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STRATEGIC RESEARCH ON CO_2 EMISSION REDUCTION FOR CHINA
—APPLICATION OF MARKAL TO CHINA ENERGY SYSTEM—

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Strategic Research on CO_2 Emission Reduction for China
－ Application of MARKAL to China Energy System －

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MARKAL was applied to the energy system for analyzing the CO_2 emission reduction in China over the time period from 1990 to 2050. First the Chinese Reference Energy System (CRES) was established based on the framework of MARKAL model. 79 kinds of energy carriers and 212 kinds of technologies that have been in active service or that might come to the fore in China were included in the corresponding database. Energy supply capability was briefly examined according to the projection of domestic energy production capacities and the assumptions about the international energy market. Empirical approach and sectoral energy elasticity analysis etc. were employed to project the useful energy demands in China from 1990 to 2050. The following conclusions can be drawn from this study. When shifting from scenario LH (low useful energy demand and high import fuel prices) to HL (high demand and low prices), another 33 EJ of primary energy will be consumed and another 2.31 billion tons of CO_2 will be emitted in 2050. Detailed analyses on the disaggregation of CO_2 emissions by Kaya Formula show. The energy intensity (primary energy／GDP) decreases much faster in scenario HL, but the higher growth rate of GDP per capita is the overwhelming factor that results in higher CO_2 emission per capita in the baseline case of scenario HL in comparison with LH. When the carbon taxes are imposed on CO_2 emissions, the residential sector will make the biggest contribution to CO_2 emission abatement from a long-term point of view. However, it's difficult to stabilize CO_2 emission per capita before

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2030 in both scenarios even with heavy carbon taxes. When nuclear moratorium occurs, more 560 million tons of CO_2 will be emitted to the atmosphere in 2050 under the same CO_2 tax regime. From the analysis of value flow, CO_2 emission reduction depends largely on new or advanced technologies particularly in the field of electricity generation. The competent technologies switch to those CO_2 less-emitting technologies when surcharging CO_2 emissions. Nuclear power shows significant potential in saving fossil energy resources and reducing CO_2 emissions.

Keywords: China, Energy System, CO_2 Emission Reduction, MARKAL.

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中国における二酸化炭素排出削減戦略の研究
－ 中国エネルギーシステムへのMARKALの適用 －

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（1995年8月25日受理）

中国のエネルギーシステムを対象とし，2050年までの期間における二酸化炭素（以下CO_2）の排出削減戦略を，MARKALモデルを用いて検討した。まず，79種類のエネルギー媒体と212種類の技術を組み込んだ基準エネルギーシステムを構築するとともに，輸入燃料の価格及び供給可能量を設定した。次に，将来人口並びに経済成長の見通しに基づいて，部門別の有効エネルギー需要を設定した。

解析結果によれば，シナリオHL（高エネルギー需要，低輸入燃料価格）の場合はシナリオLH（低需要，高価格）に比べて，2050年のCO_2排出量が23.1億トン増加した。シナリオHLでは，エネルギー強度（一次エネルギー／GDP）がシナリオLHより早く低下していくが，GDPの伸びがこれを上回って大きいため，一人当たりCO_2排出量はシナリオLHより大きくなった。

炭素税を導入してCO_2排出を抑制した場合，住宅部門での削減効果が長期的には最も大きい。しかし排出の全量を2030年以前に安定化させることはどのシナリオでも困難であった。また低排出量の発電技術の競争力が炭素税の導入によって高められ，発電用新技術もCO_2の排出削減に大きく寄与した。特に，原子力利用を行わない場合には2050年のCO_2排出が5億6000万トン増加し，原子力発電が化石燃料資源の節約とCO_2排出削減の両面で大きな寄与を期待できることが示された。

