Development of a multi regional, multi sector economy-energy model for the assessments of climate change policy

Takashi Homma*, RITE, Japan

Takanobu Kosugi, Ritsumeikan University, Japan

Shunsuke Mori, RITE, Tokyo University of Science, Japan

Keigo Akimoto, RITE, Japan

Hiromi Yamamoto, RITE, Japan

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Abstract

The purpose of this study is to assess climate change policies with a newly developed model which is capable of dealing with the changes in the energy systems and the industrial structure up to the middle of this century. Most of the assessments based on multi-sector economic models have mainly focused on the near future around 2020 while existing energy system models mainly address the long term up to 2100 and beyond. In addition, most of the economic models have mainly discussed country level while global climate policy models have the world disaggregated into 10-15 regions. In the past studies, intensive discussion was not made on globalization, industrial structure changes etc., which are important in the global environmental context. It is necessary to incorporate the industry structure changes for multi-regions to assess the longer term and global issue of carbon emission reduction potentials. The GTAP (Global Trade Analysis Project) model, which has a comprehensive and consistent world economic database, is a quantitative system that has been widely used for the economic analysis on the international trade and impacts across various sectors.

In this study, we integrated the static GTAP model and an energy technology assessment model, extending it to a dynamic model to assess the dynamics of the technologies and economy under climate policy. We formulated the model as an optimization model to evaluate the technology and policy options while the original GTAP model is a general equilibrium model without an objective function. The model described in this study has 18 economic sectors and 8 energy sectors, dividing the world into 18 regions. Carbon emission reduction strategies are evaluated for the multi-regions and multi-sectors up to the mid-century with the new model.

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*9-2,Kizugawadai,Kizucho,Soraku-gun,Kyoto,619-0292 Japan
Phone.+81-774-75-2304 Fax.+81-0774-75-2317
E-mail: homma@rite.or.jp

Introduction

This study discusses the comprehensive assessment of the climate change policies with a newly developed model, which is capable of dealing with the dynamics in the energy systems and the industrial structure up to the middle of this century. In the past studies, most of multi-sector economic models have mainly focused on the near future (Bernstein et al. 1999). On the other hand, the climate policy models, e.g., MESSAGE (Messner and Strubegger 1995), AIM (Morita et al. 1994), and MARIA (Mori 2000) utilized for IPCC-SRES (IPCC 2000), mainly address the long term up to 2100 and beyond, and deal with disaggregated 10-15 regions and one macro-economy sector. It is difficult for the models to assess the sectoral economic activities (domestic production and international trade, etc.) of the non-energy sectors with the comprehensive and consistent world economy activity. In the past studies, intensive discussion was not made on globalization, industrial structure changes etc., which are important in the global environmental context. It is necessary to incorporate the industry structure changes for multi-regions in order to assess the longer term and global issue of carbon emission reduction potentials.

The previous model approaches for the climate policies in IPCC-TAR (IPCC 2001) have mainly dealt with the long term and the short term. However, it is an important problem that the figures around the mid of 21-st century were not discussed well although around the 2050 is regards as the bifurcation turning point in the context of energy resource and technology.

The GTAP (Global Trade Analysis Project) model (Hertel 1997) is a multi-sector and multi-region applied general equilibrium model, which has a comprehensive and consistent world economic database, and is a sophisticated quantitative system that is designed to assess the international trade and production impacts of various policy options. In this study, we modified the static GTAP model to an intertemporal global economy-energy technology assessment model in which the energy conversion processes are modeled by bottom-up fashion for the assessment of the technologies and economy. We formulated the model as an optimization type to evaluate the technology and policy options while the original GTAP model is a computable general equilibrium model without an objective function. The model developed in this study has 18 non-energy industrial sectors and 8 energy sectors dividing the world into 18 regions. Thanks to the fashion of the model modification, global warming mitigation strategies are evaluated for the multi-regions and multi-sectors up to the middle of this century. The model analysis results show that the optimized strategies differ by region and sector, depending on the carbon emission reduction policy.

The model plays a main role of the integrated assessment project PHOENIX[1] (Paths toward Harmony Of Environment, Natural resources and Industry compleX) in RITE, and the outcome of this study will provide a helpful information to the energy technology development strategies and the policy measures for global warming mitigation.

The structure of the paper is as follows. Section 2 describes the design of the model experiments integrated with the economic model and the energy technology systems model, Section 3 presents the main computational results in a simulation study, and Section 4 offers conclusions and future work.

Structure of the model

Framework of the model

This model is an intertemporal multi-regional, multi-sectoral model developed for the analysis of the world economy under climate change policy. The current version of this model is built on an energy-economy data set, GTAP-EG (Ruthurford and Paltsev 2000). The base year in the proposed model is 1997, we solve at 10-year intervals through 2047. The model consists of 18 regions, which are linked by international trade, non-energy industrial sectors and energy sectors. The framework of this model is shown in Figure 1. This model has the structure that determines the sectoral production, the final consumption, investment, and international trade as the maximization of the consumption utilities. Tables1-3 summarizes the 18 regions, 18 non-energy and 8 energy sectors. In this model, Cobb-Douglass functions are used to describe production within each region, and consumption within each region and sector. The model has the following two features: (a) integration of static GTAP model and energy technology models such as DNE-21 (Fujii and Yamaji 1998) and LDNE-21 (Yamaji et al. 2000) (b) intertemporal extension of the model. Figure 2 provides a detailed structure regarding our model. The monetary economic and physical energy flow tables of the model are documented in Table 4. Figures3-4 visually describes the model structure for the production of the non-energy sector and energy sectors, respectively.

Macro-production function of whole non-energy industrial sector is defined by capital stock and the sum of energy demand by non-energy sector. The value added $V_{j,t}$ of non-energy sector as shown in Table 4 is described as follows.

$$V_{j,r,t} = \left(1 - \sum_i a_{ij,r}\right) \cdot Q_{j,r,t} - \sum_s EC_{s,j,r,t} \tag{1}$$

[1] This research is funded by the Japanese Ministry of Economy, Trade and Industry (METI).

Hence, the subscript "i" and 'j" indicate the non-energy sector, while the subscript "s" and "p" stand for the secondary and primary energy sector, respectively. The subscript "t" and "r" indicates the time and the region, respectively. Assumed that $f\left(K_{j,r,t}, L_{j,r,t}, E_{j,r,t}, N_{s,j,r,t}\right)$ equals the first term of the right hand in (1), the macro Cobb-Douglass function takes the form of the following equation for the whole sector.

$$\sum_{j} f\left(K_{j,r,t}, L_{j,r,t}, E_{j,r,t}, N_{s,j,r,t}\right) = A_{Lt,r} \cdot A_{KL,r} \cdot K_{r,t}^{\alpha_r} \cdot L_{r,t}^{1-\alpha_r-\beta_r-\gamma_r} \cdot E_{s,j,r,t}^{\beta_r} \cdot N_{s,j,r,t}^{\gamma_r}, \tag{2}$$

where $A_{Lt,r}$, $K_{r,t}$, and $L_{r,t}$ indicate the rate of technical progress, $\sum_j K_{j,r,t}$ and $\sum_j L_{j,r,t}$, respectively, and the parameters of $A_{KL,r}, \alpha_r, \beta_r$ and γ_r are obtained by benchmark data set in base year. Here, it is important to note that the sectoral capital stock is not explicitly dealt with as variables in this model.

The total capital stock and flow balance is written in Figure 5 as follows:

$$K_{r,t+1} = (1-\delta)^{\Delta t} \cdot K_{r,t} + \Delta t \cdot \sum_i I_{i,r,t}, \tag{3}$$

where δ and Δt indicate the parameter of capital wastage and time span. By the use of φ_i that indicates the share of the sectoral investment in base year, Leontief function for the sectoral capital is described by

$$I_{i,t} = \varphi_i \cdot \sum_j I_{j,t}. \tag{4}$$

We aim at the assessments of the certain technologies such as energy conversion technologies, carbon capture options, biomass production and utilization. Therefore we need to integrate the bottoming up technology into GTAP framework. As stated previously, it is easily expected that the optimization be required in order to incorporate the bottom-up energy conversion processes into the model. Our optimization model developed in this study uses the objective function that is represented as the total discounted consumption utilities of all regions as depicted in Figure 6. The objective function is described by

$$\sum_t d_t \cdot \sum_r L_{r,t} \cdot U_{r,t} \rightarrow \max, \tag{5}$$

where "d" indicates the discount rate. Here, the utilities are defined by

$$U_{r,t} = \sum_i \theta_{i,r} \cdot \log \frac{C_{i,r,t}}{L_{r,t}}, \tag{6}$$

where $\theta_{i,r}$ and $L_{r,t}$ indicate the ratio of the sectoral consumption and the population in rth region, respectively.

