Stabilization of Carbon Emissions: A Viable Option for the Republic of Korea?

by

Son Hwi Kim
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Abstract

This study assesses the viability of carbon emissions stabilization for the Republic of Korea. For this analysis, a computable general equilibrium model designed specifically for greenhouse gas emissions projection and policy assessment for Korea was developed. The model makes population, economic, energy, and greenhouse gas emissions projections from the year 1985 to 2030, and has the ability to assess the impact of carbon tax policies and energy technologies. A reference case with traditional fossil fuel energy technologies, hydroelectricity, and limited nuclear energy shows that carbon dioxide and other greenhouse gas emissions in Korea will grow nearly fivefold from 1985 to 2030. For the reference case, stabilization of carbon emissions to the 1995 level or 2 tonnes of carbon (tC)/capita required carbon taxes as high as US $1,525/tC that resulted in a GNP loss of 6.5 percent from the base case in the year 2030. To understand the impact of advanced energy technologies on reducing the cost of carbon stabilization, more efficient natural gas and coal power plants, along with solar-photovoltaic technology and alcohol fuels derived from biomass, were introduced into the model. In addition, the constraint on nuclear power was lifted. These technologies, particularly alcohol fuels, nuclear power and natural gas, significantly reduced the cost of carbon emissions stabilization to the 1995 level. However, even with these technologies, a carbon tax of $180/tC, which resulted in a GNP loss of 3 percent in 2010, was required to stabilize carbon emissions. The analysis of carbon taxes and energy technology impacts show that stabilization of carbon emissions to the current level will be extremely costly and is not a viable option for Korea.

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Chapter 1. Introduction

There are increasing concerns that emissions of carbon dioxide (CO_2) and other so-called "greenhouse gases" (GHGs) could lead to significant global warming. According to the Intergovernmental Panel on Climate Change (IPCC), increases in the concentration of CO_2 and other GHGs could raise global average temperature by 1.5 to 4.5° C over the next century (IPCC 1990). Such concerns have prompted the international community to consider actions to limit GHG emissions or mitigate their impact.

While most of the increase of GHGs to date has been due to the economic activities of industrialized countries, rapid industrialization and population growth in developing countries over the next century implies that more of the future increase in atmospheric levels of CO_2 and other GHGs will come from developing rather than industrialized countries. For instance, while CO_2 emissions from industrialized countries such as the United States and Germany have leveled off (*Trends '93*), emissions from developing countries such as China and India are expected to increase multi-fold from the current level in the next century (Chandler et al. 1990; Fisher-Vanden et al. 1994).

The rising GHG emissions and the threat of global warming has resulted in a framework for international policies on controlling global GHG emissions. The 1988 Toronto World Conference on the Changing Atmosphere was the first formal call for a global climate convention held in a broad international setting. The Toronto conference invited industrialized countries to reduce emissions of CO_2 from energy production by 20 percent from the 1987 level by the year 2005, and developing countries to release less than 1.5 times the fossil carbon emissions in 1987 by the year 2005. However, this target was relaxed in the 1992 Earth Summit in Rio de Janeiro, Brazil, which proposed that industrialized countries return GHG emissions to the 1990 level by the year 2000. Many industrialized nations have made commitments to comply with this target. In 1993, the US Climate Change Action Plan committed the United States to return GHG emissions to the 1990 levels by the year 2000.

The impact of such energy-related GHG control policies are likely to vary significantly between countries and remain highly uncertain. Many analyses of the impact of emissions control policies for industrialized countries have been conducted; however, little attention has been focused on understanding the impact of these policies on newly-industrialized or smaller developing countries. For many newly-industrialized and developing countries, meeting the 1990 emissions target or even the Toronto target for developing countries may be difficult as their energy-related GHG emissions grow rapidly.

1.1 Motivation for the Case Study of South Korea

Due to differences in economies and growth rates of countries, the effect of policies for carbon emissions reduction may vary considerably from country to country as stated above. Thus, equity is a major concern in reaching an international agreement on carbon emissions reduction. In this thesis, the cost of carbon emissions restriction for the Republic of Korea (South Korea) was analyzed. South Korea, a country with a high economic growth rate, little or no domestic energy resources, and a heavy reliance on foreign energy, is one of the most energy-intensive countries in East Asia and could be significantly affected by policies that limit carbon emissions and fossil fuel energy use. This scenario is also likely to be true for other dynamic Asian economies, such as Taiwan, Indonesia, Malaysia, Thailand, Singapore, and China. The study of South Korea thus represents an example of the impacts of carbon reduction policies and technology choices for these countries. Moreover, as the economies of countries in East Asia become increasingly more intertwined, economic activity of one country is likely to affect the region in a more significant way. Therefore, the analysis of the effect of emissions reduction for South Korea provides a basis for understanding the regional effects of GHG emissions reduction.

The Korean economy is very sensitive to energy and related policies due to the rapid pace of economic growth, the resultant high demand for energy, and the near complete reliance on foreign sources for this energy. Korea's GNP growth rate in 1990 was 9.3 percent, while the primary energy consumption growth rate was 14.1 percent. Moreover, of the total primary energy consumed in 1990, 74 percent (not including nuclear energy) was supplied by imports. Petroleum was the major energy import and represented 54 percent of the total primary energy consumption. With such dependence on foreign energy and such a high energy consumption growth rate, it is evident that the Korean economy is and will continue to be highly sensitive to the availability and cost of world energy. The rapid economic growth and high demand for fossil energy will undoubtedly result in greater emissions of carbon, and therefore, Korea could be significantly affected by policies that limit carbon emissions and fossil fuel energy use. For instance, the vulnerability of the Korean economy to energy price changes is evident from the impacts of the past two oil price shocks in 1973-74 and 1979-80. During the first oil price shock, the annual GNP growth rate fell from 13.2 to 8.1 percent, and during the second oil price shock, it fell from 7.2 to negative 3.7 percent (*Yearbook of Energy Statistics 1993*). Although the first oil price shock did not affect the economy too severely, the second oil shock, in conjunction with a sharp reduction in rice production due to cold weather and the assassination of President Park Chung Hee, produced a much more severe decline in the economy. In 1980, the GNP growth rate was negative for the first time in Korea's modern history.

Thus, policies to control and reduce GHG emissions which rely on taxes to discourage fossil fuel use are also likely to have a large impact on the Korean economy. This study investigates the impact of these policies in detail. The results from the study of Korea will contribute to the assessment of the growth in global carbon emissions and add to the knowledge of how the cost of carbon emissions reduction policies can vary among countries. Moreover, as previously noted, this study can provide insights on the relationship of economic growth to energy use and GHG emissions control for other similar dynamic Asian economies. Rapid industrialization and economic growth are now occurring in East and Southeast Asia, and issues of energy and GHG emissions in this region will become more pressing as energy consumption and GHG emissions rise dramatically. With this rapid development, multilateral energy and economic relations are emerging in the region, and the study of Korea will contribute to understanding the impact of GHG emissions control policies on East Asia as a whole.

1.2 Objectives of the Thesis

There were three specific objectives necessary to carry out the analysis of the impact of carbon emissions reduction. They were: (1) to develop a greenhouse gas emissions model for Korea; (2) to generate a reference scenario which predicts how the economy, energy consumption, and carbon emissions grow when no attempt is made to limit fossil fuel use; and (3) to study the impact of carbon stabilization policies and advanced energy technologies on economic growth and energy consumption.

Development of Greenhouse Gas Emissions Model for South Korea

To gain insight on the impact of carbon emissions control policies, a modeling tool that can assess emissions, policies and technologies is necessary. At present, the state of GHG emissions modeling in Korea is at its infancy; models that can project GHG emissions from all major human activities and link energy use to the rest of the economy do not exist. Thus far, projections of CO_2 emissions have been determined from the historical trend of energy use and therefore, these projections have no direct linkages to the rest of the economy (Jung 1993; Lee 1991). Many more elaborate models that project global GHG emissions level do exist such as GREEN, Burniaux et al. (1991), OECD (1991), Global 2100, Manne and Richels (1990), and ERM, Edmonds and Reilly (1985). However, these models do not explore Korea specifically. Aggregated regional models do not accurately portray the emissions of GHGs and their relationship to the economy of individual countries. Therefore, as a part of this study, a model that projects GHG emissions for Korea was developed. The model developed in this study is the first computable general equilibrium model designed to project carbon emissions and to study the impact of carbon control policies for Korea.

The assessment of the cost of carbon emissions reduction for Korea requires the ability to project long-term GHG emissions levels, and the ability to understand the interconnection of GHG emission to energy use and economic activity of Korea. Such an analysis can be achieved by developing a computable general equilibrium model with an accurate representation of the Korean economy and with a level of sectoral detail important for GHG emissions. The model should be able to project emissions from all human activities responsible for GHG emissions and not solely from energy use, and should have the ability to show the effects of policy and technology changes on emissions, as well as on the economy.

The GHG emissions model developed for Korea is a module of the Second Generation Model (SGM), which is a computable general equilibrium model for GHG emissions projection developed at the Pacific Northwest Laboratory (Edmonds et al. 1991). The SGM was designed specifically for long-term GHG emissions projections and for the study of carbon emissions control policies and technology impacts. The Korea module utilizes the same modeling structure as the SGM, and therefore, has the same model attributes and capabilities. The Korea module has a 45 year time horizon, from 1985 to 2030, and projects results in five year intervals.

Although the SGM modeling structure exists, building country specific computable general equilibrium models is difficult because of the extensive data and calibration requirements. Development of the Korea module required Input-Output data, historical capital stock, discards, and investment data, energy statistics data, population and demographics data, land use data, energy resources and reserves data, and other data. Then, the above raw data was transformed into a data set that can be utilized in the SGM. This is a time consuming procedure as the raw data must be aggregated or disaggregated into a format required for the SGM. Once the data set in SGM format was complete, it was used to calculate parameters such as the coefficients for production, investment, government demand, and household demand functions. After these parameters were determined, the model results were calibrated to reproduce the actual data for the base year, 1985. Then a reference case, or a baseline scenario for comparisons, was generated with projections to the year 2030.

Reference Case

A reference case was generated to determine a baseline scenario of growth in population, economy, primary energy consumption, electricity generation, and carbon emissions up to the year 2030. The reference case was developed with consideration for historical trends and with no efforts to reduce carbon emissions. In the reference case, energy supply technologies were limited to the traditional fossil fuel technologies, hydroelectricity and nuclear power. Nuclear power, however, was constrained after the year 2005, as it could be difficult for Korea to continue its massive nuclear program due to high cost, proliferation issues, public opposition, and land availability. Once the reference case was generated, it was then used as a basis for comparing the impact of carbon control policies, as well as the impact of advanced energy technologies.

The Cost of Carbon Emissions Reduction

Since Korea is so sensitive to energy issues, carbon emissions restriction policies are certain to have strong effects on the Korean economy. The impact of such policies, which may be implemented in the form of carbon taxes, on Korea's GHG emissions level, energy consumption and economic productivity was investigated. Using the Korea module of the SGM, energy prices were changed to represent the imposition of carbon taxes. Such price changes reduce the consumption of energy and result in a slow-down in the economy. Based on the level of taxes, the reduction in energy consumption and loss in the GNP were quantified. Recently, the results from the US module of the SGM has shown that stabilization of CO_2 emissions to the 1990 level in the United States requires carbon taxes that reach a peak of $140 per tonne of carbon with resulting GNP loss from the baseline of 1.2 percent (Fisher-Vanden et al. 1993). For Korea, the tax level for carbon emissions stabilization to the 1990 level will undoubtedly be much higher due to the rapid pace of economic growth and limited energy technology options. How much higher the tax will be and how much loss will result in the GNP for Korea was characterized in this study.

If Korea participates in an international global tradable permits protocol instead of stabilizing carbon emissions on its own, the cost of emissions reduction could be dramatically lower. In such a protocol, since the marginal cost of carbon emissions reduction varies from country to country, countries with high emissions and high marginal costs of emissions reduction would purchase allowances from countries with lower marginal costs. This scheme enables all countries that participate in the protocol to benefit; countries with low marginal cost of emissions reduction receive payment for allowances sold and countries with high marginal cost pay less to achieve the global carbon emissions target. The cost of Korea's participation in such a protocol was explored in this study. In theory, a tradable permits protocol is attractive in meeting a global carbon emissions target. However, there are many issues concerning the global tradable permits protocol and the reality of achieving an international agreement on such a policy may be difficult.

The choice of technologies for energy production and use can have a tremendous effect on the level of energy consumption and the emission of GHGs. Therefore, the impact of advanced energy technologies on the cost of carbon emissions stabilization was analyzed. The lack of domestic energy resources and the dependence on foreign energy have determined Korea's energy policy objectives. They are: to secure stable oil supplies, to promote the development and use of nuclear, coal, natural gas, and other alternative energy sources, to increase energy conservation, and to reduce the dependence on imported oil (Kim and Shin 1986). Therefore, advanced fossil fuel technologies, such as fluidized bed combustion technologies and natural gas combined cycled power plants, along with the use of alcohol fuels derived from biomass and solar-photovoltaic technology, were introduced into the model. Moreover, the constraint on nuclear power plants was lifted to provide an additional non-carbon based energy choice. In addition to these technologies, energy consumption was reduced exogenously to represent end-use efficiency improvements in the household sector. Korea has initiated policies to encourage energy conservation, and is increasing efforts to increase energy efficiency in all sectors of the economy (Kim and Shin 1986). Once these additional technologies, along with end-use efficiency improvements, were introduced into the model, carbon taxes were applied to fossil fuels to stabilized carbon emissions. Comparisons were then made with the reference case to determine the impact of these technologies on reducing the cost carbon stabilization.

1.3 Plan of the Thesis

The thesis is divided into five substantive parts after the introduction and a brief background on Korea in Chapter 2. In the background section, the historical growth of population, economy, energy consumption and use, and carbon emissions are provided. A clear view of these trends is important for understanding the transition from historical data to model projections. The first substantive part, Chapters 3 and 4, is a description of the modeling tool, data requirements, and key parameters and assumptions used for the study. Chapter 3 gives a description of a computable general equilibrium model called the Second Generation Model, and Chapter 4 details the data requirements, provides the steps necessary for calibration, and discusses model assumptions, as well as assumptions about the future. The second substantive part is Chapter 5, which is the first chapter on model results. In this chapter, a reference case or the "business as usual" scenario of economic growth, energy consumption, and carbon emissions for Korea is presented. The results of this chapter are important for the overall analysis as the reference case is the basis of all comparisons. The next substantive part is an analysis of fiscal policies for carbon emissions reduction. In Chapter 6, carbon taxes and their effects on carbon emissions, energy consumption, and the economy were analyzed. Carbon emissions were stabilized to the 1995, 1.5 times the 1995 and 2 times the 1995 emissions level of the reference case. These scenarios give an indication of how the impact of carbon stabilization will vary according to the time and emissions level chosen for carbon emissions stabilization. The fourth substantive part, Chapter 7, is a global carbon emissions stabilization scenario through an international tradable permits protocol. Instead of each country stabilizing carbon emissions on its own, if an international agreement for a tradable permits allocation scheme can be arranged, the cost of global carbon emissions stabilization could be lowered by utilizing the variations in the marginal cost of carbon reduction. An assessment of the cost for Korea's participation in the tradable permits protocol is investigated in this chapter. The final substantive part, given in Chapters 8 and 9, is on the impact of energy technology choices on carbon emissions in Korea. If Korea is to limit or reduce carbon emissions, the proper choice of energy technologies is crucial. Therefore, an analysis of the impact of renewable technologies, energy efficiency improvements in energy production and end-use, and increased nuclear power on reducing the cost of carbon emissions reduction is provided. The thesis is concluded in Chapter 10 with findings on whether stabilization of carbon emissions is a viable option for Korea and with a discussion on future studies necessary to better understand the full economic impact of climate change on Korea.

Chapter 2. Background on Korea

A brief introduction to Korea is necessary to better understand the relationship of land, climate, population, and economy to current and future carbon emissions levels. The most important factor for carbon emissions is the amount of fossil fuel used for energy. Energy use, however, is a direct function of land and climate characteristics, population levels, and structure and growth of the economy. For instance, the availability of land and subsurface resources determine the choice of fuel and technology for energy, climate dictates the energy needs for heating and cooling, population levels and household energy needs affect overall energy use, and the level of industrialization and energy intensity of the economy determine energy requirements as well. In addition to determining carbon emissions levels, the characteristics of the land, climate, population, and economy directly affect a country's ability to control energy use and carbon emissions through either fiscal policies or technology choices. The scarcity of resources, whether they are land, labor or capital, limits the options for carbon emissions reduction. Thus, a background to Korea is an important precursor to understanding the impacts of fiscal policies and technology choices to control carbon emissions.

2.1 Land, Climate and Population

South Korea is a small country approximately one hundred times smaller in area than the United States or about the same area as the state of Indiana or the country of Portugal. Korea has a land area of 99,873 km^2 with numerous hills and mountains covering nearly 70 percent of the country (*Handbook of Korea*). High mountains are located towards the North and East, which gradually turn into plains, low hills and basins towards the South and West. Of the total land area in Korea, 65 percent consisted of forest and woodland, 21 percent of cropland, 12 percent of other land, and 1 percent of pasture in 1989 (*World Resources*). The category, other land, consists of wastelands, rangelands, and urban settlements. Thus, the availability of total useable land is limited due to Korea's small land mass, numerous mountains, and a large population (see Tables 2.1 and 2.2 for land area and land use data).

The climate in Korea is defined by its mid-latitudinal location in Northeast Asia and peninsular configuration. This location places Korea in a temperate zone with four seasons. Spring arrives in late March and turns to summer in the beginning of June. Autumn lasts for about two months from October to November before turning into winter in December. The annual range of temperature between the coldest and hottest months for Seoul, the capital of Korea, is about 30 degrees Celsius or 86 degrees Fahrenheit (*Handbook of Korea*). The mean temperature during winter is generally below freezing; the mean temperature in Seoul in January is 4.9 degrees Celsius below freezing or 23 degrees Fahrenheit. The summer in Korea is hot and humid with the mean temperature rising above 25 degrees Celsius or 77 degrees Fahrenheit during the hottest month. Precipitation in Korea is determined by the East-Asian Monsoon, where in the summer months, the monsoon picks up moisture from the Pacific Ocean and brings heavy rainfall. Approximately 70 percent of the total annual rainfall occurs in the summer. The winter monsoon, which originates in the interior of the Asian continent, is dry and low in temperature. Thus, little precipitation is produced in the winter months except for a few snowfalls.

Korea, with a population of 43 million in 1990, is one most densely populated countries in the world. The population density of Korea is 432 persons per km^2. In comparison, the population density of Japan and the United States are 327 and 27 persons per km^2, respectively. Government programs and economic developments have slowed Korea's population growth rate in the last decade to a rate that is nearly equal to that of the United States. The population growth rate from 1980 to 1990 was 1.1 percent per year for Korea and 0.9 percent per year for the United States. Population figures from the year 1965 to 1991, shown in Figure 2.1, reveal the historical population levels and the slow-down in population growth rates. The labor force has grown at a slightly faster rate than the population growth rate, however, the growth in the labor force should decline as population growth slows.

Table 2.1 Land Area and Population Data Comparisons

	Korea	Japan	USA
Land area (1,000 km^2)	99	378	9,373
Population 1990 (million persons)	43	124	250
Population growth rate 1965-1990 (%/yr.)	1.1	0.6	0.9
Populating density (persons/km^2)	432	327	27

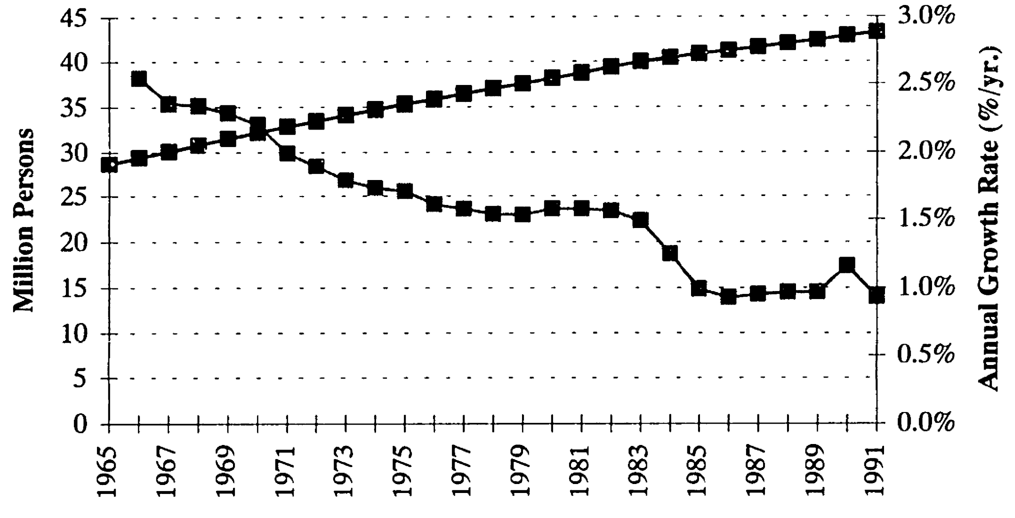
Source: *World Development Report 1992* and *World Resources 1992-93*

Table 2.2 Land Use in Korea

1989	Cropland	Permanent Pasture	Forest and Woodland	Other Land
Land use (km^2)	21,360	880	64,920	11,570
% of Total Land	21	1	65	12

Source: *World Resources 1992-93*

Figure 2.1 Historical Population and Annual Growth Rates



2.2 Economy

This small Asian country has experienced dramatic economic growth in the last 30 years. The real GNP grew from 3 billion US dollars in 1965 at approximately 10 percent per year to reach 242 billion US dollars in 1990. Korea ranked 17th in the world by GNP level in 1990. Refer to Figure 2.2 for historical GNP levels and growth rates. Comparisons of 1990 GNP levels show that Japan and the United States have economies that are 13 and 23 times larger than Korea (see Table 2.3 for GNP comparisons). Although GNP growth has been strong, Korea's per capita GNP level is still well below that of industrialized countries. The GNP per capita ratio for Korea was 5,400 US dollars in 1990, which was well below the GNP per capita level of 25,430 US dollar for Japan and 21,790 US dollar for the United States. Nevertheless, during the period from 1980 to 1990, Korea had a GDP growth rate that was significantly higher than Japan or the United States. The GDP growth rate was 9.7 percent per year for Korea, 4.1 percent per year for Japan and 3.4 percent per year for the United States for this period.

An important factor in Korea's dramatic economic growth has been international trade. The government-led export policy placed Korea as the 11th largest trading nation in the world in 1988. Exports grew by a factor of 80 from 0.175 billion US dollars in 1965 to 65 billion US dollars in 1990 (*Yearbook of Energy Statistics*). With a growth rate of 27 percent per year, this is a remarkable increase in the level of exports (see Figure 2.3 for historical export levels from 1965 to 1991). The importance of trade for Korea is clearly evident as the ratio of exports to GNP was 28 percent in 1990.

The promotion of heavy and chemical industries by the government in 1973 led the drive for industrialization and exports (Sakong 1993). In 1991, 65 percent of manufacturing consisted of heavy industries, and 58 percent of the exports was of heavy industrial goods. For example, the top ten exports consisted primarily of energy intensive industrial products such as steel, ships, chemicals, general machinery, automobiles, and petroleum products. Such an emphasis on exports, particularly of industrial products, transformed Korea from an agrarian economy to one that is now dominated by a service sector and an energy intense industrial sector. In 1990, the agriculture, industry and service sectors comprised of 9, 45, and 46 percent of the GDP, respectively.

Although Korea exports a significant amount, nearly one fourth the value of Japanese exports, net trade has been at a slight deficit overall due to an even greater import level (see Table 2.3 for comparisons of the value of exports and imports for Korea, Japan and the United States). Except for a short period from 1985 to 1989, the value of imports has consistently been greater than that of exports (see Figure 2.3). Such statistics reveal Korea's dependency on imports and the lack of domestic raw material, energy and technological resources. The mirroring of imports to exports, as evident in Figure 2.3, reveals the importance of trade to Korea's economic prosperity. The implications of import price increases are significant as it could affect balance of payments and international competitiveness.

Figure 2.2 Historical GNP Levels and Annual Growth Rates

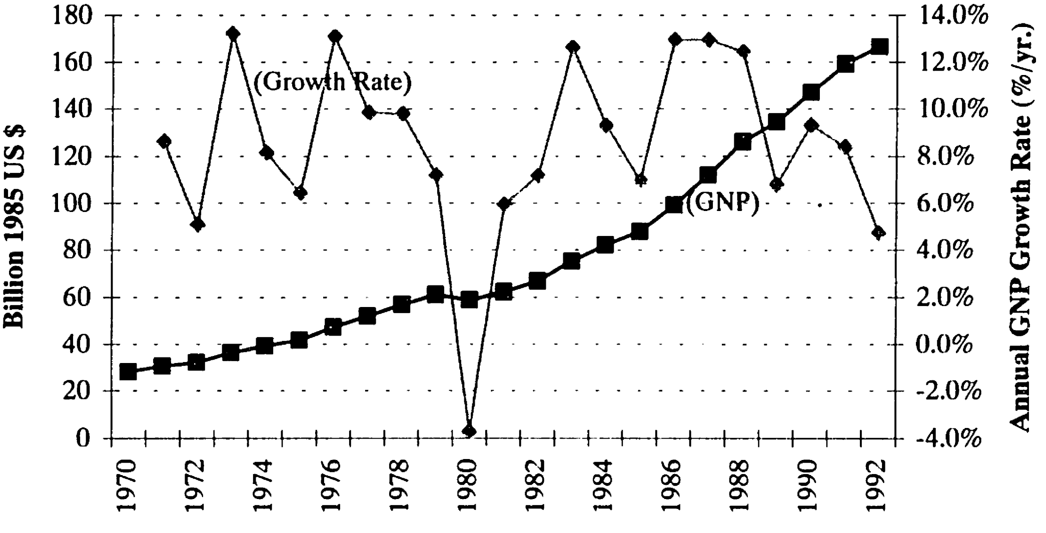
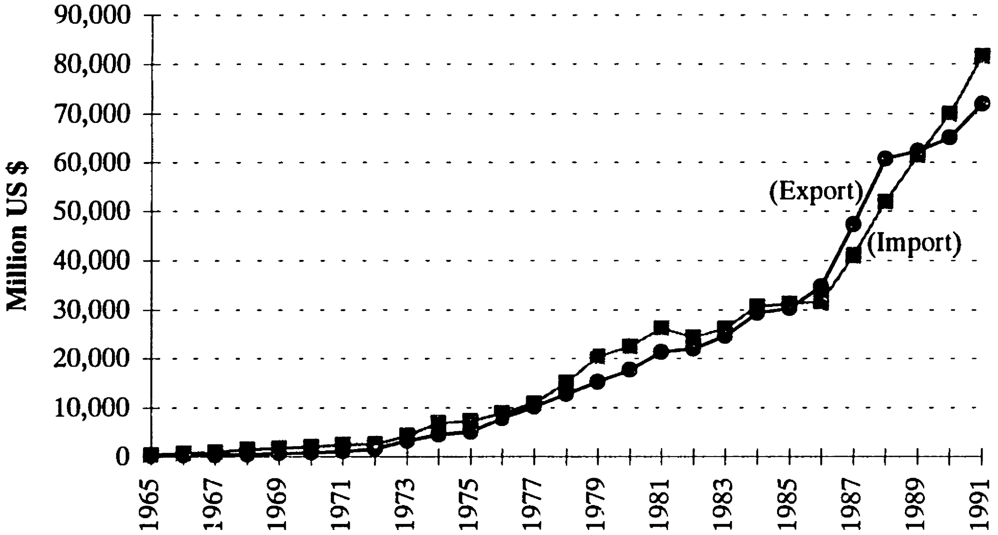


Table 2.3 Comparisons of Key Economic Parameters

	Korea	Japan	USA
GNP (billion US$, 1990)	242	3,141	5,448
GDP growth rate (1980-1990) (%/yr.)	9.7	4.1	3.4
GNP/capita (US$, 1990)	5,400	25,430	21,790
Exports (billion US$, 1990)	65.0	287.6	393.6
Imports (billion US$, 1990)	69.8	235.4	517.0
Export as % of GNP (1990)	28	10	7
Agriculture as % of GDP (1990)	9	3	2
Industry as % of GDP (1990)	45	41	29
Service as % of GDP (1990)	46	56	69

Figure 2.3 Value of Exports and Imports for Korea



2.3 Primary Energy

Along with Korea's rapid economic growth, the demand for energy has increased exponentially. From 1980 to 1990, the consumption of primary energy grew at a rate of 8.1 percent per year, which was significantly higher than the rate of 1.5 percent for the United States and a rate of 2.1 percent for Japan. In 1990, the level of primary energy consumption in Korea was 89.5 million Tonnes of Oil Equivalent (TOE) (see Figure 2.4 for primary energy consumption levels from 1965 to 1991). Total primary energy consumption level for Korea is, nevertheless, much smaller in comparison to Japan and especially, the United States. The primary energy consumption level in 1990 was 423 million TOE for Japan and 1,929 million TOE for the United States. Refer to Table 2.4 for primary energy consumption comparisons.

Although the total level of primary energy consumption is small in comparison to Japan and the United States, the emphasis of the Korean economy on the industrial sector, which consists largely of heavy industries, makes Korea one of the most energy intensive economy in the world. For example, Table 2.4 shows that in 1990, Korea used 0.379 TOE per 1,000 US dollar output of GDP, which was higher than a ratio of 0.358 TOE per 1,000 dollar for the United States. In contrast, Japan's energy to GDP ratio was 0.144 TOE per 1,000 dollar. Comparison of Korea's energy to GDP ratio to that of Japan's reveals the large capacity for energy efficiency improvements in Korea's industrial sector.

The mix of primary energy consumption in Korea has thus far been dominated by oil and coal. Of the total primary energy consumed in 1990, 54 percent was oil, 27 percent was coal, 15 percent was nuclear energy, 3 percent was natural gas, and 1 percent was hydroelectricity. Compared to Japan and the United States, the combined share of coal and oil for primary energy consumption is the highest in Korea. Coal and oil make up 81 percent of the total primary energy consumption in Korea, 76 percent in Japan, and 66 percent in the United States.

Comparisons of energy consumption per GDP ratios revealed the energy intensity of the Korean economy. However, comparisons of energy consumption per capita ratio provides a different information. In 1990, the ratios of energy consumption per capita for the United States and Japan were 3.7 and 1.6 times greater, respectively, than that for Korea. Table 2.4 shows that in 1990, the energy consumption per capita was 2.1 TOE for Korea, 3.4 TOE for Japan, and 7.7 TOE for the United States. The lower energy per capita ratio reveals that Korean households consume much less energy in comparison to Japanese and American households, whereas, the high energy per GDP ratio reflects the energy intensity of Korean industries. Nevertheless, the energy per capita ratio has been increasing at 6.9 percent per year from 1965 to 1991 and is expected to increase with time as Korean households demand more energy conveniences from appliances and automobiles.

Continued economic growth and the rising demand for energy from the industrial and household sectors of the economy will increase Korea's consumption of primary energy in the foreseeable future.

Figure 2.4 Historical Primary Energy Consumption

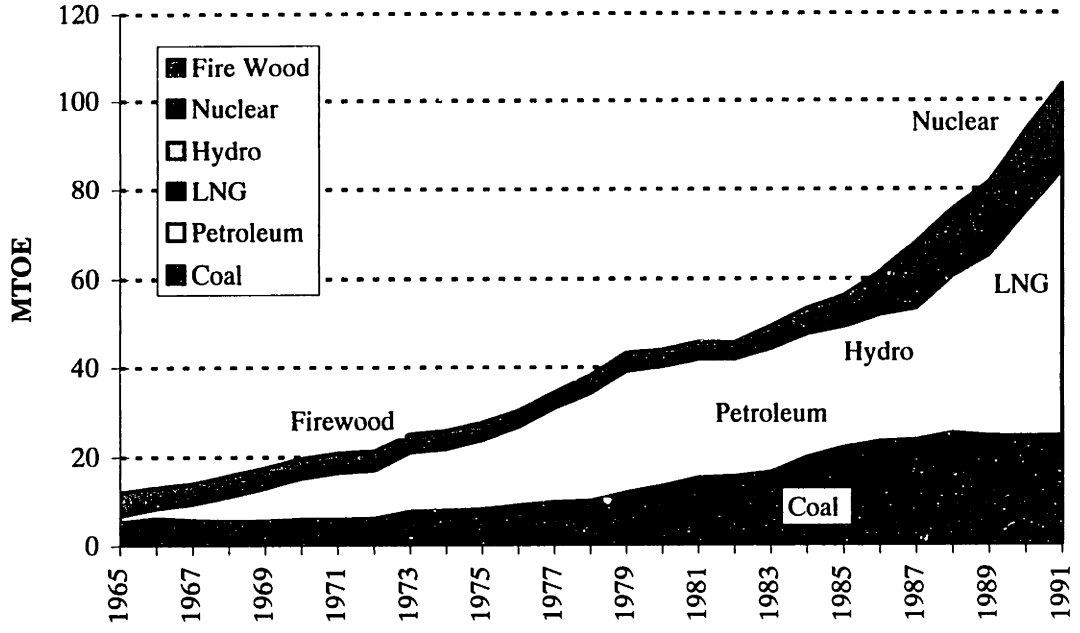


Table 2.4 Comparisons of Primary Energy Consumption

	Korea	Japan	USA
Primary energy consumption 1990 (million TOE)	89.5	422.7	1,929
Primary energy consumption growth rate (1980-1990)	8.1	2.1	1.5
Energy/capita (TOE, 1990)	2.1	3.4	7.7
Energy/GDP (TOE/1000 US $, 1990)	0.379	0.144	0.358
Primary energy mix: (1990)	%	%	%
Coal	27	18	25
Oil	54	58	41
Natural gas	3	11	25
Nuclear energy	15	12	8
Hydroelectric	1	2	1

Sources: *Yearbook of Energy Statistics 1993, World Development Report 1992, World Resources 1992-93,* and *BP Statistical Review of World Energy 1994*

2.4 Electricity Generation

Even though the consumption of primary energy has grown rapidly, the consumption of electricity has outpaced the consumption for primary energy. From an electricity consumption of 3.2 Terawatt-hour (TWh) in 1965, consumption grew at 10.2 percent per year to reach a level of 94.4 TWh in 1990. This dramatic growth, shown in Figure 2.5, is an increase in electricity consumption of nearly 30 fold from 1965 to 1990. The primary fuel source for electricity generation in the early part of this period was oil, but in recent years, the main source for electricity generation has been nuclear power.

Unique to a few countries in the world, electricity generation in Korea is dominated by nuclear power. As shown in Table 2.5, of the total electricity generated in 1990, 49 percent was generated from nuclear energy, 19 percent from coal, 18 percent from oil, 9 percent from natural gas, and 6 percent from hydroelectricity. Only France, Sweden, and Belgium have greater shares of electricity generation from nuclear power than Korea. In the future, the share of electricity generation will continue to be dominated by nuclear power as the Korean government plans to increase construction of nuclear power plants to meet the high electricity demand. In addition, a large capacity of electricity generation from natural gas (LNG) was introduced just after 1985, replacing a portion of the electricity generated from oil and coal. The competitive price of natural gas combustion technologies, its high efficiency and low pollution levels have contributed to the introduction of natural gas for electricity generation. At present, the share of electricity generation from natural gas is small, but this share is expected to increase in the near future.

Similar to the comparisons of primary energy consumption per capita ratios, the electricity consumption per capita ratio for Korea is much lower than that of Japan and the United States. Electricity consumption per capita for Japan and the United States are 2.2 and 5.0 times larger, respectively, than that for Korea. As shown in Table 2.5, the electricity per capita ratio in 1990 was 2.2, 4.9 and 10.9 MWh in Korea, Japan and the United States, respectively. The lower electricity per capita ratio for Korea again reflects the lower household consumption of electricity in comparison to Japan and the United States. However, economic growth and rising income levels will increase the desire for consumer electronics, appliances and electricity services. The demand for electricity is very strong as evident from the high electricity consumption growth rate. Moreover, the growth rate of electricity consumption, which is higher than the growth rate of primary energy consumption by 2 percent per year, indicates the growing importance of electricity services over other energy services.

Figure 2.5 Historical Electricity Generation

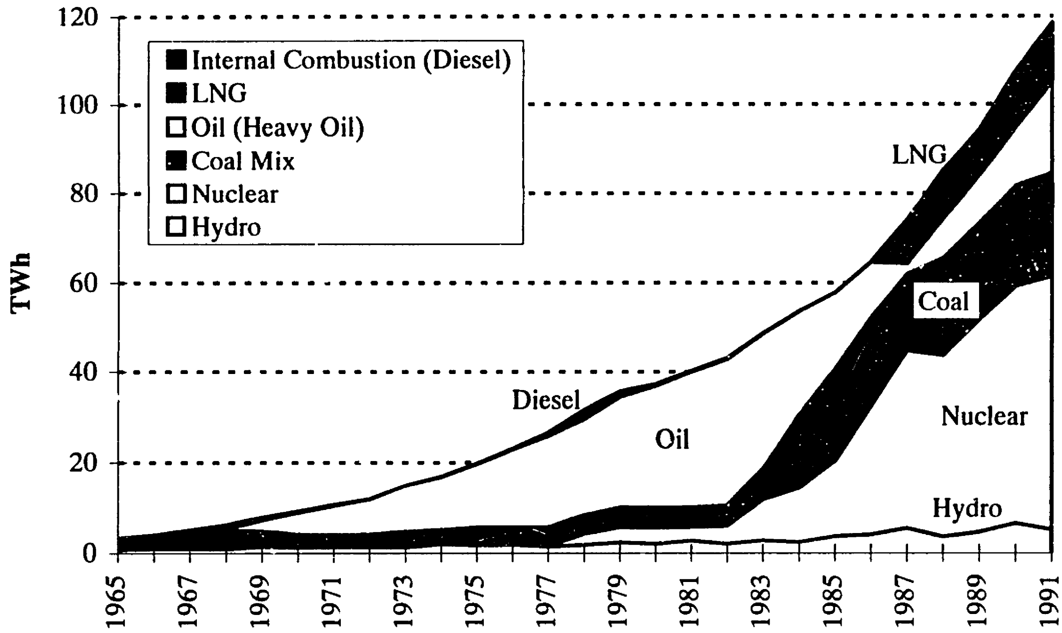


Table 2.5 Comparisons of Electricity Consumption and Generation

	Korea	Japan	USA
Electricity consumption 1990 (1,000 GWh)	94.4	678.1	2,713
Electricity consumption growth rate (1965-1991)	10.2	6.0	2.4
Electricity/capita 1990 (MWh)	2.2	4.9	10.9
Electricity/GDP 1990 (Watt-hr/US $)	399	230	503
Electricity mix 1990 (% by generation)	%	%	%
Coal	19	14	56
Oil	18	33	4
Natural gas	9	20	9
Nuclear energy	49	23	21
Hydroelectricity	6	10	10
Other	0	0.2	0.4

Source: *World Development Report 1992, World Resources 1992-1993, Yearbook of Energy Statistics 1992,* and *Annual Energy Review 1991*

2.5 Energy Dependence and Vulnerability

Korea, with a high demand for energy and virtually no domestic energy resources except for minimal quantities of coal, relies nearly completely on foreign sources for all energy needs. In 1990, 88 percent of all energy consumed in Korea came from overseas. If nuclear energy is excluded, the overseas dependence on energy is 74 percent (*Yearbook of Energy Statistics 1992*). This tremendous dependence on energy imports amounted to 10.9 billion US dollars or 5 percent of the GDP in 1990. Compared to the United States, Korea spent five times more per GDP on energy imports in 1990. Refer to Table 2.6 for energy dependence figures.

