumption of gas in producing that GDP decreases. Thus, the gas intensities for all of the industrialized countries have declined relative to economic growth. For the developing countries, China, India, and Brazil, gas intensity has also declined relative to economic growth. Indonesia inclined and peaked, but then declined. In Russia, the gas intensity initially increased with a decrease in economic wealth. Overall, economic wealth has since increased, with lower gas intensity.

The gas intensity factors have relatively smooth declining trends over time, apart from Indonesia and Russia. Russia had the highest gas intensity factor from 1992 to 2004, followed by Indonesia. These two countries are at a much higher scale compared to the other 12 countries. China started off at a high value, but decreased rapidly and converged with the other countries. All the industrialized countries were in decline, except for New Zealand who increased between 1980 and 1986. New Zealand peaked in 1986 and surpassed Canada as the highest gas intensity factor up till 1992. This peak in New Zealand's gas intensity factor is an indicator that gas's intensity curve and hence penetration into the New Zealand economy was making the transition from growth to the maturing phase. In this it has lagged all other countries studied, except for Russia, which peaked in 1998. In general, the gas intensity factors for the industrialized countries have decreased over the years and converged. Overall, the gas intensity factors for Brazil, China, and India have converged in a similar manner to those for the industrialized countries. Russia and Indonesia's gas intensity factors are in the process of getting closer to the other developing countries.

In New Zealand, gas is used for base load electricity generation. This use has increased linearly with variations about this trend from 1974 to 2006. The peaks generally correlate to dry years, 1992, 2001, and 2003, when hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations. The average efficiency for New Zealand found from the heat and net values from 1995 to 2006 was 36%. The efficiency has increased from 32.2% in 1995 to 40.4% in 2005. The weighted average efficiency worldwide for natural gas generation is 45% [38].

Each PJ of gas used in electricity generation will produce 49.9 kt of CO_2. Despite the environmental concerns of global warming and the Kyoto protocol, there is no significant reduction in CO_2 emissions from gas use in electricity generation.

14.5 OVERALL CONSUMPTION OF HYDRO

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.

Canada had the highest hydro consumption. Countries apart from China and Brazil had a fairly constant consumption with some variation throughout 1980 to 2004. China's rapid increase in hydro consumption surpassed Brazil in 2004, and became the second highest hydro consuming country in the world.

Canada had the highest hydro consumption per capita from 1980 to 2004 with New Zealand second highest. Hydro consumption per capita of the other 12 countries has been low and constant compared to Canada and New Zealand.

The hydro intensities for all countries have been in decline or stagnant from 1980 to

2004. Canada and New Zealand have a very high hydro intensity compared to the other 12 countries. For the industrialized countries, apart from Canada and New Zealand, as GDP per capita increases, consumption of hydro in producing that GDP decreases. Canada and New Zealand have been in decline, but at a higher rate compared to the other 12 countries. Thus, the hydro intensities for all of industrialized countries have declined relative to economic growth. For the developing countries, Indonesia's hydro consumption has been constant, while the other four countries decreased relative to economic growth.

The hydro intensity factors have relatively smooth declining trends over time, apart from China and India. China had the highest hydro intensity factor from 1980 to 1990, followed by India. These two countries are at a much higher scale compared to the other 12 countries. China started off at a high value, but decreased rapidly and converged with the other 13 countries. All the industrialized countries were in decline from 1980 to 2004. New Zealand and Canada have been highest equal, and decrease from a higher starting value. In general, the hydro intensity factors for the industrialized countries have decreased over the years and converged. For the developing countries, China had the largest decrease from 1980 to 2004. Indonesia's hydro intensity factor was the lowest from 1980 to 2004. Overall, the hydro intensity factors have converged in a similar manner to those for the industrialized countries.

Hydro is used for base load electricity generation in New Zealand, which has a high proportion of hydroelectricity, based on plants built from the 1930s to 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 rainfall. 1992, 2001, and 2003 were dry years where hydro generators experienced shortages of water, so electricity generation had to rely more on thermal power stations. The hydro use in electricity generation has increased linearly with variations about this trend. The efficiency of hydro use in electricity generation in New Zealand plants from 1995 to 2006 is fairly constant at 99% to 100%.

