# An Econometric Analysis of the Interdependence among Economy, Energy, and Environment in China

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## 1. Introduction

After introducing the market mechanism into the economy, China has grown so rapidly by accepting the inflow of foreign direct investment aggressively. In the 1990's, the growth rate of China is prominent among East Asian countries (See the Figure1-1). Generally, rapid development of the economy requires large consumption of energy and then exhausts great amount of $CO_2$. Actually, the amount of $CO_2$ emission in China is the second largest in the world, though the top is the US (See the Figure 1-2). In term of the emission per GDP, no other countries exceed China. Then rapidly growing China would be required for more efficient use of energy and reduction of $CO_2$ emission from the point of the global environment.

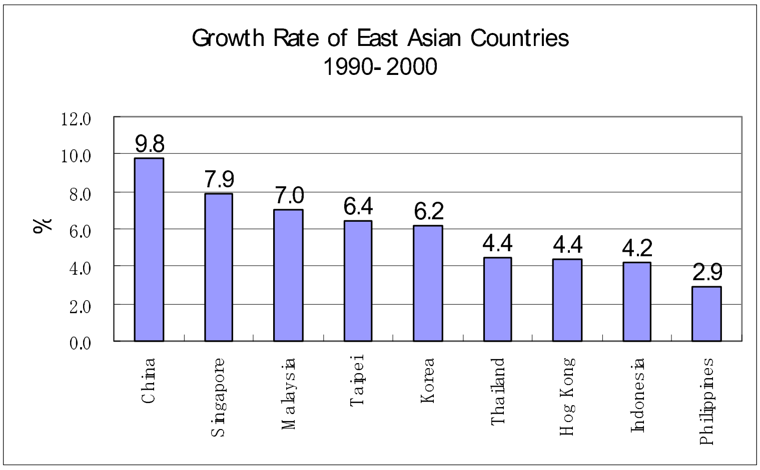
China has affluent coal resource and she has used it mainly as energy resource. The comparison of energy resource components among counties in the Figure 1-3 shows that China depends heavily on domestic coal for her energy uses. Continuous development in China might induce serious environmental problem, so it would be required the improvement of energy efficiency, and the demand shift from coal to natural gas, which has the competitiveness in the $CO_2$ emission per calorie among the fossil fuels. The economic cooperation with the developed countries and the high technology transfer to China seem important options in such situation.

Recently large-scale natural gas field was discovered in the Tarim Basin, the western region of China. On the other hand, economic development of east coastal region of China is remarkable, and there appears energy shortage and serious air pollution in the region. Therefore Chinese government conducted a construction plan of natural gas pipeline, which connected both regions, in February 2000. This plan started in 2001 aiming at the completion in 2004, and is a project to construct 4100km pipeline in total length from the Tarim Basin to Shanghai, and is estimated 146 billion Yuan in total construction. Natural gas is to be supplied by 12 billion cubic meters per year after the completion, and is to be increased to the amount of 19 billion cubic meters after 2010. The supply is estimated stable for 20 years or more and this plan is expected to contribute to the reduction of $CO_2$ emission in China.

On the other hand, the Clean Development Mechanism (CDM) is recognized as a system for which the developed country transfers some advanced technology to the developing country, and receives a certain amount of the carbon dioxide emission, which is reduced as a result in the developing country, as a ecology right of the developed country. The CDM seams attractive to both developed and developing countries, because the developed country would be able to gain a certain of $CO_2$ emission right by the lower cost than that attained in the home country, and because the developing country would be attained environmental improvement by the way of introducing high technology with lower cost otherwise expected. As a rule, the CDM projects, from large scale to small size, are considered with a private base. Among them, a natural gas thermal power plant would be a good example, because the power generation with the natural gas would promote the abandonment of coal thermal power stations, which are of the small and medium-sized scale and superannuated. As a result, this project will bring the energy shift from coal to the natural gas and reduce the $CO_2$ emission.

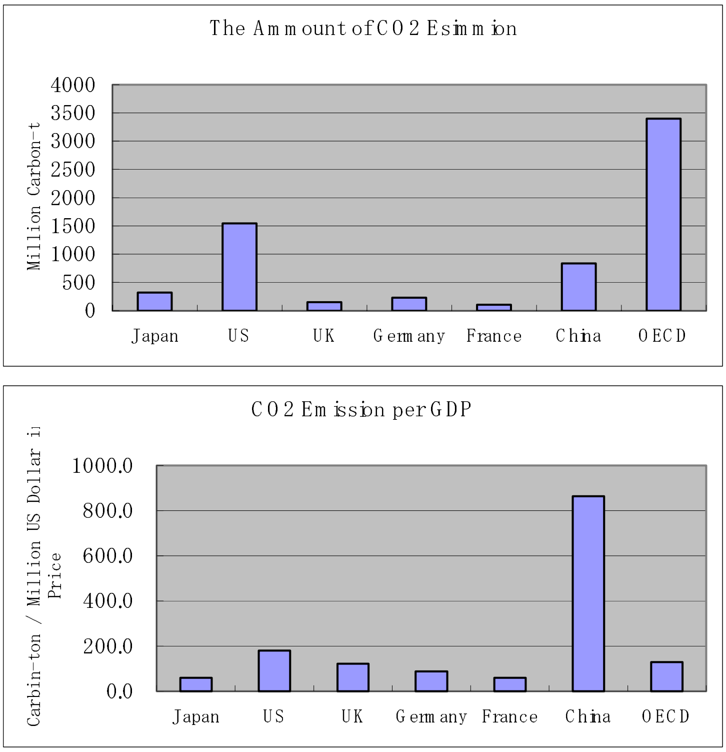
In this paper, we construct a multi-sectoral econometric model of Chinese economy, and discuss the economic impacts of the improvement of energy efficiency and the shift of energy demand within this model. In the next section, we explain the outline of our model, and discuss the performance of the model estimated. In section 3, we present a baseline project from 2000 to 2020, and in the section 4, we analyze some scenarios on the pipeline project of Chinese government and the natural gas thermal power plant project, which might be a candidate for the CDM.

Figure 1-1



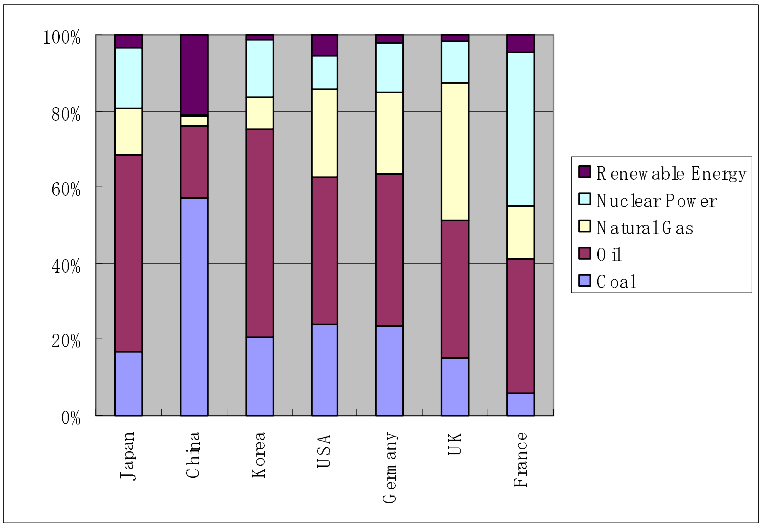

Source: 「Key Indicators of Developing Asian and Pacific Countries 2000」
Computed from the database of the Asia Development Bank.

Figure 1-2 $CO_2$ Emission of Each Country in 1999



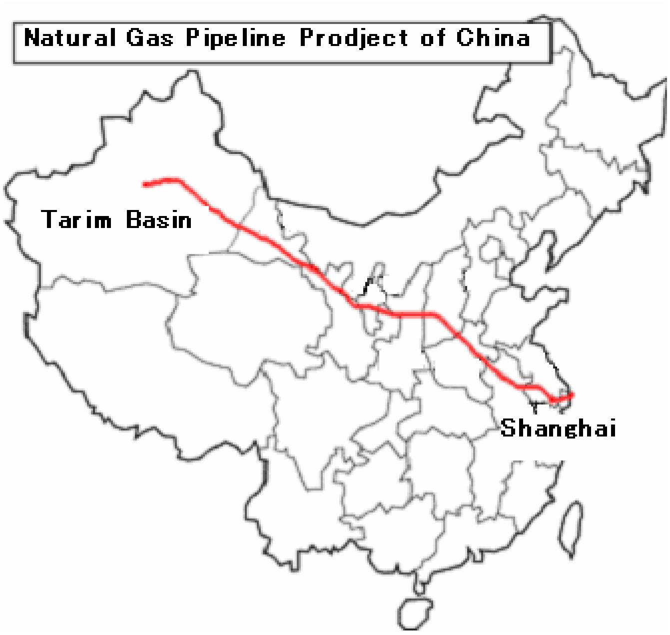

Source: IEA Energy Outlook

Figure 1-3 Primary Energy Composition of Each Counties in 1999




Source: IEA, Energy Balance of OECD Countries,
Energy Balance of Non-OECD Countries

Figure 1-4




Source: Home Page of Serchina Co.LTD with some modification

(http://news.searchina.ne.jp/2002/0705/general_0705_001.shtml)

## 2. Outline and Performance of the Model

The multi-sectoral econometric model of the Chinese economy constructed here is a demand-oriented model of a so-called Keynes-Leontief type. The sectors classified are 15 sectors shown in Table 2-1, and energy related sectors are three sectors: Coal, Oil and natural gas, and Electric power and heat supply. The database of the model covers from 1980 to 2000 for the sample periods. However, the estimation period differs for each equation mainly because of data availability. Because the sectoral time-series is not officially published data, so we estimated them by using the Chinese input output tables.[1]

### 2.1 Structure of the Model

The model structure of the macro and sectoral economy is drawn in the Figure 2-1. There appear expenditures of the final demand, production by sector, wage and prices, government expenditure and revenue, current balance and capital balance in the international transactions, and so on. Consumption is explained by income factor and the previous consumption expenditure as a consumption function. Disposable income cannot be obtained from the Chinese official statistics, then we make it by summing of sectoral value added subtracted from the sum of sectoral capital consumption as the proxy.