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1. Introduction

The climate change issue has drawn widespread public attention. A growing recognition of the link between the global warming and the emissions of carbon dioxide CO_2 has been witnessed in recent years. Of all anthropogenic activities, the combustion of fossil fuels in energy production and consumption engenders the largest portion of greenhouse gases pernicious to the biosphere. Although the world CO_2 emissions from the fossil fuels, which are illustrated in Fig. 1.1, were quite stable from 1987 to 1993 due to a decline in emissions resulted from political dislocation in Eastern Europe and recessions of varying severity in the developed countries which was off-set by the emission increase from the rapid economic growth occurring in the Rest-of-World countries, the continuance of the present nearly stable period is unlikely[6,8]. It is easy to imagine the CO_2 emissions will increase in next few decades because of the burgeoning economic development in many developing countries together with the resumption of the economic growth in Eastern Europe. It is incumbent upon all of us to make a special scrutiny of the situation in the developing countries, which fall short of studies on whether and how they can stabilize their CO_2 emissions, and take action to contend against the grievous environmental problem cosmopolitanly on a consistent basis.

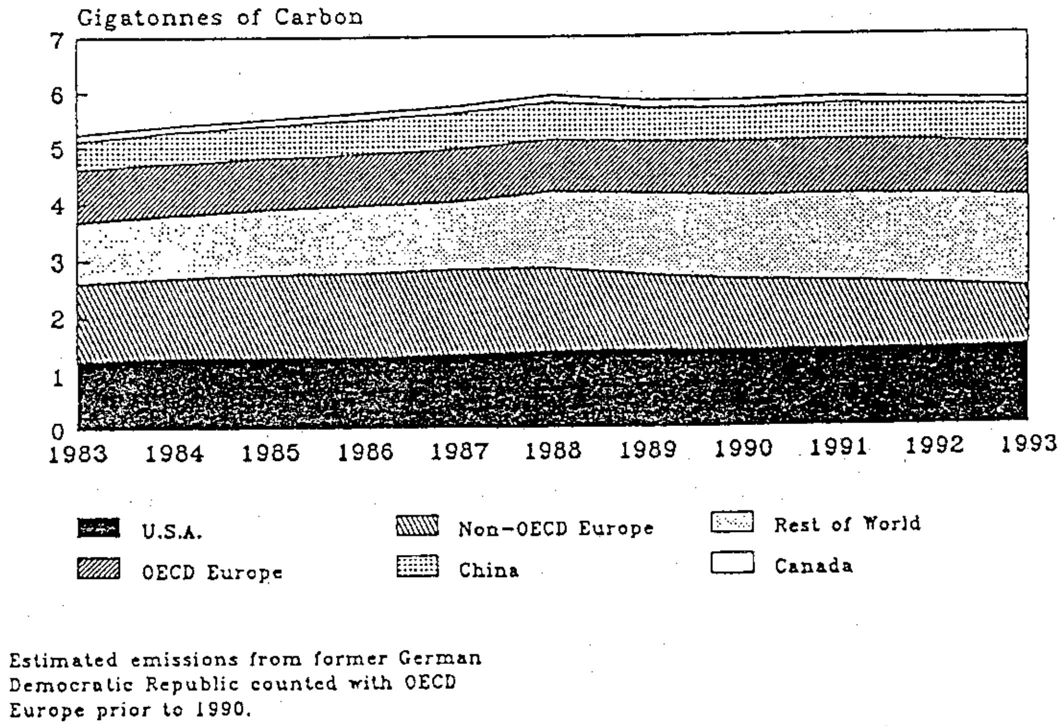


Fig.1.1 World CO_2 Emissions from Fossil Fuels Calculated from Fuel Consumption Data[6]

1.1 Energy Utilization and CO_2 Emission in China

China is a large industrializing country in a period of transition from a centrally planned economy to one ignited by market forces. The energy production and consumption is increasing with the substantial economic growth recent years. In 1990, the total commercial energy production reached 1039 Mtce and the total commercial energy consumption was 987 Mtce. The primary energy consumption and its composition from 1978 to 1993 are shown in Fig.1.2.[1,2,3,4].