14.6 OVERALL CONSUMPTION IN OTHER RENEWABLE

Other renewable includes, geothermal, solar, wind, and wood and waste electric power consumption. There is no data available for Taiwan, so only 13 countries were analyzed for other renewable. Countries apart from the United States, Germany and Japan had a small increase in other renewable consumption throughout this period. The United States had a dramatic step increase in other renewable consumption in 1989. Overall, all 13 country's other renewable consumptions are in growth.

New Zealand had the highest other renewable consumed per capita, increasing from 9.5 (GJ/person) in 1980 to 19.7 (GJ/person) in 2000. The United States was second highest from 1989 to 2000, increasing at a fairly constant rate. Germany surpassed the United States in 2001 and is now the second highest other renewable consumer per capita in the world.

The other renewable intensities for the 13 countries have been generally in decline or stagnant from 1980 to 2004. However, Germany's other renewable intensity has increased since 2000. New Zealand had a very high other renewable intensity compared to the other 12 countries. This trend shows two full typical EI curves from growth to maturity and then ageing. The points that growth started reflect the commissioning of two new geothermal power stations, Ohaaki in 1989 and Poihipi Road in 1996 [41].

For all industrialized countries, apart from Germany and New Zealand, as GDP per capita increases, consumption of other renewable in producing that GDP decreases. New Zealand has been in decline but at a higher level compared to the other 12 countries. Germany has been slightly increasing relative to economic growth. Thus, the other renewable intensities for all industrialized countries, except for Germany, has declined relative to economic growth.

For all developing countries, Indonesia and Brazil's EI has increased rapidly relative to economic growth. India's increased as well, but at a smaller rate. Russia's other renewable intensity was initially constant with a decrease in economic wealth. Russia's transition from a former industrialized state to a (re)developing country is reflected at this stage. Russia's economic wealth then increased with a decrease in other renewable intensity. China's other renewable intensity has decreased as its economic wealth has increased.

New Zealand had the highest other renewable intensity factor from 1980 to 2000, followed by Indonesia which surpassed New Zealand in 2001. While New Zealand had essentially been decreasing throughout this period, Indonesia's intensity factor had been increasing. These two countries are at a much higher scale compared to the other 11 countries. In general, the other renewable intensity factors for the industrialized countries have decreased over the years and converged.

For the developing countries, Indonesia's other renewable intensity factor had the largest increase from 0.007 (kJ/International $\$^2$) in 1982 to 0.036 (kJ/International $\$^2$) in 2004. This increase includes two typical EIF curves, which peaked in 1988 and 2001. India has also been increasing, while Brazil, China and Russia have been in decline.

In New Zealand, geothermal is used for base load electricity generation. Wairakei Power Station was commissioned in 1958 as the first geothermal plant of its kind anywhere in the world and has become an iconic symbol of New Zealand's electricity generation system [41]. Geothermal use in electricity generation has been relatively constant until 1988, then increased linearly with a peak in 1993, had a slight decrease until 1996, before another linear increase peak in 2000. Growth started again in 2004. These first two growth trends reflect the commissioning of the Ohaaki Power Station in 1989, and the Poihipi Road Power Station in 1996. In 2005, Contact Energy opened a 16 MW binary plant on the Wairakei site where there was enough new generation to increase Wairakei's total output by 10%. However, recently Ohaaki has been operating at less than capacity due to a shortage of geothermal steam [41].

The efficiency of geothermal use for electricity generation in New Zealand plants increased from 10% in 1995 to 15% in 2000, dropped back down to 10% in 2001, increased back to 14.8% in 2002, and stayed fairly constant with little increase to 15.8% in 2006. Contact's plans for three new geothermal power stations are progressing rapidly. The plans involve replacing the 50 year old Wairakei Power Station with a new power station at Te Mihi, which will be powered with steam from the Wairakei steam field. The Te Mihi power station will produce up to 220 MW of electricity, and will gradually replace the Wairakei Power Station, which will be phased out of production [42]. Other geothermal plans have also been developed by Mighty River Power [43]. These plans and upgrades should increase the efficiency and net generation of geothermal use in electricity generation.