Assumed energy conversion processes

As previously mentioned, the developed model has bottom-up energy systems, and deals with 8 energy sectors: 4 types of primary energy i.e., coal, crude oil, natural gas and others and 4 types of secondary energy i.e., solid fuel, liquid fuel, gas fuel and electricity. Energy balances in conversion processes of crude oil to liquid fuel (petroleum), coal to solid fuel, natural gas to gas fuels and various fuel to electricity are described as follows:

- conversion process of crude oil to liquid fuel

$$E_{OIL,r,t} = \eta_{OIL,r,t} \cdot E_{CRU,OIL,r,t} \tag{7}$$

$\eta_{OIL,r,t}$: conversion efficiency of crude oil to liquid fuel

- energy balance between primary energy of coal and secondary energy of solid fuel

$$E_{SLD,r,t} = E_{COL,SLD,r,t}\,, \tag{8}$$

- energy balance between primary energy of natural gas and secondary energy of gas fuel

$$E_{GDT,r,t} = E_{GAS,GDT,r,t}\,, \tag{9}$$

- conversion process of power generation

$$E_{ELE,r,t} = \left(1 - \ell_{r,t}\right) \cdot \sum_{e_s} \eta_{e_s,ELE,r,t} \cdot E_{e_s,ELE,r,t} \tag{10}$$

$\ell_{r,t}$: transmission loss rate, $\eta_{e_s,ELE,r,t}$: net efficiency of power generation by fuel e_s

Integration of a bottom-up energy systems and GTAP model

The model has the equations as the input-output structure and energy balance. The model has the relational equations between monetary and physical flow with economic and energy systems as follows.

The value added in the secondary energy sector is described by

$$V_{s,t} = \frac{E_{s,t}}{E_{s,0}} \cdot V_{s,0} \,. \tag{11}$$

The relation between the final energy consumption and economic growth is formulated by

$$E_{s,C,t} = \frac{E_{s,C,0}}{L_0} \cdot L_t \cdot \left(\frac{V_t / L_t}{V_0 / L_0} \right)^{\varepsilon_{F_s}} , \tag{12}$$

where ε_{F_s} indicates the parameter as the income elasticity of energy demand. The balanced equation of the conversion process from the primary to the secondary is described by

$$E_{s,t} = \eta \cdot E_{p,s,t} \tag{13}$$

where η indicates the conversion efficiency. In this model, the supply curve of the primary energy is characterized as follows:

$$P_{p,t} = P_{p,0} \cdot \left(\frac{E_{p,t}}{E_{p,0}} \right)^{\varepsilon_{P_p} - 1} \tag{14}$$

where ε_{P_p} indicates the parameter regarding the supply curve of the primary energy. The carbon emission limitation is given by

$$\sum_{e_s} \phi_{e_s} \cdot \left(\sum_j E_{e_s,j,t} + E_{e_s,C,t} \right) \leq TC_t \,, \tag{15}$$

where ϕ_{e_s} and TC_t indicate the emission coefficient of fuel e_s, and the upper limit of carbon dioxide emission, respectively.

Considering the relation between real and nominal values and the transport services as well as the original GTAP framework, our model has the following formulations available for relative price by industrial sector.

Value added of the electricity sector equals the total fixed costs of all kinds of various power generation processes by bottom-up systems as follows:

$$V_{ELE,r,t} = \sum_{e_s} c_{e_s,r,t} \cdot \eta_{e_s,ELE,r,t} \cdot E_{e_s,ELE,r,t} \,, \tag{16}$$

where $c_{e_s,r,t}$ represents fixed cost by generated energy of resource e_s.

We utilize the following approximate function of the supply price curve of exhaustive resources as crude oil, coal and natural gas explained bye the amount of cumulative productions.

$$P_{p,t} = P_{p,0} + \pi_p \cdot S_{p,t} , \tag{17}$$

where π_p and $S_{p,t}$ represent the rate of price increase by cumulative production and the amount of cumulative production, respectively. $S_{p,t}$ is defined by

$$S_{p,0} = 0 , \quad S_{p,t+1} = S_{p,t} + \sum_r \frac{E_{p,r,t+1} + E_{p,r,t}}{2} \cdot \Delta t . \tag{18}$$

The maximum cumulative productions of coal, oil, and natural gas are derived from the previous study (Rogner 1997).

Simulation Study

Model assumption

A simulation study was applied to our model by the use of the expanded data –18 non-energy and 8 energy sector)- combined IEA data(IEA 2002a, 2002b) and the aggregated GTAP-EG(Rutherford 2000) database which is based on the production statistics in 1997. The optimization software GAMS/CONOPT2,CONOPT3 was used for the simulation study.

Table 5 shows the assumed population scenario in this model. The population of the 18 regions aggregated country-level population and downscaled projections for the SRES B2 Scenario 1990-2100 by TGCIA data (TGCIA); the historical regional population in 1997 was adjusted by WDI (World Bank 2002).

Other assumptions used for the simulation study were summarized as follows:

discount rate：5%/year,
depreciation rate：5%/year (Manne et al. 1995),
rate of technical progress： 1%/year ,

which were assumed as the same values in all the regions and sectors. It is one of important future works that the simulation study be carried out by the use of the discount rate and the rate of technical progress estimated by other approaches such as trend analysis. It is noted that the procedure to avoid the end effect is left out of consideration, and the flow and stock of power plant is not allowed in this model at this stage. Furthermore, it is assumed that the input-output coefficients until 2047 are fixed in the benchmark year.

Computational results

Two simulation cases are assumed in order to examine how the effect of economic and energy sectors for the multi-regions up to 2047. One is the Business as Usual case (Case1), and the other is the case with carbon emission control policy where the carbon emission from the developed countries - USA, CAN, WEP, EEP, FSU, JPN, and ANZ- does not exceed that in the benchmark year (Case 2).

Figure 7 ,Figure 8 and Figure 9 show the simulation results in the Case 1 for the world total, JPN, and CHN, respectively.

In Figure 7-(a) representing the total value added by region, the world economic is expected to progress satisfactorily. The world total value added of 2027 will be twice larger than that of 1997, and then increase until 2037. There is the decreased rate of the economic growth at the end because of the end effect by the optimization model as previous mentioned. The production outputs of almost all the regions gradually increase, and specially, it is in USA that the ratio of the total value added in the world keeps enlarging up to the mid century. A finding in Figure 7-(b) depicting the sectoral value added is that there will be stable growth of the economy by sector in the future. Figure 7-(c),(d),(e) presents the results regarding the final energy consumption, power generation, and primary energy consumption, respectively. In Figure 7-(c),(d) and (e), there is the end effect near the latest part as the increasing growth of the economy. Carbon emission by region is shown in Figure 7-(f).

As depicted in Figure 8, that is the results regarding belonging to developed country, there is increase in growth of value added at an easy pace because of decrease in growth of population at the last half in JPN. The value added of the manufacturing industry including “i_s”, “crp” and “ome” etc. with relatively higher productivity is on the increase, while “cns” and “ssr” with lower productivity is on the decrease. In Figure 8, at the earlier time “gdt” scales up exponentially, while at the latest time “sld” with relatively lower price on the market keeps on increasing and “gdt” gradually diminishes. ”otr” keeps on decreasing from start to finish.

A finding from Figure 9 can be summarized as follows. There is rapid increase in growth of value added from beginning to end regarding “agr” and “ssr” with the comparative advantage in CHN belonging to developing country. In Figure 9, there is no comparative advantage regarding energy-intensive sectors such as “i_s” in CHN, and therefore the final energy consumption moderately increases. “sld” with quite low price among energy sectors in CHN keeps on increasing from beginning to finish.

Figures 10-12 visually describe the computational results under the carbon emission control policy. The results of Case 2 on the world are illustrated in Figure 10. Compared with Figures 7-10, there are almost little changes on the value added and the final energy consumption with and without carbon emission control policy, and therefore the industrial structure on the world remain almost unchanged. The structure of power generation in Case 2, however, is different from that in Case 1. In Figure 10-(d), “otr” belonging to the carbon-free energy is on the increase under the influence of carbon emission control policy. Although the production of “sld” in Case 2 moderately increases, the growth rate of “sld” in Case 2 is smaller than that in Case 1. In association of such a power generation, the share of the primary energy consumption of “otr” is on the increase as depicted in Figure 10-(e), while that of “col” is on the decrease. Furthermore, the total carbon emission in Case 2, as in Figure 10-(f), is smaller than that in Case 1 because of the effect of carbon emission control policy in developed countries. The total carbon reduction on the world, however, is less than that from developed countries as a consequence of the carbon leakage occurring in the developing countries without emission control policy.

In Figure 11, the value added of carbon-intensive sectors such as “i_s” and “t_t” in Case 2 is smaller than that in Case 1. Hence, the final energy consumption of JPN in Case 2 is smaller than that in Case 1. Specially, the share of the power generation of JPN in Case 2 is quite different from that in Case 1. The power generation by energy sectors except for “otr” is on the decrease, and the share of “otr” on the power generation is almost 100% as closer to the final year. As a natural consequence, the share of “otr” on the primary consumption in Case 2 is larger than that in Case 1, and the carbon emission in JPN keeps the level in the base year. Figure 12 shows the economic and energy effect for CHN. A finding in Figure 12-(e), the carbon emission of CHN in Case 2 is on the increase slighter than that in Case 1, and the carbon leakage is found in this case. Consequently, it is possible by the use of the proposed model to evaluate the optimized industrial structure by region with the comprehensive and consistent world economy activity, and identify the regional differences with carbon emission control policy.