The investment expenditure contains the residential investment, the private investment for plant and equipment, and the government investment. This is explained by real GDP after subtracting the government investment and the foreign direct investment. The real GDP is determined as the sum of these expenditures of final demand. In our model, the export is treated as exogenous, and the import by sector is explained endogenously as the import demand function, in which the explanatory variables are domestic demand by sector and the relative price.

The average wage is explained by the overall productivity. The wage rate by sector is linked to this average wage. The employment by sector is estimated as the employment demand function, where the production by sector and real wage are main explanatory variables. However, the employment in the agriculture sector is explained in different way. That is, the employment in this sector is determined by subtracting the sum of non-agricultural employment from the total employment.

Our model contains the fundamental structure of the input-output model. The structure of demand-production determination is expressed as,

$$\mathbf{X} = \mathbf{D} + \mathbf{E} - \mathbf{M}$$

$$\mathbf{X} = \mathbf{AX} + \mathbf{FD} + \mathbf{E} - \mathbf{M}$$

where a product vector is $\mathbf{X}$, a domestic demand vector $\mathbf{D}$, a export vector $\mathbf{E}$, and a import vector $\mathbf{M}$. Here, $\mathbf{A}$ is an input coefficient matrix, and $\mathbf{FD}$ is a domestic final demand vector. On the other hand, the structure of price determination is expressed as,

$$\mathbf{P} = \mathbf{AD}'\mathbf{P} + \mathbf{AM}'\mathbf{PM} + \mathbf{V}$$

$$\mathbf{V} = \hat{\mathbf{X}}^{-1}\hat{\mathbf{L}}\mathbf{W} + \mathbf{O}$$

where a price vector is $\mathbf{P}$, an import price vector $\mathbf{PM}$, a value added ratio vector $\mathbf{V}$, transpose of a domestic input coefficient matrix $\mathbf{AD}'$, and transpose of an import input coefficient matrix $\mathbf{AM}'$. Here, $\hat{\mathbf{X}}^{-1}$ means the inverse of the diagonal matrix, whose diagonal elements are of the production vector. $\hat{\mathbf{L}}$ is a diagonal matrix, whose diagonal elements are employed persons by sector. $\mathbf{W}$ is a wage rate vector, $\hat{\mathbf{X}}^{-1}\hat{\mathbf{L}}\mathbf{W}$ is a unit wage cost vector, and $\mathbf{O}$ means a vector that relates to other cost.

To simplify the model, however, only one input-output table is contained in our model. In the base year, the above relations are strictly maintained, though they do not hold for the other years. So we need some adjustments mechanism to explain the discrepancies between the actual domestic demand, $\mathbf{D} = \mathbf{AX} + \mathbf{FD}$, and the computed domestic demand, $\mathbf{D^0} = \mathbf{A^0 X} + \mathbf{FD^0}$, which is gained assuming that the input coefficient and the distribution ratio of the domestic final demand in the base year do not change year to year. These discrepancies are explained by the change of relative prices in our model.

Also the prices are determined by the sum of the intermediate input cost and unit value added cost. However, if we apply fixed input coefficient to this relation, there appear the differences between the actual price and the price explained from the costs. In such case, we apply the regression the actual price on the computed price.

In our model, coal, oil, natural gas, and electricity are appeared in the energy sector[2], though the oil and natural gas are treated as one sector in the input-output sector. Figure 2-2 shows the causality among the variables in the energy sector.

At first, the total power generation is explained by the total demand adjusted on the inventory factor and net export. The export and import of electricity are treated as exogenous variables in the model, because they are small in scale. The total demand of electricity is calculated as the sum of industrial demands and household's demand. Each industrial demand for electricity is a function of the corresponding production or domestic demand and relative price factor. The trend factor is added in some equations. For the household's demand is also determined by consumption and the relative price factor. The power generation consists of hydraulic power, thermal power, and the other generation, which is mainly nuclear electric power. The nuclear generation is to be exogenous. The hydraulic generation explained as a function of total generation and trend factor, considering that some part of the total generation is filled by hydraulic generation. The remaining part of total generation is covered by the thermal generation.

Given the export and import as exogenous for coal, the coal product is explained by the total demand with the adjustment of inventory factor and net export. The total demand is determined by the sum of the industrial demand and household's demand. There are some coal demands for energy conversion. The coal demand for generation is linked to the thermal generation with the coal thermal generation ratio and the fuel efficiency of coal generation.

In this equation, the data for the coal thermal ratio and the efficiency ratio of coal thermal generation is obtained from the IEA energy database. According to this data, the coal thermal ratio in China is 90.53%, oil thermal ratio is 8.46%, and natural gas thermal is 1.02% in the year 2000. The fuel efficiency of generation is 33.26% for coal, 34.14% for oil, and 44.80% for natural gas in the same year.

For each industrial demand and household's demand for coal is determined as demand function, where the explanatory variables are the production or domestic demand and the relative price. In some equation, the trend factor is included.

The oil and natural gas sectors have almost same structure as the coal sector with some differences. The overall energy production is explained as definition, summing coal production, oil production, natural gas production, hydroelectric and nuclear power generation converted to same unit. The overall energy demand is explained by summing the sectoral demand and the household's demand. Computing the overall energy export in the same way, the overall energy import is determined as the overall demand plus the overall export minus the overall production. In our model, the overall energy import is connected to the oil import with subtraction of the coal import, which means the lack of energy is filled by the overseas oil.

Finally, the $CO_2$ emission is explained from the sum of demands for coal, oil, and natural gas, multiplied the emission coefficient respectively. [3] The activities of physical base in the energy sector are connected to the real product in the energy related sectors.

Figure 2-1 Structure of the Model

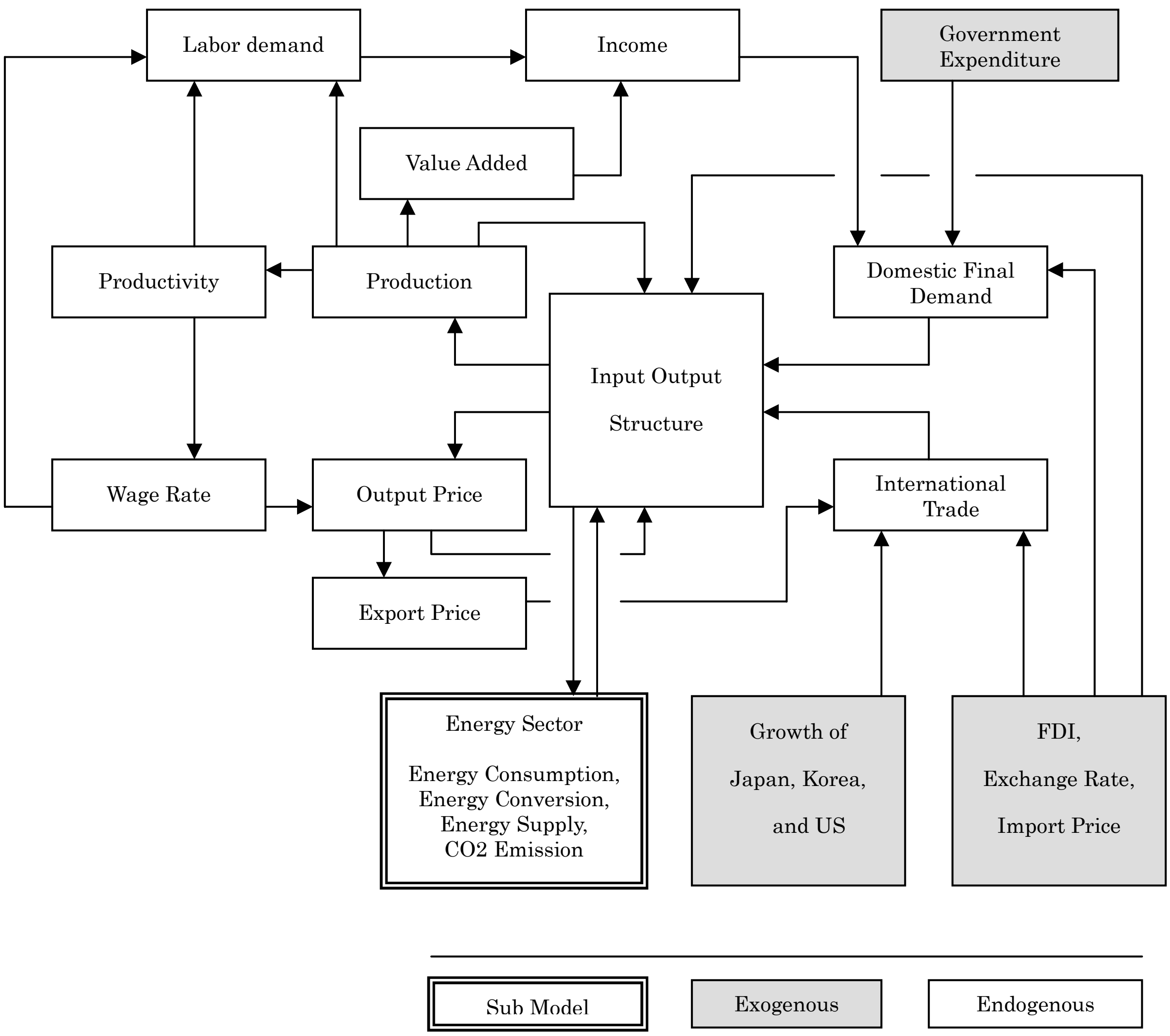
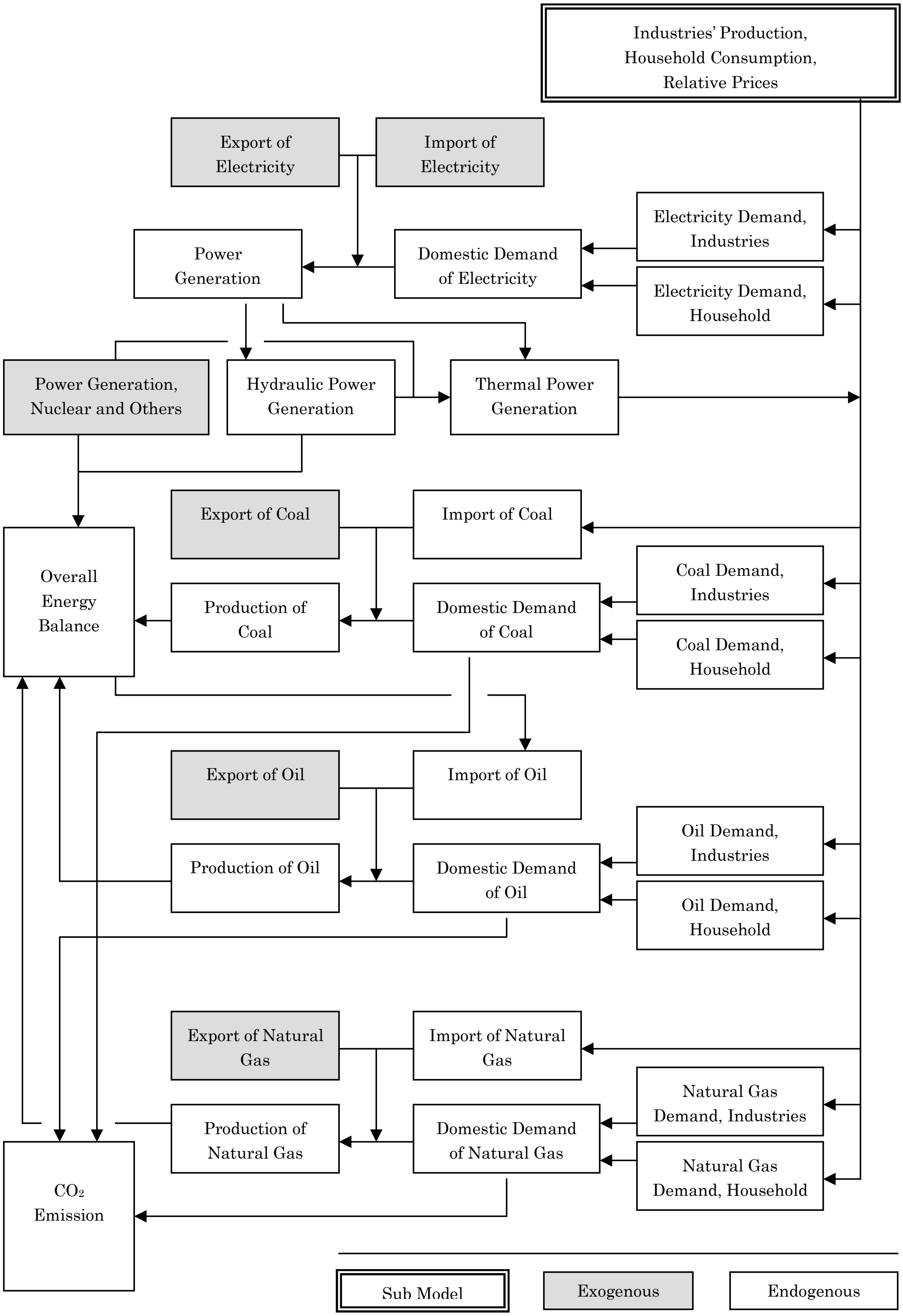