Wind is used for base load electricity generation. New Zealand has eight wind farms which have a combined installed capacity of 321 MW in 2008. Brooklyn was the first commissioned wind turbine in 1993, with 0.225 MW capacity [44]. Wind use in electricity generation has had a dramatic increase from 146.2 GWh in 2003 to 609.3 GWh in 2005. The years which generation growth started reflects newly commissioned wind farms. Each new generation of turbine installed has greater capacity than the previous. The efficiency of wind use in electricity generation in New Zealand plants was fairly constant at around 97% in 1995 to 100.2% in 2006.

14.7 OVERALL CONSUMPTION IN NUCLEAR

There is no nuclear power plants in Australia, Indonesia and New Zealand, so only 11 countries were analyzed for nuclear energy. Australia is a nation well endowed with low-cost reserves of coal. However the threat of an impending global environmental crisis arising from the combustion of fossil fuels and a government commitment to a solution based upon a 'technology fix' through its international Climate Action Partnerships [45], has given rise to the possibility for a nuclear development.

In 2005, Indonesia, the world's largest producer of natural gas and long an oil exporter, announced that it was proceeding with the construction of the country's first nuclear power plant. Construction is to begin in 2010 with completion slated for 2017 [46]. The introduction of nuclear power plants in Indonesia is not only to reach an optimum energy mix considering cost and environment, but also to relieve the pressure of rising domestic demand for oil and gas (so that oil and gas could be used for export) [47].

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 utilized. 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 [48]. Concerns about global warming due to CO_2 emissions from burning fossil fuels, especially coal, coupled with impending electricity shortages in Auckland, has put nuclear energy back on the agenda in New Zealand [48].

The United States has the highest nuclear consumption. Countries apart from the United States, France, Russia and Japan have had a small increase in nuclear consumption throughout this period. The United States had a dramatic increase in nuclear consumption from 1980 to 2004. One reason for its nuclear generation to meet the growing demand, is that the existing plants may now have a higher plant factor, as there has been no new nuclear construction since the 1970s [49]. The industry seems to have little interest in nuclear power generation except for maintaining existing plants. The United States's energy supply is shifting more towards natural gas. It is the nations of East Asia, including Japan, that are planning to construct nuclear power as a necessity for the future [49].

France has the second highest nuclear consumption and has been increasing since 1980. The present situation is due to the French government deciding in 1974, just after the first oil shock, to rapidly expand the country's nuclear power capacity. This decision was taken in the context of France having substantial heavy engineering expertise but few indigenous energy resources. As a result of this decision, France now claims a substantial level of energy independence and almost the lowest cost of electricity in Europe. It also has an extremely low level of CO_2 emissions per capita from electricity generation, since over 90% of its electricity is nuclear or hydro [50].

Japan's nuclear consumption increased from 1980 to 2001, dropped from 2002 to 2004 and started to increase again in 2005. The dip in 2004 was caused by Japanese nuclear power plants being shut down due to maintenance concerns - these have since been bought back online [50]. In countries like France or Japan, the nuclear fuel is processed in a fuel cycle. Reprocessing is the basic strategy to increase the efficiency of uranium, as wastes can be contained, managed and reused. The reuse of plutonium as a MOX fuel for light water reactors also ensures the nonproliferation of weapons using plutonium. Reprocessing reduces the volume of high-level radioactive waste and costs associated with its disposal [49].

Germany's support for nuclear energy was very strong in the mid to late 1970s, following the oil price shock of 1974 [50]. There was a perception of vulnerability regarding energy supplies. The Social Democratic Party affirmed nuclear power in 1979, but this policy faltered after the Chernobyl incident in April 1986. In August 1986 a resolution was passed to abandon nuclear power within ten years. When Germany was reunited in 1990, all the Soviet-designed reactors in the east were shut down for safety reasons and are being decommissioned.

Russia's nuclear consumption increased from 1994 to 2005. Nuclear electricity output is rising strongly due to better efficiency of the plants, with capacity factors leaping from 56% in 1998 to 76% in 2003. Several more reactors have been under construction [50]. China has been in growth since 2000, with additional reactors are planned, including some of the world's most advanced. Overall, the 11 countries, apart from France, China, the United States, Russia and Japan, nuclear consumption has been reducing.