Due to the heavy dependence on foreign energy, Korea's economic growth is sensitive to the availability and cost of energy imports. As a case in point, the vulnerability of the economy to energy price changes is evident from the impacts of the past two oil price shocks in 1973-74 and 1979-80. The first oil price shock reduced the annual GNP growth rate from 13.2 to 8.1 percent and the second oil price shock reduced it from 7.2 to negative 3.7 percent (see Figure 2.2 for GNP growth rate changes). The negative economic impact of increases in oil prices is also evident from the current account balance. In Figure 2.6, historical current account balances and the ratio of oil imports to total imports are plotted together. Figure 2.6 clearly shows that the current account balance and the ratio of oil imports to total imports are very closely related. When the ratio of oil imports to total imports was high, as during the two oil price shocks, the current account balance showed a large deficit. However, when the ratio of oil imports to total imports was low during 1986 to 1988 due to low oil prices, the current account balance showed a large surplus. During this period, the Korean economy showed outstanding economic performance with GNP growth in double digits. When the ratio of oil imports to total imports rose again from 1990 to 1992 due to higher oil prices, the current account balance returned to a deficit. Oil prices rose during 1990 to 1992 due to the Gulf War. The oil price jumped from 14 $/bbl. in 1988 to 20 $/bbl. in 1990. Other factors such as international interest rates, currency values, and internal political and labor problems have contributed to the growth and decline of the Korean economy. However, observations of the oil price changes on the current account balance illustrate the connection between oil prices and economic prosperity of Korea.

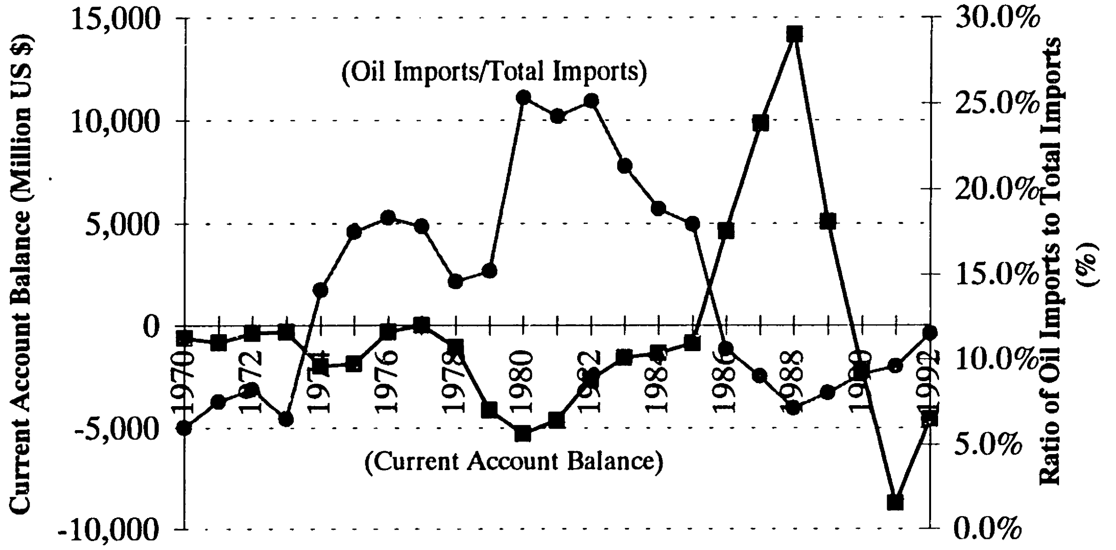
After the experience of the two oil price shocks and with the realization of the direct link between oil prices and economic growth, energy security has become a major concern for Korea. Due to the critical nature of energy security, the Korean government plays a strong role in energy planning. Their policies on energy are to secure stable oil supplies, to reduce the dependence on imported oil by promoting the development and use of nuclear, coal, natural gas, and other alternative fuel sources, and to increase energy conservation (Kim 1986). Most of the emphasis thus far has been on the development of nuclear power and natural gas imports.

Table 2.6 Comparisons of Energy Dependency

	Korea	Japan	USA
Energy dependence 1990 (%) (Not including Nuclear)	74	84	23
Total Energy Import 1990 (Billion US $)	10.9	56.7	56.5
Energy Import as % of GDP	5 %	2 %	1 %

Source: *Yearbook of Energy Statistics 1993* and *Nippon: a charted survey of Japan 1994/95*

Figure 2.6 Current Account Balance and Ratio of Oil Imports to Total Imports



2.6 Carbon Dioxide and Other Greenhouse Gas Emissions

Increased energy consumption from economic growth has contributed to the steady rise in emissions of carbon dioxide (CO_2) in Korea. In 1989, Korea emitted 66 million tonnes of CO_2 (see Table 2.7 for emissions). A historical picture of CO_2 emissions, shown in Figure 2.7, reveals the rapid increase in CO_2, due mostly to the combustion of coal and oil. From 1965 to 1989, CO_2 emissions increased by a factor of 9 at an annual growth rate of 9.5 percent per year (*Trends '90*). However, the absolute amount of CO_2 emitted is relatively small in comparison to Japan or the United States. Japan, with a CO_2 emissions level of 295 million tonnes of carbon (MtC) in 1989, emitted 4.5 times more CO_2 than Korea and the United States, with an emission level of 1,347 MtC, emitted 20 times more CO_2. Moreover, Korea's CO_2 emission on a per capita basis is also smaller than that of Japan and the United States. In 1989, per capita CO_2 emission was 1.6 tC in Korea, 2.4 tC in Japan and 5.4 tC in the United States. Although these numbers reflect low CO_2 emissions on an absolute and per capita basis, CO_2 emissions for Korea are significant when viewed in terms of economic activity. In 1989, the ratio of CO_2 emissions to GDP for Korea was 255 tonnes per US dollar. This figure is slightly higher than the ratio for the United States of 246 tonnes per US dollar and nearly three times larger than the ratio for Japan of 97 tonnes per US dollar. An emissions per GDP ratio that is so large reflects the high energy intensity of the Korean economy.

Other greenhouse gases such as methane (CH_4) have been growing as well. Methane emission for Korea in 1989 was 1,200 thousand tonnes. This is relatively small in comparison to the levels of methane emissions in Japan and the United States of 4,100 and 37,000 thousand tonnes, respectively. In Korea, 53 percent of the methane emitted was from wet rice agriculture, 30 percent from coal mining, 8 percent from solid waste, and 7 percent from livestock. In Japan, 59 percent was from solid waste, 34 percent from wet rice agriculture, 7 percent from livestock, 4 percent from coal mining, and 1 percent from oil and gas production. In the United States, 46 percent was from solid waste, 22 percent from coal mining, 16 percent from livestock, 14 percent from oil and gas production, and 2 percent from wet rice agriculture. When comparing methane emissions on a per capita basis, Korea's emission of 28 tonnes per 1,000 persons is nearly comparable to Japan's emission of 33 tonnes per 1,000 persons, but is substantially less than the United States' emission of 148 tonnes per 1,000 persons.

Figure 2.7 CO2 Emissions

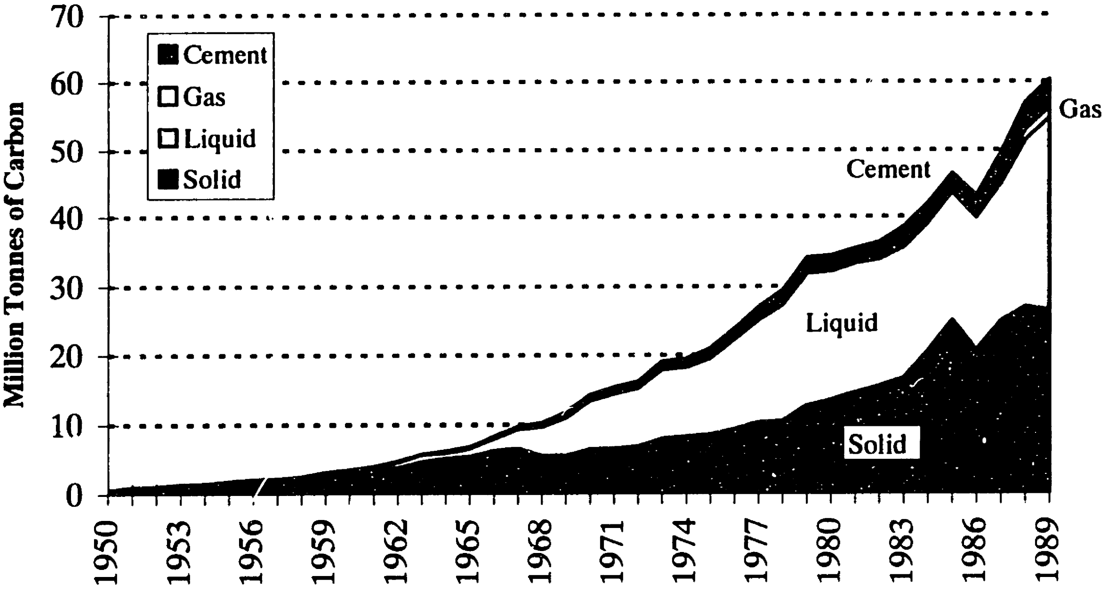


Table 2.7 Comparisons of Greenhouse Gas Emissions

	Korea	Japan	USA
CO_2 emissions (MtC, 1989)	66	295	1,347
CO_2/capita (tC, 1989)	1.6	2.4	5.4
CO_2/GDP (tC/million US $)	255	97	246
CH_4 emissions (1,000 tonnes, 1989)	1,200	4,100	37,000
CH_4/capita (tonnes, 1989)	27.91	33.06	148

Source: *Trends '90* and *World Resources 1992-1993*

2.7 Summary

The past few decades in this small and densely populated country of South Korea has been characterized by strong economic growth. From 1980 to 1990, the GDP growth rate averaged near 10 percent per year, primary energy consumption growth rate averaged 8 percent per year and electricity consumption growth rate averaged 10 percent per year. The strong growth in energy use was attributed to the energy-intensity of Korean industries and the overall growth in the economy. Moreover, the high demand for energy places Korea in a precarious position in relation to changes in the international energy market because nearly all of Korea's energy requirements are supplied by foreign sources. Along with the rising consumption of energy, however, emissions of greenhouse gases have increased multi-fold. For instance, CO_2 emissions grew by a factor of 9 from 1965 to 1989 at an average rate of 9.5 percent per year. Although population and economic growth have begun to slow-down somewhat, economic growth and energy use are expected to be robust in the near future. Therefore, control of greenhouse gas emissions will be difficult, as emissions will continue to grow rapidly.

Chapter 3. Development of a Greenhouse Gas Emissions Model for South Korea

The SGM, developed at the Pacific Northwest Laboratory, is a computable general equilibrium (CGE) model; its primary objective is to quantify the long-term global GHG emissions level from all human activities of which energy use is the most important. Thus far, SGM modules for the United States, Japan and India have been completed. Development of other country/regional modules are in progress and should be completed in the near future. The SGM is a sufficiently generic model that its structure can be applied to a wide range of economies. Moreover, since the SGM is a CGE model, it incorporates market mechanisms and policy instruments that work through price incentives. The ability to easily modify the data and parameters enables testing of energy and emissions control policies and incorporation of new technology developments into the model. The model for Korea, developed in this study, is a module of the SGM designed to examine the cost of emissions control policies and the impact of Korea's energy options on the reduction of GHG emissions.

The model for Korea uses the same modeling structure as the current SGM. The description of the SGM given below is an adaptation from *Modeling Future Greenhouse Gas Emissions: The Second Generation Model Description* by Edmonds et al. (1991).

3.1 Second Generation Model

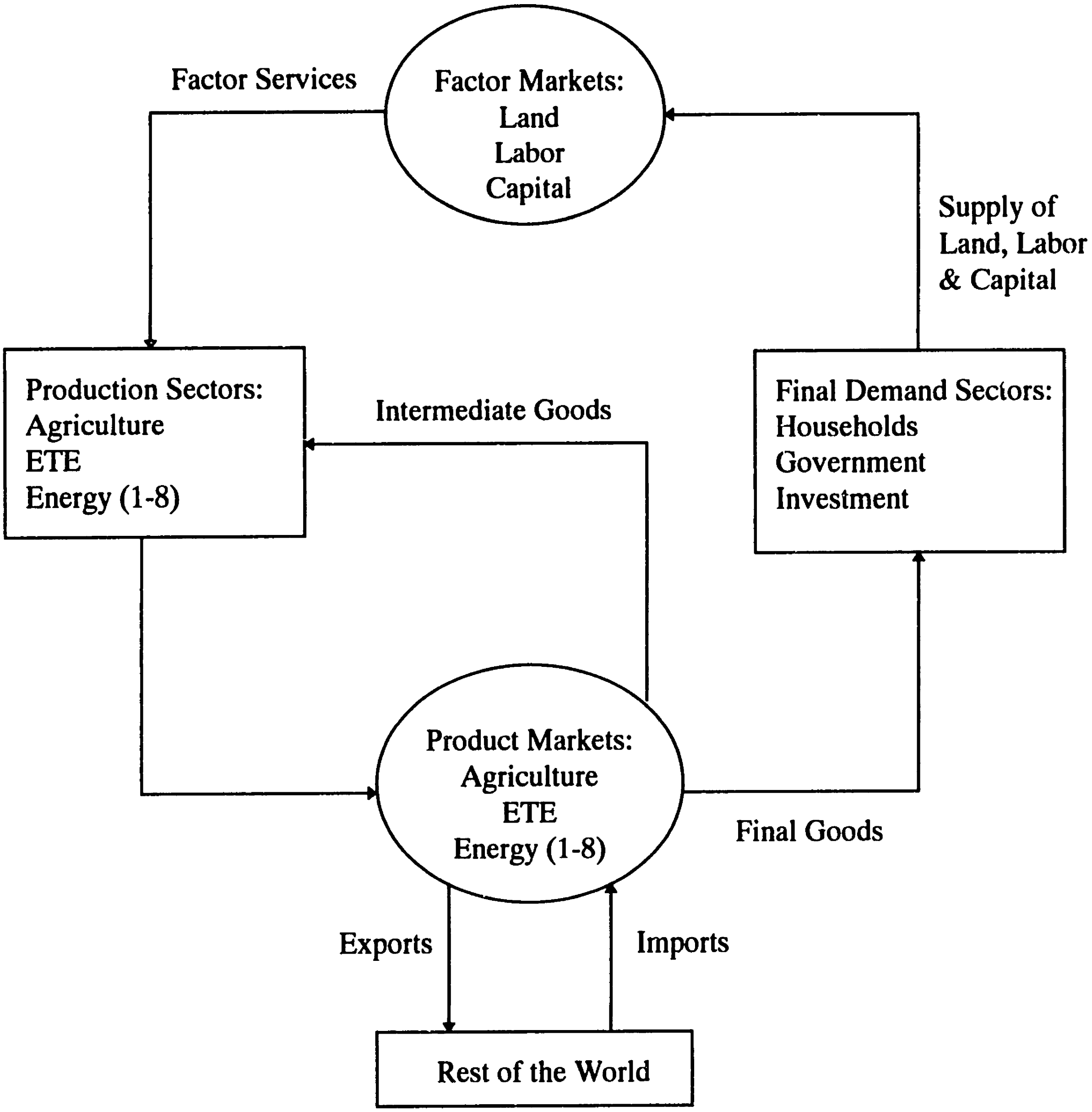
Flow of Goods and Services in the SGM

The SGM, and CGEs in general, are self consistent dynamic models of the relationship between production and demand sectors (see Figure 3.1 for the circular flow of goods and services). Sectors, as used in the SGM, are human activities which produce or consume goods and services. The core productive sectors are agriculture, energy and other products. The energy sector is disaggregated into eight sectors due to its significance to GHG emissions; agriculture is a separate sector as land use and crop growth are important for GHG emissions and absorption. Any sector not included in agriculture or the eight energy sectors is placed in the everything else (ETE) sector. Thus, the total number of productive sectors sum to ten. The agriculture and ETE sectors are not disaggregated in the current version of the SGM, but will be further disaggregated in the future to capture changes in the production of major crops and end-use of energy.

Goods from the production sectors are used as intermediate inputs to production or are consumed by the final demand sectors of household, government, investment, and trade. The household sector, in addition to demanding final goods, is a supplier of the primary factors of production of land, labor, and capital. Land is further divided into two factors, surface land and underground land resources. The capital supply comes from household savings which is determined by the interest rate. The government sector consumes final goods using the revenue generated from direct and indirect taxes. In addition, the government uses final goods to provide such services as public service, national defense, education, and investment. Additions to physical stock in the aggregate investment sector is represented as an increase in the demand for other goods. A simplified trade model exists in the SGM where goods such as crude oil and natural gas can be imported in unlimited quantities at exogenously set prices. However, a balanced trade is assumed and goods from the ETE sector must be exported in sufficient amounts to ensure a balanced trade.

The availability and consumption of goods and services are determined by the market. Markets define the primary level of aggregation in the model in which prices for a single homogeneous commodity must be solved. There are markets for each producing sector and for each primary factor of production. The total number of markets is therefore, thirteen, with ten product and three factor markets. All production sectors can be further disaggregated into subsectors if the technologies or methods used to produce the commodity are sufficiently different. However, all subsectors within a particular sector has only one market price even though the cost of production for each subsector may vary.

Figure 3.1. The Flow of Goods and Services in the SGM



A further description of all sectors, subsectors, and markets that are used in the SGM is provided in Table 3.1. There are a total of fourteen sectors of which ten are production sectors and four are final demand sectors. The ten production sectors are: agriculture, every thing else (ETE), crude oil production, natural gas production, coal production, biomass production, uranium production and refinement, electric power generation, oil refining, and natural gas transformation and distribution. The four final demand sectors are household, government, investment, and trade.

Each sector can have multiple subsectors with each subsector representing different grades of fuel, technologies and methods for production, or services rendered. The energy production sectors, such as crude oil, natural gas, coal, and uranium, may have multiple subsectors classified as grades of fuel. The various grades warrant classification into subsectors as the cost and technology of extraction can vary substantially. For the electricity generation sector, however, the classification scheme for the subsectors are based on the fuel utilized for electricity generation. The subsectors for electricity generation are: oil-fired, gas-fired, coal-fired, biomass-fired, nuclear, hydro-electric, and solar power plants. Lastly, the subsectors for the household and government sectors have been classified predominantly by the services rendered. The household subsectors provide factor services of land, labor, and capital, demographics, and consumer demand. The government sector can be further disaggregated into subsectors such as public service, national defense, education, investment, and other government.

In the Korea module of the SGM, although placeholders exist for the crude oil, natural gas, biomass, and uranium production sectors, there is no production from these sectors since domestic resources of these fuels are not available in Korea. In addition, multiple subsectors exist only for the electric power generation, household, and government sectors in the Korea module. All other sectors have only one subsector.

Market classification is similar to sector classification; however, markets and sectors represent different concepts. In markets, goods and services are bought and sold, whereas sectors exist only to distinguish the various production and demand sectors. Thus, markets do not include the final demand sectors but do include the primary factors of production. There are a total of thirteen markets in which solution prices for the good or service in each market must be solved. The thirteen markets are the ten production sectors plus land, labor and capital. Although there are no domestic production sectors of crude oil, natural gas, and uranium, a market for these goods still exists. The demand for these fuels are supplied through imports.

Resource Constraint

It is important in any energy model to keep track of the availability of resources needed for energy production. Two types of energy resources, depletable or renewable, exists in the model. A depletable resource is one in which the consumption of the resource in one period affects potential consumption in the next period. Whereas, a renewable resource is one in which the consumption of the resource in one period does not affect potential consumption of the resource in the next period. For depletable resources, the total resource available for consumption is the sum of resources available in each grade. Depletable resources in the SGM is characterized either as resources or reserves. Resources are defined as undiscovered resources, and reserves are those resources that have been found and can be extracted at current prices.

Table 3.1. SGM Sectors, Subsectors and Markets for Korea

Sector No.	Market No.	Sector Name	Subsector No.	Subsector Name
1	1	Agriculture	1	Agriculture
2	2	EveryThingElse (ETE)	1	ETE
3	3	Crude oil		
4	4	Natural gas		
5	5	Coal	1	Grade 1
6	6	Biomass		
7	7	Uranium		
8	8	Electric Power Generation	1 2 3 4 5 6	Oil-fired Gas-fired Coal-fired Biomass-fired Nuclear Hydro/Solar
9	9	Oil refining	1	Conventional oil refining
10	10	Natural gas transformation	1	Conventional gas
11	N/A	Households	1 2 3 4 5	Consumer demand Demographics Land supply Labor supply Savings
12	N/A	Government	1 2 3 4 5	Public Service National defense Education Investment Other Government
13	N/A	Investment	1	Investment
14	N/A	Trade	1	Trade
N/A	11	Labor	N/A	N/A
N/A	12	Land	N/A	N/A
N/A	13	Savings/Investment	N/A	N/A

National Income Accounting

The classification of the sectors, subsectors and markets, as shown above, is the first step in the development of the model. This classification is used to construct an input-output table which becomes a basis for the model structure. The SGM utilizes the input-output accounting framework to describe the relationship between the production, distribution, and use of goods and services in an economy. Although the SGM uses an input-output framework to describe the interrelationships in the economy, the SGM is not a traditional static input-output model. The use of input-output accounting identities to describe economic interrelationships at a point in time does not mean that the SGM simply uses a set of static input-output coefficients which are assumed to remain fixed for an indefinite period in the future to determine production levels and demands. The conjunction of input-output coefficients, which can change through technological advances, with a consistent set of prices results in a dynamic model.

To ensure that the production and demand are consistent through the model, the SGM relies on simple economic relationships for the accounting framework. This ensures that the GNP measured in terms of production or final demand is equal. For example, GNP is defined as the price weighted sum of net production of all products, which in turn is equal to the disposition of net output among final demand sectors.

$$GNP = \sum_{i=1}^{N} P_i (X_i - \sum_{j=1}^{N} A_{i,j}) = \sum_{i=1}^{N} P_i (C_i + G_i + I_i + EX_i - IM_i) \qquad (1)$$

where,

GNP = the Gross National Product
X_i = the gross domestic production of product i,
$A_{i,j}$ = the domestic use of product i in the production of product j,
P_i = the price of product i,
N = the number of product,
C_i = domestic consumption by households of product i,
G_i = domestic consumption by government of product i,
I_i = domestic investment uses of product i,
EX_i = gross exports of product i,
IM_i = gross imports of product i,

Consistent with the input-output accounting framework, the GNP can be expressed, alternatively, as the sum of payments to the factors of production,

$$GNP = \sum_{i=1}^{N} (P_i X_i - \sum_{j=1}^{N} P_j A_{j,i}) = \sum_{i=1}^{N} (TXibt_i + \pi_i + \sum_{j=N+1}^{N+M} P_j A_{j,i}), \qquad (2)$$

where,

$TXibt_i$ = indirect business taxes,
π_i = profits including net interest and capital consumption allowances,
M = the number of primary factors of production (e.g. labor and land).

3.2 Theoretical Structure of the Second Generation Model

The core of the SGM is the utilization of the constant elasticity of substitution (CES) production/cost function to determine the output of production from all sectors. Furthermore, the application of the theory of duality enables the CES production function to be used to determine production in physical or financial units. The use of the CES production/cost function provides a well behaved homogeneous production function that is generic and enables minimum coding for a wide range of analysis. The CES production function is homogeneous and has a constant return to scale. Returns to scale describes the output response to a proportionate increase of all inputs. If output increases by the same proportion, returns to scale are constant for the range of input combinations under consideration.

The basic idea of the model is to utilize the CES production/cost function to find an equilibrium between supply and demand by varying prices. Once a set of prices is found at which products and demand come to an equilibrium, levels of production and demand for all sectors are known. After determining the solution for one time period, the model evaluates investments, resources and reserves, and land, labor and capital supplies before moving on to the next time period. Each model period is five years, and model results display an annual snapshot of the economy at the end of every five years. For market economies profit maximization is the behavioral paradigm, and therefore, investment decisions in the model are based on profit rates.

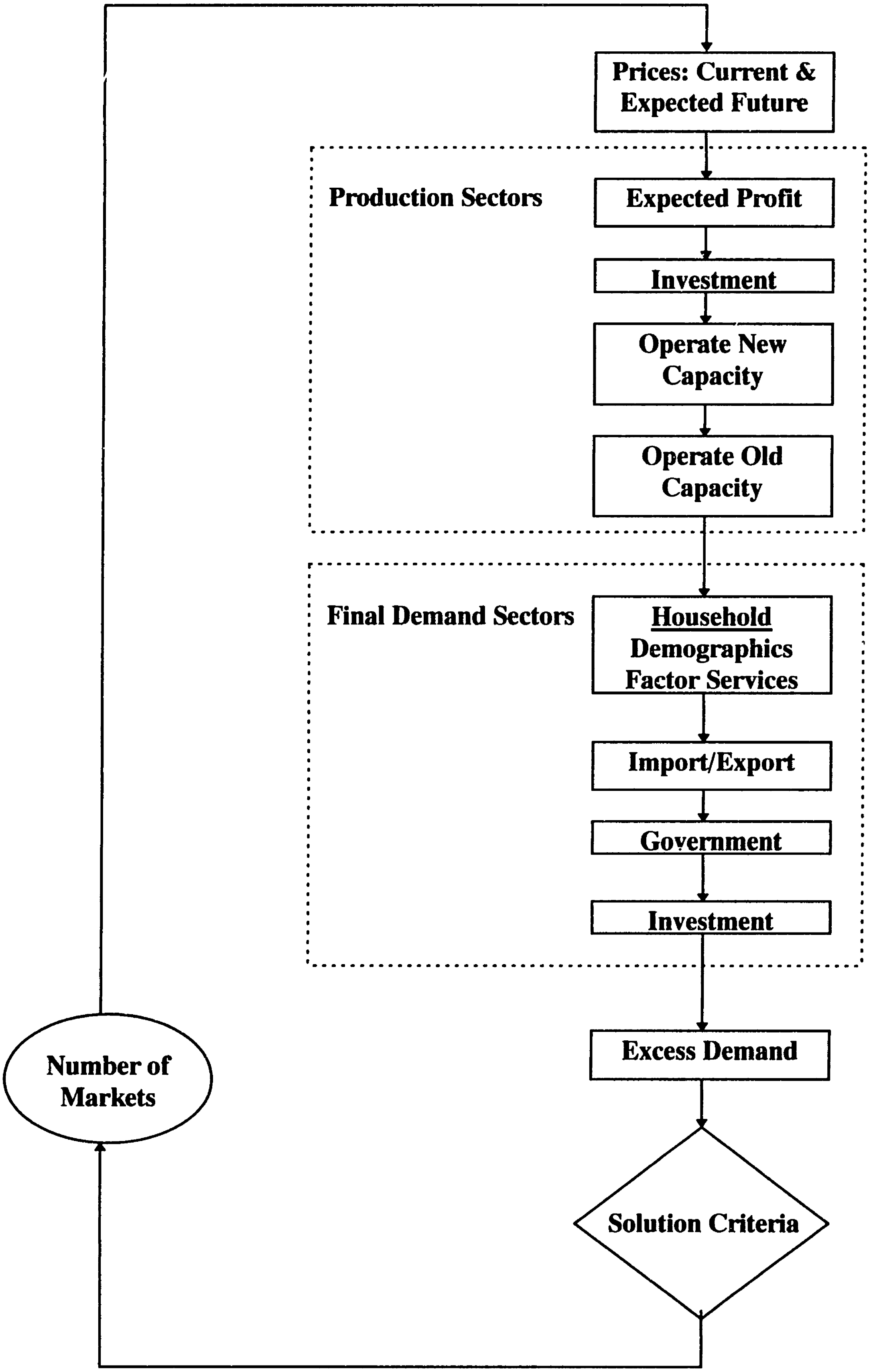
One of the major distinguishing characteristics of the SGM is that it uses a vintaged description of technologies. This has a number of important implications. First, it means that the lifetime of the technology is tracked and so history matters. When a technology is installed it remains in existence and can be operated until its retirement. New technologies affect productivity primarily at the margin. They can only affect historical decisions if they are so unattractive that they force prices down to the point where existing technologies are retired early. Another important implication is that once installed, capital stock is not malleable. It cannot be shifted around from one sector of the economy to another. In fact, once installed, capital costs no longer matter. Once the technology is installed the decision to operate or idle a technology depends solely on the ability of the technology to recover its current operating expenses plus taxes and less subsidies.

Another important characteristic of the SGM is that the growth of total factor productivity is described by Hick's neutral technical change. A growth rate is applied to the scale coefficient of the CES production function, and since the scale coefficient affects all factor demands equiproportionally, this growth rate represents a Hick's neutral technical change.

A mathematical form of Hick's neutral technical change and its specific values are provided in Section 4.2 Calculation of Model Parameters.

A flowchart of the SGM (see Figure 3.2) describes the execution path of the model. Determination of production starts from the calculation of present and expected future prices of each sector. From the expected future prices, profit rates are calculated. Investment in new capacity is then determined from the profit rates. The level of investment is determined by the profitability of the sector. Production from each sector/subsector is determined using the CES production function. Once the production side has been completed, the model goes on to calculate final demands from households, trade, government, and investment. After final demands have been calculated, an equilibrium solution, point at which production and demand are equivalent, is obtained. See Figure 3.2 for the steps in the model evaluations.

Figure 3.2 Flowchart of the SGM



I. The Production Sectors

The CES Production/Cost Function

Before describing the execution path of the SGM, it is important to explicitly describe the core equations of the model, the CES production function and its dual, the cost function. The CES production function can be written,

$$X_s = \alpha_o \left(\sum_{i=1}^{N} \alpha_i X_i^{\rho} \right)^{(1/\rho)} \tag{3}$$

where,

X_s = gross output of the process,
X_i = the use of input factor i,
α_o = scale coefficient (includes technical change),
α_i = individual factor coefficients, and
ρ = the elasticity of substitution parameter.

Profit maximization implies that,

$$P_i = P_o \frac{\partial Xs}{\partial X_i}, \; i = 1, \ldots N\text{-}1. \tag{4}$$

where,

P_i = price of ith input,
P_o = price of output, and
N = number of variable and fixed factors
$N-1$ = number of variable factors (one fixed factor)

Only one fixed factor, capital, is considered in this model and thus, $N-1$ represents the number of variable factors.

Profits can be written as the total revenue minus the summation of all costs,

$$\pi = P_o Xs - \sum_{i=1}^{N-1} P_i X_i, \tag{5}$$

Using equations (3), (4), and (5) and some algebra, profits can be expressed as a function of price and capital by,

$$\pi = \alpha_o P_o \left[1 - (\alpha_o P_o)^{\mu} \left(\sum_{i=1}^{N-1} \alpha_i^{(\mu/\rho)} P_i^{-\mu} \right) \right]^{(-\frac{1}{\mu})} \left(\alpha_k K^{\rho} \right)^{(\frac{1}{\rho})} . \tag{6}$$

where,

$$\mu = \frac{\rho}{1-\rho}, \tag{7}$$

K = capital fixed factor, and
α_k = scale coefficient for the capital fixed factor

It is well known that the partial derivative of this expression with respect to the price of the ith input is the negative of the total factor demand, that is

$$\frac{\partial \pi}{\partial P_i} = -X_i. \tag{8}$$

Taking the partial derivative of the profit equation (6), the demand for the ith factor input to the production process can therefore be calculated directly as,

$$X_i = (\alpha_o P_o \frac{\alpha_i}{P_i})^{(\mu/\rho)} (\frac{\alpha_k K^{\rho}}{Z})^{(1/\rho)}, i = 1, \ldots, N-1. \tag{9}$$

where

$$Z = 1 - (\alpha_o P_o)^{\mu} (\sum_{i=1}^{N-1} \alpha_i^{(\mu/\rho)} P_i^{\mu}). \tag{10}$$

The above equations are the core equations of the model as they determine the production levels and the demand for intermediate inputs. Moreover, the profit equation, in conjunction with current and expected future prices, is used to model both operational decision making and investment determination.

Price and Expected Prices

The first step in the model evaluation is to determine sector specific prices since operational and investment decision making is dependent on them. For a closed economy, the purchase price of the good produced by a sector includes transportation costs, taxes and adjustments. The equation for the purchase price in the ith sector is given by:

$$P_i = \alpha_i (P_i \, txa_i + txb_i), \tag{11}$$

where,

P_i = price received by the producer,
α_i = an adjustment factor to reflect markups and intra-regional transport costs,
txa_i = proportional tax on the ith product and
txb_i = additive tax on the ith product.

In most cases, the adjustment factor, α, is equal to unity. However, α is included in the above equation to provide the model with increased flexibility in describing the purchase price. The proportional tax, txa_i, includes taxes such as the indirect business tax. Moreover, by changing the tax rates in the above equation, tax policy scenarios can be evaluated. For example, carbon and energy taxes can be imposed in the model by changing the additive tax, txb_i, on the appropriate products whether they are fossil fuels or energy services.

Next, an equation for expected future prices is given so that investment decisions based on expected profitability can be made. Expected profit is obtained by substituting a set of present discounted prices directly into the profit function. The present discounted price for product j (either an input or an output), Pe_j, is calculated by,

$$Pe_j\ (T) \ = \ \sum_{t=1}^{T_{exp}} P_j\ (t_o) \cdot \left(\frac{1+r_j}{1+dis_j}\right)^t . \tag{12}$$

where,

T_{exp} = the nominal life of the investment,
r_j = the rate of expected price change, and
dis_j = the discount rate for that subsector.

The nominal life of the investment, T_{exp}, is a parameter of the technology. The nominal life of the investment can be different from the maximum potential life of the technology since the lifetime of the technology can be extended through retrofit and renovation options. The rate of expected price change, r_j, is a behavioral variable and can be controlled by the model user. Calculating expected future prices formed on the basis of imperfect foresight is to assume that current prices and taxes will remain unchanged. In this case, r_j will be set to zero. In most situations, the model operates with this assumption; nevertheless, other ways of calculating expected prices may be desired. For example, a non-zero r_j determined from exogenous price projections would assume perfect foresight. The discount rate, dis_j, is also a behavioral variable and can be controlled by the model user as well. In reality, discount rates can be quite different from the interest rate. To reflect this phenomenon, the discount rate is linked to the interest rate, *interest*, in the model by a constant factor of addition, fac_j. There is only one interest rate calculated by the model in the capital market, and therefore, the sector specific discount rate varies by fac_j only. See equation below.

$$dis_j = interest + fac_j \tag{13}$$

fac_j is determined exogenously based on current or expected future discount rates. Since fac_j expresses the relative riskiness of investments, it should vary from sector to sector.

Expected Profit Rate

One way in which economic growth is achieved from one model period to the next is through investments in new production capacity. Demand for investment in new technology is determined by the expected profit rate which is computed using the dual cost function for all sectors and subsectors. Once expected future prices have been calculated, as shown above, they are used to compute the expected profit rates for new capacity. The expected profit rate relative to the capital cost, K, denoted as π_e, is given by,

$$\pi_e = \frac{NR_e}{K} \tag{14}$$

where,

$$NR_e = \alpha_o Pe_o \, [1 - (\alpha_o Pe_o)^{\mu} \, (\sum_{i=1}^{N-1} \alpha_i^{(\mu/\rho)} Pe_i^{-\mu}) \,]^{(-\frac{1}{\mu})} \cdot (\alpha_k K^{\rho})^{(\frac{1}{\rho})} \, (1 - tx). \tag{15}$$

NR_e is the expected net revenue, which is the profit equation with expected prices, and tx is the profit tax rate. Dividing through by K, the profit rate relative to the capital cost is thus,

$$\pi_e = \alpha_o Pe_o \, [1 - (\alpha_o Pe_o)^{\mu} \, (\sum_{i=1}^{N-1} \alpha_i^{(\mu/\rho)} Pe_i^{-\mu}) \,]^{(-\frac{1}{\mu})} \cdot \alpha_k^{(1/\rho)} \, (1 - tx). \tag{16}$$

Sector Investment in New Capacity

Once the expected profit rate has been calculated and determined to be greater than one (greater than the profit tax rate), it is used to calculate the sector level investment by utilizing an accelerator from the previous period's total investment. The total new investment in a particular sector is given by

$$I_{i,t} = \beta_o \, I_{i,t-1} \, baserate_t^{\beta_1} \, f(\pi_{e,i,t})^{\beta_2} \tag{17}$$

where,

$I_{i,t}$ = total new investment in sector i, in period t,
$I_{i,t-1}$ = total investment in sector i, in period $t-1$,
$baserate_t$ = the base rate of growth of investment in period t,
$f(\pi_{e,i,t})$ = a function of the expected profit rate, π_e, for sector i, in period t,
β_o = scale coefficient, and
β_1 *and* β_2 = sensitivity parameters.

The scale coefficient and the sensitivity parameters are determined from linear regressions using historical data. Refer to Section 4.2 for an explanation on the determination of the scale coefficient and the sensitivity parameters. In this model, *baserate* and the function of the expected profit rate are determined by the following expressions,

$$baserate_t = \left(\frac{WAP_t}{WAP_{t-1}} \right) \cdot \left\{ \frac{(GNP/E)_{t-1}}{(GNP/E)_{t-2}} \right\} \tag{18}$$

where,

WAP = working age population (ages 15 to 64), and
GNP/E = gross national product divided by total employment,

and

$$f(\pi_{e,t+1}) = \left(\frac{\pi_{e,t+1}}{\bar{\pi}_t}\right). \tag{19}$$

Moreover, the expected profit rate is taken to be the average expected profit rate which is given by,

$$\pi_{e,t+1} = \bar{\pi}_{t+1} = \left(\sum_{i=1}^{NO} \pi_{i,t+1}^{\sigma}\right)^{\left(\frac{1}{\sigma}\right)}. \tag{20}$$

where $\pi_{i,t}$ is the profit rate for the i<u>th</u> technology (taken over all subsectors), in period t (Clarke 1991).

For investments in new capacity that take more than one period, the expected profit rate is adjusted so that the investment will be spread out throughout the investment periods.

Subsector Investment in New Capacity

In those sectors with multiple subsectors, the aggregate sector level investment is shared among the subsectors using the Logit function. The Logit function shares the total sectoral investment based on the ratio of the relative profitability of each subsectors to the total profitability of the sector. The share is given by:

$$S_{i,tech} = \frac{\pi_{i,tech}^{\sigma}}{\sum_{j=1}^{NO} \pi_{j,tech}^{\sigma}} \tag{21}$$

where, $\pi_{i,tech}$ is a metric of the characteristic upon which competition is based for technology, *tech*, in subsector *i*, σ is a sensitivity parameter, and

$$NO = \sum_{i=1}^{Nss} Ntech_i. \tag{22}$$

Nss is the number of subsectors and $Ntech_i$ is the number of technologies competing in subsector *i*. The Logit function is homogeneous of degree zero and therefore, any scalar change in the values of all $\pi_{i,tech}$ leaves the values of all $S_{i,tech}$ unchanged. For values of σ equal to zero, $S_i=1/(NssNtech_i)$. If greater values of $\pi_{i,tech}$ enhance market share, then the value of σ is taken to be non-negative. (If greater values of $\pi_{i,tech}$ diminish market share, then the value of σ is taken to be negative.) As the value of σ approaches ∞, $S_{i,tech}$ approaches one for the largest value of $\pi_{i,tech}$.

Investment in Depletable and Constrained Resources

For depletable and constrained resources, such as fossil fuels and some renewable resources, investment is limited by the amount of the ultimately available resource. Production of depletable resources occurs out of reserves which is computed using the amount produced per period based on expected prices and the lifetime of the investment. Reserves which have been produced is deducted from the resource base. If reserves associated with desired investment exceed available resource, then investment will be scaled so that the investment amount does not exceed the remaining resource level. Since production can occur only from reserves, the availability of the reserves for the investment must be checked.

Output and Demand from Producing Sectors

To obtain total outputs and intermediate demands from the producing sectors, the CES production/cost function is used. Calculation of production and demand is carried out in two parts, that from the operation of new capacity and that from the operation of existing capacity.

To operate new capacity, the model first checks if capital investment and profitability of each subsector are both greater than zero. If so, the new capacity is operated and factor input demands and production output is calculated. With a new capital stock, the demand for the factor inputs is calculated using equation (9) in conjunction with equation (10). Production from this subsector is calculated from the CES production function, equation (3). If either the capital investment or the profitability is less than or equal to zero, there is no production from that particular subsector.