Figure 2-2 Flow Chart of the Energy Sector



2.2 The Performance of the model

We estimate the model using the time series data; the period 1981-2000 for macro equation, the period 1985-2000 for energy sector. The estimation methods are mainly ordinal least squares. The regression with autocorrelation in error term and the estimation with coefficient restrictions are applied in some equation.

Table 2-2 shows the mean absolute percentage error of main variables for the dynamic simulation from 1995 to 1999. We can evaluate the performance of the model from these values. Some variables in the table have a little bit large MAPE. However, the important variables have considerably low values in MAPE; for example the real GDP 1.90 %, the total of real product 1.59 %, the total of nominal value added 2.08 %, the deflator of GDP 2.15 %, the total employment 0.30 %. Then we can conclude that the model is enough for the explanation of the sample period.

Table 2-1 Sector Classification

| | Sectors |
|---|---|
| 1 | Agriculture |
| 2 | Mining |
| 3 | Food |
| 4 | Textile Product |
| 5 | Chemical Product |
| 6 | Non-metallic Mineral Product |
| 7 | Iron and Steel, and Non-ferrous Metal |
| 8 | Metal Product and Machinery |
| 9 | Other Manufacturing |
| 10 | Construction |
| 11 | Transportation and Communication |
| 12 | Service |
| 13 | Coal |
| 14 | Oil and Natural Gas |
| 15 | Electric Power, and Heat Supply |

Table 2-2 Performance of the Model

| Macro Variables | MAPE(%) | Real Product | MAPE(%) |
|---|---|---|---|
| Real GDP | 1.90 | Agriculture | 2.24 |
| Real Consumption | 1.73 | Mining | 17.30 |
| Real Government Consumption | 4.95 | Food | 4.44 |
| Real Investment | 1.80 | Textile Product | 4.06 |
| Real Export | 2.66 | Chemical Product | 4.69 |
| Real Import | 7.63 | Non-metallic Mineral Product | 9.95 |
| Nominal GDP | 2.74 | Iron and Steel, and Non-ferrous Met | 2.74 |
| Nominal Consumption | 0.93 | Metal Product and Machinery | 2.77 |
| Nominal Government Consumption | 5.44 | Other Manufacturing | 12.48 |
| Nominal Investment | 2.52 | Construction | 1.91 |
| Nominal Export | 2.00 | Transportation and Communication | 3.04 |
| Nominal Import | 9.13 | Service | 5.61 |
| GDP Deflator | 2.15 | Coal | 6.49 |
| Producer's Price Index | 1.89 | Oil and Natural Gas | 3.26 |
| Consumer's Price Index | 0.90 | Electric Power, and Heat Supply | 1.85 |
| Employment, Total | 0.30 | Total | 1.59 |

Table 2-2 Performance of the Model(Continued)

| Value Added | MAPE(%) | Product Deflator | MAPE(%) |
|---|---|---|---|
| Agriculture | 4.62 | Agriculture | 6.74 |
| Mining | 11.06 | Mining | 3.23 |
| Food | 9.22 | Food | 1.90 |
| Textile Product | 9.09 | Textile Product | 2.63 |
| Chemical Product | 5.23 | Chemical Product | 4.21 |
| Non-metallic Mineral Product | 9.17 | Non-metallic Mineral Product | 1.75 |
| Iron and Steel, and Non-ferrous Meta | 14.13 | Iron and Steel, and Non-ferrous Meta | 5.25 |
| Metal Product and Machinery | 2.27 | Metal Product and Machinery | 1.89 |
| Other Manufacturing | 18.79 | Other Manufacturing | 2.34 |
| Construction | 1.52 | Construction | 1.22 |
| Transportation and Communication | 7.22 | Transportation and Communication | 7.71 |
| Service | 3.51 | Service | 3.63 |
| Coal | 10.11 | Coal | 2.43 |
| Oil and Natural Gas | 9.41 | Oil and Natural Gas | 5.16 |
| Electric Power, and Heat Supply | 6.05 | Electric Power, and Heat Supply | 4.26 |
| Total | 2.08 | Average | 1.49 |

| Employment | MAPE(%) | Energy variables | MAPE(%) |
|---|---|---|---|
| Agriculture | 3.15 | Overall Energy Production | 2.98 |
| Mining | 4.65 | Overall Energy Export | 6.65 |
| Food | 9.02 | Overall Energy Import | 8.78 |
| Textile Product | 11.04 | Overall Energy Demand | 2.70 |
| Chemical Product | 11.33 | Coal Product | 3.23 |
| Non-metallic Mineral Product | 14.10 | Coal Demand | 3.12 |
| Iron and Steel, and Non-ferrous Meta | 14.15 | Coal Demand, Industry | 3.61 |
| Metal Product and Machinery | 16.17 | Coal Demand, Household | 5.65 |
| Other Manufacturing | 15.66 | Coal Demand, Power Generation | 2.36 |
| Construction | 2.81 | Oil Product | 5.51 |
| Transportation and Communication | 2.27 | Oil Demand | 2.61 |
| Service | 3.34 | Oil Demand, Industry | 2.54 |
| Coal | 4.27 | Oil Demand, Household | 4.62 |
| Oil and Natural Gas | 6.02 | Natural Gas Product | 3.26 |
| Electric Power, and Heat Supply | 3.35 | CO2 Emission | 2.66 |
| Total | 0.30 | | |

# 3 Baseline Prediction

## 3.1 The assumption of Prediction

In this section, we discuss on the baseline prediction from 2000 to 2020, which is to be used in the scenario analysis. The assumed values, adopted here for the exogenous variables, are expressed in the Table 3-1. These values are basically extracted from the recent trend from 1995 to 2000, with some adjustments, referring the preceding research of IEA and the Institute of Energy Economics, Japan(IEEJ).

We assume that the growth rate of real export is about 9.4 % for the first 10 years, and 6.45 % for the second 10 years. The net value of foreign direct investment will grow by 9.98 % and 10.0 % respectively. The import price will grow at 3 %, and exchange rate is to be fixed at the value of 2000, and the population growth rate is assumed to be 0.79 ～ 0.62 %.

We assume that the export and import of energy grow as fast as the past trend or do not change the level. The unit ratio of the natural gas to the production, which is exogenous in the model, is set for constant as the value of year 2000.

Table 3-2 shows the composition of the thermal power generation and fuel efficiency from 2000 to 2020, which are the values of China in the Energy Outlook of IEA. In this table, the coal thermal generation is dominant in the future, though the natural gas thermal generation is gradually growing. The share of coal generation is assumed to be 88.13 % in 2020. The fuel efficiencies of coal, oil, and natural gas are assumed to improve. The efficiency of natural gas is 50.0 %, and coal 37.34 %, and oil 34.97 %.

3.2 Characteristics of the Baseline

Table 3-3 shows the result of the main variables in the baseline forecast from 2000 to 2020, as average annual growth rates for two 10 years. The growth rates of actual data from 1995 to 2000 are also referred.

The growth rate of real GDP is 6.11% for the first ten years and 4.40% for the second ten years, which is a little bit low compared with the economic growth in 1990's. Referring to the standard forecast of IEA, the growth rate of real GDP is 6.0% for the period from 1997 to 2010, and 3.7% for 2010-2020 years. The simulation study of the IEEJ shows 7.1% growth for 2010-2020 years, and 6.1 % for 2010-2020 years. (See the Table 3-4.) Though the comparison among them is limited because the assumptions of prediction and the characteristics of the models are different, the growth rate of our model corresponds to the forecasted values of IEA and the IEEJ.