Canada had the highest nuclear electricity consumed per capita from 1980 to 1995. France's consumption per capita has increased linearly, and surpassed Canada in 1996 to become the largest nuclear electric power consumer per capita in the world.

The nuclear intensities for all countries, apart from Taiwan, France and Canada, have been fairly constant or stagnant from 1980 to 2004. Taiwan, France and Canada all show growth, maturing and ageing phases. Taiwan's EI levels tend to be relatively high compared to other developed countries. This is due primarily to the country's heavy concentration of energy-intensive manufacturing industries [27]. The ageing in Taiwan's nuclear intensity may also reflect factory closures due to the shift of production to China, where costs are lower. France's nuclear intensity has decreased owing to structural changes in the economy, i.e. a reduction in the share of energy intensive industries in total GDP, and to a lesser extent, to efficiency improvements [47].

For all industrialized countries, apart from Taiwan, Canada and France, while GDP per capita increased, consumption of nuclear in producing that GDP decreases. Thus, the nuclear intensities for these countries have declined relative to economic growth. Taiwan, Canada and France all show the typical EIC, with growth, maturing and ageing stages throughout this period. For the developing countries, China and India, nuclear intensity has also declined relative to economic growth. In Russia, nuclear intensity has been stagnant as the economic growth rate decreases to one point, then the nuclear intensity started decreasing relative to the increase in economic wealth. Nuclear intensity of the other 3 developing countries is low and constant compared to Russia.

The nuclear intensity factors for the 11 countries are relatively smooth declining trends over time, apart from Taiwan, France and Russia. Taiwan had the highest nuclear intensity factor from 1980 to 1987. It peaked in 1985 and has since declined rapidly and converged with those of the other 8 countries. France's nuclear intensity factor was in growth from 1980 to 1986, it peaked in 1986 and has since declined, but at a slower rate compared to Taiwan. From the available data for Russia, the growth started from 1992 to 1996, and has since declined to the same level as France. Russia and France's nuclear intensity factor are at a much higher scale compared to the other 9 countries. In general, the nuclear intensity factors for the industrialized and developing countries have decreased over the years and converged.

14.8 OVERALL CONSUMPTION IN TOTAL ELECTRICITY

The United States has the highest net electricity consumption. China's rapid rate of increase in electricity consumption surpassed Japan in 1998, and became the second highest electricity consumer country in the world. Net electricity consumption of the other 13 countries is low and at a fairly constant value compared to the United States and China.

Canada had the highest electricity consumption per capita from 1980 to 2004. The United States was second highest. France is the only country to decrease in electricity consumption per capita with a dip between 1985 and 1994 and then increased linearly from 1995 to 2004. All other countries show an increase in electricity consumption per capita. In comparison if MER was used [15], the United States was the highest electricity consumer per capita, and New Zealand was the second highest.

The electricity intensities of all countries has been in decline or stagnant from 1980 to 2004. Russia was stagnant from 1992 to 1998, and decreased from 1999 to 2004.

Canada had the second largest electricity intensity, followed by New Zealand. From using MER [15], Russia was found to have the highest and China the second highest electricity intensity. New Zealand has the fourth highest throughout this period.

The significant difference in electricity intensity curves found when using MER was that the developing countries, which have low income per capita, all have increased energy consumption in producing that dollar of GDP [15]. Electricity intensity curves found from PPP all show a decrease in energy consumption, and all countries converge.

For all industrialized countries, as GDP per capita increases, consumption of electricity in producing that GDP decreases. Canada has been in decline but at a higher level compared to the other 13 countries. Overall, the electricity intensities for all industrialized and developing countries, apart from Indonesia, have declined relative to economic growth.

The electricity intensity factors for the 14 countries, apart from China and India, are relatively smooth declining trends over time. China had the highest electricity intensity factor from 1980 to 1991, followed by India. These two countries were at a much higher scale compared to the other 12 countries. China has since decreased rapidly and converged with the other 13 countries. Russia surpassed China and Japan in 1995, but has also decreased and converged with the other 13 countries. In general, the electricity intensity factors for all 14 countries have decreased over the years and converged.