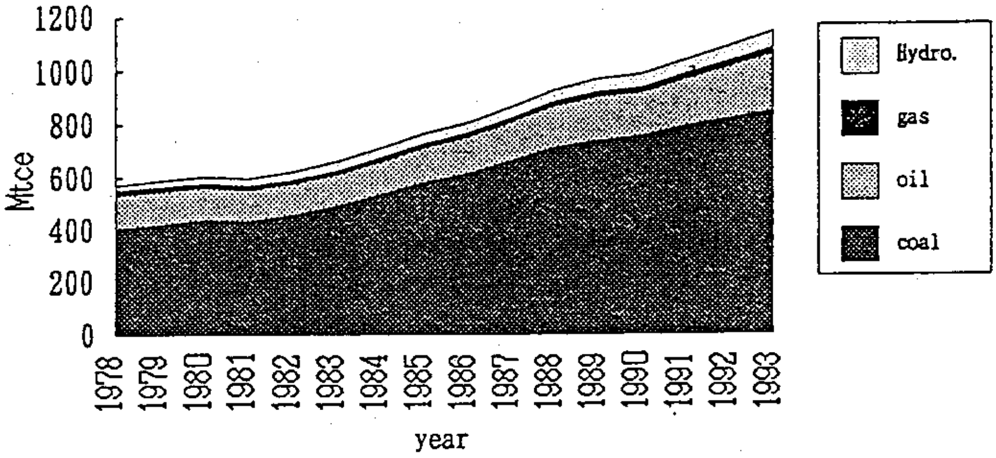


Fig.1.2 China Energy Consumption Mix: 1978 - 1993 [1,3,4]

The status quo of China energy utilization is quite different from those of developed countries, and great difference also exists as compared with other developing countries. Of the total energy consumption, coal, oil, natural gas, hydropower accounted for 73.7%, 19.3%, 1.9%, and 5.1% respectively in 1993 [1,2,3,4].

Although coal share in China's total energy consumption started to decrease while oil share started to increase lately, China is one of a few countries in the world which use coal as the principal primary energy sources and its economic activities and social life are based on domestic energy resources. The preponderance of the excavation and utilization of coal in large amount is exerting higher and higher pressure on the environment. China's fossil fuel carbon dioxide emission reached 676.1 million tons in 1993, about 11.6% of the total world's CO2 emission, though Chinese per capita release of carbon from fossil fuels is still 0.6 tones / year in 1993, less than the world per capita emissions 1.0 tones / year. The annual fossil fuel carbon dioxide emissions per capita for some countries and regions in 1993 are listed in Table 1.1

Table1.1 Annual Carbon Dioxide Emissions Per Capita
(C Tons / year) [6,8]

Country or Region	World	USA.	European Union	Non-OECD European Countries	Canada	China
Emissions	1.0	5.7	2.4	2.4	4.4	0.6