The decision to operate existing vintages (old capacity) is similar to the decision to operate new capacity. Existing vintages can be operated without change or retired. If the capital stock and the profitability at current prices are both greater than zero, then the technology will be operated. However, if either the capital stock or the profitability is less than or equal to zero, the existing vintage will be retired. In addition, unlike the operation of new capacity, a check is made on the nameplate life of the technology. If the lifetime has been exceeded, the technology will not be operated and the capital stock will be removed. If the retired capital stock is a depletable resource with remaining supply, the remaining supply is added back to the resource base. The calculation of the factor input demand and the total output are carried out with the CES production/cost function, equations (3) and (9), with existing capital stock.

II. Final Demand Sectors

After the operation of the producing sectors and the determination of total production outputs and intermediate demands, the next step in the model is to determine the supply of the factor services from the household sector and then to determine the demand for goods and services from the final demand sectors of household, import/export, government, and investment.

Household

The household sector is responsible for multiple functions in the model. The household sector determines demographics and supplies the primary factors of production while demanding final goods. See Table 3.2 for a list of all household decision functions. In the SGM, the determination of the demographic characteristics and supplies of labor, land, and savings are handled sequentially. Only the composition of demand for final goods and services is handled in a holistic utility maximization framework. Because the demographic characteristics of a region's population are an important determinant of other household behavior, this element is handled first in the model. Then, supplies of labor, land, and savings are determined. Since these factors determine disposable personal income allocated to consumption, they are calculated before the household's final demand for goods and services is calculated.

Table 3.2 Household Decision Function

Household Decision Functions
1. Demographics
2. Labor supply
3. Land supply
4. Household savings
5. Household demand for final products

Demographics

The demographic component of the household sector determines population in a region by employing assumptions with regard to three characteristics: survival rates, fertility rates, and migration rates. Survival rates (death rates), fertility rates, and migration rates are set exogenously and must be provided as data input. For any period, *t*, total population is given by,

$$POPtot_t = \sum_{age=1}^{NAGE} POP_{age,\, males} + POP_{age,\, females}, \qquad (23)$$

where,

$POP_{age,\ males}$ = Males in age group *age*,

$POP_{age,\ females}$ = Females in age group *age*, and

$NAGE$ = the number of age groups defined.

For the youngest age group, *age*=1,

$$POP_{age=1,\ gender,\ t} = \sum_{age=2}^{NAGE} g_{age,\ gender} f_{age,\ t} POP_{age,\ female,\ t},\ gender = male, female, \tag{24}$$

where,

$POP_{age=1,\ gender,\ t}$ = population in the youngest age group, *age*=1, by gender, in period *t*,

$f_{age,\ t}$ = the fertility rate for females in age group, *age*, in period *t*,

$g_{age,\ gender}$ = the fraction of births by gender, with $g_{age,1}+g_{age,2}=1$, and

$POP_{age,\ female,\ t}$ = population of females in age group, *age*, in period *t*.

For all other age groups, population is determined by survival via,

$$POP_{age,\ gender,\ t} = sv_{age,\ gender,\ t} POP_{age-1,\ gender,\ t-1} + POPmig_{age,\ gender,\ t},\ age=2,\ldots,NAGE. \tag{25}$$

where,

$sv_{age,\ gender,\ t}$ = the survival rate from age group *age* to *age+1* by gender, and

$POPmig_{age,\ gender,\ t}$ = net immigration of population by gender into the region in age group, *age*.

Labor supply

Once population has been calculated by age group, the total supply of labor that is available for factor service is determined by the working age population, rate of labor force participation, and the wage rate. The working age population is determined by summing the population in the 15 to 65 year old age group. The labor supply, X_{labor}, is expressed as,

$$X_{labor} = \sum_{male}^{female} \sum_{age=3}^{NAGE} \alpha_{age,\ gender} POP_{age,gender} [P_{labor} (1 - txa_{labor}) - txb_{labor}]^{\beta_{age,\ gender}}, \tag{26}$$

where,

P_{labor} = the wage rate for labor (price of labor),

$\alpha_{age,\ gender}$ = is a scale coefficient for the supply of labor, by age and gender,

$\beta_{age,\ gender}$ = the price elasticity of labor supply by age and gender, and

txa, txb = proportional and additive tax rates, respectively.

Land supply

The next factor of production, land, does not require any demographics information. Land supply, which is the total land area that is available as an input to production through the domestic market, is determined by the total surface area that is of potential use, the maximum potential share of land available to the market, the rental price on the unit of land, and the price elasticity of land supply. The expression for the land supply, X_{land}, is given as,

$$X_{land} = LANDtot\ \alpha_{land}\,(1 - e^{\beta_{land} P_{land}}), \tag{27}$$

where,

$LANDtot$ = total surface area potentially available for allocation,

α_{land} = the maximum potential share of land supplied to the market,

β_{land} = the price elasticity of land supply, and

P_{land} = the rental price on a unit of land.

Savings supply

The final factor service, savings supply or the capital supply, must be determined last because labor and land supplies are required for its calculation. The calculation of the saving supply requires the determination of personal income which includes the income derived from labor services and land rentals, as well as from net profits from enterprises and government transfers. The expression for personal income is given as,

$$\begin{aligned} Y = {} & X_{labor\,supply}\,[P_{labor}\,(1 - txa_{labor}) - txb_{labor}] + X_{land\,supply}\,[P_{land}\,(1 - txa_{land}) - txb_{land}] \\ & + \pi_{tot}\,(1 - tx_{\pi} - s_{\pi}) + TR_{gov}\,(1 - tx_{y}), \end{aligned} \tag{28}$$

where,

Y = disposable personal income,

π_{tot} = total net profits from the operation of all enterprises,

tx_{π} = profits tax rate,

s_{π} = rate of retained corporate earnings,

TR_{gov} = government transfer, and

tx_{y} = income tax rate.

After having determined the personal income, the savings supply can now be calculated using the equation below. Savings is essentially a function of the personal income, the interest rate, and the savings elasticity as a function of the interest rate. The total supply of savings by the household, S_{hh}, is expressed as.

$$S_{hh} = \alpha_{hhsave} Y \left(1 - e^{\beta_{hhsave} (interest + fac_{hh})} \right), \tag{29}$$

where,

α_{hhsave} = the maximum potential household savings rate,
β_{hhsave} = the household savings elasticity to the available interest rate, and
fac_{hh} = an adjustment factor linking the market interest rate to the interest rate available to households.

Household Demand for Goods and Services

Thus far, the household functions of determining demographics and supplying land, labor, and capital have been described. The final household function remaining is the computation of the demand for final goods and services. While it is usual for a general equilibrium model to maximize a utility function to determine household behavior, in this version of the SGM, a utility function for household behavior is not used. The calculation of household consumption of goods and services starts from the personal income equation shown above. Personal income is, however, adjusted by subtracting household savings and adding any rebates, such as from tax policies, the household may receive. Then, the household demand for factor inputs of land and labor are computed and these expenses are subtracted from the personal income. The remaining personal income is available for purchasing produced commodities, and is used to calculate the consumption level of each final product.

The household demand for land, $X_{land,hh}$, is given by the equation below,

$$X_{land,hh} = NHH \, \alpha_{land,hh} \, P_{land}^{\beta_{land,hh}}, \tag{30}$$

where,

NHH = the number of households,
$\alpha_{land,hh}$ = the household land intensity factor, and
$\beta_{land,hh}$ = the price elasticity of demand by households for land.

The number of households, *NHH*, is easily calculated by dividing the total population by the average number of people per household.

$$NHH = \left(\sum_{age=1}^{NAGE} POP_{age} \right) / a_{hh}, \tag{31}$$

where a_{hh} = the average number of people per household.

The household demand for labor, $X_{labor,hh}$, shown below, is a function of the total labor supply, X_{labor}, and the price of labor, P_{labor}.

$$X_{labor,hh} = X_{labor} \, \alpha_{labor,hh} \, P_{labor}^{\beta_{labor,hh}} , \tag{32}$$

where,

$\alpha_{land,hh}$ = the household labor demand intensity factor, and
$\beta_{land,hh}$ = the price elasticity of demand for labor by households.

After having calculated the household demand for land and labor, the personal income available for consumption can be calculated by the equation,

$$Y_c = Y - S_{hh} - X_{land,hh} \, P_{land} - X_{labor,hh} \, P_{labor} . \tag{33}$$

Consumption of each final product is then computed using the disposable personal income and the own price and income elasticities of demand for each product by

$$Xd_{i,hh} = \alpha_{i,hh} \, P_i^{\beta_{i,hh}} \, Y_c^{\gamma_{i,hh}} \left(\frac{1}{\lambda}\right) , \tag{34}$$

where,

$$\lambda = \sum_{i=1}^{NS} \alpha_{i,hh} \, P_i^{\beta_{i,hh}+1} \, Y_c^{\gamma_{i,hh}-1} \quad , \tag{35}$$

$Xd_{i,hh}$ = demand for good i by the household sector,
$\alpha_{i,hh}$ = the household demand intensity factor for good i,
$\beta_{i,hh}$ = the price elasticity of demand by households for good i,
$\gamma_{i,hh}$ = the income elasticity of demand by households for good i, and
NS = the number of sectors (goods).

The own price and income elasticities of demand for each product are exogenous parameters and must be specified by the model user. In equation (34), the demand for each good is scaled by λ so that the total household consumption for final products does not exceed the budget constraint.

Import/Export

Although there is no trade of factor services in the model, the trade of final goods does exist in the model. Nevertheless, the approach to trade in the Korea module of the SGM is very simplistic. Imports of a few items, such as crude oil, natural gas, coal, and uranium, are allowed in unlimited quantities as long as the consumers of these items can afford the price. The price trajectory for imported goods are set exogenously by the model user. However, the model assumes a balance trade and thus, must export products from the ETE sector in equal value to the total imports to ensure that the net trade is zero. See equation below.

$$\sum_{i=1}^{N} IM_i = EX_{ETE} \tag{36}$$

When representing the demand for final products in the import/export sector, the demand for import is represented by a negative sign and the demand for export has a positive sign.

Government Demand for Goods and Services

In addition to the household sector, the government sector is a big consumer of goods and services. The government sector usually has multiple subsectors and the allocation of goods and services across subsectors is based on a CES preference function that is normalized to exhaust the government budget. The demand for goods and services by the government sector is modeled as a constrained optimization problem. Government maximizes a utility function, presumed to be CES, defined over the five subsectors (public service, national defense, education, investment, and other government), and subject to the net income given by equation (37). The relationship between government budget and expenditures is represented by the following identity,

$$TXtot - S_{gov} = TR_{gov} + \sum_{i=1}^{N} P_i X_{i,gov}, \tag{37}$$

where,

$TXtot$ = total of all net tax revenues, where revenues from fiscal policies are included and subsidies are measured as negative taxes,

S_{gov} = net government savings, or for negative values equals net government borrowing,

TR_{gov} = transfer payments by the government, and

$\sum_{i=1}^{N} P_i X_{i,gov}$ = government expenditure on goods and services.

The net tax revenues plus the net government savings on the left hand side of the equation represents the government budget, whereas, the transfer payments plus the expenditure on goods and services represents the total government outlays.

Before government expenditures for goods and services can be calculated, the budget minus the transfer payments must be known. Thus, transfer payments are calculated first.

Transfer payments, represented by the equation below, are assumed to be a function of demographics,

$$TR_{gov} = \beta_o \; POP_{tot}^{\beta_{tot}} \left(\frac{POP_{15-} + POP_{65+}}{POP_{tot}}\right)^{\beta_a} \left(\frac{POP_{y25\%}}{POP_{tot}}\right)^{\beta_b} \left(\frac{Y_{personal}}{POP_{tot}}\right)^{\beta_c}, \tag{38}$$

where,

POP_{tot} = total population,
POP_{15-} = population under age 15,
POP_{65+} = population over age 65,
$POP_{y25\%}$ = population whose personal income is 25% or less than the mean,
$Y_{personal}$ = personal income, and
β_i = appropriate empirically determined coefficients.

Once transfer payments are subtracted from the net tax revenues, government demands for goods and services can be calculated based on the total budget available. The demand for goods and services comes from all of the government subsectors which are modeled as producing services. In the Korea module of the SGM, there are five services produced. These are listed in Table 3.3.

Table 3.3 Government Services/Subsectors

Government Subsectors
Public Service
National Defense
Education
Investment
Other Government

The demand for goods and services by the government sector is modeled as a constrained optimization problem. Government maximizes a utility function, presumed to be CES, defined over the five subsectors, and subject to the net income given by equation (37). The government utility function can be represented as,

$$G = \left(\sum_{ss=1}^{NGS} \delta_{ss} G_{ss}^{\mu}\right)^{(1/\mu)}, \tag{39}$$

where,

G = government utility, an unobservable variable,
G_{ss} = the production of government service *ss*,

δ_{ss} = a scale parameter,
μ = an elasticity parameter, and
NGS = the number of services produced by the government (the number of government subsectors).

Government services are assumed to be produced with fixed input-output coefficients. Thus the cost of an additional unit of government service, type *ss*, can be computed simply as,

$$P_{g,ss} = \sum_{i=1}^{N} a_{i,g,ss} P_i , \tag{40}$$

where,

$P_{g,ss}$ = the cost of the next unit of government service *ss*, that is government service produced by government sub-sector *ss*,
P_i = the price of input *i* in the production process,
$a_{i,g,ss}$ = the amount of input *i* required to produce government service from government sub-sector *ss*.

Because the cost of producing the next unit of government service is constant for any set P_i's (1), the determination of government demands for goods and services is greatly simplified. This problem can be stated as one of maximizing utility subject to a budget constraint, equation (37),

Maximize $G(G_1, \dots, G_{NGS})$

Subject to

$$TXtot - S_{gov} - TR_{gov} - \sum_{ss=1}^{NGS} P_{g,ss} G_{ss} = 0 . \tag{41}$$

This problem has a simple solution,

$$G_{ss} = (TXtot - S_{gov} - TR_{gov})\, \beta_{ss}\, P_{g,ss}^{(\gamma -1)} \left(\sum_{ss=1}^{NGS} \beta_{ss}\; P_{g,ss}^{\gamma} \right)^{-1} , \tag{42}$$

where,

β_{ss} = $\delta_i^{(-1/(\mu-1))}$, and

γ = $\mu/(\mu -1)$ (2)

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(1) Note that this property is characteristic of any production function which is homogeneous of degree one, such as for example the CES, and not simply the Leontieff specification.

(2) To see this note that first order conditions require that

Investment

Since investment, as used here, means additions to the physical stock of capital, the demand for investment can only be of one type, products of the everything else (ETE) sector. Thus, all private investments are collected and allocated as a final demand of ETE products.

3.3 Solving the Model

General Equilibrium

Although a description of the producing sectors and the final demand sectors has been provided thus far, the relationship between the level of production and demand has not been discussed. The concept of general equilibrium means that the level of quantity output produced is equal to the quantity demanded. In this equilibrium situation, no forces can act to bring about a change. Therefore, in an equilibrium situation, the subtraction of total aggregate production from the total aggregate demand, commonly referred to as excess demand, must be equal to zero or to some small convergence criteria. Excess demand is calculated by following equation,

$$e_i = \sum_{s=1}^{Ns} \sum_{ss=1}^{Nss_{i,n}} \sum_{tech=1}^{Ntech_{i,ss,n}} (Xd_{i,s,ss,tech} - Xs_{i,s,ss,tech}) \quad i=1,\ldots,N. \tag{43}$$

where,

$$G_{ss} = \lambda^{(\frac{1}{\mu-1})} G \, \beta_{ss} \, (P_{g,ss})^{(\frac{1}{\mu-1})}, \tag{1}$$

where lambda is a Lagrangian multiplier. For convenience define,

$Y = TXtot - S_{gov} - TR_{gov}$,

and note that

$$Y = \sum_{ss=1}^{NGS} G_{ss} P_{g,ss} . \tag{2}$$

Substitute (1) into (2) to yield,

$$\lambda^{(\frac{1}{\mu-1})} G = Y \Big(\sum_{ss=1}^{NGS} \beta_{ss} \; P^{\gamma}_{g,ss} \Big)^{-1} . \tag{3}$$

Resubstituting (3) into (1) gives the final result.

$\sum_{s=1}^{Ns} \sum_{ss=1}^{Nss_{i,n}} \sum_{tech=1}^{Ntech_{i,ss,n}} Xd_{i,s,ss,tech}$ = summation of demand for commodity *i* from all sectors, production and final demand,

$\sum_{s=1}^{Ns} \sum_{ss=1}^{Nss_{i,n}} \sum_{tech=1}^{Ntech_{i,ss,n}} Xs_{i,s,ss,tech}$ = summation of output for commodity *i* from all sectors, subsectors, and technologies, and

e_i = excess demand for commodity *i*.

For any period, equilibrium exists when a set of prices, $P = (P_1,\ldots,P_N)$ can be found for which

$$\sum e_i = 0, \quad i = 1,\ldots,N. \tag{44}$$

This set of prices is not unique. Walras' law,

$$\sum_{i=1}^{N} e_i P_i = 0\,, \tag{45}$$

which holds as an identity, guarantees that if an equilibrium set of prices exists, any positive scalar multiple of those prices is also an equilibrium set of prices. Moreover, any single commodity can be chosen as a numeraire and its price determined arbitrarily. The price, for example, could be set to one. Therefore, the number of independent market prices is always one less than the number of markets.

The algorithm to solve for equilibrium prices uses a modified Gauss-Seidel search procedure. In this solution algorithm, instead of solving markets in order, the market that has the largest disequilibrium or the largest excess demand is solved first. Within each market, the algorithm begins with an initial price vector, and then updates each element of the price vector individually. The first step in finding a solution price is to locate a price bracket in which the excess demand changes sign. Then, the price, within this bracket, is adjusted until the excess demand is less than that for next largest disequilibrium market by a set factor. This procedure is repeated for each market in disequilibrium until a price which enables the excess demand for that market to fall below the solution criteria is found.

3.4 Calculating Greenhouse Gas Emissions

Once solution prices are found, the level of production and demand for each good is known. From this information, greenhouse gas emissions levels are determined. As discussed earlier, the greenhouse issue is complicated by the fact that a wide array of gases are associated with the effect. It is important to note that the model makes no attempt to explore either the nature or the extent of the effect various gases have on the radiative balance of the Earth/atmosphere system, but simply provides a projection of the relevant greenhouse gases. The gases that is considered in this version of the Korea module are:

> CO_2 emissions from fossil fuel and biomass combustion processes,
>
> CH_4 emissions from the production and distribution of natural gas, mining of coal, raising of ruminant animals, growing of rice, sanitary landfills, and combustion processes (principally biomass burning),
>
> CO emissions, most of which emanate from incomplete combustion of carbon based fuels, principally in the transportation sector,

SGM was designed to project other relevant greenhouse gases such as VOCs, N_2O, NOx, and SO_2; however, projection of these additional gases for Korea were not considered in this version of the Korea module due to the lack of data on the emission of these gases.

Necessary for emissions level calculation are greenhouse gas emissions coefficients. These coefficients need to be included with each technology description. Emissions will be assumed to be proportional to either the scale of input utilization or output of the technology. Emissions can be calculated simply as,

$$E_m = \sum_{i=1}^{NS} \sum_{ss=1}^{NSS(i)} \sum_{tech=1}^{Ntech(i,ss)} \sum_{v=V_o}^{t} \sum_{j=1}^{NI} \left(e_{m,i,ss,tech,j}\, X_{i,ss,tech,j,v} + f_{m,i,ss,tech,j}\, Xs_{i,ss,tech,j,v}\right), \qquad (46)$$

where,

$e_{m,i,ss,tech,j}$ = the technology specific emission coefficient for emission *m*, in sector *i*, subsector *ss*, using technology *tech*, with input *j*,

$X_{i,ss,tech,j,v}$ = the input demand for factor *j* by sector *i*, subsector *ss*, using technology *tech*, of vintage *v*,

$f_{m,i,ss,tech,j}$ = the technology specific emission coefficient for emission *m*, in sector *i*, subsector *ss*, using technology *tech*, producing output *j*, and

$Xs_{i,ss,tech,j,v}$ = the output of good *j* by sector *i*, subsector *ss*, using technology *tech*, of vintage *v*.

Chapter 4. Data Requirements, Calculation of Model Parameters, and Modeling Assumptions

4.1 Description of Data Requirements

The development of CGE models are time consuming and difficult, mainly due to the extensive data requirements. The development of the Korea module of the SGM was not an exception and also required much time for data collection and transformation. Moreover, data collection could not have been completed in a smooth and timely fashion without the collaboration of the Korea Energy Economics Institute in Seoul, Korea. This section provides an overview of the information required to build a country-specific database for the SGM. Refer to Appendix A for a complete description of the data requirements, and for the database use in the Korea module.

Data requirements can be categorized into eight topics as listed in Table 4.1. They are the input-output data, historical time series data on gross capital stocks, discards, and investments, energy statistics data, population and demographics data, greenhouse gas emissions data, land use data, energy resources and reserves data, and other essential data.

One of the most important data required for the model is the input-output table. As discussed in Chapter 3, the input-output accounting framework is used to generate the CES production function coefficients. A 1985 input-output table or one that has been prepared near this time frame is used. The decision was made to used the 1985 table because a sufficient time lag is required for national governments to prepare input-output tables. For instance, complete input-output tables are prepared every seven years in the United States and every five years in the Republic of Korea. Moreover, the decision to have 1985 as the base year of the model was in many ways due to the availability of this data. After obtaining the input-output table, the original classification of the production and final demand sectors must be aggregated or disaggregated into the SGM sectors and subsectors as described in Chapter 3. This is a time consuming procedure as disaggregation of some of the original sectors into the SGM sectors and subsectors may be difficult. For example, the electric power generation sector is usually classified as one and is not divided into electric power generation by fuel type as required by the SGM. In this instance, supplemental information is required to separate the input-output information into that for electric power generation by fuel type. In addition to the production and final demand sectors, inputs to production must also be transformed to coincide with the SGM production sectors and to include the factors of production used in the SGM. See Table A-1 for the input-output table format that is required by the SGM.

In addition to the input-output table, historical time series data on gross capital stocks, discards, and investments are required for vintaging capital stocks and for parameterizing the investment equation. The capital stock for each sector and subsector is required for the calculation of the production function coefficients since capital is a factor of production. Since each model period is a five year time step, the annual additions to capital stock must be accumulated into five year amounts. To calculate future investments for capital stock, the accelerator equation, as shown in Chapter 3, is used. However, to calculate the sensitivity parameters for this equation, historical data of total investments is required. Moreover, historical investment information by sector and subsector is used to determine the apparent investment discount rate for each sector and subsector. These historical data should be consistent with the national income and product accounts so that investments match that reported in the input-output table.

Both the input-output table and historical time series data on capital stocks, discards, and investments are in currency units. However, physical units of energy production and consumption, energy resources and reserves, and GHG emissions associated with these currency values must be specified. Thus, energy statistics, greenhouse gas emissions, land use, energy resources and reserves data for all relevant SGM sectors are required. Since prices and currency values are so important in determining production and demand in general equilibrium models, care must be taken to ensure that the physical units are in agreement with the currency values and that no physical laws are violated.

Another set of data important for the model is the population and demographics data. Population and demographics affect the economy in many ways; aggregate consumption, labor supply, total household savings, and government transfers are all linked to the population levels and demographic characteristics. The specific demographics data required for the SGM are age and gender specific population levels, age specific fertility rates, the total male/female birth fraction, age and gender specific survival rates (death rates), and age and gender specific net migration rates.

All other data required but not part of the categories discussed above are placed in the "other essential data" category. These data include information necessary to generate an account of the circular flow of funds, commonly referred to as the social accounting matrix, as well as information to determine the household demand for goods and services, such as own price and income elasticities of household demand. In the SGM, although all the information necessary for constructing a social accounting matrix is used, a matrix format of the social accounts is not constructed.

Table 4.1 Data Requirements for the SGM

1) Input-output table
2) Historical time series data on gross capital stock, discards, and Investment
3) Energy statistics data
4) Population and demographics
5) Greenhouse gas emissions
6) Land use
7) Energy resources and reserves
8) Other essential data

4.2 Calculation of Model Parameters

Utilizing the data collected above, coefficients and parameters required for the model, as described in Chapter 3, must be determined. The calculation of the CES production function coefficients and the determination of the investment equation parameters will be discussed below. Calculation of other parameters required in the model are straight forward and will not be discussed in this section.

The calculation of the CES production function coefficients is achieved with the input-output data and the use of the factor input demand equation, (9), rewritten below.

$$X_i = (\alpha_o P_o \frac{\alpha_i}{P_i})^{(\mu/\rho)} (\frac{\alpha_k K^\rho}{Z})^{(1/\rho)}, i = 1,\ldots,N-1.$$

Taking the ratio of demands for one arbitrary input, $i=1$, to another, $i=2$, gives the following equation,

$$\frac{X_1}{X_2} = \frac{(\alpha_o P_o \frac{\alpha_1}{P_1})^{(\mu/\rho)} (\frac{\alpha_k K^\rho}{Z})^{(1/\rho)}}{(\alpha_o P_o \frac{\alpha_2}{P_2})^{(\mu/\rho)} (\frac{\alpha_k K^\rho}{Z})^{(1/\rho)}}. \quad (47)$$

Since $(\frac{\alpha_k K^\rho}{Z})^{(1/\rho)}$, α_o, and P_o are the same for both factor inputs, the above equation can be rewritten as,

$$\frac{X_1}{X_2} = \left(\frac{\alpha_1 / P_1}{\alpha_2 / P_2}\right)^{(\mu/\rho)} . \tag{48}$$

Solving for the ratio of α_1 to α_2 gives,

$$\frac{\alpha_1}{\alpha_2} = \left(\frac{X_1}{X_2}\right)^{(\rho/\mu)} \cdot \frac{P_2}{P_1} \tag{49}$$

Since the CES production function, equation (3), is homogeneous of degree one, only the relative values of input coefficients to each other matter. Therefore, the above equation can be normalized by letting α_2 equal 1. Thus, the expression for α_1 is

$$\alpha_1 = \left(\frac{X_1}{X_2}\right)^{(\rho/\mu)} \cdot \frac{P_2}{P_1}, \tag{50}$$

All prices except land and labor are taken to be unity. This enables the values in the input-output table, which are in currency units, to be taken as a unitless quantity of goods and used directly as input demands, X_i*'s*. Since land and labor prices are not unity, expenditures for land and labor from the input-output table are divided by its respective prices to determine the quantity of input demands. Prices for land and labor are determined by the following equations:

$$P_{land} = \frac{TE_{land}}{TLA} \quad \text{and}$$

$$P_{labor} = \frac{TE_{labor}}{E},$$

where,

TE_{land} = total land expenditure for all sectors/subsectors in 1985,
TE_{labor} = total labor expenditure for all sectors/subsectors in 1985,
TLA = total managed land area in 1985 (1,000 km^2), and
E = number of people employed in 1985 (1,000 persons).

Now that the value of all factor inputs and prices are known, Equation (50) can be used directly to calculate the value of all factor input coefficients.

After the determination of input coefficients, the scale coefficient for the base year, α_o, can be calculated using the production function equation rewritten in the following form,

$$\alpha_o = Xs\left(\sum_{i=1}^{N} \alpha_i X_i^{\rho} \right)^{(-1/\rho)} \tag{51}$$

In the SGM, the coefficient, α_o, has two functions. It is utilized to scale production output to match the actual output in the base year, and to adjust changes in production output due to technical change. Since the representation of technical change through the adjustment of α_o affects all factor demands equiproportionally, the technical change is Hick's neutral. The representation of technical change through α_o is expressed by the following equation,

$$\alpha_{o,v} = \alpha_o (1 + GR)^{5v}, \tag{52}$$

where,

$\alpha_{o,v}$ = scale coefficient with technical change for vintage, v,
α_o = base year scale coefficient,
GR = annual growth rate in productivity increase (Hick's neutral technical change), and
v = vintage.

Other model parameters calculated from the data are the scale coefficient, β_o, and sensitivity parameters, β_1 and β_2, used in the investment equation. The determination of β_o, β_1, and β_2 are based on macroeconomic information such as historical aggregate investments and the base rate of growth in the economy. The investment equation, (17), for aggregate investment levels is rewritten below,

$$I_t = \beta_o \cdot I_{t-1} \cdot baserate_t^{\beta_1} \cdot f(\pi_t)^{\beta_2}$$

where,

$$baserate_t = \left(\frac{WAP_t}{WAP_{t-1}} \right) \cdot \left\{ \frac{(GNP/E)_{t-1}}{(GNP/E)_{t-2}} \right\},$$

and

$$f(\pi_t) = \left(\frac{\pi_t}{\pi_{t-1}} \right).$$

Using the aggregate investment equation in conjunction with historical aggregate investments, working age population ratios, and GNP to total employed ratios, linear regressions were conducted to estimate the parameters of β_o, β_1, and β_2.

With the estimation of β_o, β_1, and β_2, the calculation of investment on a sector/subsector level requires the determination of one addition parameter, the apparent discount rate, dis_j. The apparent discount rate, as shown by Equation (13) in Chapter 3, is a function of the interest rate and a constant factor of addition, fac_j, specific to each sector and subsector. The apparent discount rate for each sector/subsector is determined by finding the factor additions which reproduces the actual sector/subsector investment levels in 1985 using the investment equation, Equation (17). An analytic solution for the constant factor addition does not exist, therefore, an iterative procedure is used. Starting with an initial factor addition, the expected price is calculated using Equation (12). Then, expected profit is determined using the expected prices and Equation (16). Finally, the investment equation, Equation (17), is utilized, with the calculated expected profit, to determine the 1985 investment level on a sector basis. The factor addition is adjusted and this procedure repeated until the investment calculated by Equation (17) matches the actual investment amount for that sector in 1985. The constant factor of additions determine from the above procedure for each sector and subsector is shown in Table 4.2. These factor additions plus the interest rate do not represent true discount factors, but apparent discount factors that indicate the focus of investment activity in Korea in the year 1985. The factor additions that are negative represent sectors that were either subsidized or invested in heavily by the Korean government in 1985. Infrastructure planning in Korea, especially in the energy sector, is still made by the government. In the mid 80's, the Korean government strongly favored investment in nuclear power and natural gas infrastructures. In addition, in order to reduce the dependence on foreign crude oil, the Korean government has decided to reduce electricity generation from oil. This decision is evident in the very high factor addition for oil-fired electricity generation.

Table 4.2 Constant Factor of Addition

Sector	*fac* (%)
1. Agriculture	0.61
2. ETE	0.39
3. C. Oil	N/A
4. N. Gas	N/A
5. Coal	-0.03
6. Biomass	N/A
7. Uranium	N/A
8. Electricity	
Oil	83.8
Gas	0.00
Coal	0.13
Nuclear	-0.02
Hydro	0.72
9. R. Oil	0.60
10. Gas T&D	-0.34

4.3 Modeling Assumptions

The major assumptions required for the SGM are the elasticity of substitution parameters for the CES production function, average lifetime of capital, technical change parameters, demographics, and household's own price and income elasticities of demand. In addition, since the Korea module is a model of a closed economy, assumptions about international trade and energy price trajectories were necessary.

The elasticity of substitution parameters for the CES production function, average lifetime of capital and the technical change parameters used in the model are shown in Table 4.3.

Table 4.3 Elasticity of Substitution, Average Lifetime of Capital, and Hick's Neutral Technical Change Parameter (GR)

Sector/Subsector	σ	Lifetime (Years)	GR (%/year)
1) Agriculture	0.4	20	0.6
2) ETE	0.5	20	1.0
3) Crude Oil	---	15	---
4) Natural Gas	---	15	---
5) Coal	0.5	15	0.6
6) Biomass	---	15	---
7) Uranium	---	15	---
8) Electricity			
Oil	0.2	40	0.6
Gas	0.2	40	0.6
Coal	0.2	40	0.6
Biomass	0.2	40	0.6
Nuclear	0.2	40	0.6
Hydro	0.2	65	0.6
9) Refined Oil	0.1	30	0.6
10) Gas T&D	0.15	30	0.6

The demographic rates shown in Table 4.4 are the actual rates for 1985. The fertility rate and the male birth fraction is assumed remain the same until 2030. The male and female death rates and the male and female net migration rates were assumed to decline gradually to 80 percent of the 1985 rates by 2030.

Table 4.4 Demographic Rates (per 1,000)

Age	Fertility Rates	Male Birth Fraction	Female Death Rates	Male Death Rates	Female Net Migration Rates	Male Net Migration Rates
0-4			1.23	1.41	-0.95	-0.57
5-9			0.62	0.75	-0.65	-0.40
10-14			0.40	0.48	-0.39	-0.25
15-19	9	0.519	0.57	1.23	-0.99	-0.53
20-24	119	0.519	0.72	1.39	-1.66	-0.61
25-29	162	0.519	0.85	2.02	-1.69	-1.01
30-34	40	0.519	1.09	2.74	-1.00	-0.82
35-39	8	0.519	1.31	3.45	-0.61	-0.52
40-44	2	0.519	2.04	5.41	-0.41	-0.33
45-49			3.10	9.00	-0.37	-0.24
50-54			4.54	12.83	-0.41	-0.21
55-59			6.77	18.06	-0.47	-0.22
60-64			10.49	26.53	-0.50	-0.21
65-69			17.46	42.04	-0.51	-0.21
70-74			30.71	65.15	-0.56	-0.21
75+			86.94	141.11	-0.31	-0.18

The households' own price and income elasticities of demand were obtained from the Korea Energy Economics Institute (KEEI) and they are listed in Table 4.5 (personal communication with Tae Yong Jung, KEEI).

Table 4.5 Household Sectors' Own Price and Income Elasticity of Demand

Sector	Price Elasticity	Income Elasticity
1. Agriculture	-0.24	0.44
2. ETE	-1.00	0.6
3. Crude Oil	---	---
4. Natural Gas	---	---
5. Coal	-0.30	-0.5
6. Biomass	---	---
7. Uranium	---	---
8. Electricity	-0.5	1.0
9. Refined Oil	-0.5	1.2
10. Gas T&D	-0.5	1.2

Since a global version of the SGM has not been completed thus far, international trade for Korea cannot be solved endogenously. However, trade is allowed in the model by letting the market import energy fuels at predetermined prices. Since the model also assumes balanced trade, the value of exports from the ETE sector is set equal to the value of net imports. As shown in Figure 2.3, trade has been well balanced in Korea within the last 25 years, and therefore, the balanced trade assumption in the SGM is appropriate for Korea. In the Korea module, imports of crude oil, natural gas (LNG), coal, and uranium are allowed in unlimited quantities at the exogenously set prices. Net imports of agricultural goods and refined oil are fixed at the 1985 level. A summary of trade assumptions is provide in Table 4.6.

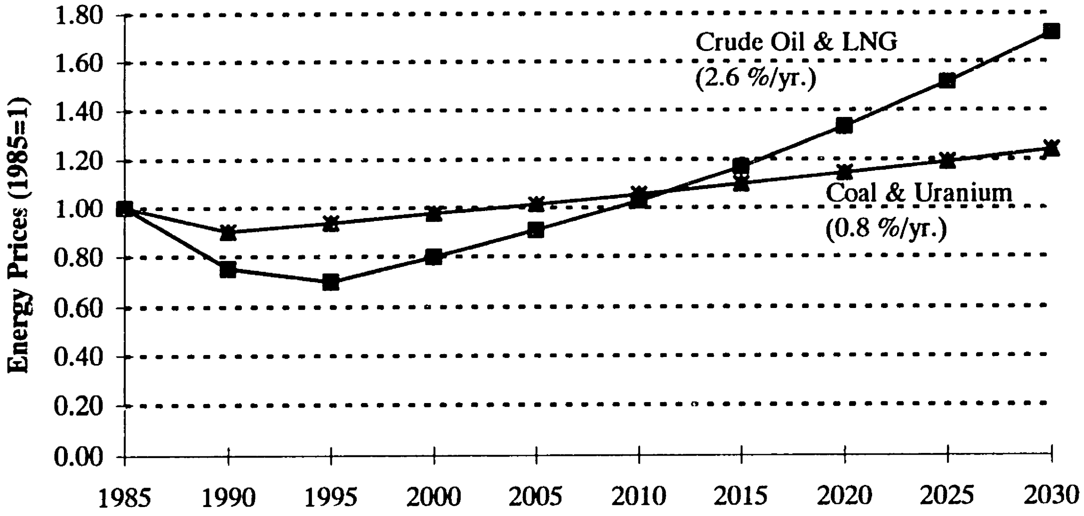
Table 4.6 Closure Assumptions

Sector	
1. Agriculture	Net import fixed
2. ETE	Set to balance trade account
3. Crude Oil	World price path given exogenously
4. Natural Gas	World price path given exogenously
5. Coal	World price path given exogenously
6. Biomass	---
7. Uranium	World price path given exogenously
8. Electricity	---
9. Refined Oil	Net import fixed
10. Gas T&D	---

Energy Price Trajectories

Since imports of crude oil, natural gas (LNG), coal, and uranium are allowed, price trajectories for these fuels were necessary. See Figure 4.1 for energy price trajectories. The price path for crude oil and LNG are the same, since international prices of these fuels are closely coupled. Crude oil prices dropped by 25 percent from 1985 to 1990 and have continued to fall from 1990 to the current level. Therefore, the 1995 price of crude oil and LNG were reduced by an additional 5 percent from the 1985 level. Prices for these fuels after 1995 are projected to rise at 2.6 percent per year according the *Annual Energy Outlook 1993*. The price trajectories for coal and uranium were coupled as well. Since there was little information on the future price trajectory of uranium, uranium prices were assumed to follow the growth rate of coal prices. From 1985 to 1990, coal and uranium prices declined by 10 percent. From 1990, coal and uranium prices are set to rise at 0.8 percent per year as expressed in the *Annual Energy Outlook 1993*.

Figure 4.1 Energy Price Trajectories



Chapter 5. Reference Case

The reference case provides a baseline scenario of growth in the Korean economy up to the year 2030, and was developed with considerations for historical trends and with no efforts to reduce carbon emissions. Furthermore, the reference case is used as a basis for comparing the impact of carbon tax policies and advanced energy technologies.

Although the structure of the SGM allows any energy technology options to be included, the available options for energy technologies, in the reference case, have been limited to traditional fossil fuel technologies, hydroelectricity, and nuclear power. In addition, the growth of nuclear power was allowed only until the year 2005; no new nuclear power plants can be built after this time.

The decision to limit nuclear power was based on the many concerns of nuclear power development now arising in Korea. Beginning in the 1970's, a massive government program in nuclear power lead to one of the most successful nuclear industry in the world. Korea currently has nine nuclear reactors in operation and plans to have fourteen more reactors in operation by the year 2006 with a total generation capacity of 23,230 MWe (Park 1992). This is a significant commitment to nuclear power, both in capital, land and human resources, and it could be difficult for Korea to maintain such an ambitious plan after 2006. Rising public opposition, lack of land availability, uncertainty of radioactive waste disposal, rising cost of power plants, shortage of highly technical manpower, and international concerns of nuclear proliferation are new challenges that the Korean nuclear industry must face now and in the near future (Park 1992). In the present plan for fourteen more nuclear reactors, sites for nine new reactors have already been designated, but sites for the additional five have not been determined. Finding new sites for these five additional reactors or any more reactors beyond 2006 could be difficult for those reasons stated above. Therefore, in the reference case, nuclear power development was not allow after 2005 (the Korea model has a five year time step).

In the following sections, model projections of demographics, GNP, primary energy consumption and production, and electricity generation, as well as carbon emissions for the reference case are presented.

5.1 Demographics

The population growth rate in Korea, which is currently 1.1 percent per year, is projected to decrease with time. By the year 2020, the population growth rate in the reference case is just 0.2 percent per year and the total population reaches a plateau at just over 52 million. From 2020 to 2030, the population growth remains minimal, and the population level does not rise over 53 million. Historical and projected population levels are shown in Figure 5.1, where population levels before 1985 are historical data and population levels from 1985 to 2030 are from model projections. The model projection of the 1990 population of 42.9 million is the same as the actual population in 1990. The current, 1994, population level of 44.4 million is slightly lower than the 1995 population projection of 45.3 million as expected.

The projection of working age population, persons of 15 to 64 years of age, reveals the effect of population stabilization on the labor supply. The population of those in the working age group grows until reaching a maximum in the year 2020 at 36.4 million and declines slightly thereafter to 34.2 million at the end of the modeling period. The working age population decreases after 2020 as the population stabilizes and the demographics shift towards a greater number of people over 65 years of age. An important factor in Korea's economic development has been the availability of a large labor supply; however, the declining labor supply could hinder future economic growth (see Table 5.1 for population data).