In general the electricity intensity factors using MER [15] for the industrialized countries have decreased over the years [15]. New Zealand has the highest, followed by the United States and the United Kingdom with similar levels. In general, the industrialized countries are converging. The trends using PPP show a closer convergence between the countries. The findings for electricity intensity factors for developing countries using MER are very similar to those using PPP.

New Zealand's total net electricity generation is generated from the fuel types, in descending order: hydro, gas, geothermal, coal, wind, wood, biogas, waste heat and oil. Wind overtook wood in 2005. The total net electricity generation increased linearly with small variations about this trend, more than doubling in the last 33 years, from 19868 GWh in 1974 to 41396 GWh in 2006.

The total CO_2 emitted from net electricity generation is calculated by adding the CO_2 emitted from using coal, estimated oil and gas in electricity generation. CO_2 emissions from electricity generation in New Zealand has nearly tripled in the last 12 years, from

3235 kt in 1995 to 8764 kt in 2006.

14.9 OVERALL SUPPLY AND CONSUMPTION IN NEW ZEALAND

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). Forecasted values from 2005 to 2020 were made using a linear extrapolation model. These forecasts assume that there is no structural changes in the economy such as those occurred with deregulation in 1986.

Imported oil supply showed a 50% decrease from 1974 to 1988, there was then a dramatic turn around and increased to 2.5 times its lowest value by 2004. 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 renewable energy appears more certain.

The imported oil market share was 46% in 1975. It dropped significantly after the oil crisis in 1973, decreasing linearly to 17.5% by 1986. There was a substitution of indigenous oil and oil products for imported oil after 1973 to just before deregulation in 1986. With the oil crisis in the 1970s, New Zealand perceived itself to be very vulnerable, with little indigenous supply to fall back on [57]. This predicament sparked off a programme aiming 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 [57]. However, deregulation in the oil industry removed price control, government involvement in the refinery, licensing of wholesalers and retailers and restriction on imported refined products [6] [51]. As a result, the market share of imported oil has been increasing linearly ever since. This is predicted to continue to not only meet demand, but to replace gas following the expected exhaustion of the Maui gas field. Imported oil is predicted to take up 46% of the market share by 2020, back to its pre energy crisis level. Indigenous oil market share is predicted to be insignificant by 2009. Given the history of the lack of oil discoveries, New Zealand is likely to remain a significant importer of oil [58].

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 shaped curve, as proposed by M. King Hubbert in 1956 [59]. With the easy half of the world 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. The world is facing the end of cheap and abundant oil.

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

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 [60]. Reserves have been estimated to be equivalent to about 30 times that of the original Maui gas field. 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 in 1955 and then gas in 1970.

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. 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 CO_2 emissions.

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. Nuclear fuel is abundant in Australia, New Zealand's nearest neighbour, and involves no opportunity cost, having virtually no other peaceful use. Nuclear may yet be a relatively sustainable and plausible option to further base-load capacity in New Zealand.

For all the EIC apart from gas, as GDP per capita increases, consumption of energy in producing that GDP decreases. Gas intensity is a typical curve, showing the growth, maturing and ageing stages. The ageing of the gas intensity curve has converged with the other EIC. Thus, all energy intensities for New Zealand have declined relative to economic growth. New Zealand has moved away from an energy intense economy to one based on other value commodities and services.

The EIF for New Zealand are relatively smooth declining trends over time, apart from gas. Gas's intensity growth reflects the commissioning of the Maui gas field, and the decline reflects the depletion of the field. Hydro had the highest EIF from 1980 to 1991, followed by oil. These two fuel types are at a much higher scale compared to the other fuels before 1991, but have decreased rapidly and converged with the other fuels.

Of the renewable energy resources, hydro's market share in electricity generation has declined from a high point of 86% in 1980 to 56% 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. 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 [22].

Gas use in electricity generation has emitted more CO_2 than coal use. The general public targets coal as being the main source of CO_2 emissions and forgets that burning gas also produces CO_2. 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. Despite the environmental concerns of global warming and the Kyoto protocol, there has been a large increase in CO_2 emissions from the use of fossil fuels. This significant increase was exacerbated by the replacement of gas by coal in order to meet the recent electricity demands of the nation.