Figure 3-1 shows the amount of the real production by sector until 2020 and its composition, in which the values from 1995 to 1999 are actual data. Figure 3-2 shows employed persons by sector. Because we assume the expansion of exports in the metal product and machinery sector, the production in this sector is also growing faster than the other sectors. Moreover, the employment in the service sector expanses relatively, and its share reaches to 40% in 2000, though the employment in the agriculture sector decreases, and the farm worker's share shrinks from 50% to 40% for the twenty years. That is, the shift of employment from agricultural sector to the service sector is expected.

Table 3-5 shows the comparison of the primary energy supply. Its growth rate is 5.30% for the fist half and 3.01% for the latter half. The energy elasticity to GDP is 0.867 and 0.684 respectively. According to the forecast of IEA, the primary energy supply is 3.56% for the period 1997-2010, and 3.11 % for the period 2010-2020. The elasticity to GDP is about 0.59 and 0.84, respectively. The simulation of the IEEJ estimates 3.23% growth for 2000-2010 years, and 3.84% for 2010-2020. The elasticity to GDP is 0.45, and 0.63 respectively. The estimates of our model are a little bit high in the growth rate for the first half period, though almost same for the latter half period.

The primary energy supply is estimated to be 2.480 billion coal equivalent ton in 2020 in our model, which is a little bit lower than the estimates of IEA and IEEJ, 2.767 and 2.747 billion coal equivalent ton respectively. The total amount of generation in our model is 3.04 trillion KWh in 2020, which is also lower than the values of IEA and IEEJ, 3.69 and 4.22 trillion KWh respectively. The difference may partly stem from the assumption in our prediction that the household's demand for electricity decreases half in its growth of the past trend.

We estimate that the supply of natural gas is 0.069 billion coal equivalent ton, which is much lower than that of IEA and IEEJ, 0.159 and 0.261 billion coal equivalent ton respectively. Our forecasts are basically dependent on the past tendency of demand and consumption, and we do not contain policy consideration in the future introduction of the natural gas, which make possibly such differences.[4]

Table 3-6 shows the amount of the $CO_2$ emission corresponding to the energy production. It becomes 1.597 billion carbon ton in 2020, though it was 0.835 billion carbon ton in 2000. In the forecast of IEA, the amounts of $CO_2$ emission in 2020 is 1.753 carbon ton. The IEEJ predicts 1.668 billion carbon ton in 2020. Our estimate is a little bit low comparing to the other two results, because energy production and consumption become a little bit lower than the others.

Figure 3-3 shows $CO_2$ emission per real GDP in our model. The ratio of $CO_2$ emission decreases from 0.1 carbon ton per thousand Yuan in 2000 to 0.0688 carbon ton per thousand Yuan in 2020. The improvement in energy efficiency and the energy shift from coal to the natural gas and oil makes this ratio lower.

Table 3-1 Assumed Values of the Exogenous Variables

(%)

| Variables | 00/10 | 10/20 |
|---|---|---|
| Real Export | | |
| Agriculture | 10.00 | 5.00 |
| Mining | 0.50 | 2.00 |
| Food | 5.00 | 3.00 |
| Textile Product | 6.49 | 3.00 |
| Chemical Product | 8.00 | 5.00 |
| Non-metallic Mineral Product | 1.50 | 1.00 |
| Iron and Steel, and Non-ferrous Meta | 5.00 | 3.00 |
| Metal Product and Machinery | 11.00 | 8.00 |
| Other Manufacturing | 9.00 | 4.00 |
| Construction | 6.49 | 5.00 |
| Coal | 10.00 | 5.00 |
| Oil and Natural Gas | 0.00 | 0.00 |
| Electric Power, and Heat Supply | 2.00 | 1.00 |
| Total | 9.40 | 6.45 |
| Foreign Direct Investment, Net | 9.98 | 10.00 |
| Import Price (dollar base) | 3.00 | 3.00 |
| International Oil Price (dollar base) | 3.00 | 3.00 |
| Exchange Rate (Yuan/dollar) | 0.00 | 0.00 |
| Government Debt from foreign | -6.01 | -3.00 |
| Government Investment | 10.00 | 8.00 |
| Government Income outside taxation | 17.47 | 10.00 |
| Average Tax Rate | 3.44 | 2.26 |
| Population | 0.79 | 0.62 |

Table 3-2 Assumptions on Thermal Electric Generation

| | | 2000 | 2010 | 2020 |
|---|---|---|---|---|
| Power generation composition | Coal | 90.53 | 89.44 | 88.13 |
| | Oil | 8.46 | 7.58 | 6.76 |
| | Natural Gas | 1.02 | 2.98 | 5.11 |
| Power generation efficiency | Coal | 33.26 | 35.26 | 37.34 |
| | Oil | 34.14 | 33.65 | 34.97 |
| | Natural Gas | 44.80 | 50.00 | 50.00 |

Table 3-3 Average Growth Rates of Macro Variables

| % | 95-00 | 00-10 | 10-20 |
|---|---|---|---|
| Real GDP | 7.39 | 6.11 | 4.40 |
| Real Consumption | 7.95 | 6.45 | 3.85 |
| Real Government Consumption | 9.61 | 5.91 | 4.11 |
| Real Investment | 8.88 | 6.43 | 4.47 |
| Real Export | 20.65 | 8.97 | 6.31 |
| Real Import | 21.25 | 9.12 | 5.68 |
| Nominal GDP | 9.98 | 9.92 | 8.33 |
| Nominal Consumption | 10.69 | 10.09 | 8.05 |
| Nominal Government Consumptior | 12.39 | 9.53 | 8.32 |
| Nominal Investment | 10.67 | 11.14 | 9.51 |
| Nominal Export | 20.57 | 9.63 | 7.57 |
| Nominal Import | 16.94 | 11.72 | 9.06 |
| GDP Deflator | 2.41 | 3.60 | 3.76 |
| Producer's Price Index | 1.51 | 3.45 | 4.18 |
| Consumer's Price Index | 2.52 | 3.42 | 4.04 |
| Employment, Total | 0.91 | 0.59 | 0.66 |

## Table 3-4 Comparison of Real GDP

| Prediction of Our Model | Average Growth Rate (%) | | |
|---|---|---|---|
| | 1995-2000 | 2000-2010 | 2010-2020 |
| Real GDP | 7.39 | 6.11 | 4.40 |
| | 2005-2010 | 2000-2010 | 2010-2020 |
| Population | 0.89 | 0.79 | 0.62 |

| IEA World Energy Outlook 2000 | Average Growth Rate (%) | | |
|---|---|---|---|
| | 2000 | 1997-2010 | 2010-2020 |
| Real GDP | 7.00 | 6.00 | 3.71 |
| | 1971-1997 | 1997-2020 | |
| Population | 1.50 | 0.70 | |

| Institute of Energy Economics, Japan | Average Growth Rate (%) | | |
|---|---|---|---|
| | 1998-2000 | 2000-2010 | 2010-2020 |
| Real GDP | 7.30 | 7.10 | 6.10 |
| | 1998-2000 | 2000-2010 | 2010-2020 |
| Population | 1.00 | 0.75 | 0.62 |