Conclusion and future work

We have presented the formulation for the integration of conversion processes of energy into GTAP framework. An important feature of the proposed model is that it has a multi-region and multi-sector structure to evaluate the global warming mitigation strategies including the industrial structure change and the energy conversion technology change to the mid-century. Industrial policies on the R&D regarding the energy and environmental technologies, technology transfer and other industry strategies can be assessed under the global warming mitigation policies.

In addition to the future works discussed in the body of this article, we should mention the following research subjects. “OTH” sector which means various other energy sectors should be disaggregated into nuclear power, geothermal power, solar power, etc.. Then we would be able to assess in more detail the energy systems change due to climate policies. This paper discussed a simulation study in simple cases with and without carbon control policy. Under the various plausible assumptions of the international industry allocation scenarios provided by other approaches in the short- to middle-term, it is necessary that we analyze more detailed quantitative estimates. In this simulation study, it is assumed the input-output coefficients and the productivity in the future are fixed. For a greater accuracy on the industrial structure changes in the future, we should allow their changes and estimate them by various methods.

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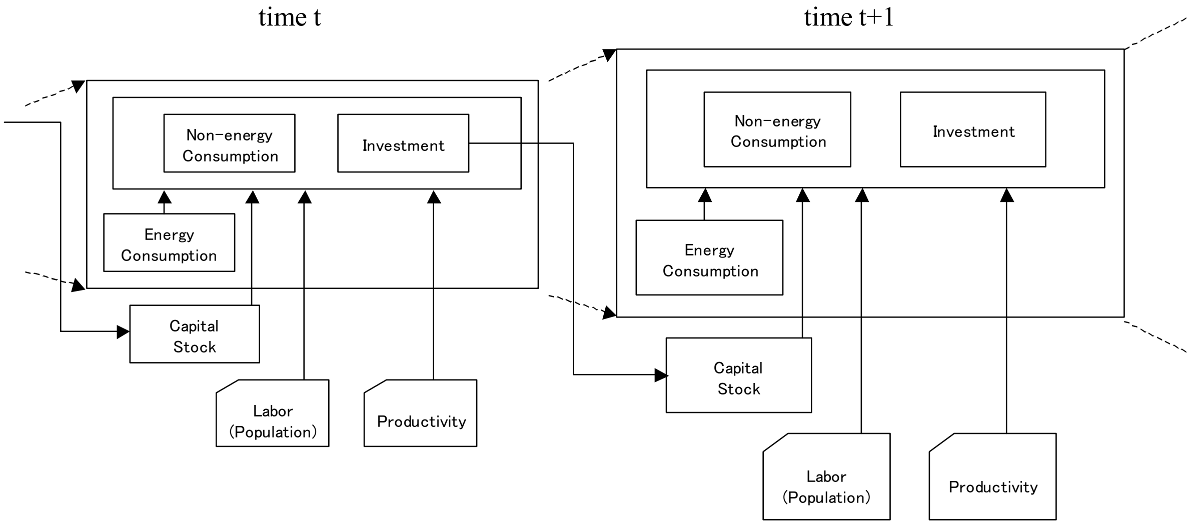