The market share of CO_2 emitted in electricity generation is made up from coal, estimated oil and gas use. Oil was estimated using the given efficiency and net value in electricity generation. 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%. Compared to coal and gas, oil's CO_2 market share was insignificant after 1980. Gas's market share declined to 44% in 2004 after the depletion of the Maui gas field, then increased to 48% in 2006. On the other hand, coal has increased its market share of emissions from 23% in 2002 to 52% 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% [38]. 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%.

Chapter 15

CONCLUSIONS AND FUTURE WORK

Background research in finding which countries to study and compare to New Zealand were made by choosing the top five rankings in different categories, namely energy consumption, industrial production and population. The final fourteen countries chosen were nine industrialized countries: Australia, Canada, France, Germany, Japan, New Zealand, Taiwan, the United Kingdom and the United States; and five developing countries: Brazil, China, India, Indonesia and Russia.

The highlights of this research are shown in the following sections: Conclusion for Fourteen Countries and Conclusion for New Zealand. The future work for this research is also stated.

15.1 CONCLUSION FOR FOURTEEN COUNTRIES

15.1.1 Market Exchange Rates versus Purchasing Power Parity

The GDP and population data for the 14 countries studied were collected to allow for a comparison between New Zealand and the other industrialized and developing countries. There are two techniques for converting and comparing GDP between countries: MER and PPP.

When MER is used to compare the standard of living or per capita GDP, it can give a very misleading picture. MER fluctuates widely and causes distortion because the price of non-trade goods and services are usually lower in poorer economies. For example, a USD exchanged and spent in the People's Republic of China will buy much more than a dollar spent in the United States. Japan has the highest GDP per capita while the United States second. Canada, the United Kingdom, France and Germany have very a similar GDP per capita throughout this period. The developing countries have a very low GDP per capita compared to the industrialized countries.

PPP uses long-run equilibrium exchange rates which equalize the purchasing power of different currencies in their own country for a given basket of goods. These special exchange rates are often used to compare the standards of living in two or more countries. They are especially useful when governments manipulated official exchange rates. Countries with strong government control over the economy sometimes enforce official exchange rates that make their own currency artificially strong.

The relative ranking of the country's GDP per capita differ between the two approaches. When using MER, Japan has the highest GDP per capita while the United States is second. The results for GDP per capita using PPP show the United States has the highest value, while Canada is second. The industrialized countries show very close and similar trends. The five developing countries all have higher growth rates when considering GDP using PPP.

15.1.2 Energy Intensity Curves and Energy Intensity Factors

The next part of the thesis combined the data of GDP, population and energy consumption of each fuel for each country and studied the variation in the patterns of total energy consumption, energy consumption per GDP, EI, EIC and EIF. The fuels include, coal, oil, gas, other renewable, nuclear and total electricity generated. The aim for this study was to see if there was a relationship between energy consumption and economic growth of a country.

The industrialized countries have higher incomes per capita and developing countries with lower income per capita. In the industrialized countries, although their energy consumptions are still high, the energy use is more stagnant or changes more slowly. Thus, the energy intensities for all of the industrialized countries have declined relative to economic growth. A general trend of a decreasing intensity in the industrialized and developing countries was also observed, as economies have become less dependent on energy use to generate economic wealth.

15.2 CONCLUSION FOR NEW ZEALAND

15.2.1 Substitution of Fuel

The market shares of energy consumed by fuel shows the substitution of oil for coal dominating 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 can be seen 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 since risen. Assuming that oil continues to be available, its share is predicted to rise back to pre energy crisis levels.

A significant increase in gas consumption and market share was caused by the discovery of the Maui gas 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 [53] predicts that gas will run out by 2011 at today's consumption rate.

15.2.2 CO_2 Emission Conversion Factors

The CO_2 emission factors published for bituminous coal in New Zealand is 88.8 kt CO_2/PJ [33], which is very close to the calculated 86.5 kt CO_2/PJ [2]. This thesis uses the 86.5 kt CO_2/PJ value for coal. For gas, the CO_2 emission factors published for distributed gas streams in New Zealand range from 51.9-53.1 kt CO_2/PJ [33], which is very close to the calculated 49.9 kt CO_2/PJ [2]. This thesis uses the 49.9 kt CO_2/PJ value for gas. This thesis focuses on the CO_2 emitted during the process of transforming the primary energy into electricity generation. Hence, the conversion factor used for hydro, wind and geothermal for New Zealand are 0 kg/CO_2 [34].