Population projections from the KEEI, the World Resources Institute (WRI), and the World Bank show similar growth paths as the projections stated above. Refer to Table 5.2 for population projections by KEEI, WRI and World Bank. KEEI reports a stable population of 50.2 million in the year 2020 that remains constant up to the year 2030 (*Yearbook of Energy Statistics 1993*). The World Resources Institute's projection is slightly higher than KEEI's but is very similar to the reference case projection made above. WRI's population projection is 51.6 million in the year 2025 (*World Resources 92-93*). The World Bank's population projection of 54 million by 2025 and a hypothetical stationary population of 56 million are the highest (*World Development Report 1992*). The population projection from the Korea module of the SGM lies in between the range set by the KEEI and World Bank projections.

Figure 5.1 Population Projections

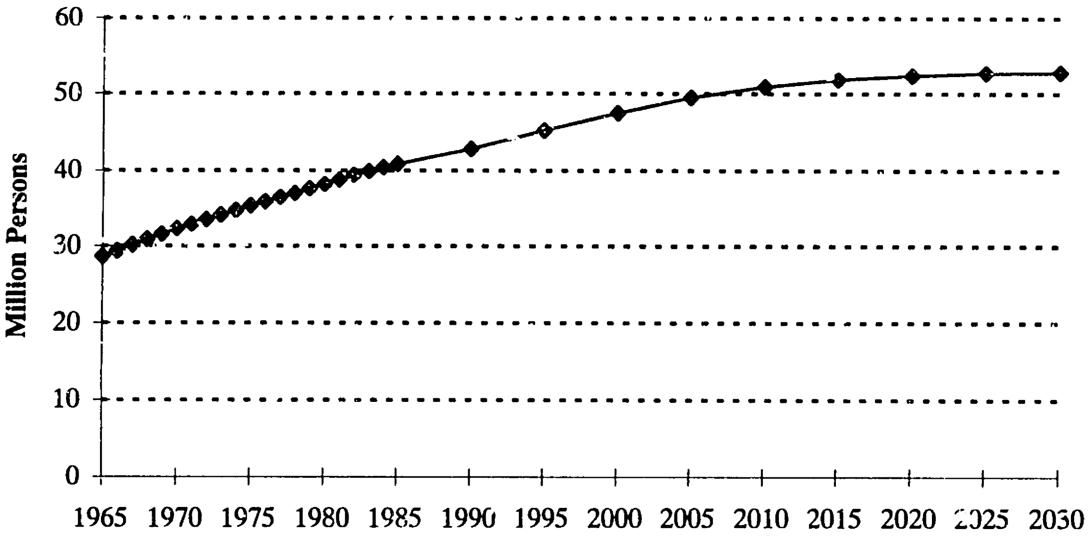


Table 5.1 Total Population and Working Age Population

Year	Total Population (Milions)	Working Age Population (Millions)	Growth Rate Total Population (%/yr)
1985	40.4	26.6	
1990	42.9	29.7	1.2%
1995	45.3	31.9	1.1%
2000	47.5	33.6	1.0%
2005	49.5	34.6	0.8%
2010	50.9	35.6	0.6%
2015	51.8	36.3	0.4%
2020	52.4	36.4	0.2%
2025	52.7	35.5	0.1%
2030	52.8	34.2	0.1%

Table 5.2 Comparison of Population Projections (1,000 persons)

Year	SGM	KEEI	WRI	WB
1990	42,900	43,520	42,790	43,000
1995	45,300	--	44,660	--
2000	47,500	46,828	--	47,000
2005	49,500	--	--	--
2010	50,900	49,486	--	--
2015	51,800	--	--	--
2020	52,400	50,193	--	--
2025	52,700	--	51,630	54,000
2030	52,800	50,193	--	--

5.2 Economic Trends

The results from the Korea module show that Korea will continue to develop rapidly for the next decade as it has in the past two decades before gradually slowing down towards 2030. Refer to Figure 5.2 for historical and projected GNP levels and Table 5.3 for projected GNP levels, growth rates and per capita GNP levels. In Figure 5.2, GNP levels and growth rates before 1985 are actual historical data and from 1985 to 2030 are model projections. The 1985 and 1990 GNP projections from the model are 78.1 and 131 billion 1985 Won ($143 and $240 billion 1990 US), respectively. By 1995, the model projects a GNP level of 183 billion 1985 Won ($335 billion 1990 US). From 1995, the GNP growth rate drops from 7 percent per year to 2 percent per year by 2030, and the GNP level in 2030 reaches 741 billion 1985 Won ($1,356 billion 1990 US). The GNP growth rate slows down during this period largely owing to the population stabilization and the decrease in the labor supply. By 2030, the standard of living in Korea is likely to be comparable to that of Japan and the United States today. As stated earlier, the 1990 GNP per capita for Japan was $25,430 US and $21,790 US for the United States. In comparison, the GNP per capita for Korea is projected to be $25,690 US (1990 dollars) by 2030.

Actual GNP levels for 1985, 1990 and 1993 provide a basis for checking GNP projections from the model. The actual GNP levels were 78.1 and 131 billion Won in 1985 and 1990, respectively. The 1985 and 1990 model projections coincide with the actual GNP levels for these years. In addition, the 1995 GNP projection of 183 billion Won is realistic, considering that the actual GNP level in 1993 was 164 billion Won. If Korea maintains a 6 percent per year GNP growth rate for 1994 and 1995, the GNP level at the end of 1995 will be equal to that projected by the model.

Comparisons of GNP projections from the Korea module of the SGM to other projections are in good agreement. The GNP projections from this model, KEEI and Oh & Kim are shown in Table 5.4 (KEEI 1994; Oh & Kim 1992). Observing the GNP projections for the SGM and KEEI in the corresponding years shows that the two projections are very similar. The difference in the two GNP projections does not diverge by more than 8 percent. An earlier GNP projection by Oh & Kim in 1992 is more optimistic than the SGM or the latest KEEI projections. The GNP projection by Oh & Kim is 4 percent greater than the SGM projection in 2000. This difference, however, grows to 25 percent by 2030 because a higher growth rate is assumed by Oh & Kim.

Figure 5.2 GNP Levels and Growth Rates (Real)

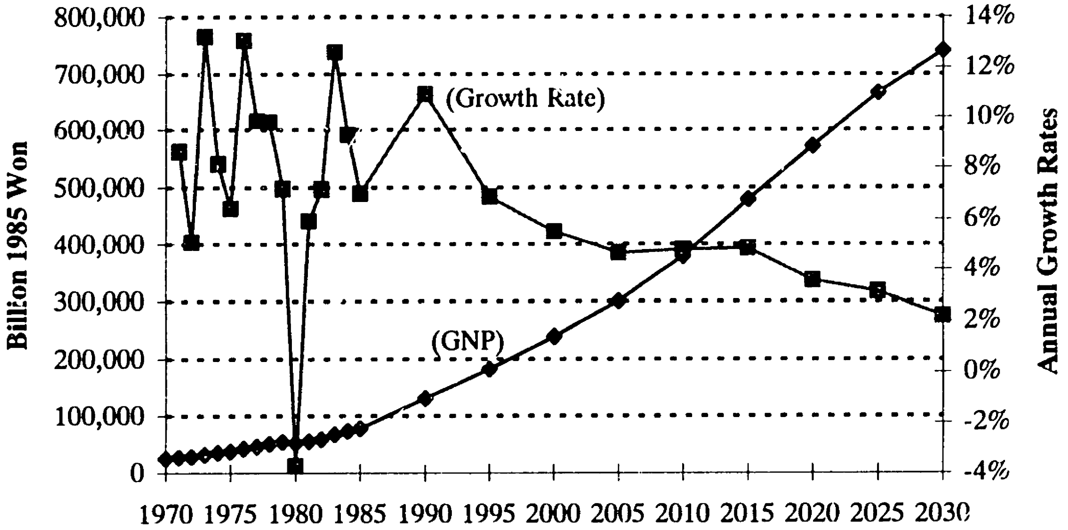


Table 5.3 GNP Projections and Growth Rates

Year	GNP (Billion 1985 Won)	GNP (Billion 1990 US $)	GNP Growth Rate (%/yr.)	GNP/Capita (1990 US $)
1985	78,112	143		3,539
1990	131,182	240	10.9%	5,606
1995	182,912	335	6.9%	7,402
2000	238,968	438	5.5%	9,208
2005	299,883	549	4.6%	11,100
2010	378,445	693	4.8%	13,616
2015	478,881	877	4.8%	16,923
2020	570,065	1,044	3.5%	19,940
2025	665,413	1,219	3.1%	23,126
2030	740,597	1,356	2.2%	25,699

Table 5.4. Other GNP Projections

Year	SGM GNP (Billion 1985 Won)	SGM GNP Growth Rate (%/yr.)	KEEI GNP (Billion 1985 Won)	KEEI GNP Growth Rate (%/yr.)	Oh & Kim GNP (Billion 1985 Won)	Oh & Kim GNP Growth Rate (%/yr.)
1992	--	--	149,500	--	--	--
1995	182,912	6.9%	--	--	--	--
1997	--	--	204,800	6.5%	--	--
2000	238,968	5.5%	239,800	5.4%	248,200	6.6%
2005	299,883	4.6%	--	--	--	--
2010	378,445	4.8%	355,000	4.0%	423,900	5.5%
2015	478,881	4.8%	--	--	--	--
2020	570,065	3.5%	525,500	4.0%	658,400	4.5%
2025	665,413	3.1%	--	--	--	--
2030	740,597	2.2%	741,300	3.5%	928,700	3.5%

5.3 Primary Energy Consumption

The rapid growth in primary energy consumption will continue into the next decade, before slowing down gradually towards the year 2030. Primary energy projections from 1965 to 2030 are shown in Figure 5.3; projections proceeding 1985 are actual historical data. Model projections of primary energy consumption in 1985 and 1990 of 54 and 92 MTOE, respectively, are very close to the actual values of 56 and 93 MTOE. Moreover, the 1995 projection of 128 MTOE is slightly higher than the actual 1993 level of 126 MTOE. By 2030, the primary energy consumption level in Korea reaches 293 MTOE, a greater than three-fold increase over the 1990 consumption level. Most of this growth in energy consumption occurs before 2010; after this time, the growth rate is relatively low and is equivalent to the current growth rates of primary energy consumption in Japan and the United States. The ten-year annual growth rates in primary energy consumption are 5.5, 3.3, 2.0, and 1.0 percent per year from 1990 to 2000, 2000 to 2010, 2010 to 2020, and 2020 to 2030, respectively. As a comparison, the 1980 to 1990 annual growth rates of energy consumption for Japan and the United States were 2.1 and 1.5 percent per year, respectively.

Consumption of all fuel sources, except for firewood, increases with time as shown in the reference case projections. Moreover, petroleum continues to be the main source of fuel for primary energy consumption throughout the modeled time period. By 2030, petroleum makes up 58 percent of the total primary energy consumption. In addition to the consumption of petroleum, coal, uranium, and hydroelectricity, large quantities of natural gas (LNG) were consumed beginning in 1990. In the reference case, the share of natural gas for primary energy consumption, which was at 3 percent in 1990, grows to 15 percent by 2030. The total consumption of coal increases with time as well; however, its share of total primary energy consumption is reduced from 27 percent in 1990 to 21 percent in 2030. Since nuclear power was constrained in this scenario, the share of nuclear power for total primary energy consumption falls from 15 percent in 2005 to below 10 percent by 2030. Due to minimal hydro power resources, the contribution to primary energy from hydroelectric power remains small at under 1 percent of the total throughout the modeled time period.

With time, nearly all of the primary energy needs for Korea are supplied by imports. Of the total primary energy consumed in 2030, 99 percent or 290 MTOE (including nuclear power) is supplied by imports. With time, even domestic coal production decreases due to the lack of coal resources, and energy production from hydroelectricity remains small due to minimal hydro power resources (see Table 5.5 for primary energy consumption levels by fuel source).

Primary energy consumption on a per capita basis increases from the 1990 level of 2.2 TOE to 5.5 TOE by 2030 (see Table 5.6 for the ratios of primary energy consumption per capita and per GNP for Korea). This level is approximately 30 percent less than the 1990 primary energy consumption per capita of the United States, but slightly greater than the 1990 level of Japan.

Although primary energy consumption continues to increase throughout the modeled years, the energy per GNP ratio declines steadily in Korea, revealing the gains in economic productivity per unit of energy consumed. By 2030, the energy per GNP ratio drops to 0.216 TOE/1,000 US dollar from the 1990 ratio of 0.370 TOE/1,000 US dollar.

Primary energy consumption projections from other sources indicate that the SGM projections lie within the range set by other projections. Primary energy consumption projections by Oh & Kim, KEEI, and Lee & Ryu are given in Table 5.7. Projections from Oh & Kim and KEEI are both higher than the SGM projections throughout the modeled time period. In the year 2000, primary energy consumption projections from Oh & Kim and KEEI are greater than the SGM projection by 12 and 16 percent, respectively, and by 2030, the corresponding projections diverge by 34 and 21 percent above the SGM projections. On the other hand, both the high and low primary energy consumption projections from Lee & Ryu are lower than the SGM projections. Projections for only two time periods, 2010 and 2025, are provided by Lee & Ryu. In 2010, Lee & Ryu's high and low energy consumption projections are lower than the SGM projection by 26 and 40 percent, respectively, and in 2025, they are lower by 24 and 40 percent. The lower primary energy projections by Lee & Ryu are due to their lower population projection and assumptions of energy efficiency improvements in the residential sector. Lee & Ryu projects a stable population of 50.3 million, which is 5 percent lower than that projected by the SGM. Moreover, they assume that the share of energy demand in the residential sector to total energy demand will decline from 31.5 percent in 1985 to 12 percent in 2025 due to efficiency improvements in heating systems and appliances. In the reference case of this model, however, no specific assumptions concerning end-use efficiency in the residential sector were made.

Figure 5.3 Historical and Projected Primary Energy Consumption

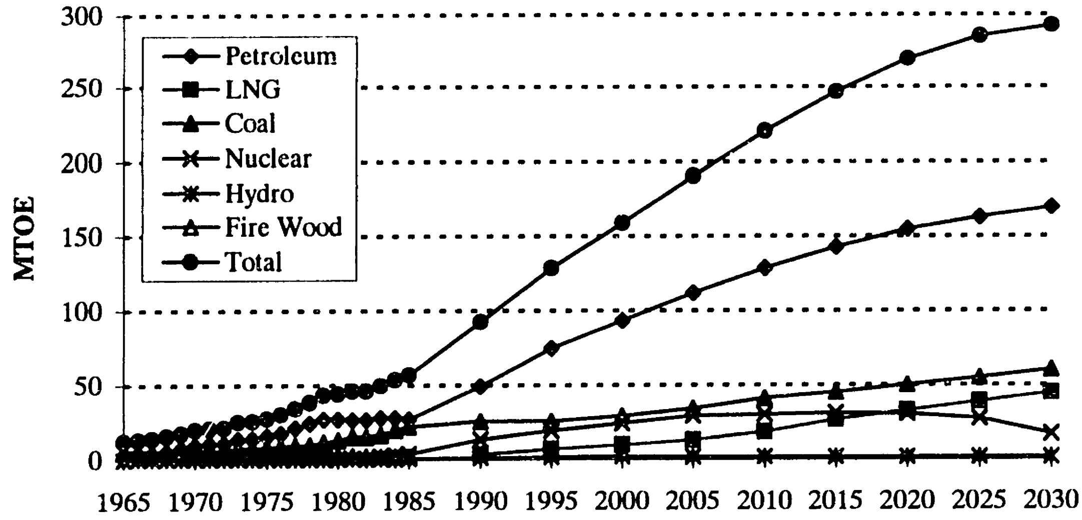


Table 5.5 Primary Energy Consumption (MTOE)

Year	Oil	Gas	Coal	Nuclear	Hydro	Total	Growth Rate
1985	27	0	22	4	1	54	
1990	49	3	25	14	1	92	11.2%
1995	75	7	26	19	2	128	6.8%
2000	93	10	29	24	2	159	4.3%
2005	112	13	34	29	2	190	3.7%
2010	128	18	41	30	2	220	2.9%
2015	142	27	45	31	2	247	2.3%
2020	154	33	50	30	2	269	1.8%
2025	163	39	55	27	2	285	1.2%
2030	169	44	60	17	2	293	0.5%

Table 5.6 Primary Energy Consumption per Capita and Primary Energy Consumption per GNP

Year	Energy/Capita (TOE)	Energy/GNP (TOE/1,000 US$)
1985	1.3	0.381
1990	2.2	0.385
1995	2.8	0.383
2000	3.3	0.362
2005	3.8	0.347
2010	4.3	0.317
2015	4.8	0.281
2020	5.1	0.258
2025	5.4	0.234
2030	5.5	0.216

Table 5.7 Comparison of Primary Energy Consumption Projections

Year	SGM (MTOE)	Oh & Kim (MTOE)	KEEI (MTOE)	Lee & Ryu High (MTOE)	Lee & Ryu Low (MTOE)
1995	128	--	--	--	--
1997	--	--	161.7	--	--
2000	159	177.7	184.1	--	--
2005	190	--	--	--	--
2010	220	253.3	239.3	162.8	133.0
2015	247	--	--	--	--
2020	269	327.4	297.1	--	--
2025	285	--	--	217.8	171.9
2030	293	392.1	354.4	--	--

5.4 Electricity Generation

Related to the growth of primary energy consumption, the consumption of electricity has grown rapidly as well. Significant growth and change in electricity generation continues to occur into the future, as projected in the reference case. Historical and projected electricity generation is plotted in Figure 5.4; the plots before 1985 are actual historical data, while the plots from 1985 to 2030 are model projections.

Checking the actual electricity generation data for 1985, 1990 and 1993 indicates that the reference case projections are realistic and in agreement with past data. The actual electricity generation levels in 1985, 1990 and 1993 were 58, 108 and 144 TWh, respectively. Projections from the reference case of the Korea module are 57, 119 and 181 TWh for 1985, 1990 and 1995, respectively. Comparisons of projection to actual data show some variations. The 1985 forecast is smaller than the actual level by 1 TWh, but the 1990 forecast is 10 percent or 11 TWh greater than the actual level. Nevertheless, the 1995 projection is reasonable, considering that the current annual growth rate in electricity generation is 12 percent per year. At this rate, the 1993 level of 144 TWh will grow to 181 TWh by 1995.

The generation of electricity after 1995 continues to grow rapidly before slowing down in the next decade. The ten-year annual growth rates of electricity generation are 7.2 percent per year from 1990 to 2000, 3.7 percent per year from 2000 to 2010, 3.2 percent per year from 2010 to 2020, and 2 percent per year from 2020 to 2030 (see Table 5.8 for annual growth rates in electricity generation). By 2030, a total of 565 TWh (49 MTOE) of electricity generation is projected in the reference case. This amount is five times greater than the level of electricity generated in 1990, and approaches the electricity generation level of Japan today. The electricity generation for Japan was 678 TWh in 1990.

The sources of electricity generation, which was dominated by nuclear power in 1990, shift to more coal, oil, and natural gas towards the end of the modeled time period. Since no more nuclear power plants can be built after 2005, the share of nuclear power for electricity generation falls after this time. From 57 TWh in 1990, electricity generation from nuclear power plants reaches a maximum of 127 TWh in 2005 and falls to 70 TWh in 2030. Electricity generation from nuclear power drops from 2005 to 2030 due to the retirement of older power plants. To generate the amount of electricity in 2005, 19 reactors with 1000 MWe capacity and annual load of 75 percent will be required. Since there are currently 9 reactors in operation, with 2 more ready to come on-line by 1995, 8 more reactors will be required to meet the generation projection in 2005. With nuclear power limited, the additional demand for electricity after 2005 is supplied predominantly by coal and natural gas (LNG). Table 5.8 provides electricity generation shares by fuel source. From the year 2015, coal replaces nuclear power as the major fuel source for electricity generation, and by 2030, the share of electricity generation from coal rises to 48 percent, while the share from nuclear power decreases to 12 percent. In addition, electricity generation from natural gas (LNG) increases to 26 percent of the total generation by 2030.

Per capita electricity consumption increases along with the increase total generation. By 2030, the reference case projection of electricity consumption per capita grows to 10.7 MWh, which is a five-fold increase in per capita consumption from the 1990 level (see Table 5.9 for per capita electricity consumption levels for Korea). The 2030 electricity consumption per capita level for Korea is equivalent to the 1990 electricity consumption per capita level for the United States, but surpasses the 1990 level for Japan.

There are only a few long-term electricity generation projections available in the literature to compare with the reference case results. Available electricity generation projections, including that from the Korea module of the SGM, are given in Table 5.10. Lee & Ryu's projections cover only two future years, 2010 and 2025, and KEEI's official projections extend only to 2005. The SGM reference case projections are very similar to the official KEEI projections; the generation levels in the two projections do not differ by more than 6 percent. Comparisons of Korea model results to Lee & Ryu's projections show larger discrepancies, however. High and low electricity generation scenarios are provided by Lee & Ryu, and both scenarios show much lower electricity generation levels than that in the SGM reference case. In 2010, Lee & Ryu's high and low projections are 24 and 33 percent lower than the SGM projection, respectively, and in 2025, they are 27 and 36 percent lower. As explained earlier in the section on primary energy consumption, the discrepancy between the two projections is due to Lee & Ryu's lower population projection and assumptions concerning energy efficiency improvements in the residential sector.

Figure 5.4 Historical and Projected Electricity Generation

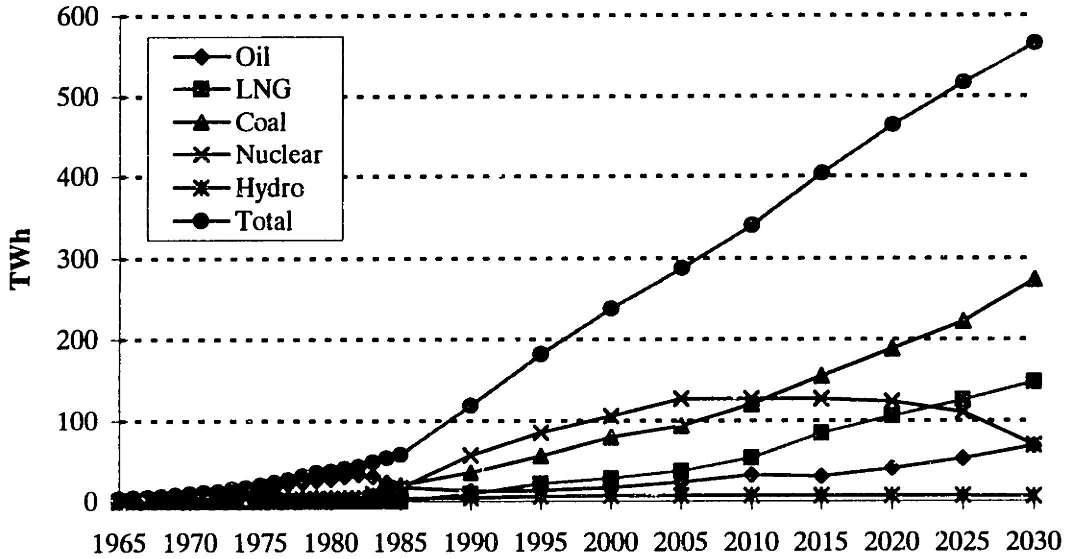


Table 5.8 Electricity Generation (TWh) and Growth Rates

Year	Oil	Gas	Coal	Nuclear	Hydro	Total	Growth Rate
1985	18	0	20	16	3	57	
1990	12	9	36	57	4	119	15.9%
1995	13	21	56	85	6	181	8.9%
2000	17	28	79	106	7	237	5.5%
2005	23	37	93	127	7	287	3.9%
2010	32	54	120	127	7	340	3.4%
2015	31	84	155	127	7	403	3.5%
2020	40	105	188	124	7	464	2.8%
2025	53	126	221	111	6	517	2.2%
2030	69	148	273	70	6	565	1.8%

Table 5.9 Electricity Consumption per Capita and Electricity Consumption per GNP

Year	Elect./Capita (MWh)	Elect./GNP (Watt-hr/US$)
1985	1.4	397
1990	2.8	494
1995	4.0	541
2000	5.0	541
2005	5.8	523
2010	6.7	490
2015	7.8	460
2020	8.9	444
2025	9.8	424
2030	10.7	417

Table 5.10 Comparison of Electricity Generation Projections

Year	SGM (TWh)	KEEI (TWh)	Lee & Ryu High (TWh)	Lee & Ryu Low (TWh)
1995	181	170	--	--
2000	237	236	--	--
2005	287	293	--	--
2010	340	--	257	229
2015	403	--	--	--
2020	464	--	--	--
2025	517	--	398	348
2030	565	--	--	--

5.5 Carbon Emissions

A historical picture of CO_2 emissions, shown in Figure 5.5, reveals the rapid increase in CO_2, owing predominantly to the combustion of coal and oil. In Figure 5.5, emissions proceeding 1985 are estimates made by the Oak Ridge National Laboratory (*Trends '91*) and the emissions from 1985 to 2030 are from SGM projections.

As large quantities of energy are consumed to fuel economic development in Korea, CO_2 emissions increase in the future. CO_2 emissions, generally, follow the path of primary energy consumption since fossil fuels are the major sources of primary energy. Reference case projections indicate that by 2030, the total CO_2 emissions will be 210 million tonnes of carbon (MtC), a three-fold increase over the 1990 level. The growth rate in CO_2 emissions is currently high but decreases towards 2030. The ten-year annual growth rates in CO_2 emissions are 4.9 percent per year from 1990 to 2000, 3.3 percent per year from 2000 to 2010, 2.2 percent per year from 2010 to 2020, and 1.4 percent per year from 2020 to 2030.

Combustion of petroleum and coal is responsible for the majority of CO_2 emissions since these fuels are the main sources of primary energy as stated earlier. In 2030, combustion of petroleum and coal comprises 54 and 32 percent of total CO_2 emissions, respectively (see Table 5.11 for CO_2 emissions by source and emissions growth rates). Emissions from natural gas combustion and cement manufacturing make up the remaining 14 percent. Although the expansion of nuclear power in the early part of the modeled time period helps to decouple the growth rate of CO_2 emissions from the growth rate of primary energy consumption, the constraint on nuclear power development forces the growth rates to be coupled again after 2005.

Although emissions of CO_2 have been growing rapidly, the current absolute and per capita emissions of CO_2 are small in comparison to other industrialized countries such as Japan or the United States. By 2030, Korea's total CO_2 emission of 210 MtC is still less than the current emissions level for the United States and Japan. However, on a per capita basis, Korea's future emission will be greater than that for Japan today, but still less than that for the United States today. Korea's CO_2 emission per capita reaches 4.0 tonnes by 2030 (see Table 5.12 for projections of CO_2 emissions per capita).

Reflecting the energy intensity of the Korean economy, the CO_2 emissions for Korea are significant when viewed on a per GNP basis. In 1990, the ratio of CO_2 emissions to GNP for Korea was 279 tC per million US dollars, which was higher than the ratio for the United States of 250 tC per million US dollars and nearly three times larger than that for Japan of 100 tC per million US dollars. However, significant improvements are made in increasing economic productivity, while reducing energy intensity towards the end of the modeled time period. By 2030, the ratio of CO_2 emissions to GNP for Korea is 155 tC per million US dollars.

Thus far, only emissions of CO_2 have been discussed. However, projections of total carbon emissions, which include carbon from methane (CH_4) and carbon monoxide (CO) emissions, are made by the SGM. Methane emissions from coal mining, agriculture and landfills have been included in the projections, as well as carbon monoxide emissions from the combustion of fossil fuels. Total carbon emissions are, therefore, somewhat greater than the CO_2 emissions given above, but the growth rates in the total carbon and CO_2 emissions are essentially the same since most of the carbon emissions come from CO_2. In 1990, the total carbon emission is estimated at 73 MtC, which grows to 230 MtC by 2030. Table 5.13 gives total carbon emissions by source and emissions growth rates, and Table 5.14 gives carbon emissions on a per capita and per GNP basis.

Comparisons of CO_2 emissions from the reference case to other available projections reveal that the reference case projections are within the range of other projections. Table 5.15, which lists all available projections, shows that SGM reference case projections are very similar to that made by Oh & Kim. Jung & Yoo's projections are, however, greater than the SGM projections by at least 20 percent, whereas both the high and low scenarios of Lee & Ryu's projections are lower than the SGM reference case projections.

Figure 5.5 Historical and Projected CO2 Emissions

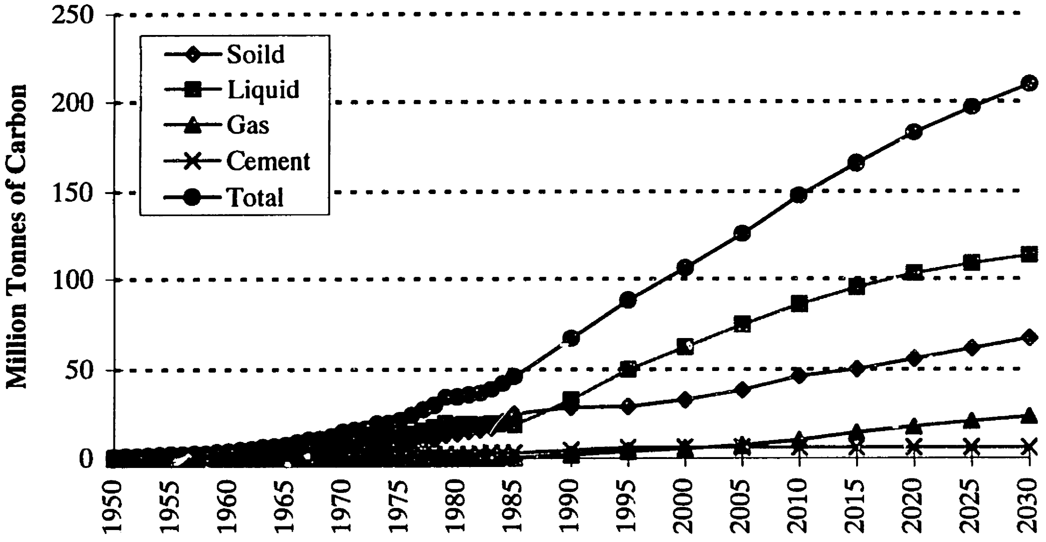


Table 5.11 Carbon Dioxide Emissions (MtC)

Year	Oil	Gas	Coal	Cement	Total	Growth Rate
1985	18	0	25	3	46	
1990	32	2	28	4	66	8.0%
1995	50	4	29	6	88	5.6%
2000	62	5	33	6	106	3.7%
2005	75	7	38	6	126	3.5%
2010	86	10	46	6	147	3.2%
2015	95	14	50	6	165	2.3%
2020	103	17	56	6	182	2.0%
2025	109	20	62	6	197	1.5%
2030	113	23	67	6	210	1.3%

Table 5.12 Ratios of CO_2/Capita and CO_2/GNP

Year	CO_2/Capita (Tonnes of Carbon)	CO_2/GNP (Tonnes/ Million US$)
1985	1.1	320
1990	1.6	279
1995	1.9	263
2000	2.2	242
2005	2.5	229
2010	2.9	213
2015	3.2	188
2020	3.5	174
2025	3.7	161
2030	4.0	155

Table 5.13 Total Carbon Emissions (MtC)

Year	Oil	Gas	Coal	Agriculture	(Landfills & Cement)	Total	Growth Rate
1985	21	0	25	1	3	49	
1990	37	2	29	1	4	73	8.2%
1995	57	4	29	1	6	96	5.8%
2000	71	5	33	1	6	116	3.8%
2005	86	7	38	2	6	138	3.5%
2010	98	10	46	2	6	162	3.2%
2015	109	14	50	2	6	182	2.3%
2020	118	17	56	2	6	200	1.9%
2025	124	20	62	3	6	215	1.5%
2030	130	23	67	3	6	230	1.3%

Table 5.14 Ratios of Carbon/Capita and Carbon/GNP

Year	Carbon/Capita (Tonne)	Carbon/GNP (Tonne/ Million US$)
1985	1.2	343
1990	1.7	303
1995	2.1	288
2000	2.4	266
2005	2.8	252
2010	3.2	234
2015	3.5	207
2020	3.8	191
2025	4.1	177
2030	4.3	169

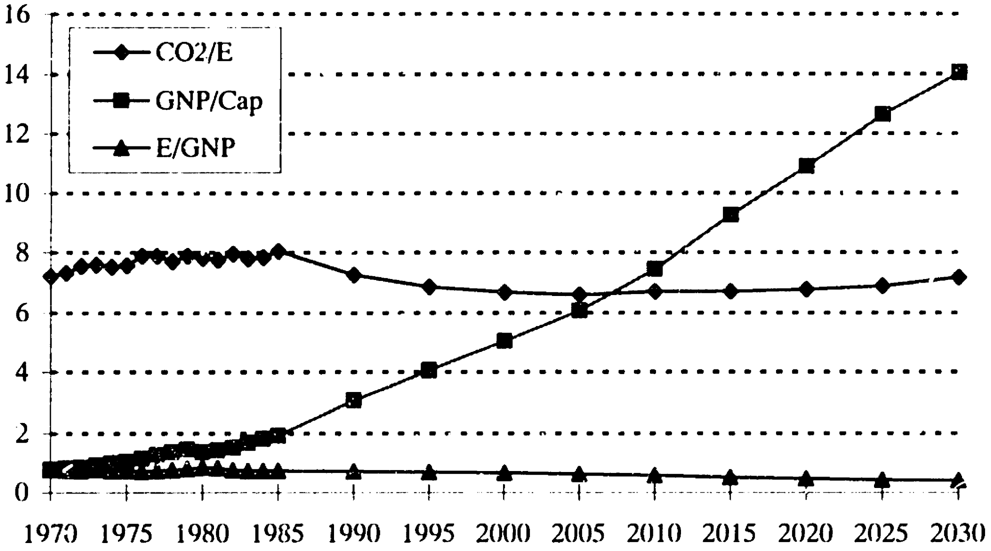
Table 5.15 Comparison of CO_2 Emissions Projections

Year	SGM (MtC)	Jung & Yoo (MtC)	Oh & Kim (MtC)	Lee & Ryu High (MtC)	Lee & Ryu Low (MtC)
1995	96	100	--	--	--
2000	116	133	122	--	--
2005	138	160	--	--	--
2010	162	183	158	140	108
2015	182	210	--	--	--
2020	200	243	195	--	--
2025	215	--	--	185	133
2030	230	--	227	--	--

5.6 Historical and Projected Ratios of CO2/Energy, GNP/Capita and Energy/GNP

As an overview of the reference case results, historical and projected values of key energy and economic parameters are plotted in Figure 5.6. The ratios plotted are CO_2 per energy, energy per GNP, and GNP per capita. The largest change occurs in the GNP per capita ratio, which indicates the rapid economic growth that is occurring in Korea and the high economic productivity that has been maintained since 1980. The declining CO_2 per energy ratio up to 2005 reveals the increased consumption of nuclear energy and natural gas for primary energy. However, the constraint on nuclear power forces increased use of coal for electricity generation and raises the CO_2 per energy ratio after 2005. The energy per GNP ratio, which declines steadily throughout the model time period, reflects the overall improvement in energy efficiency of the Korean economy driven by the exogenously determined technical change parameter.

Figure 5.6 Historical and Projected Ratios of CO2/Energy, GNP/Capita and Energy/GNP



5.7 Summary

The reference case results indicate strong economic growth for Korea with significant increases in the GNP, energy consumption and carbon emissions from the year 1985 to 2030. No efforts are made to reduce GHG emissions in the reference case, and energy supply technologies are limited to traditional fossil fuel technologies, hydroelectricity and nuclear power. Nuclear power is, however, constrained after the year 2005. In the reference case, GNP expands more than nine times over the 1985 level of

$143 billion (1990 US) to $1,356 billion by the year 2030. This represents an average annual growth rate of 5 percent per year from 1985 to 2030. The GNP growth rate falls below 4 percent per year from the year 2020, as the population stabilizes and the labor supply declines.

Furthermore, from 1985 to 2030, primary energy consumption increases five-fold from 54 to 293 MTOE, while electricity consumption grows nearly ten times from 57 to 565 TWh. Petroleum is the dominant fuel source for primary energy and maintains a 60 percent share of the total primary energy consumption throughout the modeled time period. The second largest share of primary energy is from coal, which is followed by LNG as the third largest share. The major shares of electricity generation are from coal, natural gas (LNG) and nuclear power. Until the year 2010, nuclear power is the dominant source of electricity; however, after this time, coal becomes the major source of electricity generation due to the constraint placed on nuclear power. By the year 2030, the shares of electricity from coal, natural gas and nuclear power are 48, 26 and 12 percent of the total generation, respectively.

Increasing consumption of fossil fuels in the reference case contributes to a five-fold increase in carbon emissions from the 1985 level of 49 MtC to 230 MtC by 2030. Combustion of petroleum contributes to nearly 60 percent of the total carbon emissions throughout the modeled time period, while combustion of coal and natural gas comprises 30 and 10 percent, respectively.

Chapter 6. Stabilization of Carbon Emissions in the Reference Case Using Carbon Taxes

The rapid pace of Korea's continuing economic growth demands an ever-increasing supply of primary energy. Thus, curbing the consumption of fossil fuels in the near future will be difficult. To better understand the feasibility of carbon emissions stabilization, carbon taxes were imposed on the reference case to stabilize carbon emissions at various different levels. Carbon emissions were stabilized to the 1995, 1.5 times the 1995 and 2 times the 1995 emission level of the reference scenario. The 1995 carbon emission level of 96 MtC is equal to 2 tonnes of carbon per capita. The 1.5 and 2 times the 1995 carbon emission level is equal to 3 and 4 tonnes of carbon per capita if the 1995 population level is used. The revenue generated from the carbon tax was recycled to the government. The results from the three stabilization scenarios were compared to the reference case to analyze changes in energy consumption, fuel substitution, and GNP levels.

For the carbon emissions stabilization scenarios, carbon taxes were applied to crude oil, natural gas and coal at a rate that would maintain emissions to the levels discussed above. Although the carbon tax rate applied to each fuel is a constant, the relative effect of the taxes on the price of each fossil fuel varies according to the carbon content of the fuel. A $100 US per tonne of carbon tax increases the prices of coal, crude oil and natural gas (LNG) by 95, 35 and 23 percent, respectively. Carbon taxes have the largest impact on the price of coal because it has the highest carbon content. Oil prices are less affected, due to the smaller carbon content of oil, and natural gas prices are the least affected, since natural gas contains the smallest amount of carbon.

A carbon tax is an effective economic instrument to reduce carbon emissions as it focuses emissions reduction at the source; however, the impact of the tax on emissions levels and the economy can vary significantly from country to country due to the differences in the price paid for fossil fuels, the share and composition of fossil fuels for primary energy consumption, and the stage of economic development. If higher prices are paid for fossil fuels, then the relative price increase from a carbon tax will not be as large as when lower prices are paid. Moreover, greater reliance on coal and oil instead of natural gas or non-carbon based fuels for energy will increase the impact of carbon taxes on the economy. Finally, constraint on energy use and carbon emissions during rapid economic growth periods will be difficult since energy is a primary factor for economic growth.

In the stabilization scenarios presented below, world prices of crude oil, natural gas (LNG), coal, and uranium were assumed to grow at the exogenously determined rate discussed in Chapter 4. However, world energy prices may not grow at the assumed rates under a global carbon stabilization scenario. For instance, the price of coal is likely to fall since it contains the largest amount of carbon. Changes in crude oil and natural gas prices are more uncertain since substitution from the use of coal to crude oil and natural gas will occur. It is possible that crude oil and natural gas prices may grow at a faster rate than coal prices. An analysis of the uncertainty in world energy prices under a global carbon stabilization scenario, and its effect on the results of this chapter are presented in Section 6.7.