Figure 1 Macro-economic dynamic structure of developed model

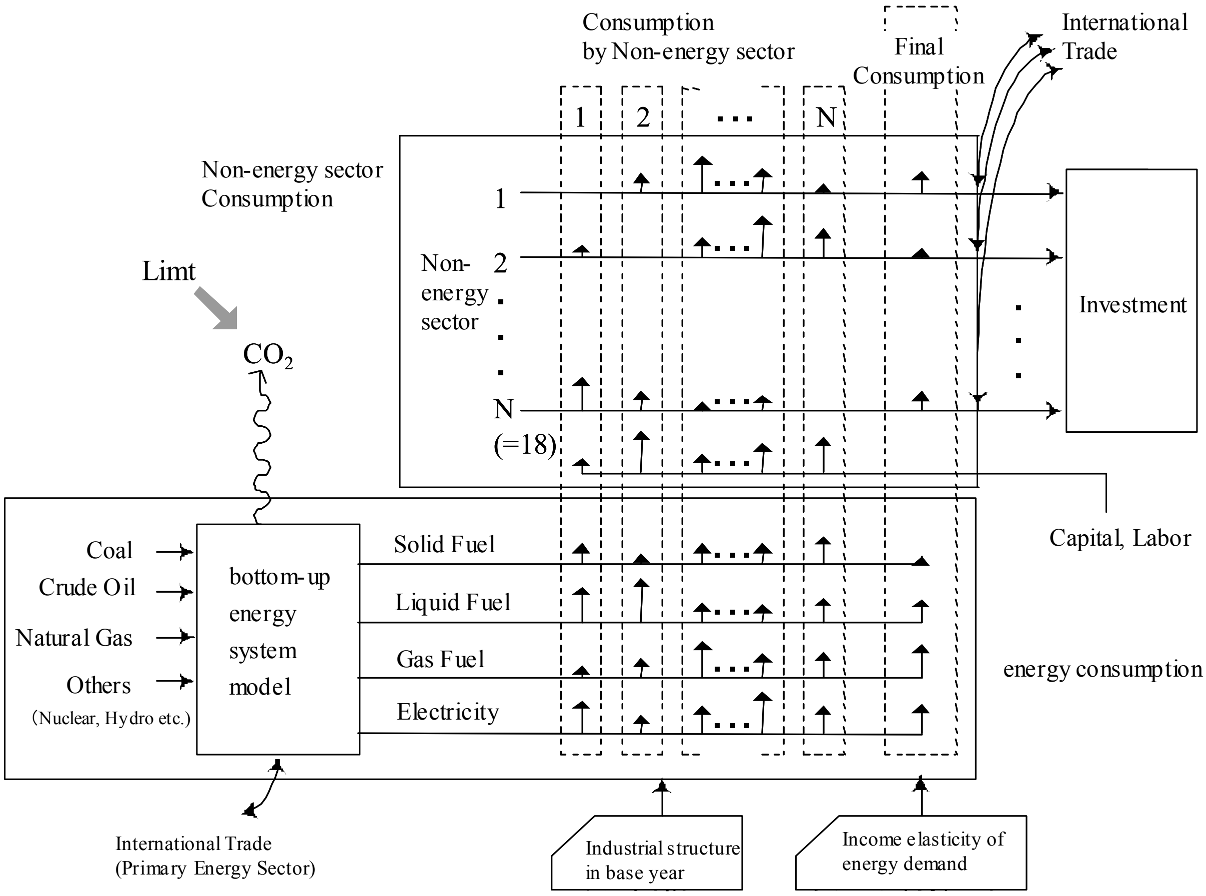

Figure 2 Integration of Non-enegy and energy sector

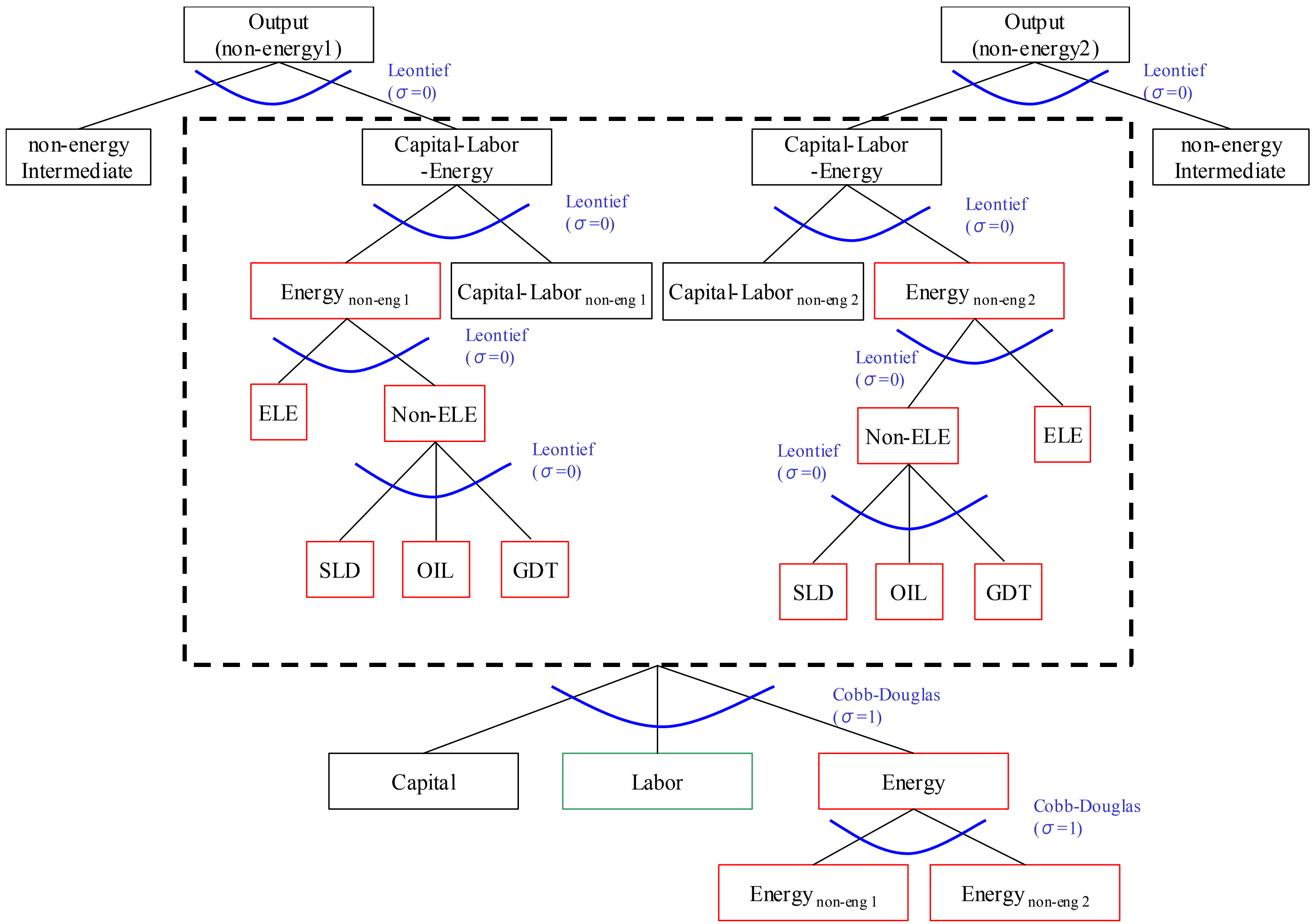

Figure 3 Model structure of non-energy sector production

note:

Red frame represents the section decided by bottom-up energy system. Green frame stands for the exogenous variables. The subscripts "t "and "rgn" which indicate time and region, respectively, are omitted.

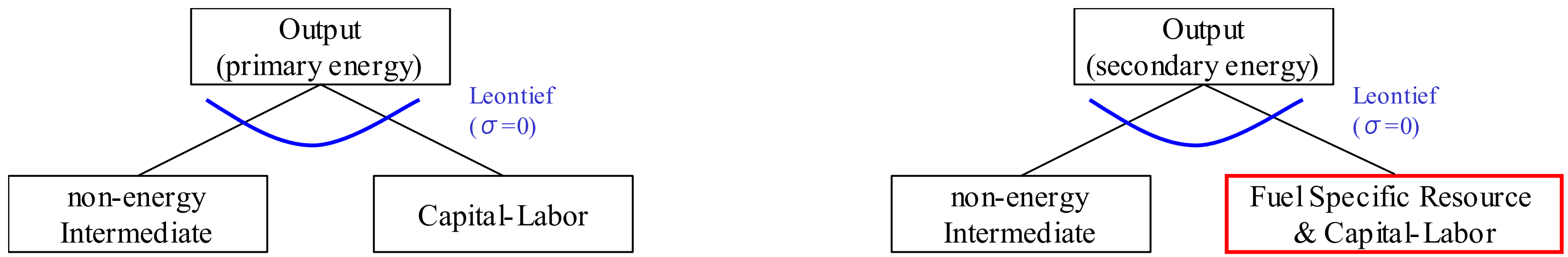

Figure 4 Model structure of energy sector production

note:
Red frame and green frame represent the section decided by bottom-up energy system. The subscripts "t "and "rgn" which indicate time and region, respectively, are omitted.