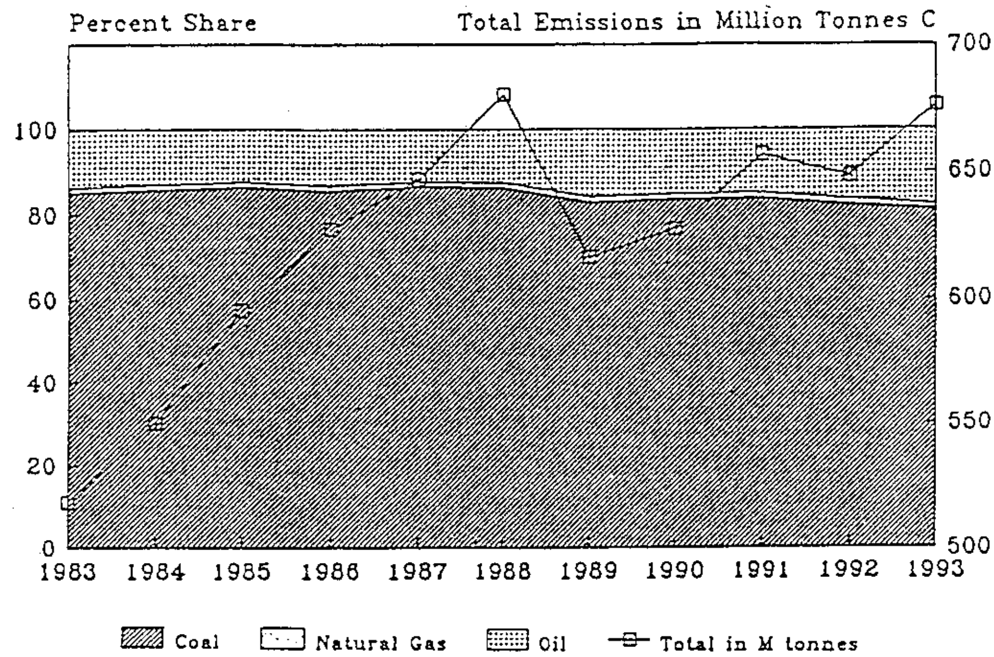


Fig.1.3 Total and Share of CO_2 Emissions from Fossil Fuels in China[6,8]

The total and share of fossil fuel CO_2 emissions from 1983 to 1993 in China are illustrated in Fig.1.3. Emissions are rising but declines are shown from 1989 to 1992 in Fig.1.3. This irregularity is believed due to an artifact of the statistical source. As the Chinese economy becomes better integrated into the would trading system and more attention is paid to the environmental protection, more reliable data about emissions of carbon dioxide, the most important greenhouse gas(GHGs), will no doubt be available in the future.[6,8]

Table 1.2 Anthropogenic Emissions of CO_2 in China(10^6 t-C/year)[9,12,13]

No	year	Coal	Oil	Gas	Flare	Bomass	Cement	Respiration	Total
1	1987	480	84	7.3	0.81	–	24	–	596.11
2	1986	442	81.5	7.51	0.81	–	24	–	728.1
	1987	476	86.3	7.63	–	99.3	22.6	76.2	774.6
	1988	511	92.6	7.9	–	102	25.3	77.3	817.4
	1989	531	97.1	7.84	–	99.4	28.6	77.4	846.1
	1990	541	101	8.09	–	102	28.6	79.5	860.1
3	1985	432.9	71.4	6.7	–	–	–	–	502
	1986	447.2	75.7	7.2	–	–	–	–	530
	1987	481.1	80.2	7.2	–	–	–	–	568.5
	1988	516.4	86.3	7.5	–	–	–	–	610.2
4	1985	492.12			–	–	19.95	–	519.47
5	1985	537.5	75.6	6.8	–	–	–	–	619.9

Source : 1–WRI; 2–Zhuong Yahui et al; 3–Yu yongnian; 4–Li Changshen et al.

As a matter of fact, several Chinese researchers have made detailed calculation of the CO_2 emissions. Results obtained by different researchers are summarized inTable 1.2[9,12,13].

Table 1.3 shows CO_2 emission from fossil fuel combustion in different sectors and it seems to be clear that industry is by far the biggest sources and accounts for more than half of the total emission. Next is the power generation sector accounting for about 25%.

The major reasons for this are China's heavy reliance on coal utilization and many inefficient, even some obsolete technologies and equipment to be operated in industry and power generation sectors beyond what would be considered their useful life in developed countries.

Table 1.3 CO_2 Emissions from Fossil Fuel Combustion in Different Sectors(10^6 T CO_2-C/year)[9,12,13]

Year	Industry	Agri.	Tansp.	Service	Civil	Power	Total	Source
1985	327.9	9.9	26.6	29.8	123.36	102.3	619.9	1
1988	314.57	14.69	14.08	19.58	107.7	140.76	612	2
1989	330.08	13.36	13.99	20.35	104.94	153.28	636	2
1988	313.64	14.64	14.03	19.53	107.4	140.35	610.2	3

Source： 1–Wu Zhongxin; 2–Zhuang Yahui; 3–Yu Yongnian.