## Figure 3-1 Real Production by Sector

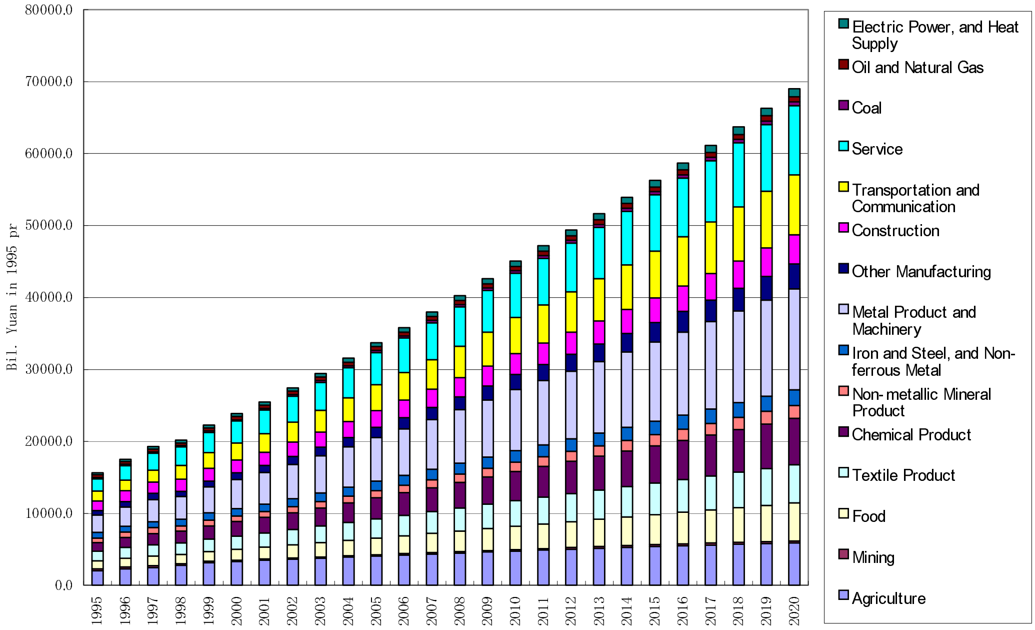


Figure 3-2 Employment by Sector

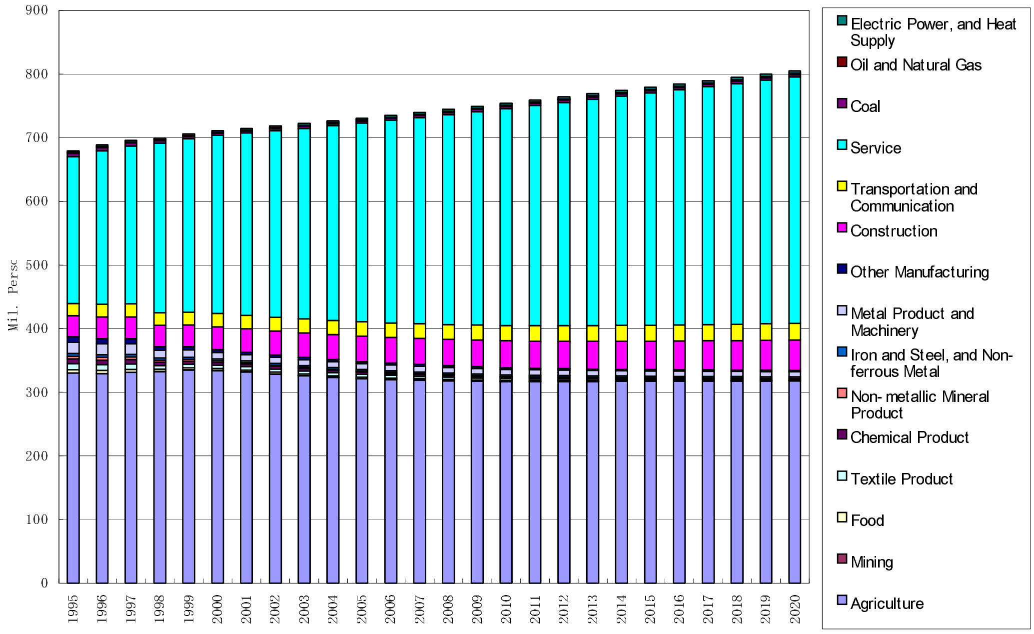



Table 3-5 Comparison of Primary Energy Supply

Prediction of Our Model

| | Million ton-Oil Equivalent | | | Million ton-Coal Equivalent | | | Average Growth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000-2010 | 2010-2020 |
| Total Primary Energ | 770 | 1290 | 1736 | 1100 | 1843 | 2480 | 5.30 | 3.01 |
| Coal | 477 | 810 | 1064 | 682 | 1158 | 1520 | 5.43 | 2.76 |
| Oil | 222 | 355 | 497 | 317 | 507 | 710 | 4.81 | 3.43 |
| Natural Gas | 22 | 35 | 49 | 32 | 49 | 69 | 4.41 | 3.45 |
| Others | 48 | 91 | 127 | 69 | 129 | 181 | 6.50 | 3.44 |
| | (Billion Kwh) | | | | | | | |
| Electricity | 13158 | 21274 | 30383 | 162 | 261 | 373 | 4.92 | 3.63 |

IEA World Energy Outlook 2000

| | Million ton-Oil Equivalent | | | Million ton-Coal Equivalent | | | Average Growth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 1997 | 2010 | 2020 | 1997 | 2010 | 2020 | 1997-2010 | 2010-2020 |
| Total Primary Energ | 905 | 1426 | 1937 | 1293 | 2037 | 2767 | 3.56 | 3.11 |
| Coal | 662 | 940 | 1192 | 946 | 1343 | 1703 | 2.73 | 2.40 |
| Oil | 201 | 371 | 541 | 287 | 530 | 773 | 4.83 | 3.84 |
| Natural Gas | 21 | 56 | 111 | 30 | 80 | 159 | 7.84 | 7.08 |
| Others | 21 | 59 | 93 | 30 | 84 | 133 | 8.27 | 4.66 |
| | (Billion Kwh) | | | | | | | |
| Electricity | 11630 | 24080 | 36910 | 143 | 296 | 453 | 5.76 | 4.36 |

Institute of Energy Economics, Japan

| | Million ton-Oil Equivalent | | | Million ton-Coal Equivalent | | | Average Growth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000-2010 | 2010-2020 |
| Total Primary Energ | 961 | 1320 | 1923 | 1372 | 1885 | 2747 | 3.23 | 3.84 |
| Coal | 684 | 829 | 1076 | 977 | 1184 | 1537 | 1.94 | 2.64 |
| Oil | 230 | 335 | 513 | 329 | 479 | 733 | 3.83 | 4.34 |
| Natural Gas | 23 | 82 | 183 | 33 | 117 | 261 | 13.53 | 8.36 |
| Others | 23 | 73 | 151 | 33 | 105 | 216 | 12.11 | 7.50 |
| | (Billion Kwh) | | | | | | | |
| Electricity | 12455 | 22283 | 42200 | 153 | 274 | 518 | 5.99 | 6.59 |

Table 3-6 Comparison of $CO_2$ Emission

Prediction of Our Model

| | Million ton-CO2 | | | Million ton-C | | | Average Grwoth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 1997-2010 | 2010-2020 |
| CO2 Emission | 3061.8 | 4393.3 | 5855.9 | 835.0 | 1198.2 | 1597.1 | 3.68 | 2.92 |
| Coal | 2335.2 | 3221.5 | 4212.9 | 636.9 | 878.6 | 1149.0 | 3.27 | 2.72 |
| Oil | 673.8 | 1088.9 | 1525.5 | 183.8 | 297.0 | 416.0 | 4.92 | 3.43 |
| Natural Gas | 52.8 | 82.9 | 117.5 | 14.4 | 22.6 | 32.1 | 4.61 | 3.56 |

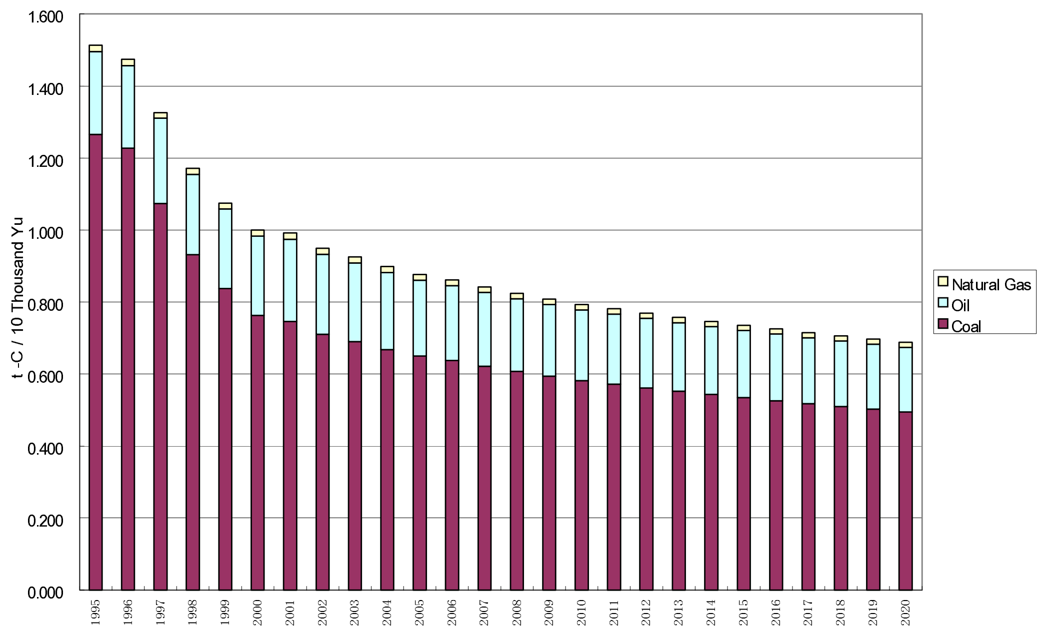
IEA World Energy Outlook 2000

| | Million ton-CO2 | | | Million ton-C | | | Average Grwoth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 1997 | 2010 | 2020 | 1997 | 2010 | 2020 | 1997-2010 | 1997-2020 |
| CO2 Emission | 3162.0 | 4822.0 | 6426.0 | 862.4 | 1315.1 | 1752.5 | 3.30 | 2.91 |
| Coal | 2548.0 | 3638.0 | 4624.0 | 694.9 | 992.2 | 1261.1 | 2.78 | 2.43 |
| Oil | 567.0 | 1060.0 | 1555.0 | 154.6 | 289.1 | 424.1 | 4.93 | 3.91 |
| Natural Gas | 46.0 | 124.0 | 247.0 | 12.5 | 33.8 | 67.4 | 7.93 | 7.13 |

Institute of Energy Economics, Japan

| | Million ton-CO2 | | | Million ton-C | | | Average Grwoth Rate (%) | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2010 | 2020 | 2000 | 2010 | 2020 | 2000-2010 | 1997-2020 |
| CO2 Emission | 3361.5 | 4381.3 | 6114.6 | 916.8 | 1194.9 | 1667.6 | 2.68 | 3.39 |
| Coal | 2709.7 | 3281.7 | 4260.7 | 739.0 | 895.0 | 1162.0 | 1.48 | 2.65 |
| Oil | 597.7 | 905.7 | 1426.3 | 163.0 | 247.0 | 389.0 | 3.25 | 4.65 |
| Natural Gas | 55.0 | 194.3 | 429.0 | 15.0 | 53.0 | 117.0 | 10.20 | 8.24 |

Figure 3-3 $CO_2$ Emission per Real GDP



## 4 Some Scenario Analysis

In this section, we discuss the following two simulations.

Case-1: The pipeline project of natural gas

Case-2: The construction of natural gas power stations

In these simulations, we use the baseline prediction, which is explained in the previous section, for 20 years from 2000 to 2020.

### 4.1 The Pipeline Project of Natural Gas

China government estimates that the cost of the pipeline project from the Tarim Basin to Shanghai of China is about 140 billion Yuan, which is 136.25billion Yuan in 1995 market price. We conduct the scenario of this project.

The construction period of this project is 4 years from 2002 to 2005. So we divide the total cost into each year, assuming that the cost of each year is same, that is 34 billion Yuan per year. According to the government plan, 90 percent of the total cost is for the purchase of equipment and materials, 65 percent of which is to be provided from the domestic market. Considering this situation, we assume the distribution ratios of the investment as in the Table 4-1. The scale of this investment, amount of which is 34 billion Yuan, is about 0.3% of GDP in the baseline forecast.

On the other hand, this project is to be completed in 2005, and the natural gas is supplied after that year. It is assumed that 12 billion cubic meters of natural gas is supplied at first, and that the supply will increase to 19 billion cubic meters after 2010. We assume that the natural gas is consumed in four sectors, electric power, chemical, transportation, and household as shown in Table 4-2. It is thought that the coal consumption is replaced at the same amount of the natural gas introduced in the calorie base. However, oil will be reduced in the transportation sector. Moreover, the difference of power generation efficiency between natural gas thermal power generation and coal thermal power generation is considered in the electric power sector.

Figure 4-1 shows the GDP changes from the baseline case. The case 1a shows the effect of increased investment, which expands GDP by the amount of 25-30 billion Yuan for the invested period. The effect on GDP has concentrated in this period. The investment multiplier is about 1.07-1.28, because the amount of domestic investment is 23.46 billion Yuan per year. This effect disappears soon after the completion of the pipeline.