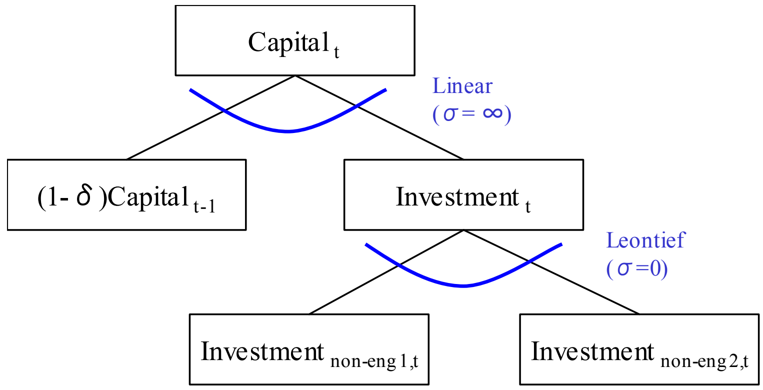

Figure 5 Model structure of capital stock and investment

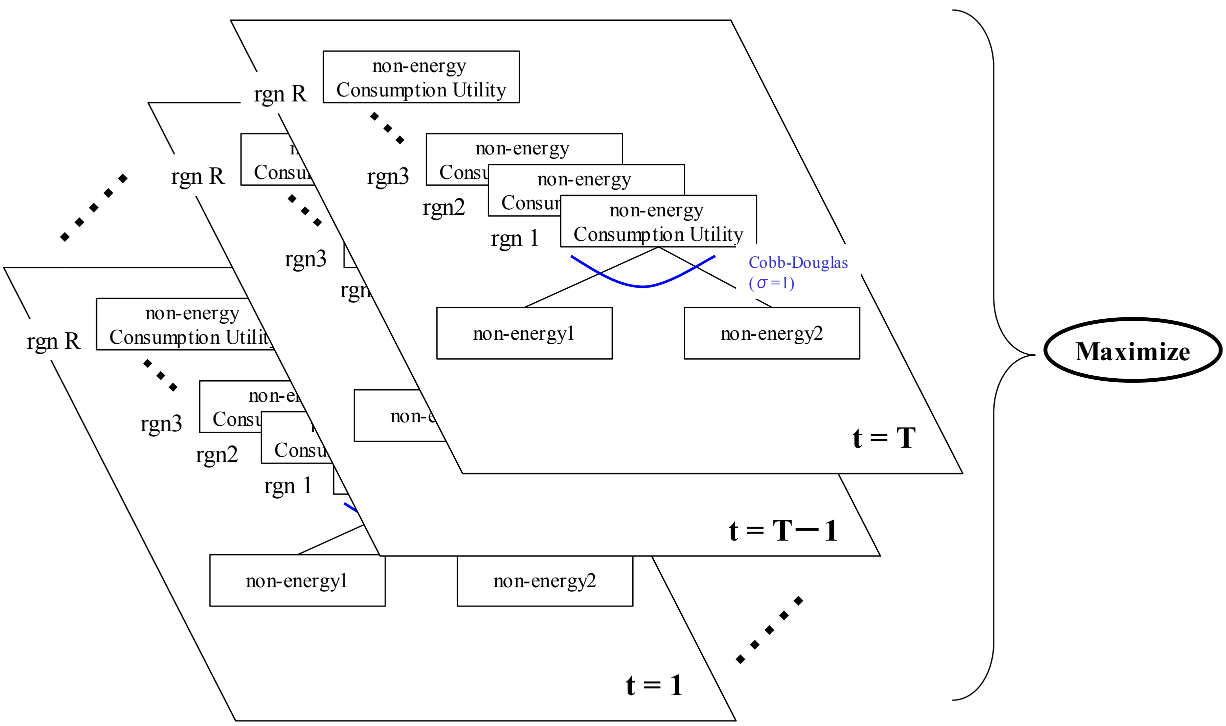

Figure 6 Model structure of non-energy sector consumption utility

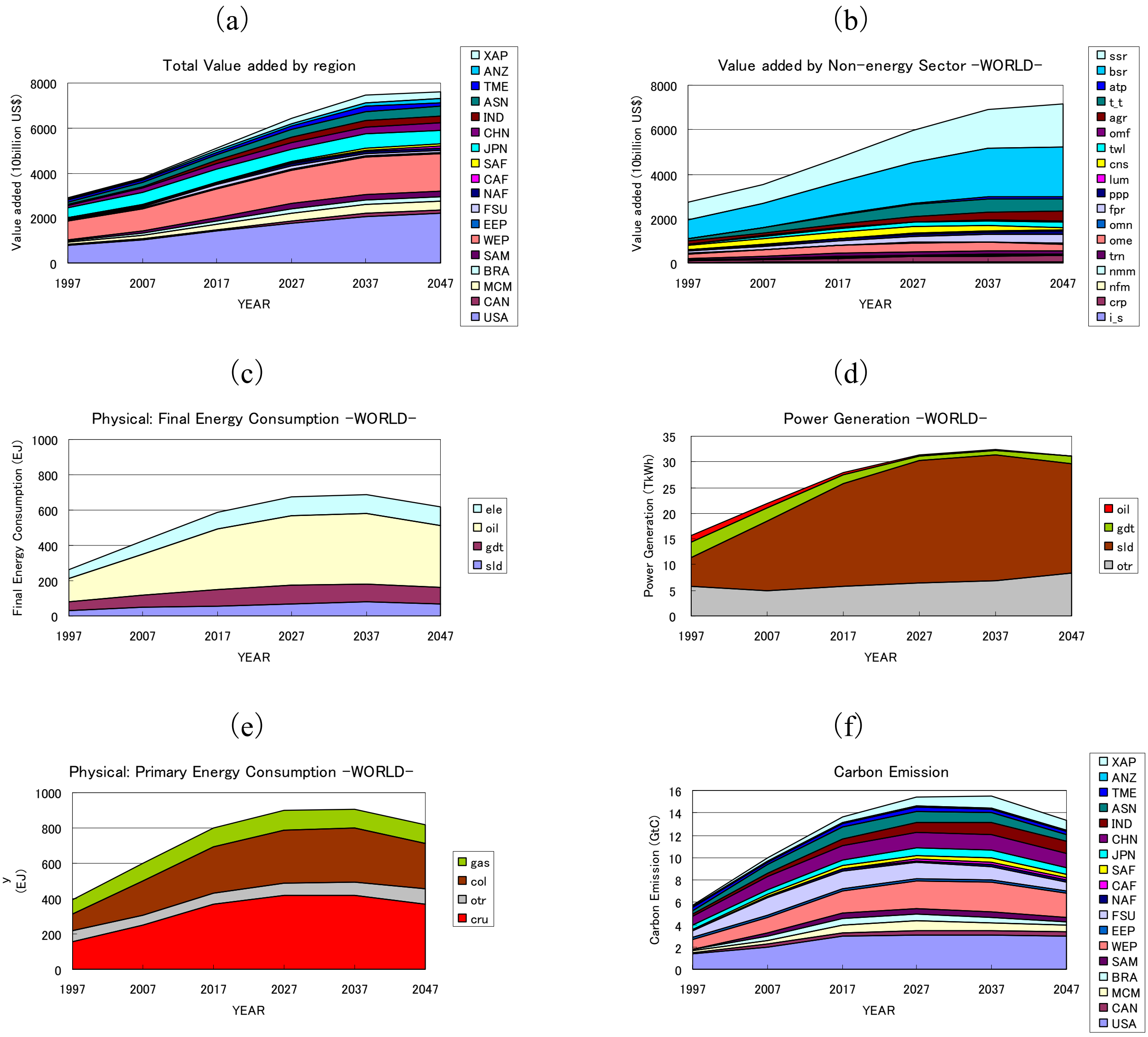

Figure 7　Computational results -WORLD-（Case1）

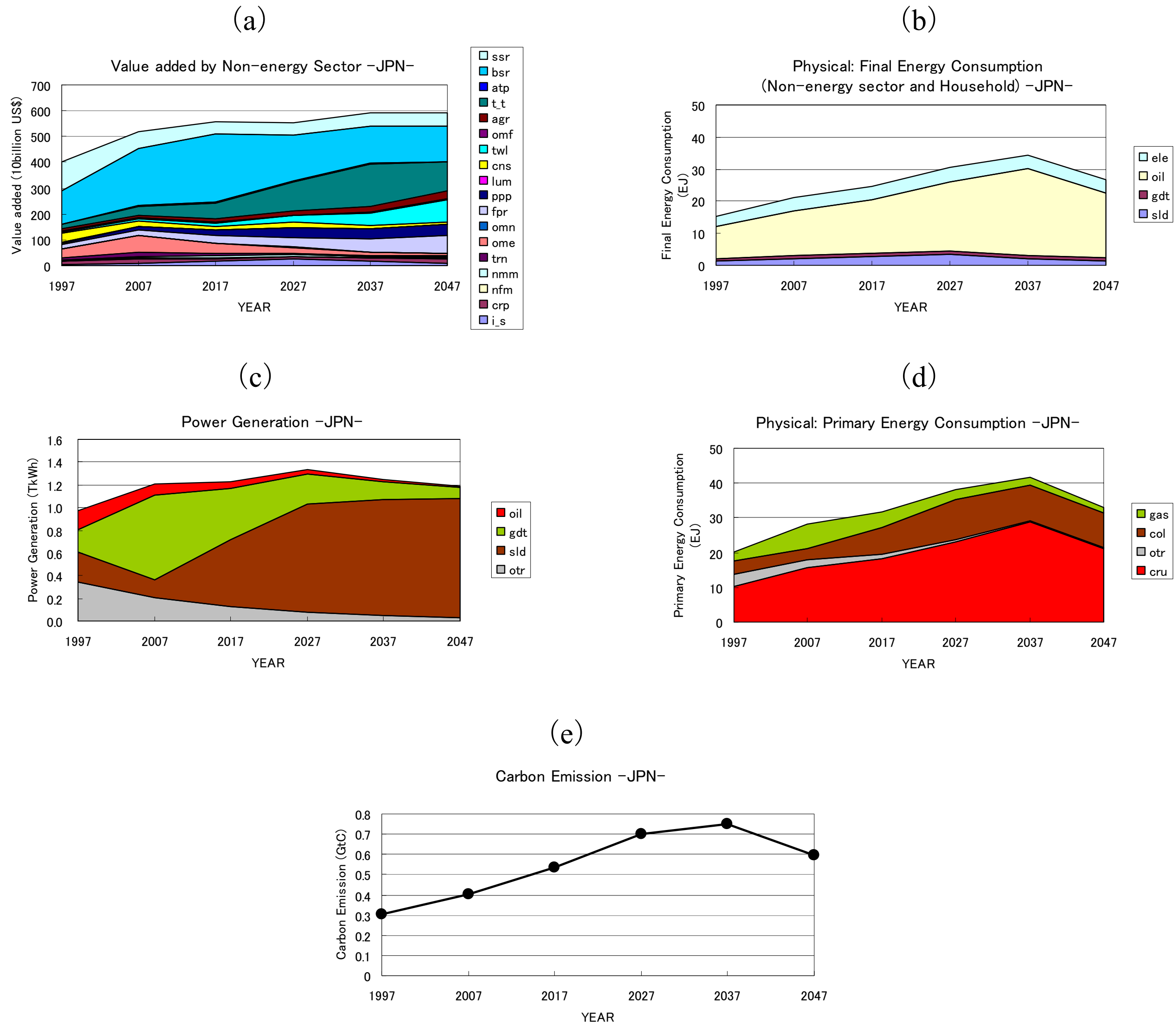

Figure 8 Computational results -JPN- （Case1）

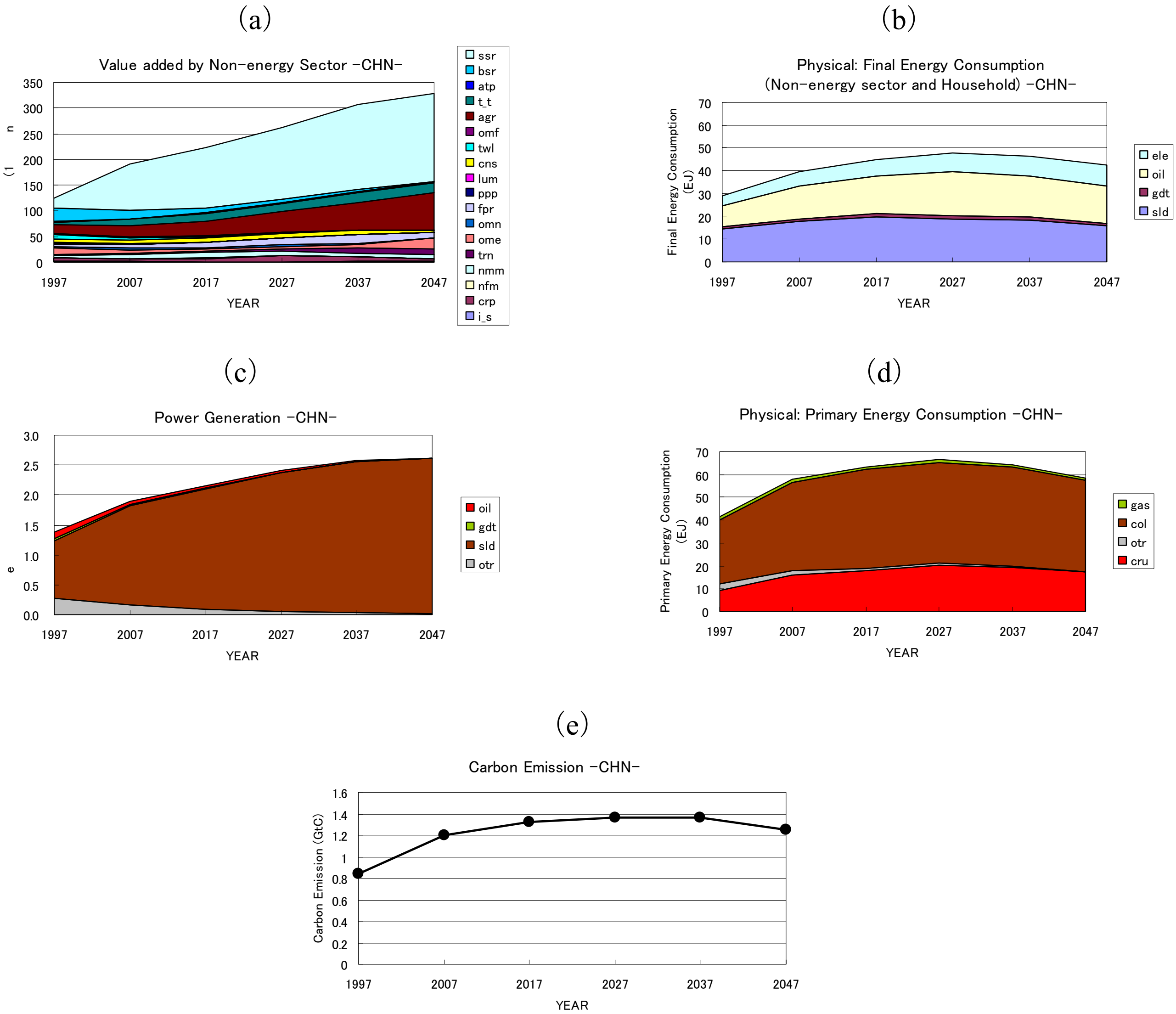

Figure 9　Computational results -CHN-（Case1）

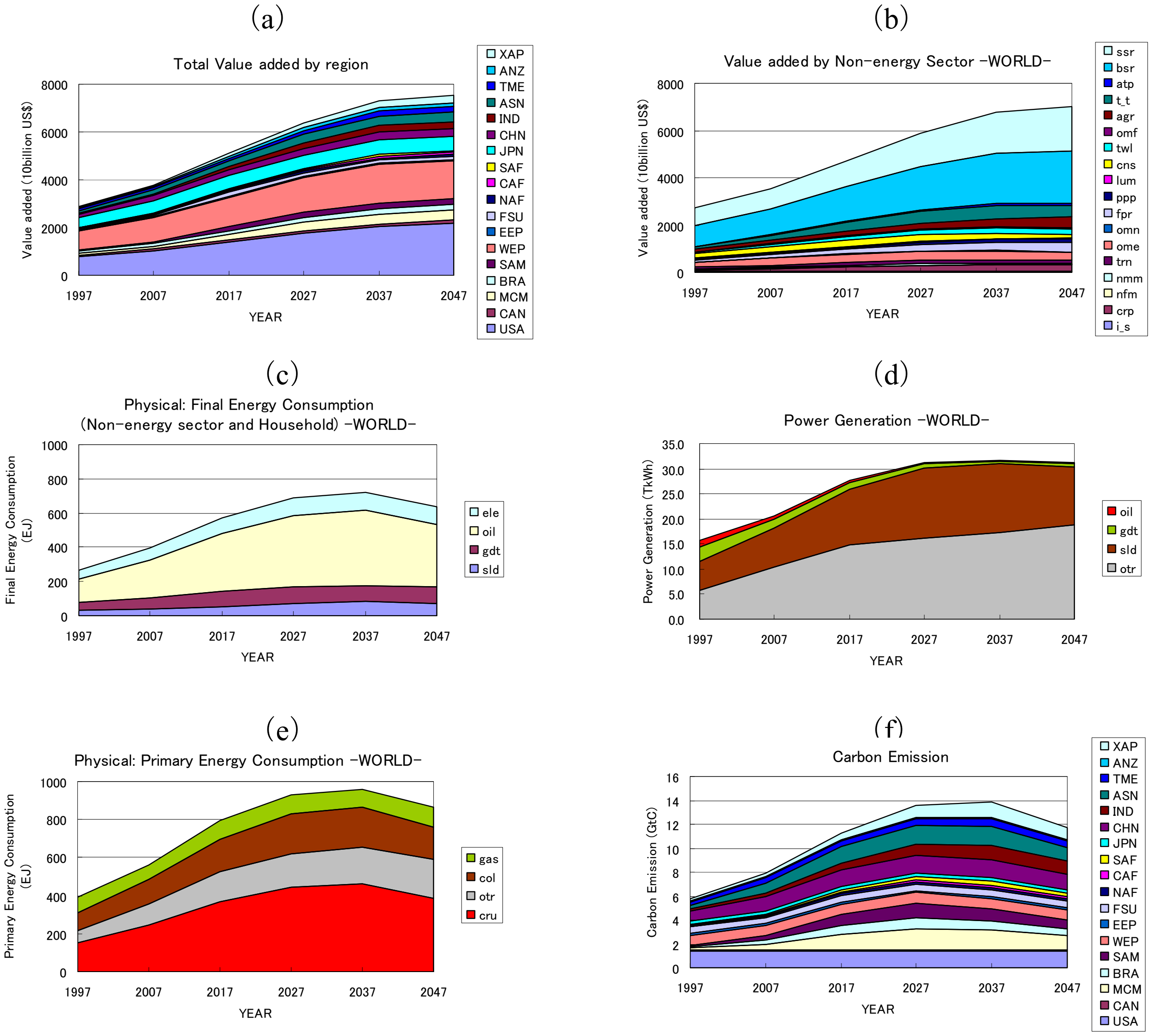

Figure 10 Computational results -WORLD- （Case2）

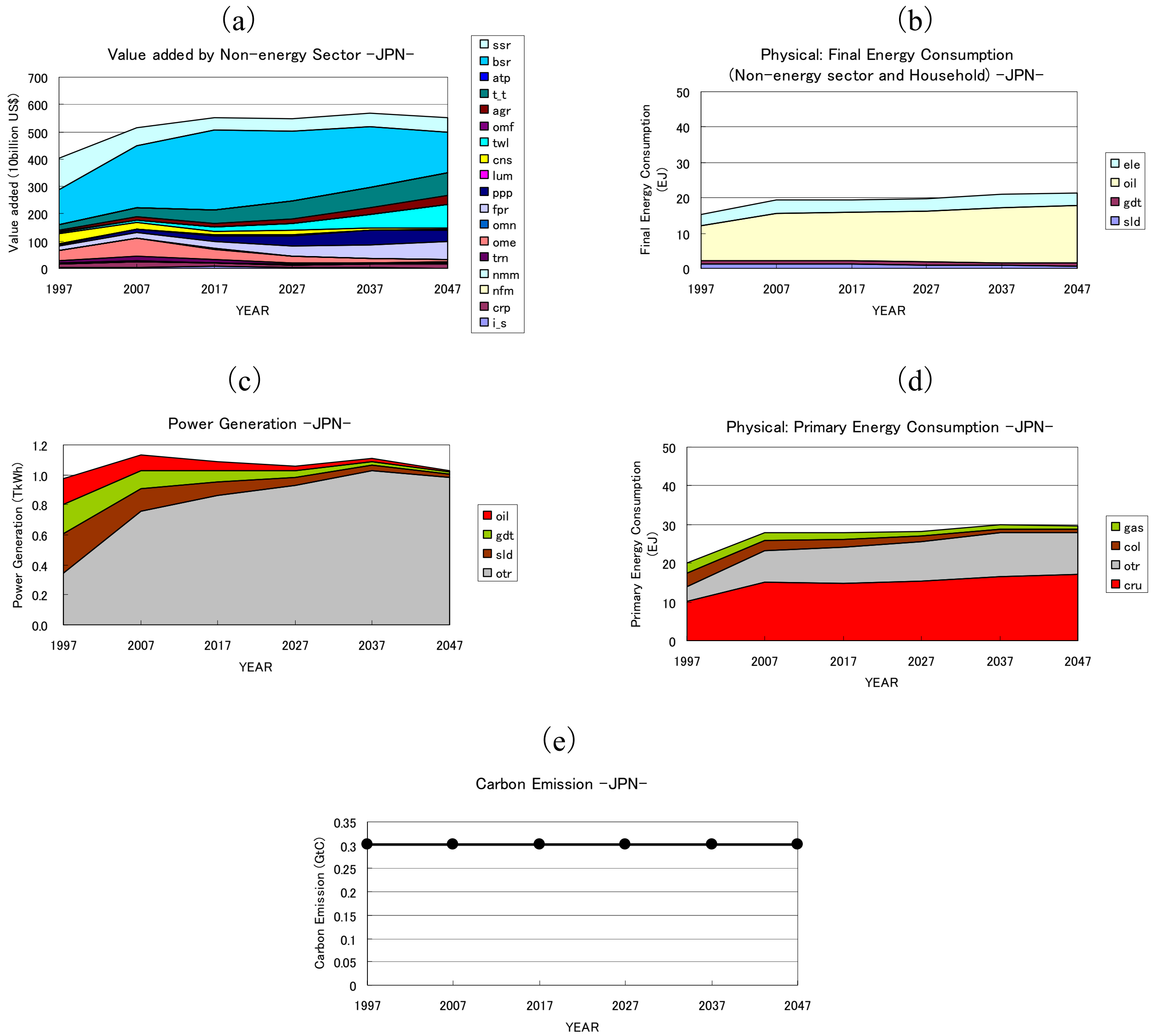

Figure 11　Computational results -JPN-（Case2）

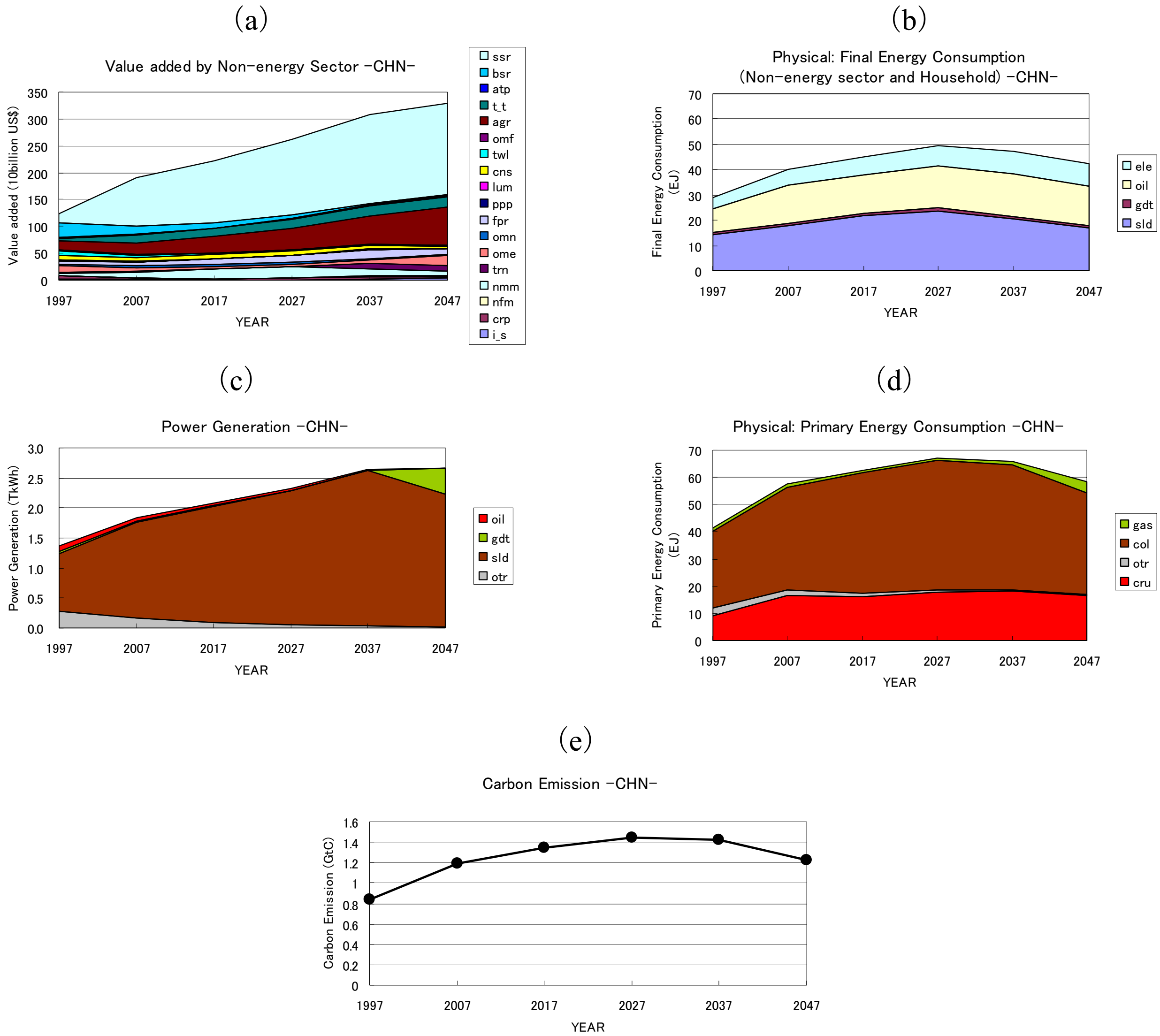

Figure 12　Computational results -CHN-（Case2）

Table 1 Aggregated 18 Regions

No.	Code	GTAP-EG Code	Description
1	USA	usa	United States of America, American Samoa, Guam, Northern Mariana Islands, Puerto Rico, United States Virgin Islands
2	CAN	can	Canada
3	MCM	mex	Mexico
		xcm	Central America and the Caribbean: Antigua & Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Montserrat, Netherlands Antilles, Nicaragua, Panama, Saint Christopher and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Isl.
		col	Colombia
		ven	Venezuela