6.1 Carbon Tax Levels

The carbon tax levels required for carbon emissions stabilization vary substantially according to the emissions level chosen for stabilization. In the first scenario, stabilization of carbon emissions to the 1995 level requires the highest carbon tax rate of the three stabilization scenarios. The reason for this is that carbon emissions in Korea increase significantly after 1995. The tax rate for emissions stabilization to the 1995 level or 2 tonnes of carbon per capita starts at $75 US per tonne of carbon in the year 2000 and rises rapidly to $1,525 US per tonne of carbon by the year 2030. Tax rates, in reality, would never reach such high levels; fuel substitution and/or other technological or socioeconomic changes are likely occur before tax rates get so high. Nevertheless, under the limited energy technology options of the reference case, such high tax rates reveal the extreme cost of stabilizing carbon emissions to the 1995 level. Refer to Figure 6.1 and Table 6.1 for carbon tax rates.

Stabilization of carbon emissions to 1.5 times the 1995 level or 144 MtC, on the other hand, requires far lower tax rates imposed at a later time than in the first stabilization scenario. In the second scenario, the tax rate begins at $50 US per tonne of carbon in 2010 and increases steadily to $500 US per tonne of carbon by 2030. Taxes required in this scenario are much lower than in the first stabilization scenario because the growth of carbon emissions slows down significantly after 2005.

In the final stabilization scenario, where carbon emissions are stabilized to 2 times the 1995 level or 192 MtC, carbon tax rates are the lowest of all stabilization scenarios. Stabilization of carbon emissions to 2 times the 1995 level requires that carbon taxes be applied from 2020 to 2030 only. The necessary tax rates are $25 US per tonne of carbon in 2020, $75 US per tonne of carbon in 2025, and $150 US per tonne of carbon in 2030.

Figure 6.1 Carbon Taxes for Carbon Emissions Stabilization

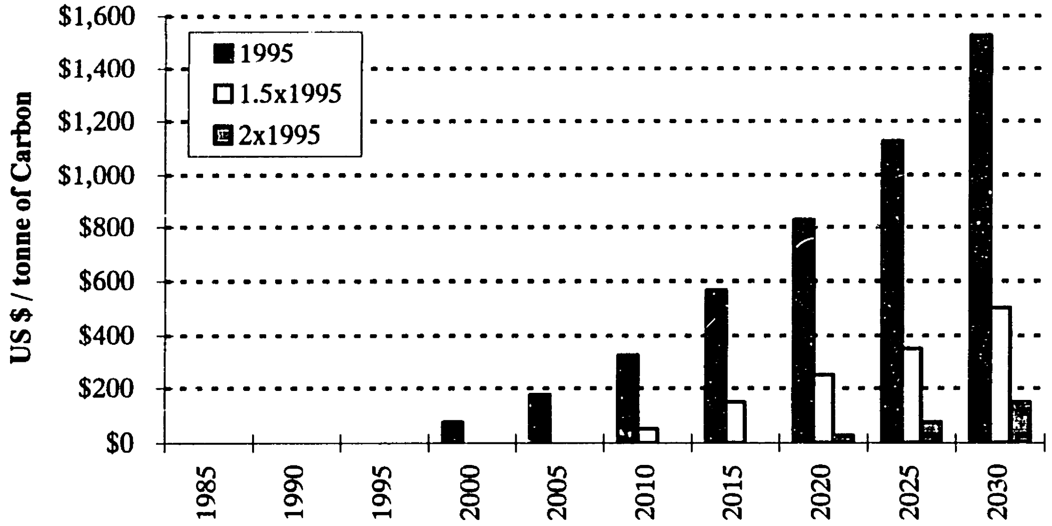


Table 6.1 Carbon Tax Levels for Carbon Emissions Stabilization (US $/tC)

Year	1995	1.5x1995	2x1995
1985			
1990			
1995			
2000	$75		
2005	$175		
2010	$325	$50	
2015	$565	$150	
2020	$825	$250	$25
2025	$1,125	$350	$75
2030	$1,525	$500	$150

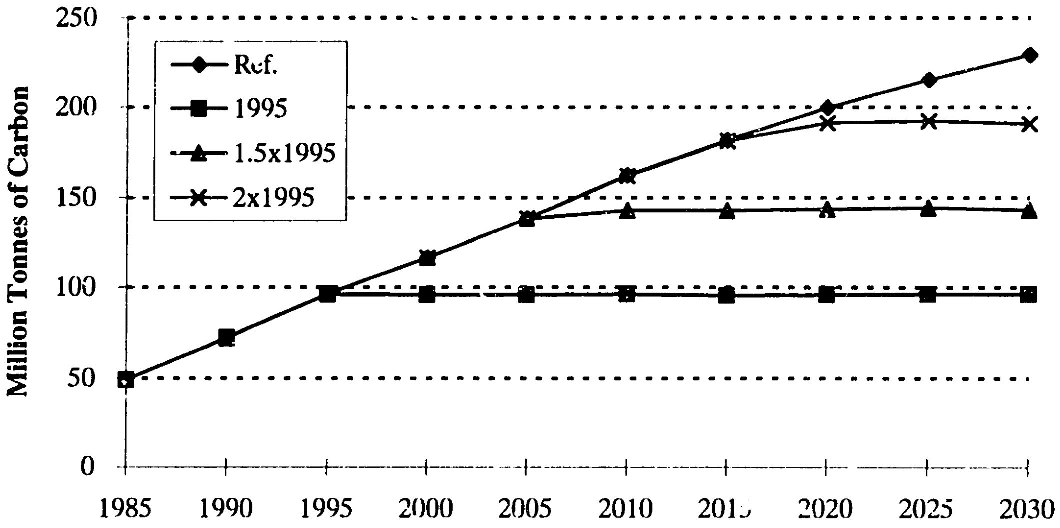
6.2 Carbon Emissions Reduction

The amount of carbon emissions reduced from the reference case for each stabilization scenario shows the degree of emissions reduction required for stabilization. In the first scenario, stabilization of carbon emissions to the 1995 level required substantial reductions in emissions by the end of the modeled time period (see Figure 6.2 for carbon emissions from all scenarios). Maintaining carbon emissions to 96 MtC requires from 20 to 133 MtC to be reduced from 2000 to 2030. This is a reduction in emissions of 17 to 58 percent from the reference case emissions. Such a large percentage of emissions foregone could not be achieved without the high tax rates.

The second scenario, which limits carbon emissions to 1.5 times the 1995 level, does not require as much emissions reduction from the reference case to maintain stabilization. In this scenario, 12 to 38 percent of the reference case carbon emissions must be reduced in 2010 and 2030 to maintain emissions at 1.5 times the 1995 level. The amount of reductions in 2010 and 2030 are 19 and 86 MtC, respectively.

In the final stabilization scenario, limiting carbon emissions to 2 times the 1995 level requires minimal emissions reduction from the reference case. The emissions reduction necessary were 4, 11 and 17 percent of the reference case emissions in 2020, 2025 and 2030. This amounted to an emissions reduction of 9, 23 and 39 MtC, respectively.

Figure 6.2 Carbon Emissions: Reference and Stabilization Cases



6.3 Primary Energy Consumption

Stabilization of carbon emissions in the reference is achieved by limiting the consumption of primary energy. In Korea, since fossil fuels supply nearly all primary energy demand, carbon taxes on fossil fuels directly affect the consumption of primary energy. Primary energy consumption levels from all stabilization scenarios are shown in Figure 6.3.

For the first stabilization scenario, in which emissions were stabilized to the 1995 level, primary energy consumption levels do not rise much over the 1995 level throughout the modeled time period. In this scenario, the consumption of primary energy reaches a maximum of 157 MTOE, an increase of only 23 percent from the 1995 level of 128

MTOE. Since the primary energy consumption level in the reference case reaches nearly 293 MTOE by 2030, limiting energy consumption to 157 MTOE is a substantial constraint to energy demand. The reduction in primary energy consumption comes mainly from the reduction of coal and oil consumption. Coal consumption is the most severely diminished, with consumption falling below the 1995 level as soon as taxes are applied. As evident from Figure 6.4, coal consumption continues to drop with time; by 2030, coal consumption is only 9 MTOE. This is an 85 percent reduction from the coal consumption level in the reference case. Oil consumption is also strongly minimized in this scenario. Oil consumption rises slightly from 1995 to 2005, but falls steadily, thereafter, to 2030. By 2030, oil consumption is 69 MTOE, which is a 60 percent reduction from the consumption level in the reference case.

Consumption of natural gas, nuclear power and hydroelectricity increases only slightly in the first stabilization scenario. Since carbon taxes promote fuel substitution away from carbon intense fuels such as coal and oil to low carbon fuels such as natural gas, there are some increases in natural gas consumption as taxes are initially imposed. However, after 2010, taxes are so high that even natural gas becomes expensive to use. By 2030, there is only a 4 percent increase in natural gas use over the reference case. Energy from nuclear power increases as taxes are applied; however, since the development of nuclear power is not allowed after the year 2005, only slight increases can be achieved. By 2030, 10 percent more energy is provided by nuclear power than in the reference case. See section below on electricity generation for more detail on nuclear power. Energy from hydroelectricity increases by 23 percent in 2030, but since the contribution of hydroelectricity to total primary energy is so small, this increase is insignificant. The overall shares of primary energy consumption by 2030 in the first stabilization scenario are 47 percent from oil, 31 percent from natural gas, 14 percent from nuclear power, 6 percent from coal, and 2 percent from hydroelectricity.

In the second scenario, stabilization of carbon emissions to 1.5 times the 1995 level enables primary energy consumption expands to 210 MTOE by 2030. This is an increase of 65 percent over the 1995 level of 128 MTOE. Nevertheless, the total consumption is still lower than the reference case level, in 2030, by 30 percent. The effect on the mix of fuels for primary energy consumption in this scenario is similar to that in the first stabilization scenario. Refer to Figure 6.5 for primary energy consumption levels by source for the second stabilization scenario. Coal and oil consumption is reduced, although not as much as in the first stabilization scenario, while natural gas, nuclear power and hydroelectricity consumption is increased. Coal and oil consumption drops by 75 and 33 percent, respectively, from the reference case in 2030. On the other hand, the consumption of natural gas, nuclear power and hydroelectricity rises by 28, 4 and 14 percent, respectively, from the reference case in 2030. The rise in the consumption of natural gas is more significant here than in the first stabilization scenario because the tax rates are not so high as to discourage natural gas use. Rather, taxes encourage substitution of oil and coal for natural gas. The increases in primary energy consumption from nuclear and hydroelectric power are less than in the first stabilization scenario and do not contribute much to the overall increase in consumption. For the second stabilization scenario, the shares of primary energy consumption in 2030 are 55 percent from oil, 28 percent from natural gas, 9 percent from nuclear power, 7 percent from coal, and 1 percent from hydroelectricity.

Primary energy consumption levels in the third stabilization scenario are not much lower than the consumption levels in the reference case. Stabilization of carbon emissions to 2 times the 1995 level requires that only small amounts of primary energy need to be constrained towards the end of the modeled time period. By 2030, a reduction in primary energy consumption of 14 percent from the reference case was necessary. In this scenario, the mix of fuels for primary energy, shown is Figure 6.6, is not particularly different than in the reference case. Only in the last ten years of the modeled time period are there any changes. By 2030, oil and coal consumption decreases by 13 and 31 percent, respectively, from the reference case, while consumption of natural gas, nuclear power and hydroelectricity remains the same. In 2030, the shares of primary energy consumption for this stabilization scenario are 58 percent from oil, 18 percent from natural gas, 16 percent from coal, 7 percent from nuclear power, and 1 percent from hydroelectricity.

Figure 6.3 Primary Energy Consumption: Reference and Stabilization Cases

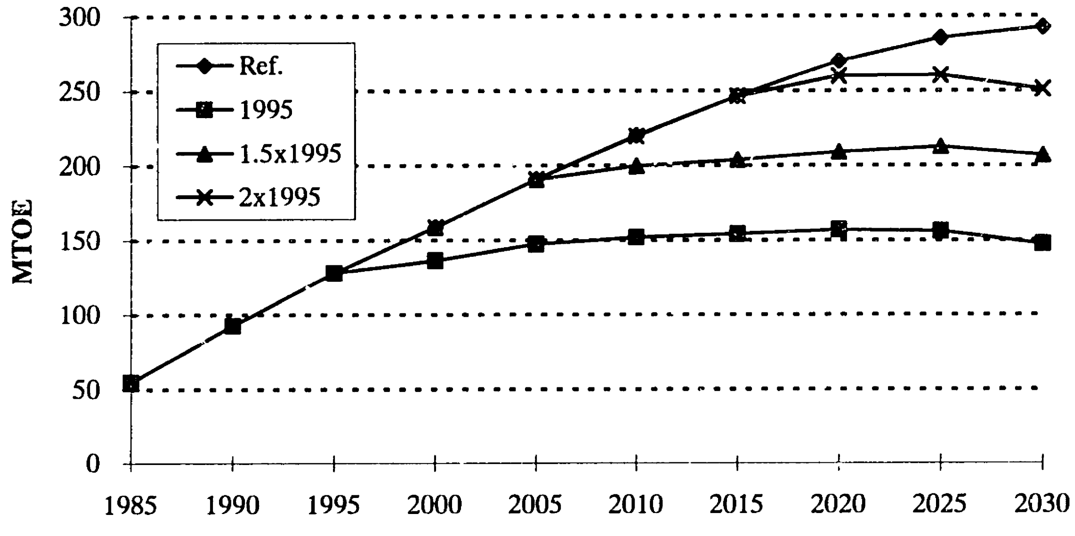


Figure 6.4 Primary Energy Consumption: Stabilization to 1995

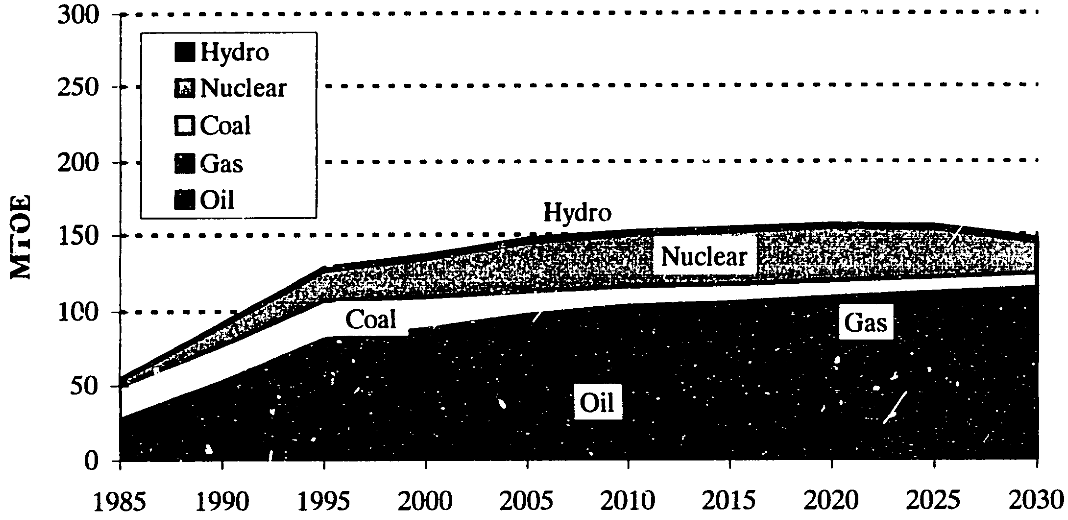


Figure 6.5 Primary Energy Consumption: Stabilization to 1.5 x 1995

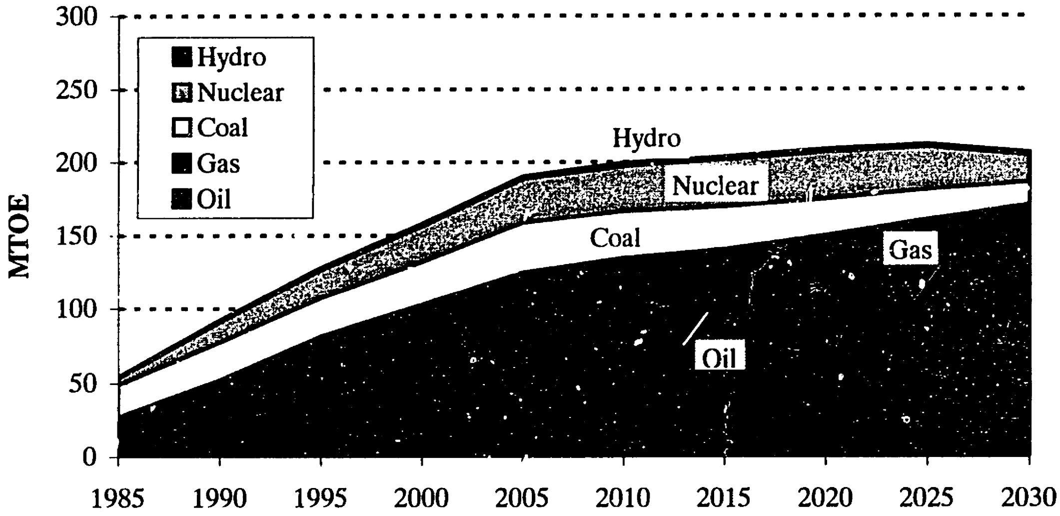
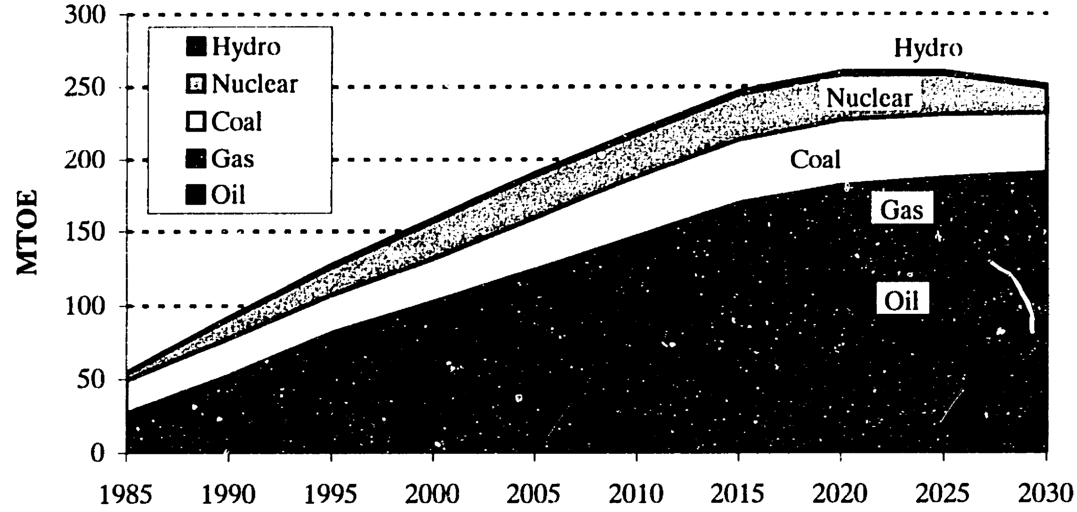


Figure 6.6 Primary Energy Consumption: Stabilization to 2 x 1995



6.4 Electricity Generation

Although the total levels of electricity generation in all stabilization scenarios are less than in the reference case, the reductions in electricity generation are not as severe as the reductions in primary energy consumption (see Figure 6.7 for electricity generation projections for all scenarios). In all stabilization scenarios, a large degree of fuel substitution, mostly from coal to natural gas, occurs in the electricity sector enabling the growth in electricity generation.

In the first stabilization scenario, electricity generation reaches 323 TWh by 2030. Even with high carbon taxes, an annual growth in electricity generation of 2 percent is achieved. Total electricity generation is, however, 43 percent less by 2030 than in the reference case. Stabilization of carbon emissions to the 1995 level results in major changes in the mix of fuels for electricity generation (see Figure 6.8 for electricity generation levels from each fuel source). There is no electricity generation from coal as carbon tax rates increase. After 2010, carbon taxes greater than $500/tC eliminate the use of coal for electricity generation. Electricity generation from oil is also severely affected by carbon taxes, but is not completely eliminated. By 2030, electricity generation from oil is 95 percent less than in the reference case.

Losses in electricity generation from coal and oil are compensated by increases in electricity generation from natural gas, nuclear power and hydro power in the first stabilization scenario. The largest increase in electricity generation comes from the combustion of natural gas. Power plants using natural gas generate up to 236 TWh of electricity by 2030. This is an increase of 60 percent from the electricity generated by natural gas in the reference case. Moreover, by 2030 of the first stabilization scenario, the share of electricity generated by natural gas increases to 73 percent of the total. Although primary energy consumption from natural gas does not increase significantly as stated earlier, more of the available supply of natural gas is consumed by the electricity sector than any other sectors. The household and other non-electricity sectors consume smaller shares of natural gas than in the reference case because the price of natural gas rises faster than the price of electricity.

In addition to greater electricity generation from natural gas, electricity generation from nuclear power increases to a small degree in the first stabilization scenario. A maximum of 7 TWh of additional electricity is generated from nuclear power when carbon taxes are applied. One additional nuclear power plant at 1000 MWe capacity and 75 percent annual load would be required for this additional amount of generation. The total number of nuclear power plants in this scenario is, therefore, 20. In 2030, nuclear power generates 77 TWh of electricity and comprises 24 percent of the total generation. Lastly, hydroelectricity contributes slightly more to the total electricity generated; approximately 1 TWh of additional electricity is generated from hydro power. The share of electricity from hydro power is only 2 percent of the total generation in 2030.

Stabilization of carbon emissions to 1.5 times the 1995 level enables more electricity generation overall than in the first stabilization scenario. Electricity generation grows to 400 TWh by 2030 in this second scenario. In comparison to the reference case, however, electricity generation is still lower by 29 percent in 2030. Again, most of the reductions come from coal and oil fueled power plants, as evident from Figure 6.9. Electricity generated from coal and oil are reduced by 98 and 27 percent, respectively, from the reference case in 2030. This decrease is compensated predominantly by increases in electricity generation from natural gas. In 2030, 80 percent more electricity is generated from natural gas than in the reference case. Slightly more electricity is generated from nuclear and hydro power; however, the additional electricity from these sources is not significant.

Stabilization of carbon emissions to 2 times the 1995 level enables electricity generation levels to return nearly to the original reference case levels. Electricity generation levels by fuel source for this stabilization scenario are shown in Figure 6.10. There is only an 8 percent reduction in total electricity generation from the reference case in 2030. The slight reduction in electricity generation in this stabilization scenario is from coal power plants.

Figure 6.7 Electricity Generation: Reference and Stabilization Cases

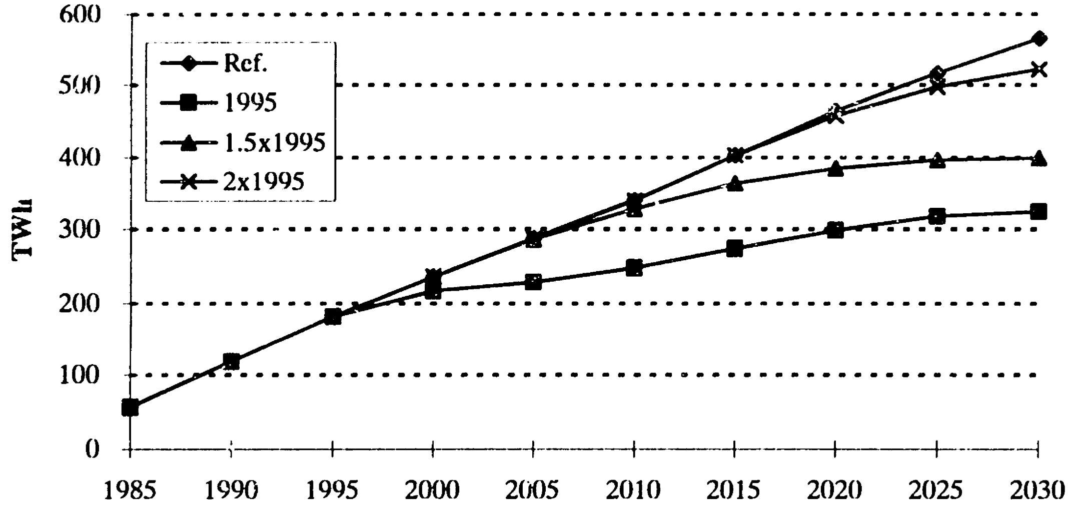


Figure 6.8 Electricity Generation: Stabilization to 1995

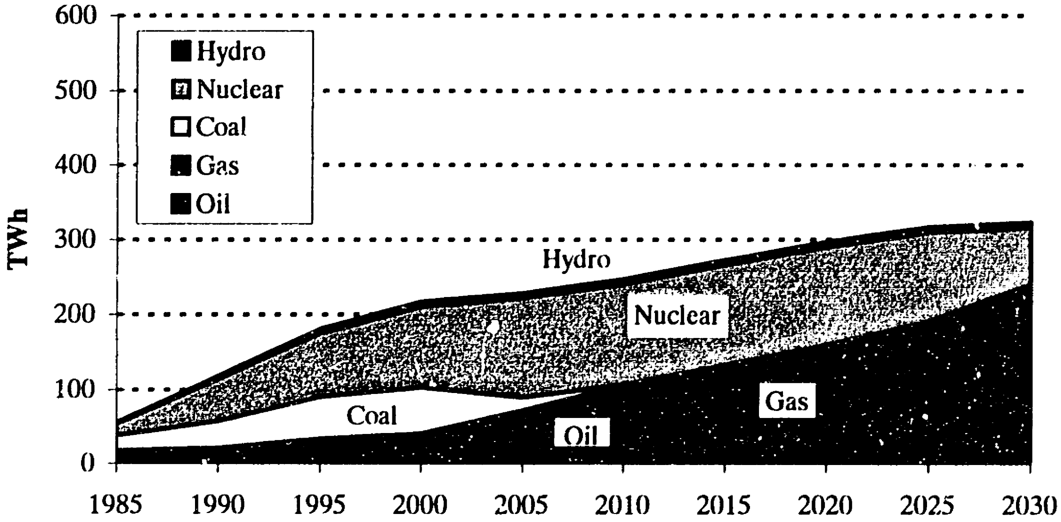


Figure 6.9 Electricity Generation: Stabilization to 1.5 x 1995

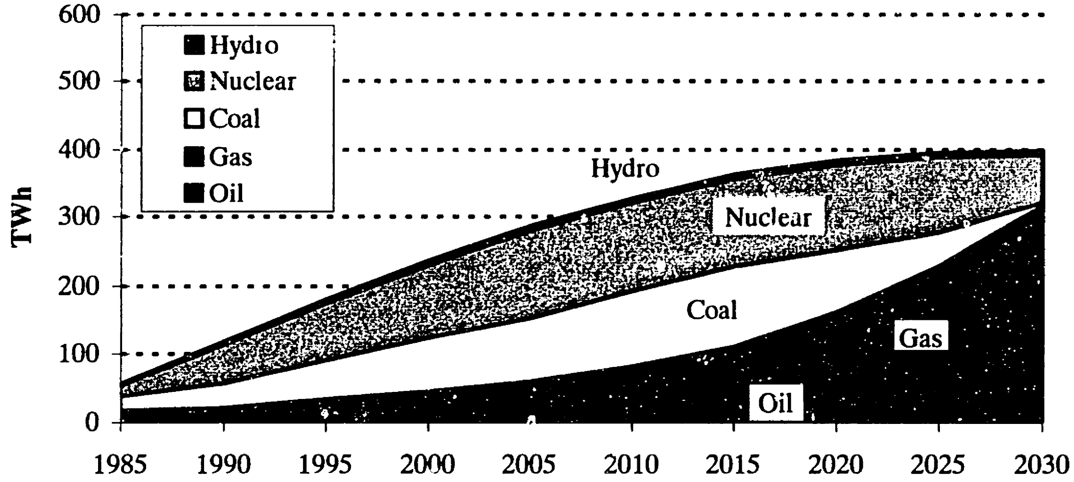
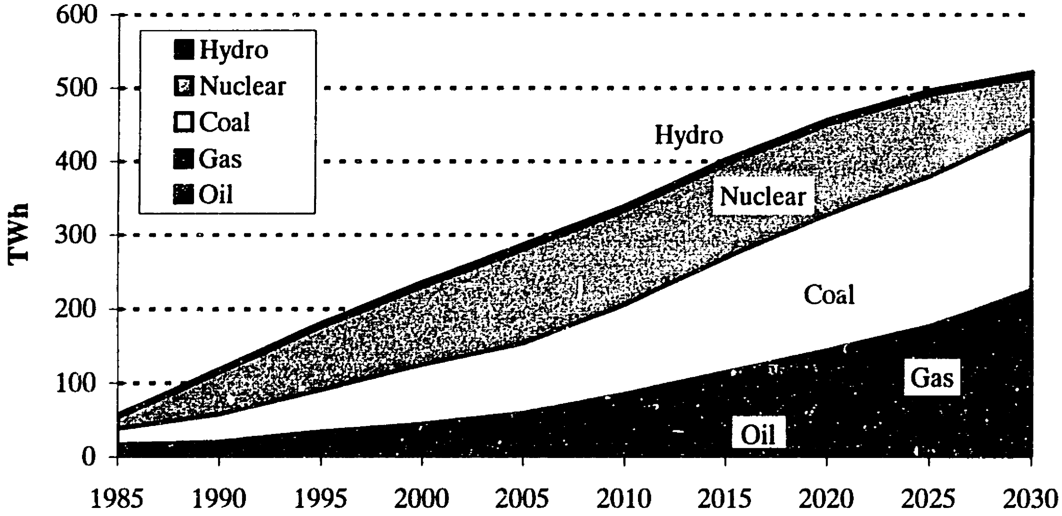


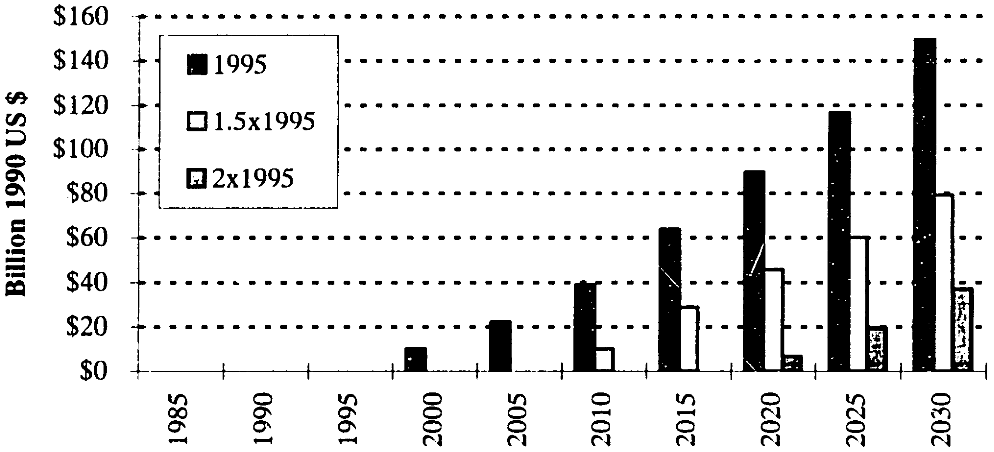
Figure 6.10 Electricity Generation: Stabilization to 2 x 1995



6.5 Revenue from Carbon Taxes

While reducing carbon emissions and promoting energy substitution, carbon taxes have the potential to generate large revenues. Carbon taxes in the first stabilization scenario generate tax revenues of $10 billion US (1990 dollars) in the year 2000 to $149 billion US in the year 2030. In the second stabilization scenario, lower taxes result in less revenue. From $10 billion to $79 billion are collected from 2010 to 2030 in the second stabilization scenario. The third stabilization scenario, with the smallest carbon taxes, generates the least amount of revenue. Seven billion US dollars to $37 billion US are generated from 2020 to 2030. Refer to Figure 6.11 for carbon tax revenues.

Figure 6.11 Carbon Tax Revenue: Carbon Stabilization Cases



6.6 Costs to the Economy

The cost to the economy of carbon emissions stabilization is measured as the difference in the GNP levels of the three stabilization scenarios from the GNP level in the reference case. Although GNP does not provide a direct measure of human welfare, it provides a common and quantifiable measure of the impacts carbon stabilization. Cost, as measured in this study, does not included possible external benefits of carbon emissions reduction.

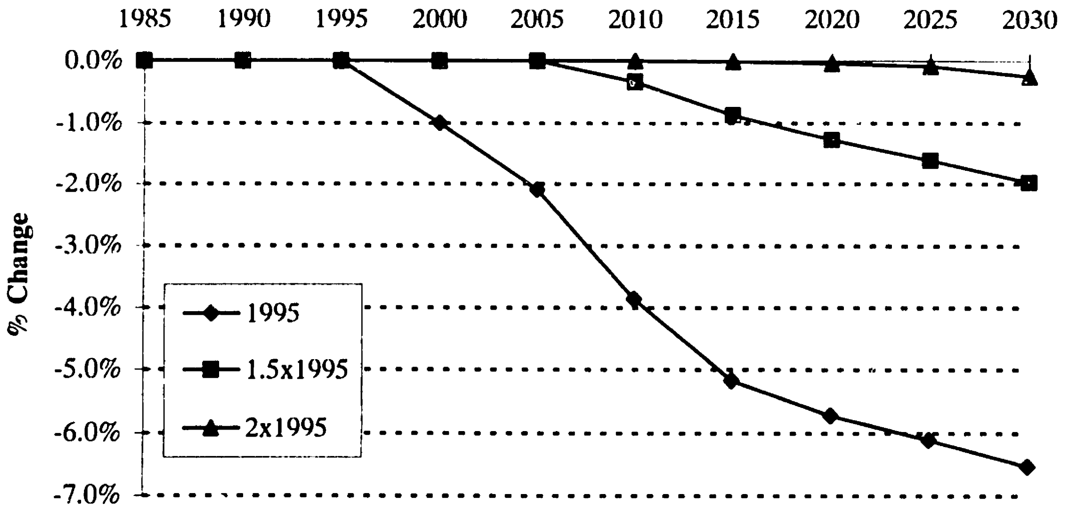
Since the first stabilization scenario has the highest carbon tax rate that is applied very early in the modeled time period, it results in the largest GNP loss. In first stabilization scenario, the tax of $75 US per tonne of carbon applied in 2000 results in a GNP loss of 1 percent. As taxes are raised, the GNP loss continues to increase, and by 2030, the tax rate of $1,525 US per tonne of carbon results in a GNP loss of 6.5 percent. Figure 6.12 shows GNP losses from all three stabilization scenarios.

Substantially less GNP loss results when carbon emissions are stabilized to 1.5 times the 1995 level. This is because the constraint on carbon emissions is not as severe and carbon taxes are applied ten years later when economic growth begins to slow down. Introduction of a $50 US per tonne of carbon tax in 2010 produces a GNP loss of 0.3 percent. GNP loss steadily worsens as taxes are raised; by 2030, the tax of $500 US per tonne of carbon produces a GNP loss of 2 percent from the reference case.

The final stabilization scenario results in only minimal GNP losses since the higher emission allowance requires much lower carbon tax rates. Taxes of $25 and $75 US per tonne of carbon applied in 2020 and 2025 result in GNP losses of approximately 0.1 percent, and the tax of $150 US per tonne of carbon applied in 2030 results in a GNP loss of approximately 0.2 percent.

Consumption and investment losses are responsible for the GNP reductions in all stabilization scenarios. Stabilization of carbon emissions to the 1995 level results in consumption losses that range from 4 percent in 2000 to 20 percent in 2030. Investment losses are not as significant and range from 2 percent in 2000 to 13 percent in 2030. Stabilization of carbon emissions to 1.5 times the 1995 level results in consumption losses of 2 percent in 2010 to 9 percent in 2030 and investment losses of 1 percent in 2010 to 6 percent in 2030. In the final stabilization scenario, carbon taxes do not significantly reduce consumption and investment levels. Consumption and investment losses both range from 1 to 3 percent from 2020 to 2030. The increase in the government sector from carbon tax revenues offsets the loss from consumption and investment to some degree in all stabilization scenarios, but this increase is not enough to maintain GNP levels at the reference case level.

Figure 6.12 Changes in GNP of Stabilization Cases (Relative to Reference Case)



6.7 Uncertainty of World Energy Prices

The results presented thus far were based on the assumption that fossil fuel prices will grow at a steady rate after the year 1995. As discussed in Chapter 4.3 Modeling Assumptions, a growth rate of 2.6 percent per year was assumed for crude oil and natural gas, and a growth rate of 0.8 percent per year was assumed for coal and uranium. However, under an international agreement in which the global carbon emissions are stabilized, tremendous uncertainty in future prices of crude oil, natural gas, coal, and uranium would arise. It is possible that fossil fuel prices could fall significantly due to the constraint on fossil fuel consumption, whereas the uranium price could rise due to greater demand for a non-carbon based energy source. However, it is difficult to predict how energy prices will change under a global stabilization scenario through carbon taxes. Since the effect of taxes on the price of each fossil fuel varies according to the carbon content of the fuel, some amount of fuel substitution will occur. The degree of fuel substitution will also affect fuel prices, but it may be difficult to assess the degree of substitution that is likely to occur.

To investigate the effect of varying energy prices on the cost of carbon emissions stabilization, a stabilization scenario was run in which world prices of crude oil, natural gas, coal, and uranium were held constant at their 1995 prices through the end of the modeled time period. With constant energy prices, carbon taxes were applied to crude oil, natural gas and coal to limit carbon emissions to the 1995 level, and comparisons to the former stabilization scenario were made. For comparison purposes, the former stabilization scenario, in which energy prices are rising at the assumed rate, is referred to as Case A, and the stabilization scenario with constant energy prices is referred to as Case B. The growth rate in fuel prices for the two cases are summarized below.

Growth Rate in Energy Prices: Case A and B

Primary Fuels	Case A (%/yr)	Case B (%/yr)
Crude Oil	2.6	0.0
Natural Gas	2.6	0.0
Coal	0.8	0.0
Uranium	0.8	0.0

Carbon Tax Levels

With crude oil, natural gas, coal, and uranium prices held constant, carbon taxes required to stabilize emissions to the 1995 level were higher than the previous Case A tax levels. The carbon tax necessary for emissions stabilization in Case B starts at $95/tC in the year 2000 and increases to $1,810/tC by the year 2030. Case B taxes were 19 to 27 percent greater than Case A tax levels because higher taxes were required to counter increases in fossil fuel consumption resulting from lower fuel prices. Table 6.2 compares the carbon tax rates required to stabilize carbon emissions to the 1995 level for Case A and Case B. The higher taxes required for stabilization with lower energy prices reveals that the important parameter in constraining fossil fuel use is the final price or the end-user price (world price plus the tax) of the fossil fuel.

Table 6.2 Comparison of Carbon Tax Rates for Carbon Stabilization to the 1995 Level

Year	Tax Rates (Case A) ($/tC)	Tax Rates (Case B) ($/tC)	Increase in Tax Rates (%)
1985	-	-	-
1990	-	-	-
1995	-	-	-
2000	75	95	27%
2005	175	220	26%
2010	325	410	26%
2015	565	685	21%
2020	825	990	20%
2025	1,125	1,350	20%
2030	1,525	1,810	19%

Primary Energy and Electricity Consumption

Although energy prices were lower in Case B than in Case A, the higher carbon tax rates in Case B deterred any additional consumption of primary energy. As in the previous Case A stabilization scenario, primary energy consumption levels were held below 160 MTOE throughout the modeled time period. Moreover, with the higher carbon taxes, the total electricity generation levels did not change from the levels in the original stabilization scenario. Although uranium prices were also held constant, electricity generation from nuclear power did not grow since its expansion was not allowed after the year 2005.

Tax Revenue and GNP Loss

Comparison of the two stabilization cases reveal that carbon emissions, primary energy consumption, and electricity generation do not change since the final prices of fossil fuels have not changed; however, differences between the two cases arise in the amount of revenue generated and the GNP loss resulting from carbon taxes. Higher taxes in Case B result in greater revenue than the Case A stabilization scenario; $3 to $27 billion additional revenue is generated with higher taxes from 2000 to 2030. This is an increase in revenue of 18 to 25 percent, respectively, from Case A (see Table 6.3 for a comparison of carbon tax revenues). The same amount of energy is consumed in both cases, but the additional revenue generated from higher taxes compensates for the GNP loss resulting from the overall increase in fossil fuel prices. In Case A, GNP loss was as high as 6.5 percent of the reference case level in the year 2030; however, in Case B, the

GNP loss for the year 2030 was 4.7 percent. Refer to Table 6.4 for comparison of GNP losses.