On the other hand, the Case 1b shows the effect after the completion of the pipeline. A slightly negative influence on GDP is seen. We can observe the overall effect in Case 1. The multiplier effect of the investment works and there is a positive effect on

GDP until 2005. However, the deflationary effect by the decreased coal demand becomes predominant after the year.

Figure 4-2 shows the changes in the production by sector from the baseline for the year 2005, 2010, and 2020. The primary metal sector, machinery sector, construction, transportation and communication, and service sector are received positive effects in 2005, when investment is enlarged. On the other hand, the natural gas supply starts in 2005, and the demand shift effect of the natural gas infiltrates in 2010 and 2020. The production of machinery sector, transportation and communication, and service sector will be decreased in relation to the production decrease in the coal industry.

Figure 4-3 shows the difference of the amount of the $CO_2$ emission of each case from the baseline. When energy demand shift happens from the coal to the natural gas, the Case 1b shows that the amount of the $CO_2$ emission decreases, though the $CO_2$ emission increases in accordance to the investment demand expansion, which can be seen in the Case 1a. When the natural gas begins to be used, $CO_2$ is gradually reduced, though $CO_2$ increases at the project investment period, which Case 1 indicates what happen if two effects piles up.

Table 4-1 Distribution of the Investment demand

| Sectors | share | domestic | import |
|---|---|---|---|
| Agriculture | 0.00 | 0.00 | 0.00 |
| Mining | 0.00 | 0.00 | 0.00 |
| Food | 0.00 | 0.00 | 0.00 |
| Textile Product | 0.00 | 0.00 | 0.00 |
| Chemical Product | 0.00 | 0.00 | 0.00 |
| Non-metallic Mineral Product | 0.00 | 0.00 | 0.00 |
| Iron and Steel, and Non-ferrous Metal | 0.70 | 0.46 | 0.25 |
| Metal Product and Machinery | 0.20 | 0.13 | 0.07 |
| Other Manufacturing | 0.00 | 0.00 | 0.00 |
| Construction | 0.07 | 0.07 | 0.00 |
| Transportation and Communication | 0.01 | 0.01 | 0.00 |
| Service | 0.02 | 0.02 | 0.00 |
| Coal | 0.00 | 0.00 | 0.00 |
| Oil and Natural Gas | 0.00 | 0.00 | 0.00 |
| Electric Power, and Heat Supply | 0.00 | 0.00 | 0.00 |
| Total | 1.00 | 0.69 | 0.32 |

Table 4-2 Sectoral Shares in Natural Gas Consumption

| Stecors | 2005 | 2010 | 2020 |
|---|---|---|---|
| Electric Power, and Heat Supply | 0.60 | 0.60 | 0.60 |
| Chemical Product | 0.20 | 0.20 | 0.20 |
| Transportation and Communication | 0.10 | 0.10 | 0.10 |
| Household | 0.10 | 0.10 | 0.10 |
| Total | 1.00 | 1.00 | 1.00 |

Figure 4-1 Effect on Real GDP

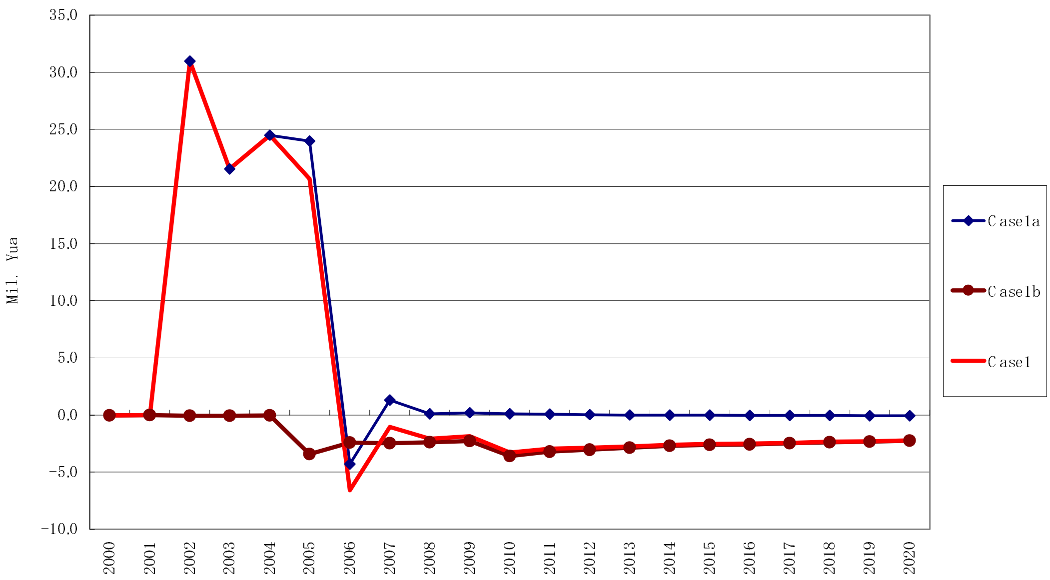



Figure 4-2 Effect on Real Production by Sector

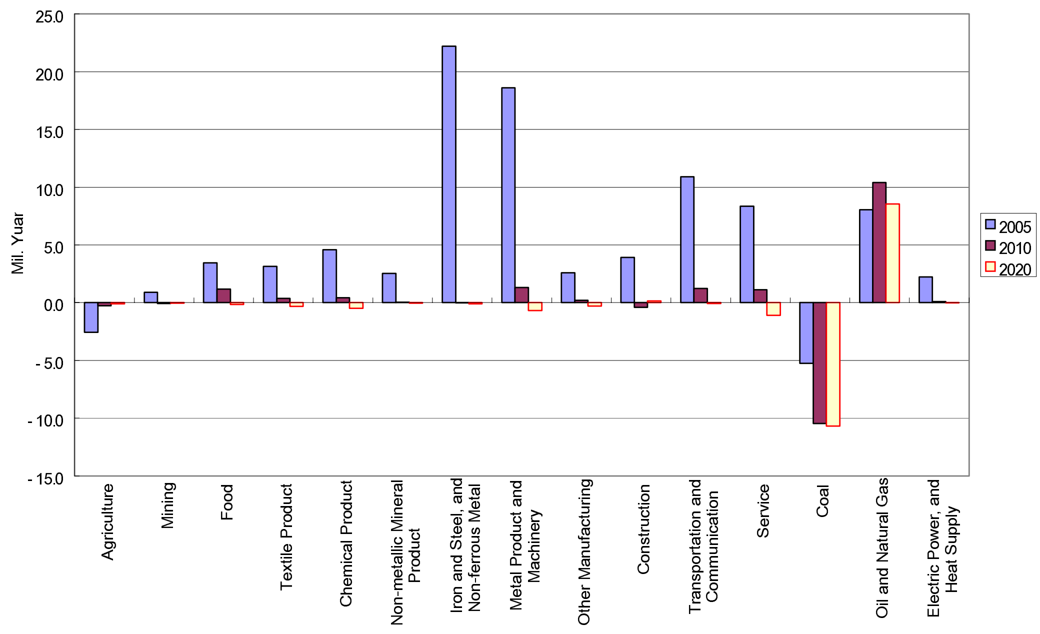
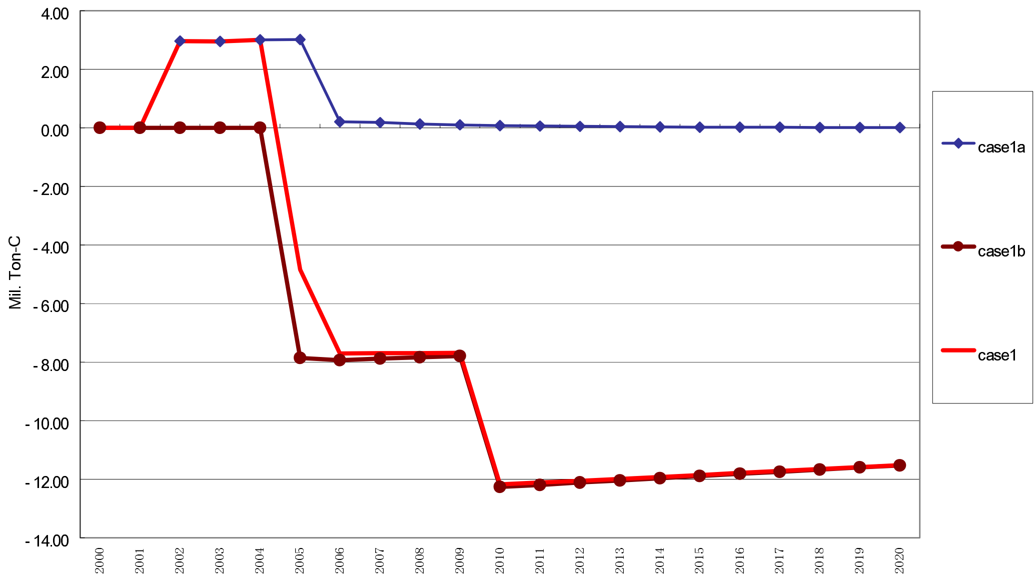


Figure 4-3 Changes in $CO_2$ Emission




4.2 The Construction of Natural Gas Thermal Generation Stations

Here we discuss on the influence of the construction of the natural gas thermal stations, which is well-known as a candidate of the CDM activities. The supply of electricity from the natural gas thermal station will reduce that from the coal power generation, because of the advantage in fuel efficiency. As a result, that makes fuel shift from coal to natural gas in the generation process.

From the previous scenario, we find that the shift from coal to the natural gas brings the society $CO_2$ reduction immediately. However, at the same time, investment demand causes the society additional $CO_2$ emission. Similar is expected for this case. It becomes a problem whether the effect of the $CO_2$ reduction is large still even if the investment effect is considered.

According to the research of the Energy Research Institute of China, the construction cost of the typical natural gas thermal power plant, which has ability to supply 42 KWh per year, is estimated 4.2 billion Yuan. The scenario will be made here based on this information.

Here, to supply 1% of the amount of power generation in 2010 in our baseline, which is about 21 billion KWh, five thermal power plants, stated above, will be newly built. The total construction cost is assumed here to be 21 billion Yuan, which becomes 20.44 billion Yuan in 1995 market price.

The construction period of five power plants is assumed 5 years from 2005 through 2009. Then, 4.088 billion Yuan will be invested each year. Power generation will begin after 2010. Then 11 years until 2020 are evaluated here for this purpose.