		xap	Rest of Andean Pact: Bolivia, Ecuador
4	BRA	bra	Brazil
5	SAM	per	Peru
		arg	Argentina
		chl	Chile
		ury	Uruguay
		xsm	Rest of South America: Guyana, Paraguay, Surinam.
6	WEP	aut	Austria
		bel	Belgium
		dnk	Denmark
		fin	Finland
		fra	France
		deu	Germany
		gbr	United Kingdom, Channel Islands, Isle of Man
		grc	Greece
		irl	Ireland
		ita	Italy
		lux	Luxembourg
		nld	Netherlands
		prt	Portugal
		esp	Spain
		swe	Sweden
		che	Switzerland
		xef	Rest of EFTA: Iceland, Leichtenstein, Norway, Svalbard and Jan Mayen Is.
7	EEP	hun	Hungary
		pol	Poland
		xce	Rest of Central of Central Eastern European Associates: Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.
8	FSU	xsu	Former Soviet Union: Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan.
9	NAF	mar	Morocco, Western Sahara.
		xnf	Rest of North Africa: Algeria, Egypt, Libya, Tunisia.
10	CAF	xss	Rest of Sub-Saharan Africa: Uganda,Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mauritania, Mayotte, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan, Togo, Zaire.
11	SAF	xsc	Rest of South African Customs Union: Botswana,Lesotho, Namibia, South Africa, Swaziland.
		moz	Mozambique
		tza	Tanzania
		zmb	Zambia
		zwe	Zimbabwe
		xsf	Rest of Southern Africa: Malawi,Angola, Mauritius.