Table 6.3 Comparison of Carbon Tax Revenues

Year	Tax Revenue (Case A) (Billion 1990$)	Tax Revenue (Case B) (Billion 1990$)	Increase in Tax Revenue (%)
1985	-	-	-
1990	-	-	-
1995	-	-	-
2000	$10	$13	25%
2005	$22	$27	24%
2010	$39	$48	25%
2015	$64	$77	21%
2020	$89	$107	19%
2025	$116	$138	19%
2030	$149	$176	18%

Table 6.4 Comparison of GNP Losses (relative to reference case)

Year	GNP Loss (Case A)	GNP Loss (Case B)
1985	-	-
1990	-	-
1995	-	-
2000	-1.0%	-0.2%
2005	-2.1%	-0.9%
2010	-3.9%	-2.4%
2015	-5.2%	-3.6%
2020	-5.7%	-4.2%
2025	-6.1%	-4.5%
2030	-6.5%	-4.7%

Comparisons of Case A and Case B results indicate that when fossil fuel prices are lower, there is greater incentive to consume more fossil fuels. Therefore, in order to stabilize carbon emissions, higher carbon taxes are required to maintain end-user fossil fuel prices at a level that does not lead to any additional demand for fossil fuels. However, the benefits of lower world energy prices and higher taxes are that the same amount of fossil fuels can be consumed while greater revenue is generated. Moreover, the additional tax revenue compensates for GNP losses resulting from the higher end-user price of fossil fuels.

6.8 Summary

Stabilization of carbon emissions to the current level will require high carbon taxes resulting in large reductions in energy consumption and significant negative impacts on the GNP. For instance, stabilization of carbon emissions to the 1995 level is extremely costly and requires carbon taxes that increase from $75/tC in the year 2000 to $1,525/tC in the year 2030. The tax rate in 2030 quadruples the refined oil price in Korea. Such high carbon tax rates result in a GNP loss of 6.5 percent from the baseline by the year 2030. Moreover, stabilization of carbon emissions to the 1995 level forces a 50 percent reduction in primary energy consumption and a 40 percent reduction in electricity consumption from the baseline by 2030. Primary energy consumption of coal and oil is substantially curtailed, and there is no electricity generation from coal after the year 2010. The main sources for electricity generation are from natural gas and nuclear power. However, the contribution from nuclear power declines with time since it has been constrained.

Stabilization of carbon emissions to a higher limit enables more energy consumption and lowers the cost of emissions stabilization. Limiting carbon emissions to 1.5 times the 1995 level does not require any carbon taxes until the year 2010. The tax rates necessary to maintain emissions to this limit increase from $50/tC in year 2010 to $500/tC by the year 2030, and the maximum GNP loss from the carbon tax, which occurs in the year 2030, is 2 percent. Stabilization of carbon emissions to 2 times the 1995 level is even less costly and does not require any carbon taxes until the year 2020. By this time, the growth rate in energy consumption is minimal and, therefore, carbon emissions do not increase significantly. A carbon tax of $150/tC was required for stabilization in the year 2030 and there was very little impact on energy consumption and the GNP from this tax. This particular scenario indicates that stabilization of carbon emission in Korea is much more feasible 10 to 20 years from now.

Scenarios with varying world energy price trajectories reveal that carbon tax rates for emissions stabilization are dependent on the end-user price of fossil fuels (world price plus the carbon tax) paid by consumers in Korea. The end-user price, and not solely the carbon tax rate, determines the amount of fossil fuel consumed. In a stabilization scenario, world fossil fuel prices and carbon taxes are inversely related. Lower world fossil fuel prices than those used in the above scenarios would require higher carbon taxes to maintain the end-user price of fossil fuels at a level that discourages its use. Although higher carbon taxes would be necessary for carbon stabilization, lower world fossil fuel prices have a positive impact on the GNP since the fossil fuels are imported at a lower cost.

Chapter 7. Global Tradable Permits

There is wide interest in stabilizing global carbon emissions through a global tradable permits protocol (Welsch 1993; Edmonds et al. 1993; Haughland et al. 1992). In this protocol, many nations participate to limit emissions to a predetermined collective target. Participation in such a protocol by many nations is a more cost-effective method of meeting the combined emissions target than meeting an emissions target on an individual country basis. In this chapter, the cost of Korea's participation in a global tradable permits protocol is investigated and compared to the results of Chapter 6 in which Korea stabilizes its own emissions through carbon taxes.

In a tradable permits protocol, a pool of carbon emissions allowances which totals the combined emissions target is created. Each participating nation is given a share of this pool according to a predetermined allocation scheme and must cover their emissions with these allowances. If a participant's emission is more than the allowed limit, additional allowances, in sufficient amount to cover excess emissions, must be purchased from another participant. Participating nations that emit less than their allowance cannot save their excess allowances for future use, but must sell the excess allowances to other participants that exceed their emissions limit. Such a protocol, if it can be implemented on a wide scale, is a cost-effective method of stabilizing global carbon emissions because it takes advantage of the considerable variations in abatement costs from country to country. Moreover, tradable permits have income redistribution properties and may be desirable as a means to redistribute substantial amounts of income.

One of the major difficulty in the tradable permits protocol is the equity of the emissions allocation scheme. Since current emissions, growth in emissions, and economic impact of emissions abatement varies considerably for individual countries, the choice of allocation scheme can significantly affect the cost of participation in the protocol. Many options for the allocation scheme have been suggested; however, only two simple allocation schemes were investigated in this study. They are:

(1) "Grandfathered Emissions" Allocation: Allowances are allocated based on each country's 1990 carbon emissions.

(2) Equal per Capita Emissions Allocation: Allowances are allocated based on the 1990 global per capita emission.

The tradable permit market is not directly modeled in the Korea module, instead the market is modeled using the economic equivalence of permits and taxes. Carbon emitters are presumed to be indifferent between paying additional costs in the form of a tax or permit fee. The value of the permit is set equal to the tax used to achieve global emissions stabilization. The global permit price trajectory determined by Edmonds, Barns, Wise, and Ton (1992) was used in this analysis (see Table 7.1 for tradable permit prices). A pool of allowances is generated by applying a uniform carbon tax that is equal to the permit price. This carbon tax is applied to Korea and the resulting total emissions are compared to the emissions right. The difference between the two is interpreted as the net purchase or sale of permits.

It is important to note that in the analysis of tradable permits, carbon emissions were stabilized to the global 1990 level, whereas in the previous chapter, carbon emissions were stabilized to Korea's 1995 emissions level. Therefore, the results from the previous chapter should not be directly compared to the results of tradable permits presented here. The resulting costs of the two approaches should, however, reveal the differences in the cost-effectiveness of the two approaches.

Table 7.1 Global Tradable Permit Price

Year	Permit Price ($/tC)
1990	0
1995	13
2000	27
2005	40
2010	60
2015	79
2020	99
2025	120
2030	141

7.1 Tradable Permits with "Grandfathered Emissions" Allocation

As discussed in the reference case, Korea's carbon emission continues to grow rapidly beyond the 1990 level with time. Therefore, under the "Grandfathered Emission" allocation scheme, emissions exceeding the 1990 level, after applying the uniform carbon tax, must be covered by the purchase of allowances. In this scheme, Korea must purchase allowances to cover 18 MtC in 1995 to 116 MtC by 2030. The results of the "Grandfathered Emissions" allocation scheme are given in Table 7.2. The amount of purchase is equivalent to $238 million (1990 $) worth of allowances in 1995 and $16.4 billion worth in 2030. The revenue for the purchase of allowances comes from proceeds of the carbon tax applied. The revenue from the carbon tax is sufficient to cover the purchase of allowances. The total loss to the Korean economy is the cost of the purchased allowance and the GNP loss incurred from the carbon tax. The total loss amounts to $1.2 billion in 1995 and $23.4 billion in 2030. This corresponds to 0.4 % and 1.7 % GNP losses, respectively, in comparison to the reference case GNP level.

Compared to the previous carbon stabilization scenario, in which Korea's emissions were stabilized to the 1995 level through carbon taxes, the tradable permits scheme with the "Grandfathered Emissions" allocation is much less costly. In 2030, the GNP loss for the global tradable permits scheme is nearly four times less than the GNP loss incurred for Korea to stabilize emissions on its own.

Table 7.2 "Grandfathered Emissions" Allocation Scheme

Year	Carbon Emissions (MtC)	Net Buyer of Allowances (MtC)	Net Purchase (1990 $Mil.)	GNP loss (1990 $Mil.)	Total Loss (1990 $Mil.)	GNP Loss (%)
1985	49			$0	$0	0.0%
1990	73			$46	$46	0.0%
1995	90	18	$238	$1,001	$1,239	0.4%
2000	107	34	$919	$1,652	$2,572	0.6%
2005	124	51	$2,040	$2,492	$4,532	0.8%
2010	139	67	$3,972	$4,152	$8,124	1.2%
2015	156	83	$6,613	$5,107	$11,720	1.3%
2020	170	97	$9,590	$5,576	$15,166	1.5%
2025	179	107	$12,805	$6,054	$18,859	1.6%
2030	189	116	$16,405	$7,010	$23,415	1.7%

7.2 Tradable Permits with Equal Per Capita Emissions Allocation

Per capita carbon emissions in Korea also continue to increase rapidly with time. Population growth in Korea declines and population levels plateaus by the year 2020. Nevertheless, the demand for energy and thus, carbon emissions grow faster than the population level resulting in an increasing per capita emissions (see Table 7.3 for per capita emissions level). The 1990 global carbon emissions level was 5.6 GtC, according to the IPCC estimates, and the global population was 5.3 billion in 1990. Therefore, the global per capita carbon emissions was 1.1 tC in 1990. Since the global per capita limit in this allocation scheme is 1.1 tC, even under the Equal per Capita emissions allocation scheme, Korea purchases allowances beginning in 1995 and continues to purchase allowances up to the year 2030. Refer to Table 7.3 for Equal per Capita Emissions allocation scheme results. In 1995, 45 MtC worth of allowances, $603 million, were purchased, and in 2030, 136 MtC worth of allowances, $19.2 billion, were purchased. Adding these amounts to the $1.0 and $7.0 billion GNP losses from carbon taxes for 1995 and 2030, respectively, results in a total loss of $1.6 billion in 1995 and $26.2 billion in 2030. On a percentage basis, this is equivalent to a reduction from the reference case GNP of 0.5% to 1.9 %, respectively.

The cost of the Equal per Capita Emissions allocation is slighter greater than the "Grandfathered Emission" allocation because the per capita limit of 1.1 tC is a more stringent emissions constraint for Korea than the constraint based on the total 1990 emissions level. By 1990, Korea's per capita emissions of 1.7 tC had already exceeded the global per capita level of 1.1 tC. Comparison to the carbon stabilization scenario result in Chapter 6, in which the GNP loss was 6.5 % in the year 2030, again shows that even tradable permits based on an equal per capital allocation is a more cost-effective strategy for stabilizing global carbon emissions.

Table 7.3 Equal Per Capita Emissions Allocation Scheme

Year	Carbon Emissions (MtC)	Carbon Emissions (tC/person)	Net Buyer of Allowances (MtC)	Net Purchase (1990 $Mil.)	GNP Loss (1990 $Mil.)	Total Loss (1990 $Mil.)	GNP Loss (%)
1985	49	1.21	8.61	$0	$0	$0	0.0%
1990	73	1.70	29.79	$0	$46	$46	0.0%
1995	90	2.00	45.22	$603	$1,001	$1,604	0.5%
2000	107	2.25	59.59	$1,589	$1,652	$3,242	0.7%
2005	124	2.50	74.17	$2,967	$2,492	$5,459	1.0%
2010	139	2.73	88.31	$5,269	$4,152	$9,422	1.4%
2015	156	3.01	104.18	$8,265	$5,107	$13,372	1.5%
2020	170	3.24	117.16	$11,599	$5,576	$17,175	1.6%
2025	179	3.40	126.67	$15,200	$6,054	$21,254	1.7%
2030	189	3.58	136.22	$19,207	$7,010	$26,217	1.9%

7.3 Problems with Tradable Permits

Trade in emission rights can be a cost-effective means to control global carbon emissions. However, in order for such a policy to become reality, many difficult issues must be resolved. The success of a tradable permits protocol hinges on the participation of many nations and agreement among participants on the global emissions target, the permit price and the most equitable choice for an emissions allocation scheme.

The most difficult problem is getting the largest emitters such as the Unites States, former USSR, China, Japan, Germany, and India to participate in such a protocol. The cost of participation in the protocol will vary considerably among these countries due to the differences in economic growth, and energy structure and flexibility (Haughland et al. 1992). Therefore, the choice of the allocation scheme is crucial as it would affect the equity of income distribution.

A tradable permits protocol based on the "Grandfathered Emissions" allocation would favor industrialized countries whose emissions are not rising significantly, but would hurt developing countries with rapidly rising emissions. As emissions in developing countries grow, they are likely to transfer income to industrialized countries. The permit scheme based on the Equal per Capita Emissions allocation is considered more equitable. With this allocation, more income is likely to be transferred from industrialized to developing countries. However, this allocation method may not transfer enough wealth to developing nations, raising the cost to developing nations to unacceptable levels and leading to a "dropout" problem.

Even with a more equitable allocation scheme, large monetary transfers from industrialized to developing countries are inevitable. However, it is difficult to believe that industrialized nations, such as the United States, or even transitional economies like Korea would be willing to transfer billions of dollars to developing countries. Moreover, global carbon emissions will continue to increase as developing countries grow and consume more energy. Therefore, the future availability of allowances is in question. Due to these issues, it is difficult to foresee an actual implementation of the global tradable permits protocol.

Chapter 8. The Impact of Advanced Energy Technologies

It was shown earlier that, without any energy technology options, the stabilization of carbon emissions to the 1995 level of 2 tonnes of carbon per capita would require carbon taxes that could reach $1,525 per tonne of carbon. Moreover, such a tax could result in a GNP loss of 6.5 percent from the base case. The cost of emissions reduction was high in the earlier stabilization scenario because energy supply technologies were limited mainly to those that used fossil fuels. In the previous scenario, nuclear power, which does not produce carbon emissions, was constrained and could not contribute to emissions reduction. In addition, the only renewable energy technology available in this scenario was hydropower, and since hydro resources are limited in Korea, it does not make a significant contribution to energy production.

In the following analysis, however, the impact of advanced energy supply technologies on the cost of carbon emissions stabilization is examined. The additional technologies incorporated into the model are alcohol fuels from biomass, solar-photovoltaics, and more efficient technologies for conversion of natural gas and coal to electric power. In addition, the earlier constraint on nuclear power is lifted.

In addition to the energy supply technologies described above, end-use energy efficiency improvements can help to reduce energy demand and carbon emissions. However, specific end-use technologies are difficult to investigate with the current model of Korea because it does not have sufficient detail of the energy consuming sectors, particularly the household sector. Therefore, increases in end-use efficiency were determined exogenously to investigate the benefit of efficiency improvements on the reduction of carbon emissions. This analysis is carried out in Section 9.9.

A base case which incorporates the additional energy supply technologies is constructed for comparison to the reference case and to provide a basis for analyzing the impact of carbon emissions stabilization with these energy technologies. From here on, this base case will be referred to as the advanced technology case. Carbon emissions, GNP, primary energy consumption, and electricity generation projections for the advanced technology case are presented below.

8.1 Energy Technology Assumptions

Nuclear, coal and natural gas power plants are well proven technologies and will surely play a large role in Korea's electric power industry. Currently, the official government plans for power plant construction to the year 2006 call for large increases in the construction of nuclear, coal, and natural gas power plants (KEEI 1994). Although a massive program in nuclear power may be difficult to maintain, the constraint on nuclear power was lifted in this scenario. Moreover, advanced coal and natural gas power technologies for electricity generation were included in the model. In addition to these technologies, solar-photovoltaic technology for electricity generation and biomass derived liquid fuels for petroleum substitution were included in this analysis as these energy resources are renewable and can be utilized with little or no accumulation of carbon emissions. Refer to Table 8.1 for a summary of the energy technology options.

In the reference case, nuclear power was constrained after the year 2005. In this analysis, the constraint on nuclear power is lifted and additional construction of nuclear power plants is allowed after this time. Although a technical change parameter or autonomous energy efficiency improvement parameter of 0.6 percent per year is applied, nuclear power plants throughout the modeled time period are assumed to be of the same type as those that exist in Korea today, namely light water reactors. Because of low construction, operation and maintenance costs along with good operating performance, and the ability to independently design, build and operate nuclear power plants, the nuclear power program in Korea is one of the most economically successful in the world (Park 1992). For this reason, it is possible that nuclear power could continue to play a strong role in Korea's energy future beyond the year 2005.

Other than nuclear power, major investments in electricity generation are currently occurring in coal and natural gas power plants. Therefore, it was necessary to incorporate advanced coal and natural gas-fired power plants with significantly higher efficiencies, such as the fluidized bed combustion and natural gas combined cycled plants, into the Korea module of the SGM. These technologies and their improved efficiencies were represented in the model by raising the neutral technical change parameters for the coal and natural gas electricity subsectors from 0.6 to 1.2 percent per year. These changes increase the electricity generation efficiency of coal-fired thermal plants from 34 percent in 1985 to 49 percent by 2030 and natural gas-fired plants from 37 percent in 1990 to 58 percent by 2030. Refer to Table 8.2 for all technical change parameters, and Table 8.3 for electricity generation efficiencies for coal and natural gas power plants. Current pressurized fluidized bed combustion technologies using coal and combined cycle combustion turbine technologies using natural gas have efficiencies of 40 and 45 percent, respectively (US DOE 1991).

For the renewable energy option, only the option for solar-photovoltaic technology was introduced into the model because it is the largest potential renewable energy source in Korea. Other renewable energy technologies, such as wind, biomass and tidal power, are not likely to play a significant role in Korea's energy future because their total potential recoverable energy is small (Boo 1991). Solar energy has a proven potential of 2,800 MTOE per year; however, the recoverable potential amounts to 10 MTOE per year (Boo 1991). The proven potential for wind, biomass and tidal power are only 3, 5 and 4 MTOE per year, respectively, while recoverable potentials are even smaller. In the Korea module of the SGM, solar-photovoltaic technology was introduced as an additional subsector in the electric power sector. Current characteristics and cost data for photovoltaic technology were used to generate new production function coefficients to incorporate this technology into the model. According to the US DOE (1991), the current cost of photovoltaic technology is $0.27 per KWh based on a capital cost of $3,620 per KW and cell efficiency of 12 percent. The photovoltaic technology characteristics and cost are shown in Table 8.4.

A final energy option, importation of biomass derived liquid fuels (ethanol or methanol), is allowed at the current cost of production as a backstop technology. The model assumes that biomass derived alcohol can be directly substituted for refined oil, and that costs for equipment modification for their use are negligible. Moreover, the model assumes that combustion of alcohol derived from biomass results in zero net emission of carbon. Although carbon dioxide emitted during combustion is reabsorbed when biomass is grown sustainably, some fossil fuel will be required for processing and transportation of biomass fuels, and therefore, the net emission of carbon dioxide will be slightly greater than zero. According to Bull et al. (1993), the fossil fuel required for alcohol production is minimal, and the use of alcohol as fuel will result in only 4 to 9 percent of the carbon dioxide emitted from gasoline. These emissions were, however, ignored in the analysis presented here. In the model, unlimited imports of biomass derived alcohol are allowed at a predetermined price that is fixed throughout the modeled time period. According to Wyman et al., methanol or ethanol derived from biomass is available today at a price of US$15 per GJ or less (Johansson 1993). This is equivalent to $0.315 per liter of alcohol using an energy conversion factor of 21 MJ per liter for anhydrous alcohol. At this price, the cost of alcohol from biomass is 50 percent greater, on a per volume basis, than the cost of gasoline at $0.21 per liter derived from crude oil at $25 per barrel. Alcohol derived from biomass will be competitive with gasoline, on a per volume basis, when the crude oil price reaches $37 per barrel. At this price, alcohol will be imported instead of crude oil in the model. On a per volume basis, refined petroleum such as gasoline contains approximately 50 percent more energy than alcohol; however, the characteristics of alcohol, such as a high octane number and low flammability in air, make alcohol an excellent motor fuel.

Table 8.1 Technology Assumptions

1) Nuclear Power	Unlimited construction of light-water reactors
2) Advanced Natural Gas Combustion for Electric Power	58 % efficiency by the year 2030
3) Advanced Coal Combustion for Electric Power	49 % efficiency by the year 2030
4) Solar-Photovoltaics	Available at $0.27/KWh
5) Liquid Fuels from Biomass (Ethanol or Methanol)	Available at $0.315/liter ($15/GJ)

Table 8.2 Technical Change Parameters

Sector/Subsector	Technical Change (%/year)
1) Agriculture	0.6
2) ETE	1.0
3) Crude Oil	--
4) Natural Gas	--
5) Coal	0.6
6) Biomass	--
7) Uranium	--
8) Electricity	
Oil	0.6
Gas	1.2
Coal	1.2
Biomass	--
Nuclear	0.6
Hydro	0.6
Solar	1.2
9) Refined Oil	0.6
10) Gas T&D	0.6

Table 8.3 Efficiencies of Natural Gas and Coal Power Plants

Year	Natural Gas	Coal
1985		34%
1990	37%	36%
1995	39%	39%
2000	41%	40%
2005	43%	40%
2010	46%	40%
2015	48%	41%
2020	51%	43%
2025	54%	46%
2030	58%	49%

Table 8.4 Costs Estimates for Solar-Photovoltaics

Capital cost ($/kW)	3,620
O & M cost (mills/kWh)	2
Land requirement (W/m2)	1,000
Cell efficiency	12 %
Lifetime (years)	20
Electricity cost ($/kWh)	0.27

Source: US DOE 1991.

8.2 Carbon Emissions

In the advanced technology case, carbon emissions rise from the 1985 level of 49 MtC to 212 MtC in 2025, and decrease to 202 MtC in 2030 (see Figure 8.1 for carbon emissions projections). The emissions level drops from 2025 to 2030 because alcohol derived from biomass are competitive with petroleum after 2025, and substitution of petroleum for alcohol occurs at this time. Refer to Table 8.5 for carbon emissions level by source and the growth rate of total carbon emissions.

The major source of carbon emissions throughout the modeled time period comes from the combustion of petroleum, with coal combustion being the next major source of carbon emissions. In 2030, the shares of carbon emissions from the combustion of petroleum, coal and natural gas were 50, 38 and 8 percent of the total emissions, respectively.

The projected carbon emissions in the advanced technology case are not markedly less than in the reference case. Only in the last 10 years of the modeled time period are there any significant reductions in carbon emissions from these technologies. In 2025 and 2030 of the advanced technology case, the total carbon emissions are 1.4 and 12 percent lower, respectively, than the levels in the reference case. Substitution of alcohol for petroleum, increased energy from nuclear power, and decreased consumption of natural gas are the reasons for the reduction in carbon emissions from 2025 to 2030.

Figure 8.1 Carbon Emissions: Advanced Technology Case

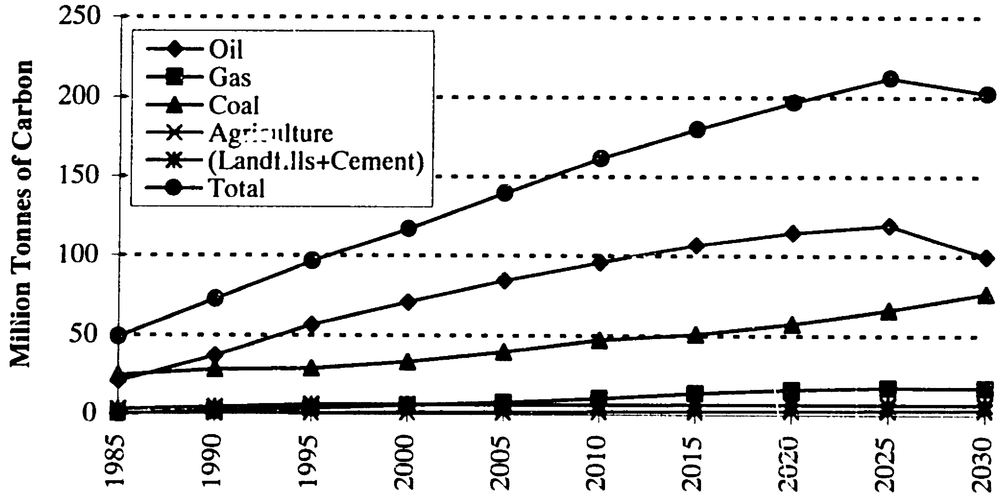


Table 8.5 Total Carbon Emissions (MtC): Advanced Technology Case

Year	Oil	Gas	Coal	Agriculture	(Landfills & Cement)	Total	Growth Rate
1985	21	0	25	1	3	49	
1990	37	2	29	1	4	73	8.2%
1995	57	4	29	1	6	97	5.9%
2000	71	6	34	1	6	117	3.9%
2005	84	8	40	2	6	139	3.6%
2010	96	10	47	2	6	161	3.0%
2015	107	14	51	2	6	180	2.2%
2020	115	16	57	2	6	197	1.8%
2025	120	17	66	3	6	212	1.5%
2030	100	17	76	3	6	202	-0.9%

8.3 GNP Levels

The GNP projection in the advanced technology case starts at 78 trillion Won ($143 billion 1990 US) in 1985 and grows to 742 trillion Won ($1,366 billion 1990 US) by 2030. Refer to Figure 8.2 and Table 8.6 for GNP projections and growth rates. The growth rate in the GNP is high in the early part of modeling time period, but slows down quickly after the year 2000. The annual growth rates in the GNP fall below 6 percent per year after the year 2000. By 2030, the annual growth rate in GNP is only slightly above 2 percent per year. The introduction of the energy technologies slightly increases the GNP levels from the reference case in the years from 2015 to 2030. The GNP levels in the advanced technology case are higher than in the reference case by 0.1, 0.2, 0.4, and 0.7 percent in 2015, 2020, 2025, and 2030, respectively.

Figure 8.2 GNP Projections (Real): Advanced Technology Case

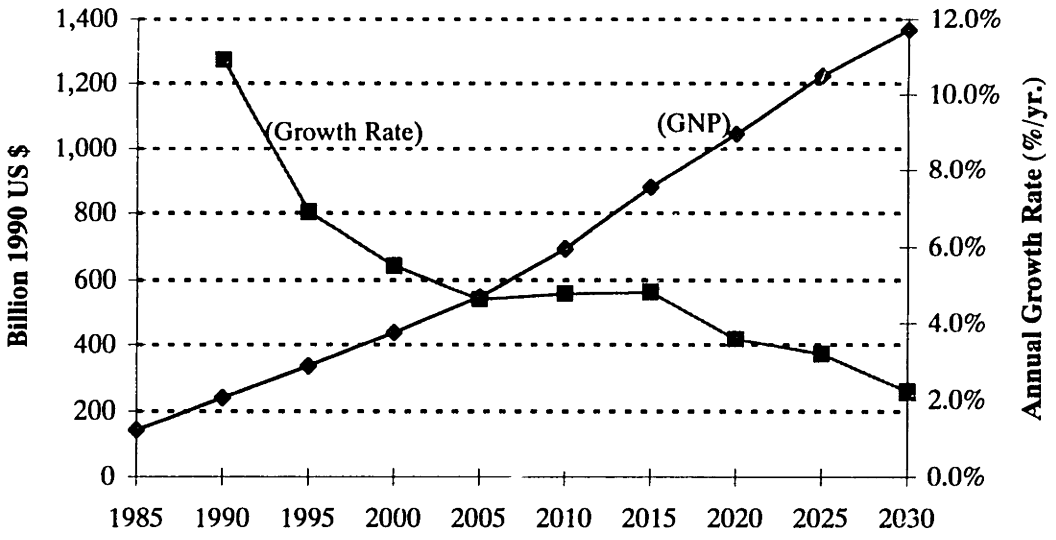


Table 8.6 GNP Projections and Growth Rates: Advanced Technology Case

Year	GNP (Billion 1985 Won)	GNP (Billion 1990 US$)	Growth Rate
1985	78,112	143	
1990	131,078	240	10.9%
1995	182,736	335	6.9%
2000	238,926	438	5.5%
2005	299,740	549	4.6%
2010	378,622	693	4.8%
2015	479,240	878	4.8%
2020	571,246	1,046	3.6%
2025	668,215	1,224	3.2%
2030	745,777	1,366	2.2%

8.4 Primary Energy Consumption

The total primary energy consumption, which was at 54 MTOE in 1985, grows to 301 MTOE by 2030 in the advanced technology case. The growth rate in primary energy consumption is 11 percent per year from 1985 to 1990 and slows down gradually to 1 percent per year from 2025 to 2030. Refer to Figure 8.3 for primary energy consumption projections and Table 8.7 for energy consumption by fuel type and growth rates of total consumption.

The major sources of primary energy throughout the modeled time period are petroleum, coal and nuclear power. In 1985, the primary energy consumption of petroleum, coal and nuclear power was 27, 22 and 4 MTOE, respectively. On a percentage basis, petroleum, coal and nuclear power comprised 50, 41 and 7 percent of the total primary energy consumption in 1985. By 2030, primary energy consumption of petroleum, coal and nuclear power increases to 130, 68 and 39 MTOE, respectively, which comprises 43, 23 and 13 percent of the total primary energy consumption, respectively, on a percentage basis. Throughout this time span, the shares of primary energy from petroleum and coal fall by 7 and 18 percent, respectively, while that from nuclear power increases by 6 percent. Although these three energy sources are still the major sources of primary energy, an increase in energy consumption from natural gas and biomass derived alcohol occurs towards end of the modeling period. The total contribution of natural gas and all renewable energy to primary energy consumption was 2 percent in 1985. By 2030, their total contribution increases to 21 percent.

With the constraint on nuclear power lifted, primary energy consumption from nuclear power increases as well. Energy consumption from nuclear power reaches a maximum of 41 MTOE in 2025, and drops slightly to 39 MTOE in 2030 due to the retirement of older power plants. (The assumed lifetime for nuclear power plants are 40 years.) This is a significant increase in energy consumption from nuclear power than in the reference case. In 2030, two times more energy is generated from nuclear power when the constraint is lifted. Refer to the section below on electricity generation for greater detail on nuclear power.

In addition to changes in nuclear power, increases in the technical change parameters for coal and natural gas-fired power plants affect primary energy consumption levels of coal and natural gas. In comparison to the reference case, the consumption of coal in the advanced technology case increases in the last 15 years of the model, whereas, the consumption of natural gas decreases within the same time period. For instance, in 2030, coal consumption increases from 60 to 68 MTOE, whereas, natural gas consumption decreases from 44 to 32 MTOE. Advanced coal power plants are more attractive than advanced natural gas power plants as natural gas prices rise faster than coal prices towards the end of the modeled time period. See section on electricity generation for changes in electricity generation from coal and natural gas.

Primary energy consumption from biomass derived alcohol increases dramatically in the last period of the model. After 2025, the price of crude oil rises to a level that enables alcohol to be competitive with gasoline, and therefore, 30 MTOE of alcohol is consumed in place of oil in 2030. Other renewable energy sources, such as energy from hydropower, contribute only minimally to the total primary energy consumption and do not exceed 2 MTOE throughout the modeling period. Furthermore, due to the high cost of photovoltaic technology, photovoltaic energy does not make any contribution to primary energy consumption. See section on electricity generation for more detail on photovoltaic energy.

Comparison of total primary energy consumption levels between the advanced technology case and the reference case reveals that slightly more energy is consumed with the additional energy options. By 2030, 8 MTOE or 2.7 percent more primary energy is consumed in the advanced technology case than in the reference case. This increase arises from a higher consumption of nuclear power, coal and alcohol as discussed above.

Figure 8.3 Primary Energy Consumption: Advanced Technology Case

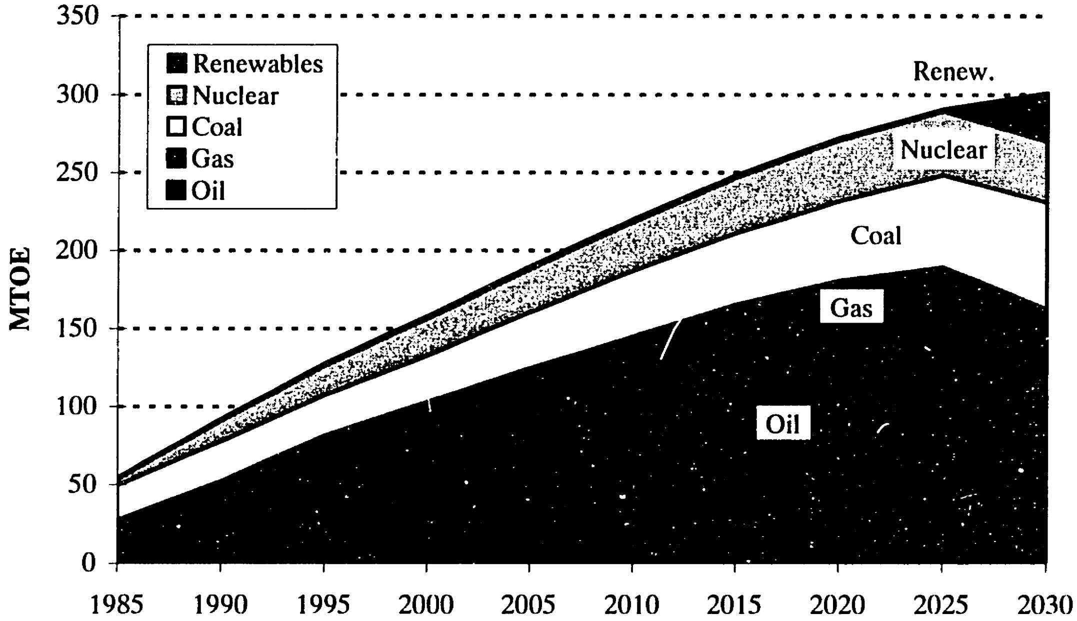


Table 8.7 Primary Energy Consumption (MTOE): Advanced Technology Case

Year	Oil	Gas	Coal	Nuclear	Renewable	Total	Growth Rate
1985	27	0	22	4	1	54	
1990	49	3	25	14	1	92	11.1%
1995	74	7	26	19	2	128	6.8%
2000	92	11	30	23	2	158	4.3%
2005	110	15	35	28	2	190	3.7%
2010	125	19	42	32	2	220	3.0%
2015	140	26	45	36	2	248	2.4%
2020	150	30	51	39	2	272	1.9%
2025	156	33	59	41	1	291	1.3%
2030	130	32	68	39	32	301	0.7%

8.5 Electricity Generation

Electricity generation in the advanced technology case increases to 724 TWh by 2030 from the 1985 level of 57 TWh. This is a 13-fold increase in electricity generation in the advanced technology case (see Figure 8.4 for electricity generation projections). The growth rate in electricity generation is over 10 percent per year from 1985 to 1990 and slows down gradually to 3 percent per year from 2025 to 2030.

The largest sources of electricity generation are from coal combustion and nuclear power. Although nuclear power dominates electricity production up to the year 2005, coal power plants replace nuclear power as the dominant source of electricity after this time. By 2030, 440 TWh or 60 percent of the total electricity generation is from coal combustion. Refer to Table 8.8 for generation levels by source. The increase in the technical change parameter for coal-electricity improves the efficiency and the overall profitability of coal power plants. Nuclear power's contribution to electricity generation is 184 TWh or 25 percent of the total in 2030. The amount of electricity generated from nuclear power in 2030 would require 28 reactors with 1000 MWe capacity and an annual load of 75 percent. With the constraint on nuclear power lifted, electricity generation from nuclear power in 2030 is 51 percent greater than the level in 2005.

The remaining share of electricity generation comes from natural gas, oil and hydroelectricity. Of these three sources, natural gas is the largest source of electricity, followed by oil and hydroelectricity. In 2030, electricity generated from natural gas, oil and hydroelectricity are 91, 5, and 3 TWh, respectively, which combine to make up 15 percent of the total electricity generated. Electricity generation from natural gas actually declines after 2025, as electricity generation from coal combustion becomes a cheaper source of electricity. Contribution of electricity from oil combustion declines substantially with time as oil prices continue to rise, and the contribution of electricity from hydropower remains relatively steady throughout the modeling time period.

Photovoltaic cells do not contribution to electricity generation throughout the modeled time period. Under the technology cost assumptions used in this model, electricity from photovoltaic technology is too expensive to compete with other sources of electricity. Although the real electricity price rises with time, it does not reach a high enough level to allow photovoltaic technology to enter the market at the assumed cost. Electricity from photovoltaic technology for remote use may already be competitive with other sources of electricity, however, such use of photovoltaic technology is not included in the model. For photovoltaic technology to be competitive as a centralized source of electricity, the price of electricity from photovoltaic technology must fall below $0.08 per KWh.

Comparison of electricity generation levels in the advanced technology case to the reference case reveals that greater amounts of electricity are generated with the additional energy technologies included in the model. With these technologies, electricity generation levels between the two cases begin to deviate soon after 1995. By 2030, 159 TWh or 28 percent more electricity is generated in the advanced technology case than in the reference case. The increase in the technical change parameter for coal power plants and the removal of the constraint on nuclear power results in an overall increase in electricity generation.

Figure 8.4 Electricity Generation Projection: Advanced Technology Case

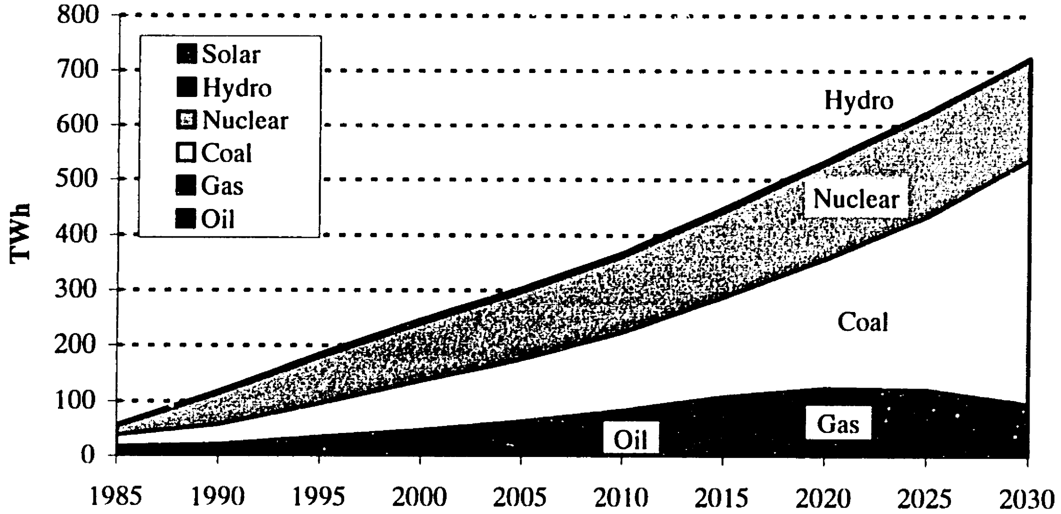


Table 8.8 Electricity Generation (TWh) and Growth Rates: Advanced Technology Case

Year	Oil	Gas	Coal	Nuclear	Hydro	Solar	Total	Growth Rate
1985	18	-	20	16	3	-	57	
1990	12	9	36	57	4	-	118	15.9%
1995	11	23	61	84	6	-	185	9.3%
2000	12	35	90	103	6	-	247	5.9%
2005	14	49	112	122	6	-	304	4.3%
2010	15	68	140	139	6	-	369	3.9%
2015	14	94	179	156	6	-	450	4.0%
2020	14	111	233	172	6	-	536	3.6%
2025	10	112	312	187	5	-	626	3.2%
2030	5	91	440	184	3	-	724	3.0%

Chapter 9. Carbon Emissions Stabilization with Advanced Energy Technologies

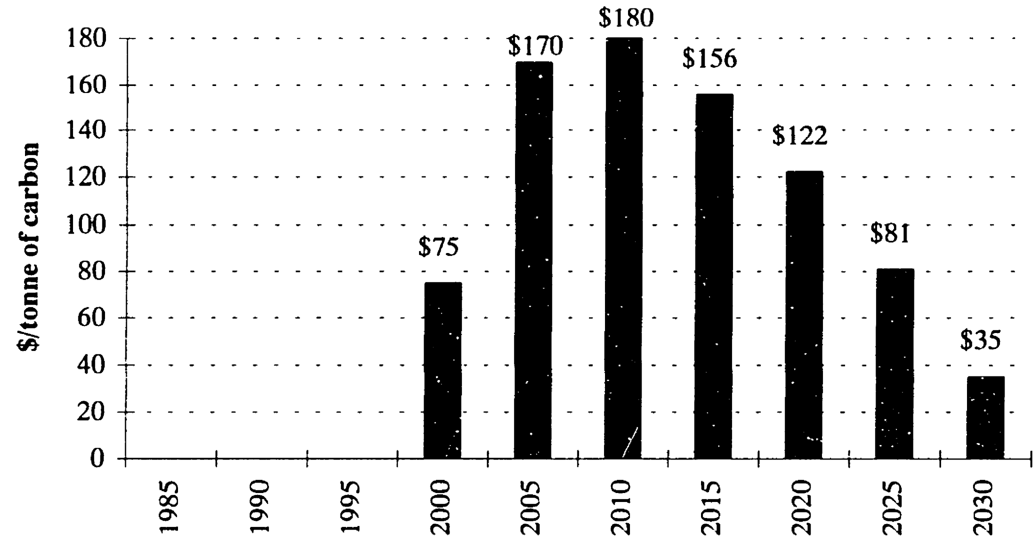
The impact of the advanced energy technologies in reducing the cost of carbon emissions stabilization is analyzed below. With advanced energy technologies in place, carbon taxes were, once again, applied to crude oil, natural gas, and coal to stabilize carbon emissions to the 1995 level of 96 MtC (2 tonnes per capita). The carbon taxes required for stabilization and the changes in primary energy consumption, electricity generation and GNP levels are assessed. Fuel substitution, encouraged by the implementation of the additional technologies are also quantified.