15.2.3 CO_2 Emissions from Electricity Generation

Gas use in electricity generation has emitted more CO_2 than has coal use in electricity generation in New Zealand. Although gas emits only 0.58 times CO_2 than coal on a per kg basis, gas was the main fossil fuel used in electricity generation, gas had an 80% market share in emissions from 1995 to 2002. It has since dropped to 44% after the reduction of Maui gas use in 2002. The replacement for gas has been coal, with its market share increasing from 23% in 2002 to 52% in 2006. Despite the environmental concerns of global warming, the Kyoto protocol, and awareness of coal use being the main source of CO_2, New Zealand is continuing to replace gas with coal. This is the quickest and easiest fuel to turn to for electricity generation in a short time frame. The other renewable increase is not enough to cover New Zealand's growing energy demand.

15.2.4 Gas Depletion in New Zealand

The Maui gas field was fully commissioned in 1979. It 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 [61].

15.2.5 Wind and Hydro Most Efficient

The efficiency of each fuel in electricity generation was calculated using the ratio of the net to heat values. The heat values for oil in electricity generation were not available. However, the efficiency of oil-fired plant's weighted average is 38% [38]. 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%.

15.2.6 Other Renewable Not Sufficient

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 a solution to New Zealand's energy supply, the increase in market share of other renewable to date is limited. At the current rate of increase, they are unlikely to be sufficient to cover New Zealand's increasing energy demand in the near future. It will take some time before New Zealand can reach its commitment to 90% renewable electricity [22].

15.2.7 Nuclear for New Zealand

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.

15.3 FUTURE WORK

This thesis concentrated on studying energy patterns for the 14 countries selected, and further analysis was performed for New Zealand. By understanding the historical patterns and substitution of various energies, a technological substitution model which shows the replacement of old technology with new technology [62] could be made.

To accurately forecast energy consumption, many technical parameters (fuel reserves, conversion efficiency, infrastructure), economic and social factors (GDP, prices, end use patterns), and political and policy actions (taxes, incentives and subsidies, regulations), all led to the proliferation of energy scenarios [3]. For example, the gas reserve was not considered when previous studies [12] [9] [11] forecasted that primary gas for New Zealand from 1980 to 2020 would increase linearly, whereas the main gas field depleted in 2002.

Most forecasts made after the oil crisis in the 1970s, overestimated the United States energy consumption in 2000 [1]. Today's fuel mix has not changed significantly since 1985, whereas many forecasts prior to that date predicted significant decreases in fossil fuel use (especially oil and gas).

Forecasts can be improved by combining separate forecasts obtained by different methods. Combining scenario analysis and technological substitution models could improve forecasts, where the former deals with the uncertain future, while the latter offers data-based forecasts from quantifiable parameters [63]. The distinction between scenarios and forecasts is that the former does not attempt to predict the future, but rather to envision what type of futures are possible [3].

This thesis covered the parameters of conversion efficiency, GDP, end use patterns and the deregulations in New Zealand. Any future work performed would be to further consider the fuel reserve, infrastructures, LCA and carbon taxes before making forecasts. Future work would use the EIFs shown as a predictor for each fuel type, to see whether it is in a growth, maturing or ageing phase.

More scenarios, apart from business as usual could also be taken into account when making forecasts. The two variables are the GDP growth rate and the environmental impact. These extra scenarios include: hard times, technological improvement, high tech future and new society [3]. Disruptions could result in unanticipated technical, social, economic, or political factors that constrain the supply, increase or decrease demand, or wreak havoc with the fuel mix. All the scenarios except for hard times require technological advances, and business as usual and high tech future require increases in energy supply.

There are some questions to be answered from future work. When will oil and gas resources cease to meet growing demand? What will replace oil in transportation? Who will drive the market growth and cost reduction of renewable energy sources? [64]

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