Natural gas thermal power generation will supply 21 billion KWh of electricity per year. On the other hand, the amount of power generation of coal thermal power generation is decreased, and the coal consumption is reduced as a result. The power generation efficiency of natural gas thermal power is assumed to be 50%, and the efficiency of coal thermal power generation is assumed same as set by the baseline forecast.

We assume that 80% of the investment expenditure is machinery products, which are machines related to power generation, 15 % is construction, 3% transport, and 2% service, as shown in Table 4-3. In addition, 35% of the machinery demand is assumed to leak as import demand, and 65% is domestic demand. It is thought as a whole that 72% of the amount of the investment is domestic.

Figure 4-4 shows the influence on real GDP. The investment brings positive effect on GDP, though the demand shift in energy contributes a negative effect after electricity is supplied by the natural gas thermal generation. This pattern is almost same as the scenario of the previous scenario, though these effects have the difference in the scale.

Figure 4-5 shows the effect on the production by sector. The influence on the machinery sector is the largest, and construction and transportation communication sector follows. Moreover, the coal production is reduced and the natural gas production increases after the natural gas generation starts. A lot of sectors receive a negative influence, though they are not so large.

Figure 4-6 shows the changes in the amount of the $CO_2$ emission. The increase in 0.16-0.18 million Carbon-ton a year is observed in the invested periods, though the decrease of about 3.0-3.2 million Carbon-ton a year is seen after the generation starts.

Table 4-3 Distribution of the Investment Demand

| Sectors | share | domestic | import |
|---|---|---|---|
| Agriculture | 0.00 | 0.00 | 0.00 |
| Mining | 0.00 | 0.00 | 0.00 |
| Food | 0.00 | 0.00 | 0.00 |
| Textile Product | 0.00 | 0.00 | 0.00 |
| Chemical Product | 0.00 | 0.00 | 0.00 |
| Non-metallic Mineral Product | 0.00 | 0.00 | 0.00 |
| Iron and Steel, and Non-ferrous Meta | 0.00 | 0.00 | 0.00 |
| Metal Product and Machinery | 0.80 | 0.52 | 0.28 |
| Other Manufacturing | 0.00 | 0.00 | 0.00 |
| Construction | 0.15 | 0.15 | 0.00 |
| Transportation and Communication | 0.03 | 0.03 | 0.00 |
| Service | 0.02 | 0.02 | 0.00 |
| Coal | 0.00 | 0.00 | 0.00 |
| Oil and Natural Gas | 0.00 | 0.00 | 0.00 |
| Electric Power, and Heat Supply | 0.00 | 0.00 | 0.00 |
| Total | 1.00 | 0.72 | 0.28 |

Figure 4-4 Effect on Real GDP

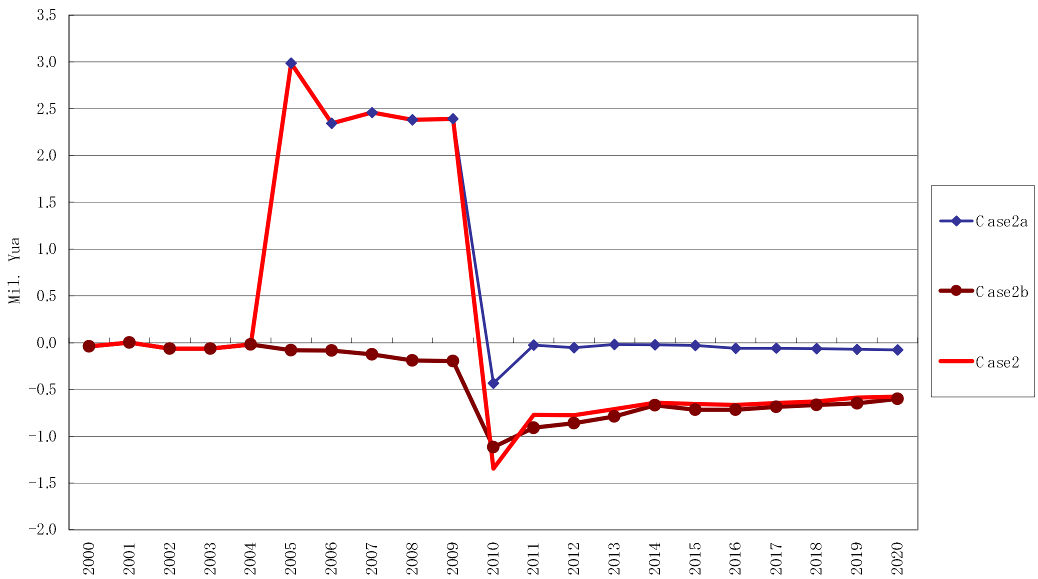


Figure 4-5 Effect on Real Production

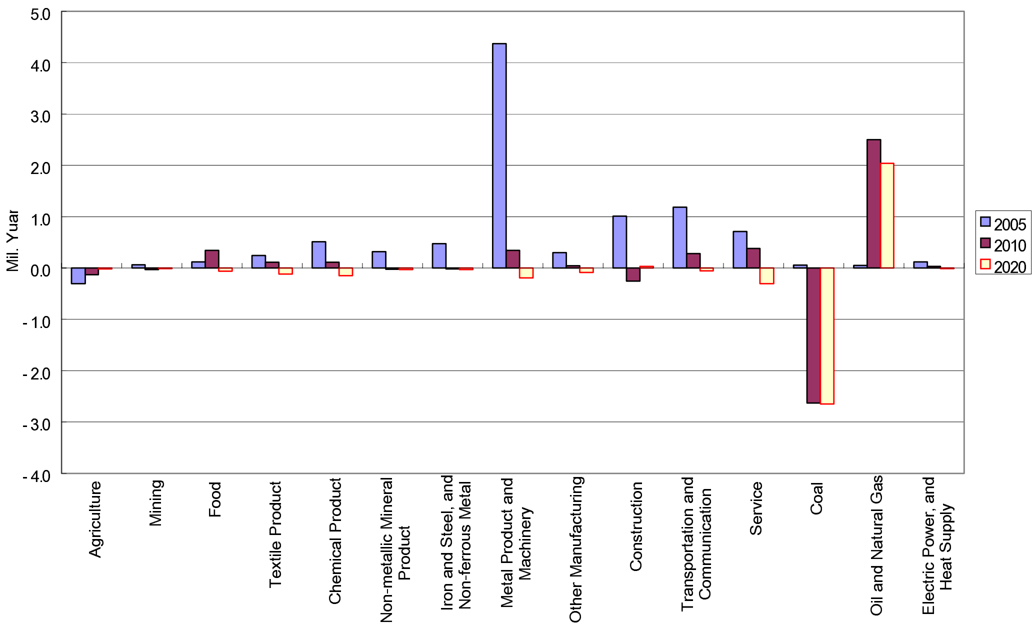
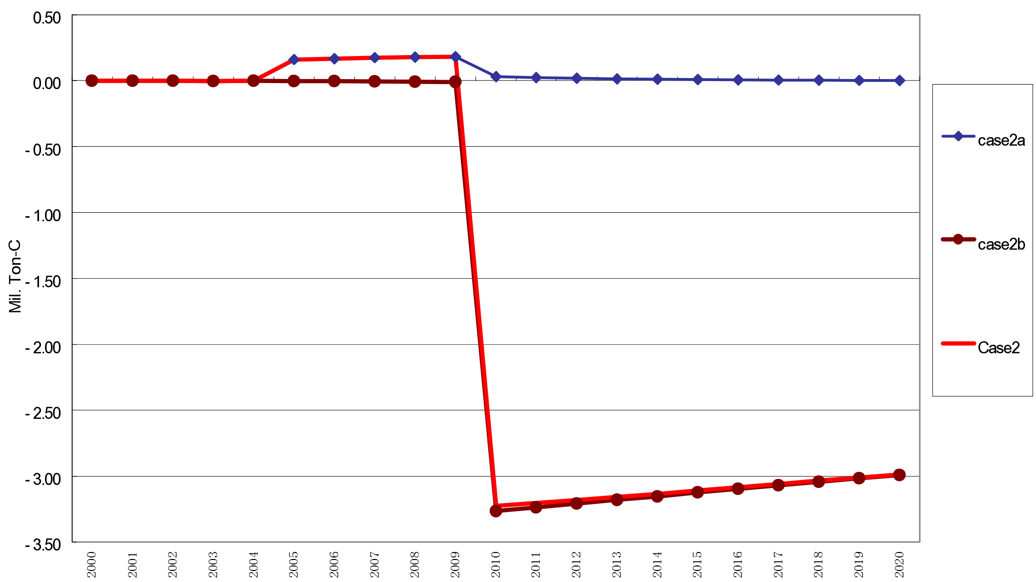



Figure 4-6 Changes in $CO_2$ Emission




4.3 Comparison of $CO_2$ Emissions and its Costs

Figure 4-7 compares the total amount of the $CO_2$ emission in each scenario. The pipeline project reduces 170.11 million carbon-ton of $CO_2$ emission, though the pipeline investment increases 12.94 million carbon-ton of $CO_2$. As a whole, the expected reduction is 157.04 million carbon-ton of $CO_2$. On the other had, the $CO_2$ reduction in the natural gas thermal power plant project is expected 34.43 million carbon-ton, though increase of 0.97 million carbon-ton is brought by the plant investment. In this case, the total effect is considered 33.33 million carbon-ton of $CO_2$ as a whole.

Table 4-4 shows comparison of the effects of the $CO_2$ reduction. The amount of the $CO_2$ reduction in the table means the total amount of $CO_2$ reduction, which is same value in Figure 4-7. Carbon-ton values are converted into ton-$CO_2$. The reduction cost means the initial investment cost of each project. The unit reduction costs, which are costs per $CO_2$ reduced, are evaluated as Yuan, Yen, and US dollar.[5]

Moreover, "Direct effect of the reduction" in the table means the evaluated value as the effect of the $CO_2$ reduction obtained directly in the sector, which is assumed to shift the demand from the coal (partially the oil) to the natural gas by each scenario. On the other hand, these changes brings certain influence to not only a sector concerned but also other sectors through the interdependence of production among sectors. The amount of the reduction, which is brought in the model simulation, is called "Total effect of the reduction" here. This effect is divided in two in the table. One is the case (Case1b, Case2b) to evaluate the effect of demand shift from the coal to the natural gas, and the other (Case1, Case2) to consider not only the demand shift of energy but also the effect of the investment.