Earlier in Chapter 6, the uncertainty of world energy prices under a global carbon stabilization was addressed. The same concerns exist in the carbon stabilization scenario with additional energy technologies. However, the introduction of alcohol fuels that can be a substitute for refined petroleum brings about an additional uncertainty in energy prices. In the following analysis, crude oil, LNG, coal, and uranium prices are assumed to grow at the rates stated in Chapter 4, and the price of alcohol is assumed fixed. Nevertheless, in a scenario of global carbon stabilization through carbon taxes, the demand for biomass derived alcohol fuels could rise rapidly as they are substituted for petroleum. Such a scenario, which is likely to result in rising biomass and alcohol prices, is addressed separately in Section 9.8.

9.1 Carbon Tax Levels

Stabilization of carbon emissions to the 1995 level with the advanced technologies required much lower carbon taxes than in the stabilization of carbon emissions in the reference case. With the energy technologies, the carbon tax required for emissions stabilization starts at \$75/tC in 2000, reaches a maximum of \$180/tC in 2010, and declines steadily to \$35/tC by 2030. The tax trajectory is shown in Figure 9.1. Carbon taxes reach a maximum of \$180/tC because at this rate, the price of crude oil is high enough to allow importation of biomass derived alcohol. Moreover, since crude oil prices continue to rise at a rate of 2.6 percent per year, carbon taxes necessary to enable continued importation of alcohol decrease with time. In addition to biomass derived alcohol, greater consumption of imported natural gas (LNG) and increased electricity generation from nuclear power contribute to reductions in the carbon tax rates after the year 2010.

Figure 9.1 Carbon Taxes for Carbon Emissions Stabilization with Advanced Energy Technologies



9.2 Fuel Prices

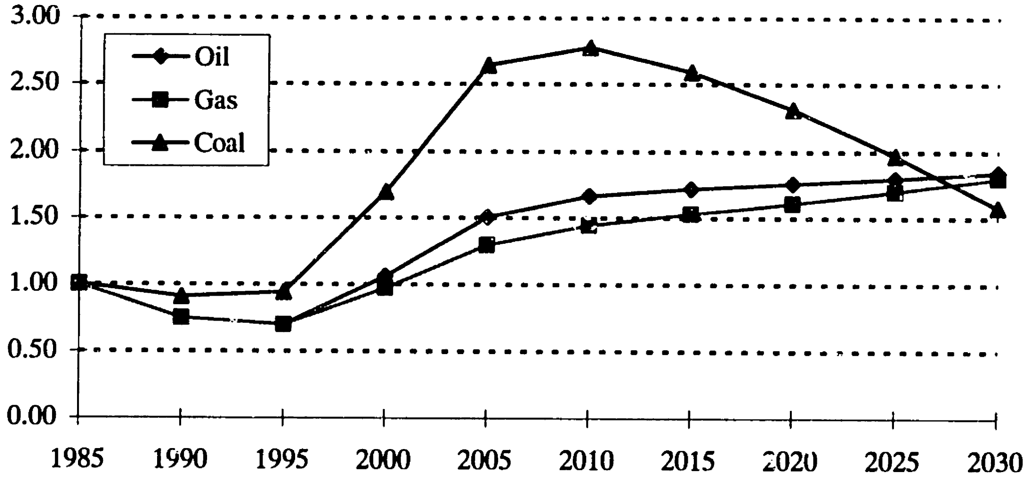
Carbon taxes directly affect the price of crude oil, natural gas (LNG) and coal, and the prices of these fuels are raised abruptly when carbon taxes are introduced. The maximum carbon tax of $180/tC, applied in the year 2010, increases the price of crude oil, natural gas and coal over the 1985 base year prices by 63, 42 and 171 percent, respectively. At this tax rate, the price of crude oil is $44 per barrel (based on an 1985 crude oil price of $27 per barrel), which is high enough to enable substitution of crude oil for biomass derived alcohol to occur. Since tax rates fall after 2010, the relative increase in fossil fuel prices from carbon taxes declines after this time. In 2030, the tax of $35/tC raises the price of crude oil, LNG and coal by 12, 8 and 33 percent, respectively, over the 1985 base year prices for these fuels. Refer to Table 9.1 for percentage increases in fossil fuel prices relative to 1985 prices from carbon taxes.

The greater impact of carbon taxes on coal prices, owing to the higher carbon content of coal, is evident from Figure 9.2. The overall price of coal, which includes the 0.8 percent per year assumed growth and the increase from carbon taxes, is dominated by the carbon tax. The price of coal reaches a maximum when the carbon tax reaches a maximum and declines as the carbon tax declines. On the other hand, crude oil and LNG prices are not as strongly affected by carbon taxes. Although carbon taxes raise the price of crude oil and LNG, the 2.6 percent per year assumed growth in prices strongly affects the overall prices for these fuels. Even though taxes fall after 2010, the price of crude oil and LNG continues to rise until the end of the modeled time period.

Table 9.1 Increases in Fossil Fuel Prices from Carbon Taxes (Relative to 1985 Prices)

Year	Carbon Tax ($/tC)	Crude Oil (%)	LNG (%)	Coal (%)
1985	--	--	--	--
1990	--	--	--	--
1995	--	--	--	--
2000	75	26	17	71
2005	170	60	39	162
2010	180	63	42	171
2015	156	55	36	149
2020	122	43	28	116
2025	81	29	19	77
2030	35	12	08	33

Figure 9.2 Crude Oil, LNG and Coal Prices in the Stabilization Case (Relative to 1985)



9.3 Carbon Emissions Reduction

Carbon emissions from the stabilization case and the advanced technology case are plotted together in Figure 9.3 to show the amount of carbon emissions reduction necessary for stabilization. Substantial reductions in emissions are required with time; approximately 200 million tonnes of carbon are forgone from 2020 to 2030. This reduction in emissions was achieved mainly through the limitation of petroleum use. For instance, carbon emissions from petroleum use fell from 100 MtC in the advanced technology case to 13 MtC in the stabilization case by 2030. In the same year, emissions from coal combustion dropped from 76 MtC in the advanced technology case to 51 MtC in the stabilization case, whereas emissions from natural gas combustion increased from 17 MtC to 23 MtC. Refer to Table 9.2 for carbon emissions levels by source. With biomass derived alcohol replacing petroleum as fuel, substantial amounts of carbon emissions from petroleum are avoided.

Figure 9.3 Carbon Emissions: Advanced Technology and Stabilization Cases

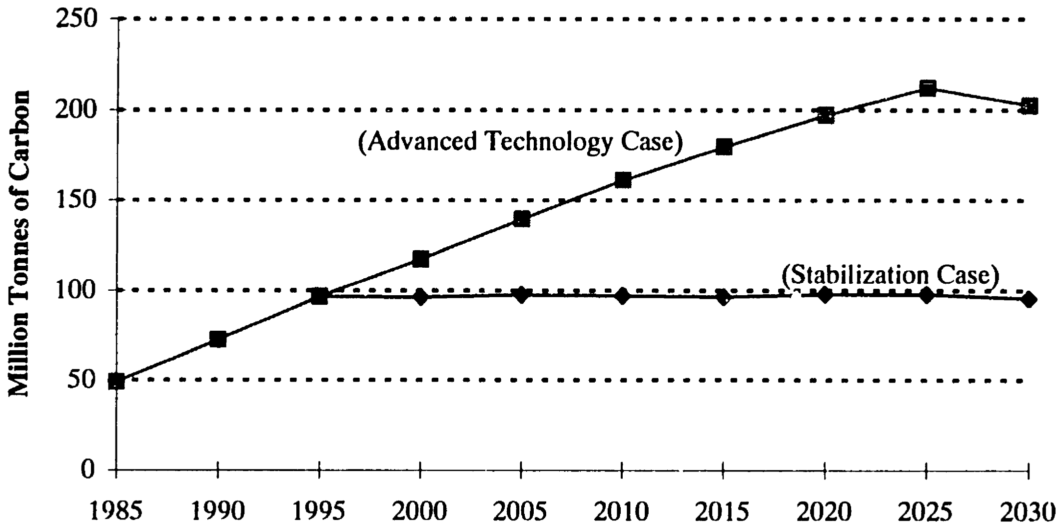


Table 9.2 Total Carbon Emissions with Advanced Energy Technologies (MtC): Stabilization Case

Year	Oil	Gas	Coal	Agriculture	(Landfills & Cement)	Total
1985	21	0	25	1	3	49
1990	37	2	29	1	4	73
1995	57	4	29	1	6	97
2000	60	6	24	1	6	96
2005	62	9	19	1	6	97
2010	57	12	20	2	6	97
2015	48	16	25	2	6	96
2020	40	19	31	2	6	98
2025	29	21	39	3	6	98
2030	13	23	51	3	6	96

9.4 Primary Energy Consumption

Comparison of total primary energy consumption levels from the stabilization case and the advanced technology case shows that stabilization of carbon emissions can be achieved without a significant reduction in the consumption of primary energy, if technology options for emissions reduction are provided. With the availability of biomass derived alcohol, nuclear power and more efficient natural gas and coal power plants, differences in primary energy consumption between the stabilization and advanced technology cases are minimized. As shown in Figure 9.4, the largest reduction in primary energy consumption of 22 percent occurs in the year 2010. After this time, increased use of alcohol fuels, LNG and nuclear power raises the level of primary energy consumption in the stabilization case to the level of consumption in the advanced technology case. Primary energy consumption levels in both cases are approximately 300 MTOE by 2030.

Although the total primary energy consumption levels in the stabilization and advanced technology cases are similar, the mix of energy sources in the two cases is very different. In the stabilization case, carbon taxes reduce the consumption of petroleum and coal, while increasing the consumption of natural gas, nuclear power and biomass derived alcohol. This substitution ensures that the total primary energy consumption levels do not fall significantly from the advanced technology case. With carbon taxes, there is significant substitution of petroleum for alcohol after the year 2005. As shown in Figure 9.5, the consumption of petroleum reaches a maximum in 2005 at 81 MTOE and falls, thereafter, to 17 MTOE by 2030. After 2005, large quantities of alcohol are substituted for petroleum. Petroleum consumption in 2005 and 2030 is 26 and 87 percent lower, respectively, than in the advanced technology case. In addition to reductions in petroleum consumption, coal consumption also falls below the levels in the advanced technology case. Coal consumption levels are directly related to the carbon tax rates, falling the most when carbon taxes are the highest and increasing again as carbon taxes are lowered. In 2010, when the carbon tax is at its peak, coal consumption is 57 percent lower than in the advanced technology case, but in 2030, when the carbon tax falls to a minimum, coal consumption is only 34 percent lower than in the advanced technology case.

Decreased consumption of petroleum and coal are compensated by increased consumption of natural gas, nuclear power and biomass derived alcohol. Since the carbon content of crude oil and coal is higher than that of natural gas, carbon taxes make natural gas (LNG) more competitive in price relative to crude oil and coal. Therefore, consumption of natural gas increases as carbon taxes are imposed. Natural gas consumption levels in the stabilization case are higher than the levels in the advanced technology case by 3 percent in 2000 and 33 percent in 2030. Nuclear energy is also favored over coal and petroleum for electricity generation when carbon taxes are imposed. With carbon taxes, energy from nuclear power increases by an additional 28 percent over the baseline level by 2030. For greater detail on electricity generation from nuclear power, refer to the section below on electricity generation. The most significant change in primary energy consumption comes from the consumption of alcohol fuels (see Table 9.3 for primary energy consumption levels by fuel source). From the year 2010, large quantities of alcohol fuels are imported as a petroleum substitute. In 2010, 20 MTOE of alcohol is consumed, and by 2030, alcohol consumption expands to 140 MTOE.

An international market in alcohol fuels derived from biomass does not currently exist. However, long experiences with alcohol fuel production in Brazil and the United States indicate that large quantities of alcohol fuels can be available if crude oil prices are sufficiently high. According to Goldemberg et al. (1993), 12 billion liters of ethanol was produced in Brazil in 1989 from sugarcane, grown on 2.3 million hectares of land. This translates to 5.2 billion liters of ethanol per million hectares. In the United States, 395 billion liters of ethanol can be produced from 77 million hectares of land (Wyman et al. 1993). To meet Korea's alcohol demand of 140 MTOE or 280 billion liters in the year 2030 would require approximately 50 million hectares of land for energy crop production. This amount of land is equivalent to five times the area of South Korea. Such large land requirements indicate that the level of alcohol fuel consumption in the above scenario may not be feasible.

Figure 9.4 Primary Energy Consumption: Advanced Technology and Stabilization Cases

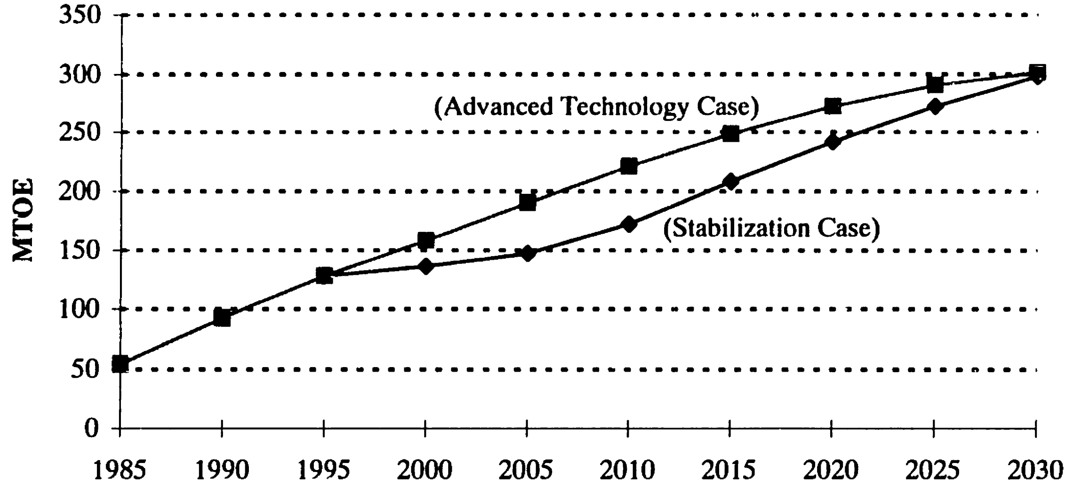


Figure 9.5 Primary Energy Consumption with Advanced Energy Technologies: Stabilization to 1995

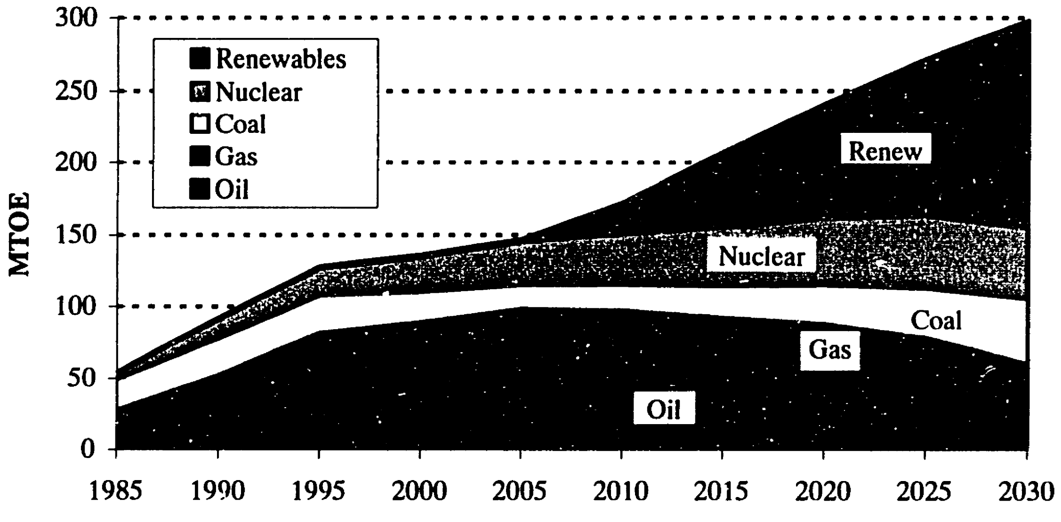


Table 9.3 Primary Energy Consumption with Advanced Energy Technologies (MTOE): Stabilization Case

Year	Oil	Gas	Coal	Nuclear	Renewables	Total	Growth Rate
1985	27	0	22	4	1	54	
1990	49	3	25	14	1	92	11.1%
1995	74	7	26	19	2	128	6.8%
2000	78	11	21	24	2	136	1.2%
2005	81	17	17	30	2	147	1.5%
2010	75	23	18	35	22	172	3.2%
2015	62	30	22	41	52	208	3.8%
2020	52	36	27	47	80	241	3.1%
2025	38	40	34	51	109	272	2.4%
2030	17	43	45	50	143	298	1.8%

9.5 Electricity Generation

As carbon taxes are imposed to stabilize emissions in the advanced technology case, electricity generation levels fall below the levels in the baseline scenario. In general, electricity generation levels in the stabilization case are 10 to 20 percent lower than in the advanced technology case when taxes are imposed. The electricity generation levels from the two cases are shown in Figure 9.6. In the stabilization scenario, the electricity generation level grows from the 1985 level of 57 TWh to 636 TWh by 2030.

Significant changes occur in the mix of electricity generation with the introduction of carbon taxes in the advanced technology case. Namely, electricity output from coal-fired power plants are substantially reduced as carbon taxes are introduced and are replaced by large increases in electricity output from nuclear and natural gas-fired power plants. Although the efficiency of coal power plants was improved through the neutral technical change parameter, carbon taxes and their large impact on coal prices discourage the use of coal for power generation. Electricity generation from coal combustion are lower than the baseline scenario by as much as 78 percent. As evident from Figure 9.7, output of electricity generation from coal coincides with the tax rate. The lowest output occurs in 2010 when the tax rate is the highest, and after 2010, electricity generation from coal increases as tax rates fall. By the 2030, electricity generation from coal amounts to 209 TWh, which is 52 percent lower than the level in the advanced technology case.

While electricity generation from coal decreases, the increased efficiency of the natural gas power plants, in conjunction with carbon taxes, raise the output of electricity generation from natural gas. Twice as more electricity is generated from natural gas in the stabilization case, than in the advanced technology case by the end of the modeled time period. In 2030, 182 TWh of electricity is generated by natural gas, which comprises 30 percent of the total electricity generated.

In addition to the increase in electricity generation from natural gas, electricity generation from nuclear power plays a larger role in stabilizing carbon emissions. Since carbon taxes make nuclear power more attractive over fossil fuel plants, electricity generation from nuclear power increases as carbon taxes are applied. By 2030, an additional 26 percent more electricity is generated from nuclear power compared to the baseline scenario. The electricity generated from nuclear power, as shown in Figure 9.7, is 233 TWh in 2030. If each nuclear reactor has a capacity of 1,000 MWe and an annual load of 75 percent, 35 nuclear reactors would be required by 2030.

Even with carbon taxes, large scale power generation from solar-photovoltaics is not competitive with other sources of electricity generation. The cost assumption of $0.27/kWh is much higher than the cost of electricity generation from other sources throughout the modeled time period. Consequently, there is no electricity generated from photovoltaics. When carbon taxes are imposed, electricity prices do not rise significantly because nuclear and natural gas power plants are substituted for coal power plants. Therefore, the price of electricity from photovoltaic technology must be competitive with the price of electricity from nuclear power and natural gas power plants for photovoltaic technology to enter the market.

Figure 9.6 Electricity Generation: Advanced Technology and Stabilization Cases

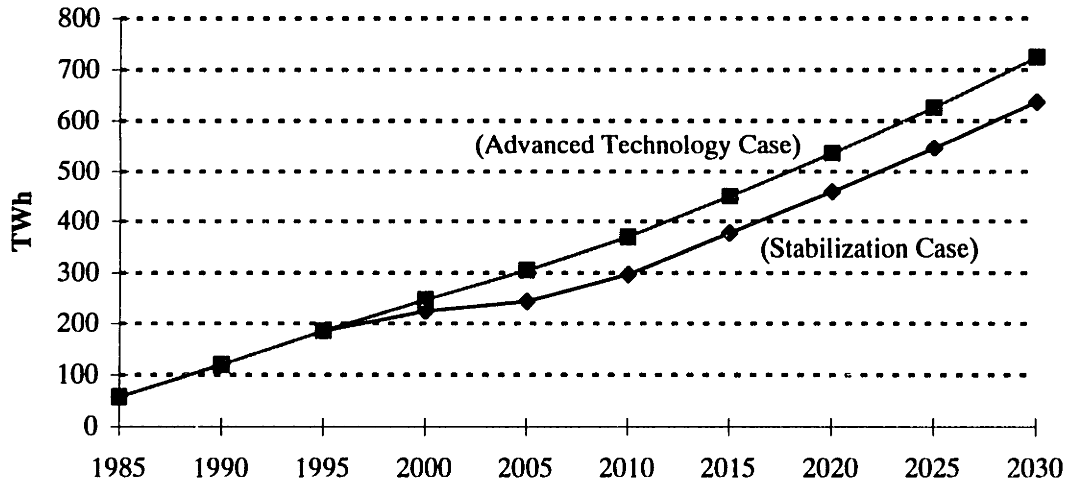


Figure 9.7 Electricity Generation with Advanced Energy Technologies: Stabilization to 1995

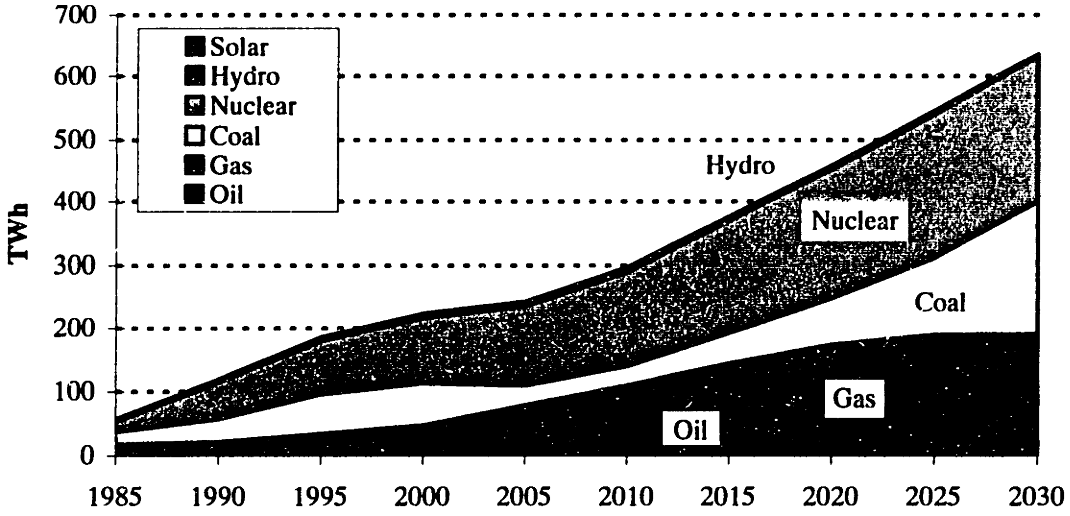


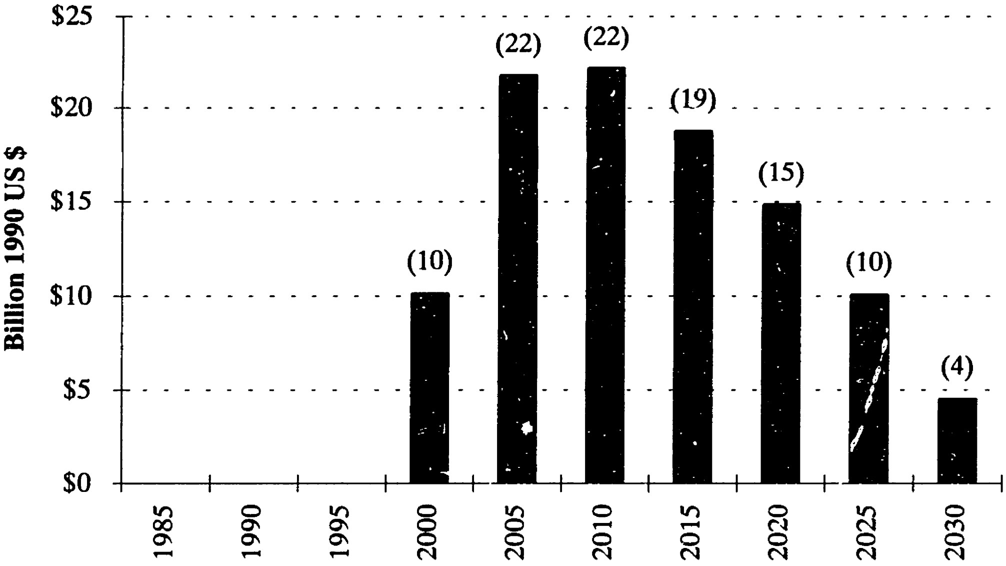
Table 9.4 Electricity Generation with Advanced Energy Technologies (TWh): Stabilization Case

Year	Oil	Gas	Coal	Nuclear	Hydro	Solar	Total	Growth Rate
1985	18	-	20	16	3	-	57	
1990	12	9	36	57	4	-	118	15.9%
1995	11	23	61	84	6	-	185	9.3%
2000	7	40	66	104	7	-	224	3.9%
2005	7	71	31	127	7	-	243	1.6%
2010	7	102	30	151	7	-	297	4.1%
2015	8	135	49	178	7	-	376	4.9%
2020	9	165	75	205	6	-	459	4.1%
2025	9	180	123	229	6	-	546	3.5%
2030	8	182	209	233	4	-	636	3.1%

9.6 Revenue from Carbon Taxes

Revenue from carbon taxes, shown in Figure 9.8, ranges from $4 billion US (1990 dollars) to $22 billion US. The first carbon tax, imposed in the year 2000, generates $10 billion US of revenue, and as the tax rate reaches a maximum of $180/tC in 2010, the revenue grows to $22 billion US. After 2010, the tax rate declines steadily and so does the revenue. By 2030, the tax of $35/tC generates $4 billion US of revenue.

Figure 9.8 Carbon Tax Revenue with Advanced Energy Technologies



9.7 Costs to the Economy

The cost to the Korean economy of carbon emissions stabilization in the advanced technology case is determined from measuring the reductions in GNP levels from the baseline scenario. The percent changes in GNP levels from the baseline scenario due to carbon taxes are shown in Figure 9.9. The greatest GNP loss occurs when carbon taxes are the highest; the carbon tax of $180/tC results in a GNP loss of 3 percent in 2010. Since tax rates decline after 2010, GNP losses are minimized after this time. By 2030, the GNP in the stabilization case is only 0.6 percent lower than that in the baseline scenario. GNP reductions from carbon taxes results from consumption and investment losses. The differences in consumption and investment levels between the stabilization and baseline scenarios are shown in Table 9.5. With carbon taxes, there is a maximum of 10.4 and 3.9 percent reduction in consumption and investment, respectively, from the baseline scenario. Losses in consumption and investment are compensated by increases in the government budget, since the carbon tax revenue is recycled to the government. However, the revenue alone is not enough to balance the losses in consumption and investment.

Figure 9.9 Changes in GNP Levels from Carbon Stabilization (Relative to Advanced Technology Case)

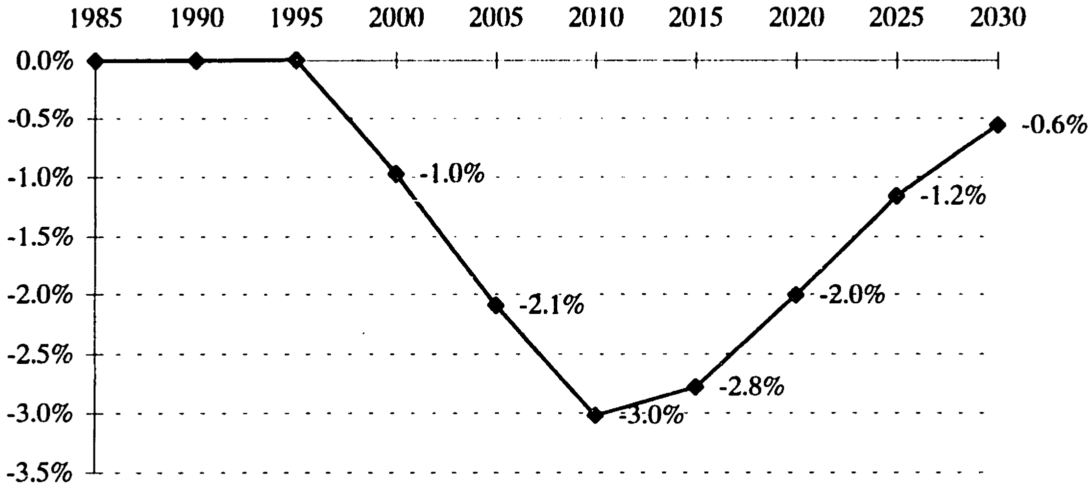


Table 9.5 Changes in the GNP: Stabilization Case (Relative to Advanced Technology Case)

Year	Consumption (%)	Investment (%)	Government (%)	Imp/Exp (%)	GNP (%)
1985	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.0	0.0
1995	0.0	0.0	0.0	0.0	0.0
2000	-4.2	-1.2	18.3	0.0	-1.0
2005	-7.4	-3.4	31.6	0.0	-2.1
2010	-7.4	-3.9	25.2	0.0	-3.0
2015	-5.8	-3.2	16.8	0.0	-2.8
2020	-4.1	-1.9	11.4	0.0	-2.0
2025	-2.3	-1.4	6.9	0.0	-1.2
2030	-1.0	-0.6	2.7	0.0	-0.6

9.8 Uncertainty of World Energy Prices with Advanced Energy Technologies

The analysis of carbon emissions stabilization with the advanced energy technologies assumed rising fossil fuel prices and a fixed alcohol price. These price assumptions resulted in lower cost for carbon emissions stabilization since the constant price of alcohol enabled large quantities of alcohol to be substituted for petroleum. However, in a global carbon stabilization scenario, the global demand for biomass derived alcohol could rise rapidly and cause the price of alcohol fuels to rise. This would increase the cost of carbon stabilization for Korea. Therefore, a range of possible fuel price trajectories is required to better understand how changes in fuel prices can affect the cost of emissions stabilization.

The results presented, thus far, with rising fossil fuel prices and a fixed alcohol price represents a lower bound of the emissions stabilization cost since the alcohol price is fixed. For an upper bound to the stabilization cost, alcohol prices were assumed to grow at 2.6 percent per year, while fossil fuels prices were assumed to grow at the same rate. To clarify the comparison of the two cases, the previous case with the fixed alcohol price will be referred to as Case C and the case with the rising alcohol price will be referred to as Case D. The growth rate in fuel prices for the two cases are summarized below.

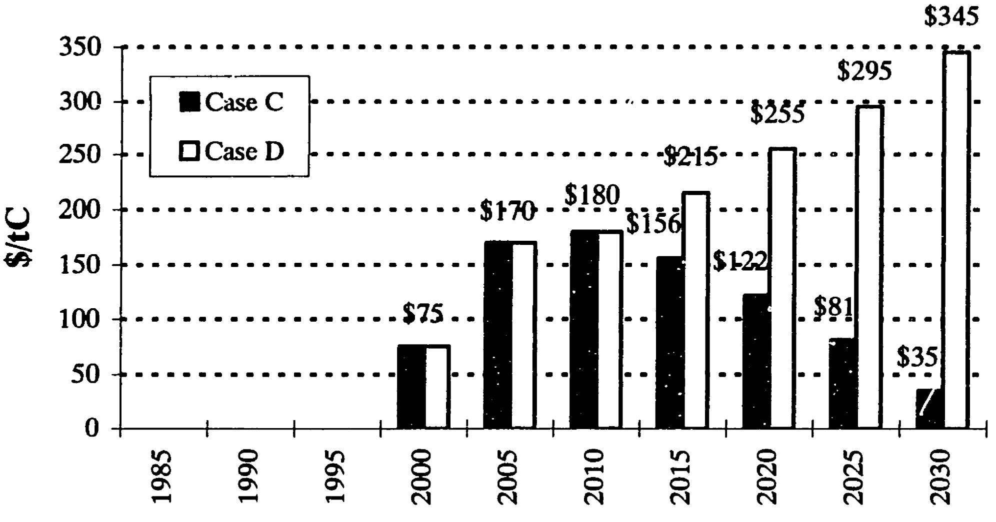
Growth Rate in Fuel Prices: Case C and D

Primary Fuels	Case C (%/yr)	Case D (%/yr)
Crude Oil	2.6	2.6
Natural Gas (LNG)	2.6	2.6
Coal	0.8	0.8
Uranium	0.8	0.8
Alcohol	0.0	2.6

Carbon Tax Levels

Taxes required for carbon emissions stabilization with rising alcohol prices were higher after 2010 than with fixed alcohol prices. Substitution of alcohol fuels for petroleum begins in 2010 when the end-user price of petroleum rises above the alcohol price. As the alcohol price continues to increase at 2.6 %/year after 2010, the tax rate required to induce substitution of alcohol for petroleum also rises. The carbon tax rate exceeded the previous high of 180 $/tC in Case C and reached 345 $/tC by 2030 in Case D (see Figure 9.10 for carbon tax rates in the two cases).

Figure 9.10 Carbon Taxes for Carbon Emissions Stabilization: Case C & D



Primary Energy and Electricity Consumption

Rising alcohol fuel prices and higher carbon taxes necessary for emissions stabilization reduce the consumption of primary energy and electricity generation after 2010. As shown in Table 9.6, total primary energy consumption in Case D is 5 to 19 percent lower in 2015 and 2030 than the consumption levels in Case C. Since alcohol prices are higher in Case D, less alcohol is used for primary energy; only 60 MTOE of alcohol is used for primary energy by 2030, whereas in Case C, 140 MTOE of alcohol was consumed. Higher carbon taxes in Case D also reduces the consumption of coal. In Case D, coal consumption decreased to 18 MTOE by 2030, whereas in Case C, 45 MTOE of coal was consumed in 2030.

Similar reductions in electricity generation result as alcohol prices rise and higher carbon taxes are required for emissions stabilization. In Case D, total electricity generation levels decline by 6 percent in 2015 and 18 percent in 2030 from the generation levels in Case C. Refer to Table 9.7 for a comparison of electricity generation for the two cases. Higher carbon taxes have the largest impact on coal prices, and therefore, reductions in total electricity generation are due largely to decreases in electricity production from coal. In Case D, only 15 TWh of electricity is generated from coal in 2030, whereas in Case C, 209 TWh of electricity is generated from coal. The sharp decrease in electricity generation from coal is compensated by increases in electricity generation from natural gas and nuclear power. However, these increases do not fully recover the loss in electricity generation from coal.

Table 9.6 Primary Energy Consumption for Case C and D

Year	Primary Energy Consumption (Case C) (MTOE)	Primary Energy Consumption (Case D) (MTOE)	Reduction in Primary Energy Consumption (%)
1985	54	54	0%
1990	92	92	0%
1995	128	128	0%
2000	136	136	0%
2005	147	147	0%
2010	172	172	0%
2015	208	197	-5%
2020	241	217	-10%
2025	272	233	-14%
2030	298	242	-19%

Table 9.7 Electricity Generation for Case C and D

Year	Electricity Generation (Case C) (TWh)	Electricity Generation (Case D) (TWh)	Reduction in Electricity Generation (%)
1985	57	57	0%
1990	118	118	0%
1995	185	185	0%
2000	224	224	0%
2005	243	243	0%
2010	297	297	0%
2015	376	355	-6%
2020	459	416	-9%
2025	546	475	-13%
2030	636	521	-18%

Tax Revenue and GNP Loss

Higher carbon taxes result in greater tax revenue in Case D, but reduce the growth in the GNP. With higher taxes in Case D, 6 to 33 billion dollars more revenue is generated from 2015 to 2030 than in Case C (see Figure 9.11). This additional revenue does not, however, compensate for the greater GNP loss that results from the higher alcohol costs and higher carbon tax rates. In Case C, the maximum GNP loss was 3 percent in 2010, but in Case D, the GNP loss increases to 3.4 percent in 2015 and remains at 3 percent throughout the rest of the modeled time period (see Figure 9.12 for GNP losses). When alcohol prices grow at the assumed rate of 2.6 percent per year, alcohol is no longer a cheap fuel substitute for petroleum. Higher alcohol prices and higher fossil fuel prices from carbon taxes raise the cost of energy use in all sectors of the economy and result in decreased GNP levels.

For biomass derived alcohol to play a role in reducing carbon emissions, taxes must be raised to a level such that the end-user price of petroleum is greater than the alcohol price. Within the model, as long as petroleum prices are higher than alcohol prices, substitution of alcohol for petroleum will occur. When the alcohol price is assumed fixed, tax rates fall as soon as the petroleum price exceeds the alcohol price. However, when the alcohol price grows at the assumed rate, tax rates must increase if substitution of alcohol for petroleum is to occur. Therefore, taxes must be raised to stabilize carbon emissions as the alcohol price continues to rise, but since taxes required grow at a constant rate, the GNP loss remains at near 3 percent from 2010 to 2030.