Compared with those in developed countries, China has relatively inefficient energy production and use technologies. Therefore, there should be a great potential of energy conservation and CO_2 emission reduction opportunities in China . However, control of CO_2 emission will involve a strong constraint on energy systems and thus may have a significant negative impact on economic activities and the improvement of living standard.

With a view to keeping pace with the booming economy's soaring energy demand and meanwhile keep a benign natural environment, it is important and necessary to perform study on the development of China energy system to assess the costs for reducing CO_2 emission and to analyze what kinds of measures such as energy conservation, fuel switching, technology substitution etc. should be proper to be taken for CO_2 abatement as fast as possible.

1.2 Objectives of this Research Work

Our study works based on the framework of MARKAL model and IEA/ETSAP common guidelines were accomplished in Energy System Assessment Laboratory of Japan Atomic Energy Research Institute. They consist of the following steps:

1) Configuring the China Energy System in MARKAL model over the time period from 1990 to 2050 in 5-year steps.

2) Establishing a database on energy resources and technologies that have been in active service and that might come to the fore in China.

3) Projecting the useful energy demands in terms of scenario assumptions which indicate socioeconomic development within the whole time horizon in China and compiling the calculation program correspondingly.

4) Examining the configured model by running MARKAL program and assessing the optimal results for the examplified scenarios and cases.

It should be clearly mentioned that MARKAL is not a simulation model designed to predict the future. It is a normative model that is used to describe future energy system in a parametric way [23,24,25,27]. In other words it is suited to say that the world situation were given like this, how should you develop the energy system with the conceivable energy resources and viable technologies to satisfy your cost and other criteria. So the essential nature of the present energy modeling exercise is not to predict future but to describe and discuss scenarios and cases within a range of possibilities.

2. Reference Energy System

MARKAL, an acronym for MARKet ALlocation, is a large scale Linear Programming optimization model which captures the complex interrelationships of energy system across the spectrum from primary energy supply through energy transformations to energy service demands. The MARKAL program is formed upon a set of linear constraints, with variables and coefficients defined by the user as input data. The total cost of the energy system or others is then minimized subject to these constraints, and the resulting energy flows, technological options and costs are output for inspection and analysis. The mathematical and programming details of MARKAL are described elsewhere. [23,24 ,25, 27,28,31,32].

Our research works begin with establishing a reference energy system for China energy system based on the framework of MARKAL model. The structure of Chinese reference energy system (CRES), simulating the flow of energy in various forms (energy carriers) from the sources of supply through transformation systems to the demand devices that satisfy the end-use demands, is shown in Fig 2.1, Fig 2.2 and Fig 2.3 [40,41,42,45,47, 48,49]. The elements of the Chinese reference energy system are described as follows:

2.1 Energy Demand Sector and Demand Technology(DMD)

The energy demand sector, shown in the upper rows in Fig.2.2, is disaggregated into five subsectors: agriculture, industry, commercial (service), residential and transportation. Each subsector includes several demand categories. The demand structure can be easily modified to suit special needs. For example, in industry subsector, crude steel, cement and paper production technologies etc. were defined and the additional technology details were employed to the existing database. This modification could be used either for a special study or maintained as a permanent part of the database. High and low useful energy demand projections are exogenously given for each time period over the time horizon in these subsectors for different scenarios respectively. This will be discussed more detail in Section 3.3.

Demand technologies(DMD), which consume energy carriers to meet useful energy demand, are presented by circles in the matrix depicted in Fig.2.2. Demand technologies utilizing over one kind of energy carrier are indicated by the asterisks in the circles. Total of 135 kinds of demand technologies are included in the reference energy system.

2.2 Energy Carriers

In Chinese reference energy system, the term of "energy carrier" is used instead of fuel because of its broader connotations. There are 79 kinds of energy carriers in the reference energy system. Secondary energy, most shown in the left column in Fig.2.2, includes all the energy going into demand technologies, for which a number of distinct energy carriers are defined in the model. Six classes of oil products are distinguished, shown in Table 2.1.