12	JPN	jpn	Japan
13	CHN	chn	China
		hkg	Hong Kong
		twn	Taiwan
14	IND	ind	India
15	ASN	kor	Korea
		idn	Indonesia, East Timor.
		mys	Malaysia
		phl	Philippines
		sgp	Singapore
		tha	Thailand
		vnm	Vietnam
16	TME	tur	Turkey
		xme	Rest of Middle East: Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen, Yemen Democratic.
17	ANZ	aus	Australia, Heard & McDonald Islands, Norfolk Island.
		nzl	New Zealand
18	XAP	bgd	Bangladesh
		lka	Sri Lanka
		xsa	Rest of South Asia: Bhutan, Maldives, Nepal, Pakistan.
		xrw	Rest of World: Afghanistan, Albania, Andorra, Bermuda, Bosnia and Herzegovina, British Indian Ocean Territories, Brunei, Burma, Cambodia, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Croatia, Cyprus, Falkland Islands, Faroe Islands, Fiji, French Polynesia, Gibraltar, Greenland, Johnston Island, Kiribati, Laos, Macao, Macedonia, Malta, Marshall Islands, FS Micronesia, Mongolia, Nauru, New Caledonia, Niue, North Korea, Pacific Islands, Palau, Papua New Guinea, Pitcairn Islands, Saint Helena, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wake Island, Wallis and Futura Isl., Western Samoa, Yugoslavia, French Guiana, Guadeloupe, Vatican Holy See, Martinique, Monaco, Reunion, Saint Pierre and Miquelon San Marino.