Figure 9.11 Carbon Tax Revenue: Case C & D

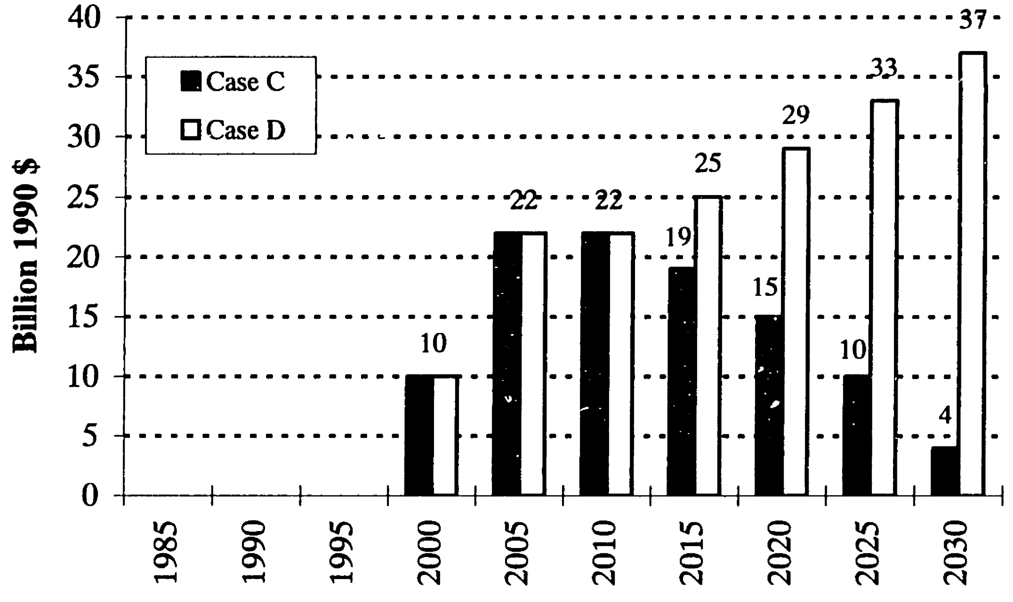
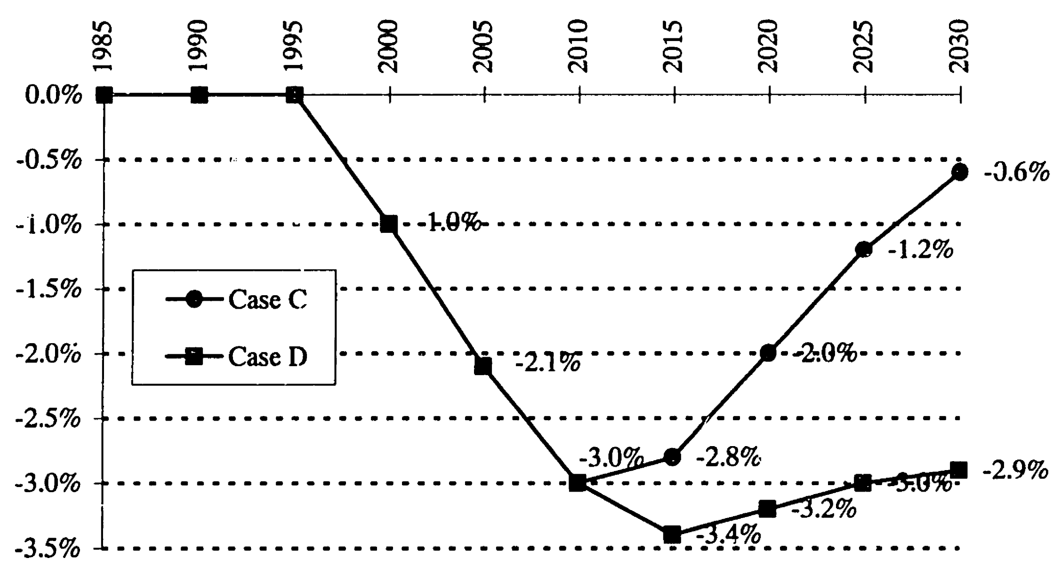


Figure 9.12 Changes in GNP Levels from Carbon Stabilization: Case C & D (Relative to Technology Base Case)



9.9 Impact of End-Use Efficiency Improvements

As carbon taxes are applied in an emissions stabilization scenario, it is likely that greater emphasis will be placed on improving energy efficiency in all sectors of the economy. This raises the question of how much emissions reduction can actually be achieved from a program of improving end-use energy efficiency. In this section, an examination of the impact of greater end-use efficiency on reducing carbon emissions was carried out.

In the Korea model, energy efficiency improvements for industries (production sectors) are accounted for by the neutral technical change parameter as discussed Chapter 4. However, energy efficiency improvements from households cannot be directly modeled by the current version of the model due to insufficient detail of the household sector. Therefore, the analysis of the impact of end-use efficiency improvements in the Household Sector was carried out exogenously. The analysis was focused on the reduction of electricity consumption from improvements in end-use efficiency only. Reductions in the demand for electricity was determined outside of the model and the projection of carbon emissions with the lower electricity demand was determined from the model.

Household and commercial demand for electricity in the reference case is shown in Table 9.8. The current demand for electricity in the household and commercial sector is very high, as evident from the annual growth rate in electricity demand of nearly 17 percent from 1985 to 1990. This demand slows down gradually to an annual growth rate of 2.6 percent per year by 2030. Without any specific end-use efficiency technologies in mind, the growth rate in electricity demand was reduced by 2 percent per year after 1995 to see how much reduction in electricity consumption could be achieved. Shown in Table 9.8, a 2 percent per year lower growth rate reduces the demand for electricity from the household and commercial sectors by a maximum of 49 percent in 2030. This percentage reduction is very significant for the household and commercial sectors, but amounts to only 25 percent of the total electricity consumption in 2030 (see Table 9.9).

Although significant decreases in the household and commercial electricity demand were achieved by lowering the annual growth rate of electricity demand by 2 percent per year, the overall impact on the reduction of carbon emissions was not significant. As shown in Table 9.10, the maximum reduction in carbon emissions achieved was only 5 percent in 2030. What is important for emissions reduction is the total amount of primary energy reduced, and since the primary energy required for electricity generation comprises only a portion of the total primary energy demand, the relatively large reduction in electricity consumption from end-use efficiency results in a relatively small reduction in carbon emissions. According to Table 9.11, 25 to 41 percent of the total primary energy consumption is used for electricity generation in the years from 1985 to 2030. Therefore, the actual amount of primary energy reduced from reduced electricity demand is even less. With the consumption of primary energy increasing by a factor of three from 1990 to 2030, a reduction in the demand for electricity alone will not have any major impacts on the reduction of carbon emissions.

In another study, Shin (1993) investigated the impact of end-use efficiency technologies in reducing CO_2 emissions from Korea's electric power sector. Shin measured the impact of three demand-side management (DSM) technologies, compact fluorescent lamps, electronic ballasts, and high efficiency motors, on decreasing electricity consumption from all sectors of the economy from 1991 to 2006. He concludes that CO_2 emissions from the power sector could be cut by as much as 24 percent with the DSM options by the year 2006. However, he does not point-out that the 24 percent reduction, which amounts to 7.6 MtC, is less significant when compared to the total projected CO_2 emissions in 2006. Total CO_2 emission in 2006 is projected to be 140 MtC as shown by Shin, as well as from this model (refer to Chapter 5 Reference Case). Therefore, the 24 percent reduction in emissions from the power sector amounts to only a 5 percent reduction of the total CO_2 emissions.

Both analyses presented above show that end-use efficiency technologies can help to reduce emissions, but these technologies alone cannot be relied on to have any major impacts in reducing overall carbon emissions. The growth in the consumption of primary energy, that consists mostly of fossil fuels, overwhelms any emissions reduction achieved by efficiency improvements. Finally, with such a minimal impact on total carbon emissions, the cost of emissions stabilization will not be significantly affected by end-use efficiency technologies.

Table 9.8 Household and Commercial Electricity Demand
(Reference Case and Reference Case with End-Use Efficiency)

Year	Household/ Commercial (GWh)	Annual Growth Rate (%/yr)	Household/ Commercial with Efficiency (GWh)	Annual Growth Rate (%/yr)	Reduction in Elect. Demand (GWh)	% Reduction
1985	13,435		13,435		-	-
1990	29,171	16.8%	29,171	16.8%	-	-
1995	52,231	12.4%	52,231	12.4%	-	-
2000	77,513	8.2%	70,610	6.2%	6,903	9%
2005	105,573	6.4%	87,464	4.4%	18,109	17%
2010	137,523	5.4%	103,529	3.4%	33,994	25%
2015	175,585	5.0%	120,065	3.0%	55,519	32%
2020	215,313	4.2%	133,630	2.2%	81,684	38%
2025	254,209	3.4%	143,087	1.4%	111,122	44%
2030	288,381	2.6%	147,099	0.6%	141,282	49%

Table 9.9 Total Electricity Demand
(Reference Case and Reference Case with End-Use Efficiency)

Year	Total (Ref.) (GWh)	Total (Efficiency) (GWh)	Reduction (%)
1985	56,773	56,773	-
1990	118,563	118,563	-
1995	181,299	181,299	-
2000	236,564	229,661	3%
2005	287,012	268,903	6%
2010	339,850	305,856	10%
2015	403,484	347,965	14%
2020	463,837	382,153	18%
2025	516,544	405,422	22%
2030	565,188	423,906	25%

Table 9.10 Carbon Emissions Reduction with End-Use Efficiency

Year	Total (Ref.) (MtC)	Total (Efficiency) (MtC)	Reduction (MtC)	Reduction (%)
1985	49	49	0	0
1990	73	73	0	0
1995	96	96	0	0
2000	116	116	0	0
2005	138	137	-1	-1%
2010	162	160	-2	-1%
2015	182	178	-4	-2%
2020	200	194	-6	-3%
2025	215	207	-8	-4%
2030	230	219	-11	-5%

Table 9.11 Share of Primary Energy For Electricity Generation

Year	Primary Energy Consumption (MTOE)	Primary Energy for Electricity Generation (MTOE)	Share of Primary Energy for Electricity Generation (%)
1985	54	14	25%
1990	92	27	29%
1995	128	40	31%
2000	159	53	33%
2005	190	64	34%
2010	220	77	35%
2015	247	92	37%
2020	269	105	39%
2025	285	114	40%
2030	293	121	41%

9.10 Summary

The introduction of advanced energy supply technologies into the model reduced the cost of emissions stabilization while enabling greater consumption of energy; however, stabilization still requires carbon taxes with negative impacts on the GNP. More efficient natural gas and coal power plant technologies, solar-photovoltaic technology, and biomass derived alcohol fuels were introduced into the model, and the constraint on nuclear power was removed. Of these energy sources, alcohol fuels, nuclear power and natural gas power plants significantly reduced the cost of carbon emissions stabilization to the 1995 level. A maximum carbon tax of $180/tC in the year 2010 was sufficient for emissions stabilization; however, the resulting GNP loss from this tax was 3 percent from the baseline.

Total primary energy consumption and electricity generation under the stabilization scenario were not significantly affected with the additional energy technologies in place. Substitution of alcohol fuels for petroleum occurs and maintains primary energy consumption levels at the baseline. The share of primary energy consumption from alcohol fuel is 47 percent by the year 2030. Increases in electricity generation from nuclear and more efficient natural gas power plants replace that generated from coal and keep electricity consumption levels from falling. There are a total of 35 nuclear power plants by 2030 (assuming 1000 MWe and 75% annual capacity), which produces nearly 40 percent of the total electricity consumed.

Again, stabilization of carbon emissions is dependent on the end-user price of fossil fuels. But with the availability of alcohol fuels, the end-user price of crude oil is the key determinant of the carbon tax rate. Alcohol fuels are substituted for refined oil (crude oil) and contribute to carbon emissions reduction only if refined oil prices are greater than alcohol prices. If the alcohol price is not fixed, but grows at the same rate as the crude oil price, carbon taxes must be raised to maintain end-user price of crude oil at levels sufficient to induce substitution of refined oil for alcohol. Rising alcohol prices, therefore, result in greater GNP loss since carbon taxes must be raised.

Other technologies that improve energy efficiency at the end-use level are not expected to contribute to major reductions in carbon emissions. The growth in primary energy consumption, that consists mostly of fossil fuels, overwhelms any emissions reduction achieved by improvements in end-use efficiency, such as from compact fluorescent lamps, electronic ballasts and high efficiency electric motors.

Chapter 10. Conclusions

Projections from the Korea module of the SGM show that Korea will maintain rapid economic growth and high energy demand into the next decade. Beyond the next decade, the economic growth will begin to slow down, owing primarily to population stabilization and reduction in the labor supply. Along with this growth, carbon emissions from fossil fuel use will nearly triple the current emissions level by 2030. Such growth in emissions indicates that stabilization of carbon emissions to the current level will be very costly and difficult to achieve. Carbon tax scenarios show that extremely high taxes will be required to stabilize emissions to the current level and that large GNP losses will result from these taxes. Moreover, energy efficiency improvements and energy from nuclear power and biomass derived alcohol can help to reduce carbon emissions, but these technologies alone are not sufficient to stabilize carbon emissions. For these reasons, stabilization of carbon emissions to the current level is not a viable option for the Republic of Korea.

A baseline scenario of growth in the Korean economy was represented by the reference case. In the reference case, the GNP grew by more than a factor of nine from the 1985 level of 143 billion dollars to 1.36 trillion dollars by 2030. By 2030, the per capita GNP level for Korea is equivalent to the current per capita level for Japan and the United States. Strong economic growth required large additional primary energy and electricity consumption. Primary energy consumption increased by more than five times the 1985 level of 54 MTOE to reach 293 MTOE by 2030, whereas electricity consumption expanded by ten times from 57 TWh in 1985 to 565 TWh in 2030. The large additional demand for energy from economic growth resulted in significant increases in carbon emissions. Carbon emissions grew nearly five times from the 1985 level of 49 MtC to reach 230 MtC by 2030. On a per capita basis, carbon emissions grew from 1.2 tC in 1985 to 4 tC by 2030.

The cost of carbon emissions stabilization in the reference case was shown to be very sensitive to the emissions level chosen for stabilization. With the assumption of world crude oil and LNG prices rising at 2.6 percent per year and world coal and uranium prices rising at 0.8 percent per year, stabilization of carbon emissions to the 1995 level required carbon taxes as high as $1,525 US per tC, that resulted in a GNP loss of 6.5 percent from the reference case. Limiting carbon emissions to 1.5 times the 1995 level, 144 MtC or approximately 3 tC per person, was shown to be much less costly than the previous case but still prohibitive to achieve. For this carbon limit, action on emissions reduction is necessary only after 2005. In this scenario, a maximum carbon tax of $500 US per tC was required in 2030, with resulting GNP loss of 2 percent. Finally, increasing the carbon emissions allowance to 2 times the 1995 level, 192 MtC or approximately 4 tC per person, required only minimal emissions control measures. Carbon taxes necessary to achieve this limit were required only after the year 2015 and at a rate that did not exceed $150 US per tC. The resulting GNP loss from this tax was small, approximately 0.2 percent. These scenarios reveal that stabilization of carbon emissions in the immediate future, without additional energy technology options, will be extremely costly. However, since the growth in the economy and the rate of energy demand in Korean will decrease with time, waiting another decade or more before carbon emissions are stabilized will sharply reduce the cost of carbon stabilization.

Although carbon taxes necessary for emissions stabilization depend on the price path of future world fossil fuel and uranium prices, the analysis on the uncertainty of energy prices revealed that emissions stabilization is a function of the end-user price of energy. In the reference case, regardless of how world fossil fuel prices change, the end-user price of fossil fuel must be maintained at a level that discourages its use. This is achieved by adjusting the carbon tax rates. However, since there is little variability in the end-user price of energy required for emissions stabilization, the cost of emissions stabilization was shown not vary significantly from that stated above.

Clearly, reductions in carbon emissions will be difficult to achieved in Korea without the introduction of advanced energy technologies. This study showed that with greater nuclear power, more efficient natural gas power plants, and biomass derived alcohol fuels, the cost of stabilizing carbon emissions to the 1995 level can be reduced significantly. With these energy supply technologies and a fixed alcohol fuel price, a carbon tax that reached a maximum of $180/tC in 2010 was enough to maintain carbon emissions at the 1995 level of 96 MtC. The resulting GNP loss from this tax was 3 percent. After 2010, carbon tax rates fall and GNP losses are minimized as more energy from alcohol, nuclear power and natural gas are used. By 2030, 140 MTOE (280 billion liters of ethanol) of biomass derived alcohol and 43 MTOE (52 billion cubic meters) of natural gas are imported, and 35 nuclear reactors (assuming 1000 MWe capacity and 75% annual load) are in operation. However, when the alcohol price is not fixed but assumed to be rising at the same rate as crude oil, higher taxes are required after 2010 for emissions stabilization. Higher taxes are required to raise the end-user price of petroleum over the price of alcohol so that substitution of alcohol for petroleum continues to occur. With higher alcohol prices, however, less alcohol is imported. By 2030, only 60 MTOE of alcohol is used for primary energy. Moreover, since taxes required to induce substitution of alcohol for petroleum grow at a constant rate, GNP losses from emissions stabilization remain at 3 percent from 2010 to 2030.

These energy technologies, particularly alcohol derived from biomass, can have a large impact in reducing carbon emissions in Korea. However, it is uncertain whether the implementation of these technologies can come about in reality. Issues of land availability and public opposition may hinder the development of many more nuclear power plants in Korea. These issues will be especially important after 2005, when new sites for nuclear power plants are required. As for alcohol use, the large demand for this fuel would necessitate substantial land requirements. Approximately 50 million hectares of land will be required to produce 280 billion liters of ethanol. Moreover, for alcohol use to be a true benefit to reducing carbon emissions, sustainable farming methods for energy crop production must be practiced. Whether such large amounts of land can be made available without reducing the land required for food production, and whether biomass can be grown sustainable without creating other environmental degradation are issues that must be considered.

The scenarios for Korea, presented here, are likely to be similar for other rapidly growing Asian countries, such as Taiwan, Indonesia, Malaysia, Thailand, Singapore, and China. For these Asian countries, past economic and energy consumption growth rates have been impressive, and this trend will more than likely continue into the future. The 1980 to 1990 GDP growth rates for these Asian countries range from 5.2 to 9.5 percent per year (*World Development Report 1992)*. Malaysia had the lowest growth rate, China had the highest and the rest were within the above range. Energy consumption growth rates from 1980 to 1990 were also high for all of these countries. The lowest energy consumption growth rate was exhibited by Indonesia at 4.1 percent per year, while Malaysia exhibited the highest at 14.4 percent per year (*World Development Report 1992)*. According to the Oak Ridge National Laboratory in their publication *Trends '93*, CO_2 emissions from the Far East, which includes India, South Korea, Indonesia, Taiwan, Thailand, Pakistan, Malaysia, the Philippines, and other less populous nations, were 16 times greater in 1991 than in 1950. This represents an average growth rate of 7.0 percent per year in the 41 year time span.

Rapid industrialization and economic growth have not slowed in East and Southeast Asia, and along with this growth, the demand for energy is continually on the rise. Therefore, energy-related GHG emissions in this region will increase significantly in the future. Due to the similarities in economic, energy and GHG emissions growth among these Asian countries, the analysis of carbon stabilization and technology impacts for Korea provides an example for these countries. Like Korea, stabilization of carbon emissions to the current level will be extremely costly for these countries and thus, is not expected to be a viable option.

10.1 Future Studies

This study of Korea has been limited to the analysis of the cost of carbon emissions abatement. However, the cost of emissions abatement must be weighed against the benefits of emissions reductions to determine whether taking such strong actions for emissions reduction is warranted. For this comparison, the economic impact of climate change on Korea must be determined. However, no study of the economic damage from global warming has been carried out for Korea thus far. The degree of climate change and its impact on agriculture, forestry, space cooling and heating, sea-level rise, water supply, and trade for Korea are not well understood. Such an assessment is, however, necessary to bring emissions abatement costs into perspective and to determine which course of action Korea must take.

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APPENDIX A

Data requirements for the Korea module of the SGM

Input-Output Table

A commodity-by-commodity table for 1985: The commodity-by-commodity table provides the production of commodities (goods and services) by each SGM industry, the use of commodities by each industry, the commodity composition of GNP, and the industry distribution of value added

- 1985 commodity-by-commodity IO table. 1985 is the base or reference year for the model.

- The Everything Else (ETE) sector includes all sectors that are not included in Agriculture, Crude Oil, Natural Gas, Coal, Biomass, Uranium, Electric Power, Refined Oil, and Natural Gas Transmission and Distribution sectors.

- Land and labor expenditures in the 1985 IO accounts were imbedded in the "other value added" portion of the IO tables. The following data were used to extract land and labor expenditures from "other value added": average land price, average labor price, estimated land area used by each sector, and estimated labor used by each sector.

- Indirect Business Tax (IBT) represents the amount paid in sales tax, property tax, excise tax, and import tax.

- "Other value added" (after extracting out land and labor expenditures) would therefore include items such as corporate profits, corporate income tax, retained earnings, rent on capital, and capital depreciation.

- The Electric Power industry was separated into seven industries based on type of generation: oil-fired, gas-fired, coal-fired, biomass generated, nuclear, hydroelectric, and solar. Electric power generation was disaggregated into fossil fuel thermal, hydro, and nuclear in the IO table. Therefore, data on electric power by type of generation was required to split the IO table values for the fossil fuel thermal power sector.

- Government final demand in the IO table was separated into five categories for the Korea: Defense, Education, General Public Service, Investment, and Other Government.

Table A.1

SGM Sectors	BEA Category	Standard Industrial Classification	BEA Classification
1) Agriculture	Agriculture, Forestry and Fishing, Food and Kindred Products	01-09, 20	01-04, 14
2) ETE	All other industries		
3) Crude Oil	Crude Petroleum & Natural Gas	13	08
4) Natural Gas	Crude Petroleum & Natural Gas	13	08
5) Coal	Coal Mining	12	07
6) Uranium	Nonferrous Metal Ores Mining, except copper Industrial Inorganic Chemicals n.e.c.	1094 2819	0602 270104
7) Biomass			
8) Electricity	Private Electric Services (Utilities) Federal Electric Utilities State & Local Electric Utilities	4911	6801 7802 7902
9) Refined Oil	Petroleum Refining Products of Petroleum & Coal n.e.c.	2911 2999	310101 310103
10) Gas T&D	Private Gas Production	492	6802

Historical times series data on annual gross capital stocks, discards, and investments

Data for Korea were obtained from the Korea Energy Economics Institute. These data are consistent with Korean national income and product accounts.

Energy statistics data

Data cover all major energy activities, including consumption, production, trade, stocks, and prices, for all major energy commodities, including fossil fuels and electricity. Data for Korea were obtained from the Korea Energy Economics Institute.

ELECTRICITY GENERATION WORKSHEET

Electricity production is divided into subsectors based on the type of fuel used in the production process. The following data for each electricity subsector were used to share out input-output values for the electricity generation sector into subsectors. These data are required unless input-output data are already available by electricity subsector.

1. Installed Capacity - the generating capacity by each fuel type in megawatts (MW).

2. Capacity Share - the share of total installed capacity by each fuel type.

3. Net Generation - the amount of electricity generated by each fuel type, in terawatt-hours (TWh).

4. Share by generation

5. Operations and Maintenance (O&M) costs for each type of power generation.

6. Capacities of Plants Under Construction as of 1985 - in MW.

7. Share of Transmission & Distribution (T&D) in Capital Costs - the portion of total capital costs represented by T&D costs.

8. Amount of land used for electricity production in each subsector (Hectares).

9. Labor costs for each subsector.

Population and demographics data

Data include 1985 population by age group and gender, fertility rates by age group, death rates by age group and gender, net migration rates by age group and gender, and birth rates by gender.

Greenhouse Gas Emissions

Data consist of 1985 greenhouse gas emissions by economic activity.

GREENHOUSE GAS WORKSHEET

1. Greenhouse Gas Emitting Activities

Greenhouse Gas Emitting Activities, in exajoules.

2. Emission Coefficients Table

Emission coefficients for greenhouse gas producing activities - oil combustion, gas transmission and distribution (T&D), cement manufacturing, etc. The coefficients are in units of teragrams of gas per exajoule of energy.

Land use data

Data include a breakdown of total land area by land type: agricultural land, urban land, parks and recreational land, defense land, and unusable land, such as bare rock, marshes, tundra, deserts.

Resources and reserves data

Data include resources and reserves (in exajoules) of crude oil, natural gas, and coal.

Other Essential Data

Other essential data required for the year 1985:

1) Extracted energy in exajoules

Data required to split Crude Oil, Natural Gas, and Coal into grades.

2) Well-head/minemouth prices of grades
3) Extraction prices of grades
4) Production of grades (in Exajoules)
5) Resources of crude oil, natural gas, coal and uranium, divided into grades if

necessary

Data required to calculate retained earnings as a function of interest rate.

6) Actual Retained Earnings (RE)
7) RE(0), maximum retained earnings rate

$$RE\ RATE = \frac{Retained\ Earnings}{(Other\ Value\ Added - Corporate\ Income\ Tax)}$$

8) Interest Rate, *i*

$$Actual\ Retained\ Earnings = OVA(1 - CITR) * RE(0)(1 - e^{RE(1)i})$$

where,

OVA = Other Value Added,
CITR = Corporate Income Tax Rate, and
RE(1) is determined from the above data

Data required to calculate personal income.

9) Total corporate income tax rate (CIT)
10) Any other tax on corporate earnings. For example, the U.S. Social Security tax.

Data required to calculate labor supply as a function of labor price.

11) Actual labor supply
12) Working age population (age 16 to 64)
13) Average annual price of labor
14) LB(0), maximum fraction of working age population available for labor supply

$$Actual\ Labor\ Supply = Working\ Age\ Pop. * LB(0)(1 - e^{LB(1) * PriceofLabor})$$

where,

LB(1) is determined from above data.

Data required to calculate land supply as a function of the average price of land.

15) Total land area (TLA)
16) Actual land supply (land in use)
17) Average price of land (P_{land})
18) R(0), maximum fraction of total land area that can be used

$$Actual\ Land\ Supply = TLAR(0)_{land}(1 - e^{R(1)_{land} P_{land}})$$

where,

R(1) is determined from the above data.

19) Number of households
20) Actual household land demand (total land used for lodging)
21) Share of land used for lodging, parks, education, industrial, agriculture, and other

Data required to calculate government transfer as a function of population.

22) Total population
23) Total personal income tax paid

Data required to calculate savings as a function of interest rate.

24) Total household savings
25) S(0), maximum savings rate
26) Savings elasticity, as a function of interest rate

$$Total\ Household\ Savings = (PINC + GOVT\ TRANS) * S(0)(1 - e^{S(1)i})$$

where,

PINC = personal income,
i = the interest rate, and
S(1) is determined from above data.

Data required for household consumption.

27) Price elasticity - changes in household consumption of all SGM commodities as a function of changes in the price of commodities
28) Income elasticity - changes in household consumption of all SGM commodities as a function of changes in personal income

Input-Ouput Table for SGM KOREA (1985)

Unit: 1985 Currency (in Million Won)

Input - Ouput - SGM, 1985	Agriculture	ETE	Crude Oil	Natural Gas	Coal	Biomass	Uranium
Agricuture	13,042,814	3,762,790	0	0	28,239	0	0
Everything Else	4,070,066	72,824,623	0	0	390,991	0	0
Crude Oil	0	103,613	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0
Coal	27,084	734,871	0	0	944,710	0	0
Biomass	0	0	0	0	0	0	0
Uranium	0	0	0	0	0	0	0
Electricity	160,543	3,011,837	0	0	57,133	0	0
Refined Oil	465,360	5,202,427	0	0	18,207	0	0
Gas Transmission and Distribution	402	12,115	0	0	142	0	0
Land	1,890,354	414,762	0	0	1,570	0	0
Labor	2,223,798	29,333,558	0	0	347,068	0	0
Indirect Tax	1,317,291	5,590,525	0	0	(10,465)	0	0
Other Value Added	7,392,514	26,516,486	0	0	183,407	0	0
Total Input	30,590,226	147,507,607	0	0	1,961,002	0	0

1980

Indirect Tax	41,382	4,856,364	0	0	3,730	0	0
Other Value Added	6,114,111	20,119,855	0	0	54,639	0	0
Total Input	9,119,158	110,637,489	0	0	528,853	0	0

Input-Ouput Table for SGM KOREA (1985)

Unit: 1985 Currency (in Million Won)

Oil	Gas	Electricity Coal	Biomass	Nuclear	Hydro	Refined Oil	Gas T & D
0	0	0	0	0	5	0	0
150,279	0	71,422	0	75,589	26,222	116,671	24,121
0	0	0	0	0	0	5,121,980	0
0	0	0	0	0	0	0	0
0	0	307,337	0	20	16	0	0
0	0	0	0	0	0	0	0
0	0	0	0	66,310	0	0	0
10,887	0	2,034	0	983	301	22,139	691
804,995	0	0	0	3,230	691	140,257	10,344
19	0	10	0	12	4	0	1,655
637	0	955	0	508	233	1,674	103
171,439	0	76,215	0	87,536	33,469	73,993	1,470
34,379	0	29,897	0	27,751	4,656	516,144	292
520,101	0	488,603	0	858,732	141,381	576,086	863
1,692,737	0	976,472	0	1,120,670	206,977	6,568,944	39,539
37,469	0	3,148	0	4,442	2,789	929,415	513
433,818	0	33,619	0	145,578	49,897	412,177	588
1,898,989	0	143,655	0	199,753	114,251	5,303,499	6,903

Input-Ouput Table for SGM KOREA (1985)

Unit: 1985 Currency (in Million Won)

FINAL DEMAND Consumption	Investment & Change in Business Inventories	Exports	Imports	General Public Service	Defense	GOVERNMENT Education	Other Gov't	Investment
14,802,486	1,276,327	1,062,822	(3,396,838)	0	0	0	0	11,581
31,056,813	19,023,077	25,815,773	(18,548,979)	1,194,130	3,534,653	1,779,782	1,566,005	4,336,369
0	(177,324)	0	(5,048,269)	0	0	0	0	0
0	0	0	0	0	0	0	0	0
773,740	129,433	13,141	(969,350)	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	(66,310)	0	0	0	0	0
730,308	0	0	0	0	0	0	0	0
237,642	(82,567)	825,186	(1,056,828)	0	0	0	0	0
25,597	0	151	(568)	0	0	0	0	0
				1,618	423	1,405	2,474	7,690
							3,239,259	

Input-Ouput Table for SGM KOREA (1990)

Unit: 1990 Currency (in Million Won)

Input - Ouput - SGM, 1990	Electricity Gas	Gas T & D
Agricuture	0	0
Everything Else	21,901	73,467
Crude Oil	0	0
Natural Gas	15,142	325,764
Coal	0	0
Biomass	0	0
Uranium	0	0
Electricity	359	1,167
Refined Oil	0	55,711
Gas Transmission and Distribution	1	102,261
Land	158	1,091
Labor	6,877	71,496
Indirect Tax	1,785	14,343
Other Value Added	28,433	47,045
Total Input	74,655	692,345

Investment - Capital Stock
In Billion Won

	Agriculture	ETE	Crude Oil	Natural Gas	Coal	Biomass	Uranium	ELECTRICITY Oil	Gas	Coal
Investment :										
1971	704	4,471	0	0	24	0	0	0	0	178
1972	591	4,113	0	0	25	0	0	0	0	146
1973	848	5,935	0	0	19	0	0	0	0	120
1974	1,539	7,561	0	0	62	0	0	0	0	352
1975	719	7,039	0	0	65	0	0	0	0	434
1976	753	7,621	0	0	50	0	0	27	90	381
1977	1,042	7,910	0	0	69	0	0	46	754	732
1978	1,770	10,268	0	0	86	0	0	3	489	962
1979	1,953	11,006	0	0	104	0	0	8	118	1,830
1980	1,420	8,005	0	0	74	0	0	1	0	1,744
1981	1,313	6,849	0	0	151	0	0	1	0	1,908
1982	1,215	6,522	0	0	117	0	0	0	0	1,865
1983	1,392	7,915	0	0	107	0	0	39	3	1,722
1984	1,326	10,426	0	0	113	0	0	43	3	942
1985	1,768	10,767	0	0	165	0	0	74	0	330
Capital Stock :										
In place through end of 1970	4,444	45,167	0	0	215	0	0	737	0	325
In place between 1971 and 1975	4,171	28,018	0	0	184	0	0	0	0	1,168
In place between 1976 and 1980	8,633	54,818	0	0	470	0	0	92	1,652	7,150
In place between 1981 and 1985	10,940	66,366	0	0	1,013	0	0	251	10	10,425

Investment - Capital Stock
In Billion Won

Vintage Investment for period -2 and -1.
In Billion Won

Biomass	Nuclear	Hydro	Refined Oil	GAS T & D		Agriculture	ETE	Crude Oil	Natural Gas	Coal	Biomass	Uranium	ELECTRICITY Oil	ELECTRICITY Gas
0	63	63	49	73										
0	108	28	37	5										
0	205	38	65	13										
0	638	16	88	16										
0	1,111	29	94	32	1975	4,401	29,119	0	0	194	0	0	0	0
0	909	54	102	38										
0	882	84	150	3										
0	1,018	173	141	46										
0	2,161	164	159	3										
0	3,301	55	112	21	1980	6,939	44,810	0	0	382	0	0	85	1,451
0	4,095	94	105	48										
0	4,924	118	103	61										
0	5,214	191	101	92										
0	5,795	283	127	133										
0	6,401	237	139	135	1985	7,015	42,479	0	0	653	0	0	157	6
0	0	199	289	0										
0	1,983	173	319	136										
0	10,558	652	804	138										
0	41,315	1,451	896	738										

Vintage Investment for period -2, -1 and 0.
In Billion Won

Coal	Biomass	Nuclear	Hydro	Refined Oil	GAS T & D
1,228	0	2,127	174	333	140
5,650	0	8,272	529	663	110
6,766	0	26,429	923	575	470

Unit : 1985 Billion Won

	Profit Rate (%)	Interest Rate (%)	GDP (Constant)	GNP (Constant)	GNP Price Deflator	Investment (Constant)	Total Gov't Transfer (Constant)
1970	21.6	14.7	24,813	24,973	11	4,440	230
1971	22.6	13.4	27,113	27,128	13	4,496	264
1972	23.2	12.0	28,564	28,505	15	5,122	389
1973	22.8	8.6	32,432	32,274	17	7,548	540
1974	21.2	10.5	35,117	34,904	22	7,523	955
1975	20.4	11.3	37,621	37,143	27	7,497	827
1976	22.0	11.9	42,471	42,002	33	10,939	800
1977	21.2	13.1	46,749	46,135	39	13,432	985
1978	20.3	12.4	51,289	50,646	47	15,876	1,043
1979	17.2	14.4	55,182	54,290	57	16,331	1,188
1980	13.7	18.7	53,989	52,261	70	12,619	1,158
1981	13.6	18.4	57,615	55,354	82	13,263	1,166
1982	13.0	16.0	61,821	59,322	88	15,446	1,293
1983	12.9	13.6	69,101	66,803	92	18,563	1,469
1984	13.1	14.4	75,606	73,004	96	21,425	1,688
1985	12.7	12.5	80,847	78,088	100	22,893	1,693
1986	13.2	12.5	90,868	88,174	103	29,690	1,749
1987	13.0	12.5	101,804	99,612	106	37,536	1,897
1988	13.0	13.0	113,492	111,980	113	43,842	2,172
1989	12.2	13.6	120,477	119,577	119	43,039	2,723
1990	11.2	12.7	131,503	130,685	131	46,581	3,360

	(Millions)		(1985 Billion Won)	
	Working Age Population	Total Employment	Gross Stock	Discards
1970	18.253	9.745	51,375	154
1971	18.984	10.066	56,974	171
1972	19.724	10.559	62,772	188
1973	20.438	11.139	69,965	210
1974	21.148	11.586	78,363	235
1975	21.833	11.830	87,526	263
1976	22.549	12.556	98,568	296
1977	23.336	12.629	110,393	331
1978	24.024	13.490	130,053	390
1979	24.678	13.664	151,764	455
1980	25.335	13.706	172,492	517
1981	25.969	14.023	193,299	580
1982	26.531	14.379	216,612	650
1983	27.130	14.505	243,764	731
1984	27.793	14.429	273,716	821
1985	28.489	14.970	305,897	918
1986	28.225	15.505	342,002	1,026
1987	28.955	16.354	383,777	1,151
1988	29.602	16.870	416,733	1,250
1989	30.217	17.511	455,304	1,366
1990	30.801	18.036	503,312	1,510

Electricity Generation

			ELECTRICITY PRODUCTION BY FUEL				
	OIL	GAS	COAL	BIOMASS	NUCLEAR	HYDRO	TOTAL
Installed Capacity (MW)	6,225	2,550	3,700	0	2,866	2,223	17,564
Share by Installed Capacity	0.35	0.15	0.21	0	0.16	0.13	1.00
Net Generation (TWH)	19.96	9.60	17.64	0	16.75	3.66	67.61
Share by Generation	0.30	0.14	0.26	0	0.25	0.05	1.00
Operations & Maintenance Costs (Million Won)	4,289	2,064	3,790	0	3,598	786	14,527
Capacities of Plants Under Construction as of 1985 (MW)	0	0	1,060	0	0	412	1,472
Share of Transmission & Distribution in Capital Cost (%)	0.11	0.04	0.06	0	0.05	0.04	0.30
Land Use for Electricity Generation (M^2)	3,159,005	1,875,814	7,337,371	0	5,836,242	1,658,274	19,866,706
Labor Costs (Million Won)	798	327	474	0	367	285	2,252

Population - Demographics

AGE	Population (x 1,000) Male	Population (x 1,000) Female	Age-specific Fertility Rates	Male Birth Fraction Rates	(per 1,000) Age-specific Death Rates Male	(per 1,000) Age-specific Death Rates Female	(per 1,000) Net Migration Rates Male	(per 1,000) Net Migration Rates Female
0-4	1,923	1,780		0.519	1.4	1.2	-0.6	-0.9
5-9	2,025	1,891			0.7	0.6	-0.4	-0.7
10-14	2,311	2,165			0.5	0.4	-0.2	-0.4
15-19	2,227	2,089	9		1.2	0.6	-0.5	-1.0
20-24	2,186	2,059	119		1.4	0.7	-0.6	-1.7
25-29	2,027	2,043	162		2.0	0.8	-1.0	-1.7
30-34	1,590	1,526	40		2.7	1.1	-0.8	-1.0
35-39	1,324	1,257	8		3.4	1.3	-0.5	-0.6
40-44	1,109	1,079	2		5.4	2.0	-0.3	-0.4
45-49	1,043	1,046			9.0	3.1	-0.2	-0.4
50-54	810	886			12.8	4.5	-0.2	-0.4
55-59	561	707			18.1	6.8	-0.2	-0.5
60-64	440	566			26.5	10.5	-0.2	-0.5
65-69	307	416			42.0	17.5	-0.2	-0.5
70-74	191	311			65.1	30.7	-0.2	-0.6
75+	155	371			141.1	86.9	-0.2	-0.3

ALL DATA FOR THE YEAR 1985

		Crude Oil	Natural Gas	Coal	Uranium	Electricity	Oil Refining	Gas T & D
1	Extracted Energy in EJ			0.4246		0.2088	1.3386	

		Crude Oil *			Natural Gas *		
		Grade 1	Grade 2	Grade 3	Grade 1	Grade 2	Grade 3
2	Well Head/Minemouth Prices						
3	Extraction Prices						
4	Production (EJ)						

		Coal *			
		Grade 1	Grade 2	Grade 3	
2	Well Head/Minemouth Prices	34.25			thou. Won/MT
3	Extraction Prices				
4	Production Prices				

* - may not have 3 grades in every country

		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
5	Resources (EJ):					
	Oil					
	Gas					
	Coal	13.93				
	Uranium					

6	Actual Retained Earnings Rate	36.9%	12,884	Billion Won
7	RE (0)	0.60		
8	Interest Rate	12.5%		

9	Total Corporate Income Tax Rate	4.8%	1,744	Billion Won
10	Other Taxes	0		

		Total	Male	Female	
11	Actual Labor Supply	14.97	9.137	5.833	Million Person
12	Working Age Population	28.489	13.779	14.71	Million Person
13	Average Annual Price of Labor	2,160.9	thou. Won/per.		
14	LB (0)	0.698			

15	Total Land Area	99,173	Km^2	99.173	1,000 Km^2
16	Actual Land Supply	27,425	Km^2	27.425	1,000 Km^2
17	Average Price of Land	8,293	Won/m^2		
18	R (0)	1.0			
19	Number of Households (x1000)	9,571			
20	Actual Household Land demand	1,533.4	Km^2		

		Lodging	Parks	Education	Industrial	Agriculture	Other
21	Share of Land Used For	0.015	0.000	0.002	0.004	0.226	0.752

22	Total Population (x1,000)	41,429	
23	Total Personal Income Tax Paid	1,418,600	Million Won

24	Total Household Savings	8,216,800	Million Won	Savings Rate	14.65%
25	S(0)	25%			
26	Savings Elasticity	0.39			

		Agriculture	EveryThing Else	Coal	Biomass	Electricity	Refined Oil	Refined Gas
27	Price Elasticity	-0.237	-1	-0.297		-0.5	-0.5	-0.5
28	Income Elasticity	0.436	0.6	-0.5		1.0	1.2	1.2