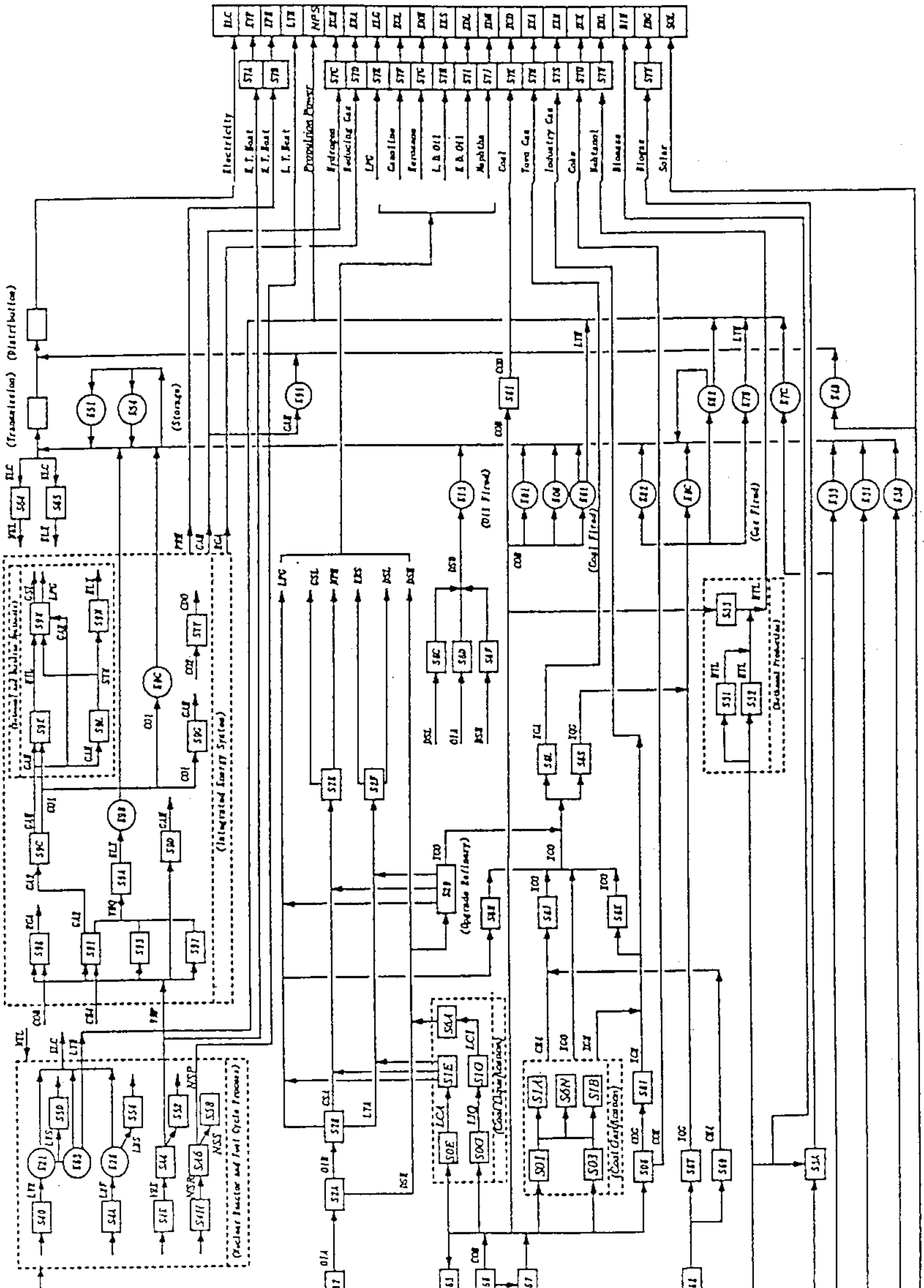


Fig.2.1 The Chinese Reference Energy System (Part 1)