Table 2 Aggregated 18 Non-energy Industrial Sectors

Phoenix 18Sec	Code	Sector Name	GTAPinGAMS Code	Sector Name	Discription
1	I_S	Iron and Steel industry	i_s	Iron & Steel	basic production and casting
2	CRP	Chemical industry	crp	Chemical Rubber Products	basic chemicals, other chemical products, rubber and plastics products
3	NFM	Non-Ferrous Metals	nfm	Non-Ferrous Metals	production and casting of copper, aluminium, zinc, lead, gold, and silver
4	NMM	Non-Metallic Minerals	nmm	Non-Metallic Minerals	cement, plaster, lime, gravel, concrete
5	TRN	Transport equipment	mvh	Motor Vehicles	cars, lorries, trailers and semi-trailers
			otn	Other Transport Equipment	
6	OME	Other Machinary	ele	Electronic Equipment	office, accounting and computing machinery, radio, television and communication equipment and apparatus
			ome	Other Machinery & Equipment	electrical machinery and apparatus n.e.c., medical, precision and optical instruments, watches and clocks
			fmp	Fabricated Metal Products	Sheet metal products, but not machinery and equipment
7	OMN	Mining	omn	Other Mining	mining of metal ores, uranium, gems. other mining and quarrying
8	FPR	Food Products	omt	Other Meat	pig meat and offal. preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or inedible meat offal; greaves
			vol	Vegetable Oils	crude and refined oils of soya-bean, maize (corn),olive, sesame, ground-nut, olive, sunflower-seed, safflower, cotton-seed rape, colza, mustard, coconut palm, palm kernel, castor, tung jojoba, babassu and linseed, perhaps partly or wholly hydrogenated,inter-esterified, re-esterified or elaidinised. Also margarine and similar preparations, animal or vegetable waxes, fats and oils and their fractions, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils; flours and meals of oil seeds or oleaginous fruits, except those of mustard; degras and other residues resulting from the treatment of fatty substances or animal or vegetable waxes.
			mil	Milk	dairy products
			pcr	Processed Rice	rice, semi- or wholly milled
			sgr	Sugar	
			ofd	Other Food	prepared and preserved fish or vegetables, fruit juices and vegetable juices, prepared and preserved fruit and nuts, all cereal flours, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers•wares, starches and starch products; sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.
			b_t	Beverages & Tobacco	
			cmt	Cattle Meat	fresh or chilled meat and edible offal of cattle, sheep, goats, horses, asses, mules, and hinnies. raw fats or grease from any animal or bird.
9	PPP	Paper-Pulp-Print	ppp	Paper & Paper Products	includes publishing, printing and reproduction of recorded media
10	LUM	Wood and wood-products	lum	Lumber	wood and products of wood and cork, except furniture; articles of straw and plaiting materials
11	CNS	Construction	cns	Construction	building houses factories offices and roads
12	TWL	Textiles-Wearing apparel-Lether	tex	Textiles	textiles and man-made fibres
			wap	Wearing Apparel	Clothing, dressing and dyeing of fur
			lea	Leather	tanning and dressing of leather; luggage, handbags, saddlery, harness and footwear
13	OMF	Other Manufacturing	omf	Other Manufacturing	includes recycling
			wtr	Water	collection, purification and distribution
14	AGR	Agricultural Products	pdr	Paddy Rice	rice, husked and unhusked
			wht	Wheat	wheat and meslin
			gro	Other Grains	maize (corn), barley, rye, oats, other cereals
			v_f	Veg & Fruit	vegetables, fruitvegetables, fruit and nuts
			osd	Oil Seeds	oil seeds and oleaginous fruit; copra
			c_b	Cane & Beet	sugar cane and sugar beet
			pfb	Plant Fibres	cotton, flax, hemp, sisal and other raw vegetable materials used in textiles
			ocr	Other Crops	live plants; cut flowers and flower buds; flower seeds and fruit seeds; vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets; swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
			ctl	Cattle	cattle, sheep, goats, horses, asses, mules, and hinnies; and semen thereof
			oap	Other Animal Products	swine, poultry and other live animals; eggs, in shell (fresh or cooked), natural honey, snails (fresh or preserved) except sea snails; frogs•legs, edible products of animal origin n.e.c., hides, skins and furskins, raw , insect waxes and spermaceti, whether or not refined or
			rmk	Raw Milk	
			wol	Wool	wool, silk, and other raw animal materials used in textile
			for	Forestry	forestry, logging and related service activities
			fsh	Fishing	hunting, trapping and game propagation including related service activities, fishing, fish farms; service activities incidental to fishing
15	T_T	Transport	otp	Other Transport	road, rail ; pipelines, auxiliary transport activities; travel agencies
			wtp	Water Transport	
16	ATP	Air Transport	atp	Air Transport	
17	BSR	Business Service	trd	Trade	all retail sales; wholesale trade and commission trade; hotels and restaurants; repairs of motor vehicles and personal and household goods
			ofi	Other Financial Intermediation	includes auxiliary activities but not insurance and pension funding (see next)
			isr	Insurance	includes pension funding, except compulsory social security
			obs	Other Business Services	real estate, renting and business activities
18	SSR	Social Service	cmn	Communications	post and telecommunications
			ros	Recreation & Other Services	recreational, cultural and sporting activities, other service activities; private households with employed persons (servants)
			osg	Other Services (Government)	public administration and defense; compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
			dwe	Dwellings	ownership of dwellings (imputed rents of houses occupied by owners)

Table 3 8 Energy Sectors

Primary Energy	COL	Coal
	CRU	Crude Oil
	GAS	Natural Gas
	OTH	Others
Secondary Energy	SLD	Coal
	OIL	Petroleum
	GDT	Gas
	ELE	Electricity

Table 4 Input-Output Table and Energy balances Table

Monetary flow

				Intermediate Input											Final Demand				
				Non-Enegy (sct)			Energy								C	I	Export	Import	Output
							Primary(e_pre)				Secondary(e_scd)								
				sct1	...	sct N	CRU	OTH	COL	GAS	SLD	GDT	OIL	ELE					
Intermediate Input	Non-Enegy(sct)	sct1		$a_{ij}Q_{jt}$			$b_{ie}EC_{e,t}$								$C_{i,t}$	$I_{i,t}$	$x_{i,t}$	$m_{i,t}$	$Q_{i,t}$
		...																	
		sct N																	
	Energy	Primeary (e_pre)	CRU	0			0				0	0	$EC_{CRU,OIL,t}$	0	0	0	$P_{p,t}\cdot EX_{p,t}$	$P_{p,t}\cdot EM_{p,t}$	$EC_{e,t}$
			OTH										0	$EC_{OTH,ELE,t}$					
			COL								$EC_{COL,SLD,t}$			0					
			GAS								0	$EC_{GAS,GDT,t}$							
		Secondary (e_scd)	SLD	$EC_{s,j,t}=e_{sj}Q_{j,t}$								0		$EC_{SLD,ELE,t}$	$EC_{s,C,t}$		0		
			GDT											$EC_{GDT,ELE,t}$					
			OIL											$EC_{OIL,ELE,t}$					
			ELE											0					
Value-added				$V_{j,t}$			$V_{e,t}$												
Output				$Q_{j,t}$			$EC_{e,t}$												

Physical flow

			Intermediate Input											Final Demand					
			Non-Enegy (sct)			Energy								C	I	Export	Import	Output	Pfice
						Primary(e_pre)				Secondary(e_scd)									
			sct1	...	sct N	CRU	OTH	COL	GAS	SLD	GDT	OIL	ELE						
Energy	Primeary (e_pre)	CRU	0			0				0	0	$E_{CRU,OIL,t}$	0	0	0	$EX_{p,t}$	$EM_{p,t}$	$E_{e,t}$	$P_{e,t}$
		OTH										0	$E_{OTH,ELE,t}$						
		COL								$E_{COL,SLD,t}$			0						
		GAS								0	$E_{GAS,GDT,t}$								
	Secondary (e_scd)	SLD	$E_{s,j,t}$								0		$E_{SLD,ELE,t}$	$E_{s,C,t}$		0			
		GDT											$E_{GDT,ELE,t}$						
		OIL											$E_{OIL,ELE,t}$						
		ELE											0						

note: The subscript “p” and “s” indicate the primary and secondary energy, respectively. The subscript “t” stands for time.

Table 5　18 area Population for SRES B2 Scenario

	1997	2002	2007	2012	2017	2022	2027	2032	2037	2042	2047	2052	2057
USA	277	289	297	308	320	331	339	344	347	349	352	354	356
CAN	30	31	32	33	35	36	36	37	37	37	36	36	37
MCM	243	262	281	301	320	338	356	373	389	403	415	425	432
BRA	165	174	184	194	203	212	219	226	232	237	241	245	249
SAM	85	91	97	103	108	114	119	124	128	132	136	139	141
WEP	387	389	388	387	385	383	379	373	367	359	351	347	345
EEP	98	97	96	96	95	95	94	92	91	90	89	88	87
FSU	293	292	295	296	297	297	297	296	295	294	292	290	286
NAF	131	146	165	178	190	202	214	226	236	245	253	262	272
CAF	476	546	631	720	817	917	1,018	1,117	1,208	1,292	1,373	1,453	1,526
SAF	139	158	181	203	226	249	273	295	316	335	354	373	391
JPN	127	127	127	127	125	123	120	118	115	113	111	107	103
CHN	1,242	1,295	1,345	1,389	1,431	1,468	1,495	1,510	1,520	1,525	1,525	1,522	1,521
IND	966	1,044	1,110	1,176	1,235	1,295	1,352	1,403	1,446	1,484	1,516	1,546	1,578
ASN	480	515	548	578	606	633	660	685	706	724	739	747	748
TME	221	251	290	323	355	387	417	446	473	498	521	542	560
ANZ	22	23	24	26	27	28	29	30	30	30	30	30	29
XAP	439	492	555	607	657	705	749	791	831	868	903	928	943