"Direct effect of the reduction" in the pipeline project is estimated 28.51 US dollar per $CO_2$-ton, and that of the natural gas thermal power plant project becomes 20.98 US dollar per $CO_2$-ton. The difference between them is a little bit large, partly because the sector, in which the demand shift in energy directly appears, is not same. In the former project, not only the electricity sector but also chemical, transportation, and household changes their demand of energy mix, though the only electricity sector concerns in the latter project. The effect on the electricity sector is expected large in $CO_2$ reduction.

On the other hand, seeing the "Total effect of the reduction", the unit reduction cost becomes a little bit lower than the case of “Direct effect of the reduction”. For the pipeline project, the cost is estimated 28.06 US dollar per $CO_2$-ton, though it rises further to 30.39 US dollar per $CO_2$-ton, when we add the effect of the investment. It becomes 20.79 US dollar per $CO_2$-ton, 21.48 US dollar per $CO_2$-ton respectively for the natural gas thermal power plant project.

The demand shift from coal to the natural gas increases the natural gas production, while the coal production is decreased. These changes in production affect the other production through changes in the demand of intermediate input and the relative prices. It is shown that such changes work the entire economy at the direction where the effect of $CO_2$ reduction is strengthened. In addition, investment of the project causes additional $CO_2$ emission. The $CO_2$ reduction cost of the society as a whole rises when we consider this effect.

It should be noted that the whole life of each project was not considered. The costs obtained are values evaluated in our simulation period from 2000 to 2020. Therefore, each reduction cost has the possibility to become lower, generally considering the period of durability longer than these years.[6]

Figure 4-7 The Sum of $CO_2$ Emission from 2000 through 2020

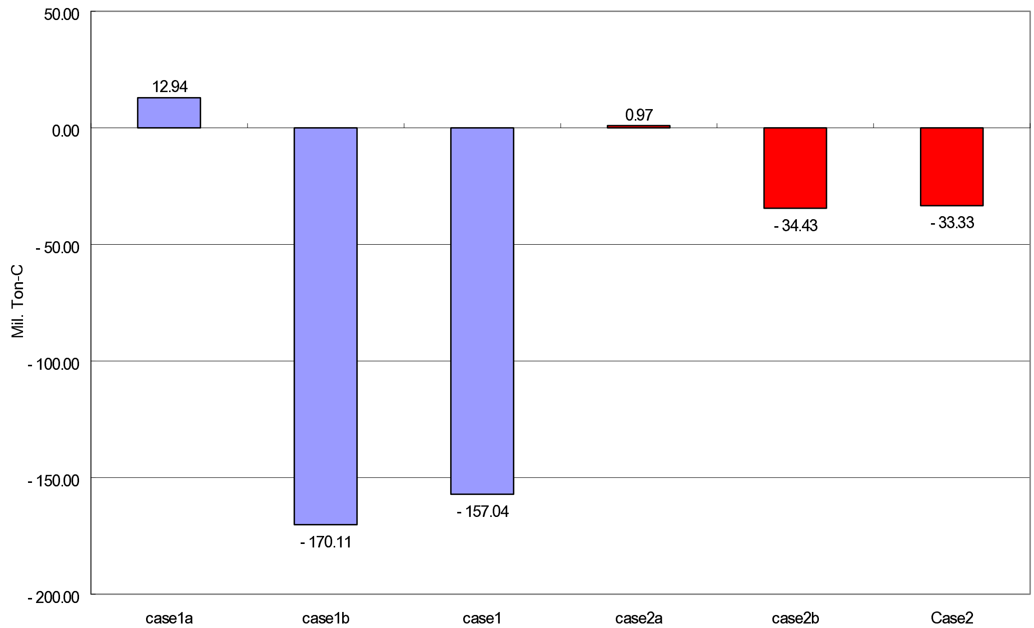



Table4-4 Comparison of the Reduction Cost of $CO_2$ Emission

| | | | CO2 Reduction | | Reduction Cost | Unit Reduction Cost | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mil. t-C | Mil. t-CO2 | Bil. Yuan | Yuan/ t-CO2 | Yen/ t-CO2 | Dollar/ t-CO2 |
| Pipeline Project | Direct Effect | | 167.39 | 613.75 | 140.0 | 228 | 3,422 | 28.51 |
| | Total Effect | Demand Shift Only | 170.11 | 623.74 | 140.0 | 224 | 3,367 | 28.06 |
| | | Demand Shift and Investment | 157.04 | 575.80 | 140.0 | 243 | 3,647 | 30.39 |
| Natural Gas Electric Power Plant Project | Direct Effect | | 34.13 | 125.14 | 21.0 | 168 | 2,517 | 20.98 |
| | Total Effect | Demand Shift Only | 34.43 | 126.25 | 21.0 | 166 | 2,495 | 20.79 |
| | | Demand Shift and Investment | 33.33 | 122.22 | 21.0 | 172 | 2,577 | 21.48 |

5 Concluding Remarks

Our simulation aims two targets. The one is to predict the growth of Chinese economy until 2020, and the other is to evaluate the effect of two possible projects on the Chinese economy and environment.

According to our prediction, China will continue to grow at relatively high rate, through the growth rate will decline gradually to less than 5 percent per year. The amount of real GDP in 2020 will enlarge to 2.78 times of the amount in 2000. The overall energy demand in 2020 will increase to 1.95 times of the amount in 2000. Though the efficiency of energy use will increase, the amount of energy demand will continue to rise, which will induce more $CO_2$ emission. The emission will grow to 1.91 times in volume from 2000 to 2020.

The impact analyses of the pipeline project and the thermal power plant, both of which relates to the natural gas usage, suggest several points. The pipeline project, which we evaluate in out model, does not bring so large impact on the macro economy of China as a whole, in the sense that the project changes the future growth path of the economy. This is simply because the investment of the project is only 0.3% scale of the GDP. Off course, the investment of the projects induces positive impacts on the economy. The effect is limited for the period, when the investment occurs, and the production in metal and machinery industries, which product capital goods, increases largely. However, the energy shift in both projects brings slightly negative impact on the production as a whole, mainly because the difference in efficiency induces more coal reduction.

The $CO_2$ emission is increased through the expansionary period. On the other hand, the demand shift from the coal to the natural gas has the effect of reducing $CO_2$ emission, because the natural gas has high efficiency in generating the power and low CO2 exhaust. Though these two effects are offsetting, the $CO_2$ reduction is enough larger for the simulation periods throughout. A similar effect is basically expected as for natural gas thermal power plant project, though the scale of impacts differs. The direct cost of CO2 reduction is estimated 28.51 US dollar per $CO_2$-ton for the pipeline project, and 20.98 US dollar per $CO_2$-ton for the power plant project. However, the cost increases to 30.39 US dollar per $CO_2$-ton, and 21.48 US dollar per $CO_2$-ton respectively for the economy as a whole.

These results are tentative in the sense that our model simulation is limited in the demand aspects and that the effects of changes supply condition and improvement of productivity are not sufficiently considered. These issues remain to be solved by the future extension of out model. At the same time, we should consider the international aspects of interdependency mainly among East Asian countries.

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Footnote

1. The input-output tables are published by the Center of Statistics, China Government, for years 1985, 1987, 1990, 1992, 1995, and 1997. We make the tables of 15 sectors from these tables, and estimate the time series data with some interpolations.

2. Coal, oil and natural gas are measured as the coal-equivalent ton. The conversion ratios, which we use, are in the following table.

| | Oil | Coal | Electricity | Natural Gas |
|---|---|---|---|---|
| Unit | (10 000 tons) | (10 000 tons) | (100 million kwh) | (100 million Cubic Meters) |
| Calorific value | 10000 | 7000 | 860 | 9310 |
| | kcal/ kg | kcal/ kg | kcal/ kWh | kcal/ m3 |
| Standard coal conversion | 1.429 | 1.000 | 0.123 | 1.330 |
| Conversion ratio | 0.7 | 1 | 0.814 | 0.075 |

Source: Energy Statistics of China (1997-1999)(2001)

3. The $CO_2$ emission ratios by energy are in the following table.

| | Coal | Oil | Natural Gas |
|---|---|---|---|
| Exhaust coefficient | 1.080(t-c/toe) | 0.837(t-c/toe) | 0.641(t-c/toe) |

Source: Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories

4. The energy research institute of China estimated the future demands of the natural gas, which are shown in the following table. The volume of demand in 2020 is relatively large.

| Sector | Actual data Unit:BCM 1997 | 2010 | 2020 | Growth rate (%) 2010 | 2020 |
|---|---|---|---|---|---|
| Power generation | 2.2 | 35.0 | 81.2 | 23.76 | 8.78 |
| Chemical industry | 8.4 | 19.0 | 32.5 | 6.45 | 5.51 |
| Other industry | 6.3 | 20.0 | 40.0 | 9.32 | 7.18 |
| Household | 2.1 | 22.0 | 50.0 | 19.72 | 8.56 |
| Total | 19.6 | 96.0 | 203.7 | 13.02 | 7.81 |

5. The exchange rate used here is 15 Yen per Yuan, and 120 Yen per US dollar.

6. If we extend the simulation periods to 2030 under same condition, the direct cost of $CO_2$ reduction decreases to 17.23 US dollar per $CO_2$-ton for the pipeline project, and 10.93 US dollar per $CO_2$-ton for the power plant project.

Comparison of the Reduction Costs of $CO_2$ Emission

| | | CO2 Reduction Mil. t-C | Mil. t-CO2 | Reduction Cost Bil. Yuan | Unit Reduction Cost Yuan/t-CO2 | Yen/t-CO2 | Dollar/ t-CO2 |
|---|---|---|---|---|---|---|---|
| Pileline Project | Direct effect through 2020 | 162.38 | 595.38 | 140.0 | 235 | 3,527 | 29.39 |
| | Direct effect through 2030 | 277.07 | 1,015.92 | 140.0 | 138 | 2,067 | 17.23 |
| Natural gas Electric Power Plant Project | Direct effect through 2020 | 34.31 | 125.80 | 21.0 | 167 | 2,504 | 20.87 |
| | Direct effect through 2030 | 65.50 | 240.16 | 21.0 | 87 | 1,312 | 10.93 |

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