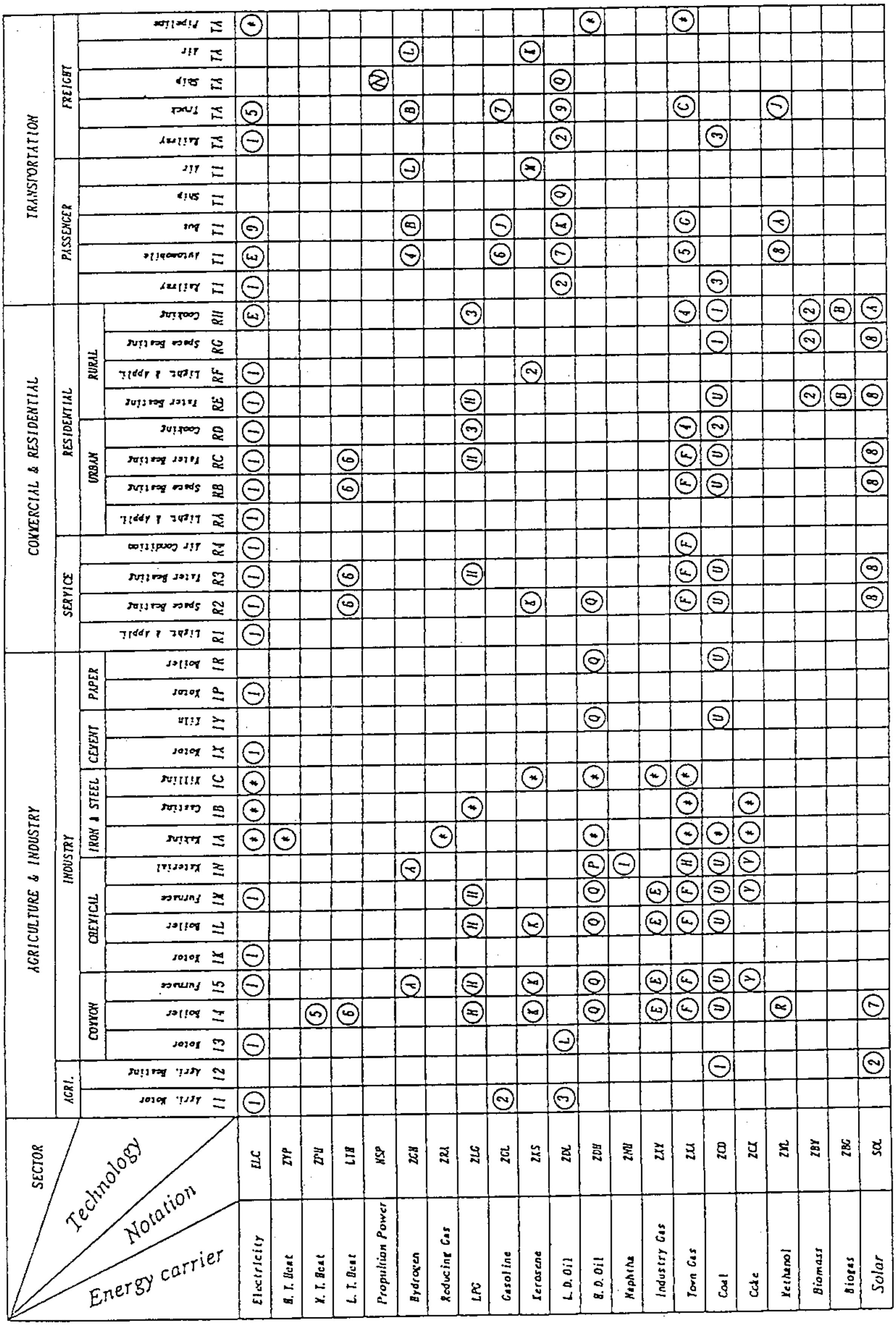


Fig.2.2 The Chinese Reference Energy System (Part 2)

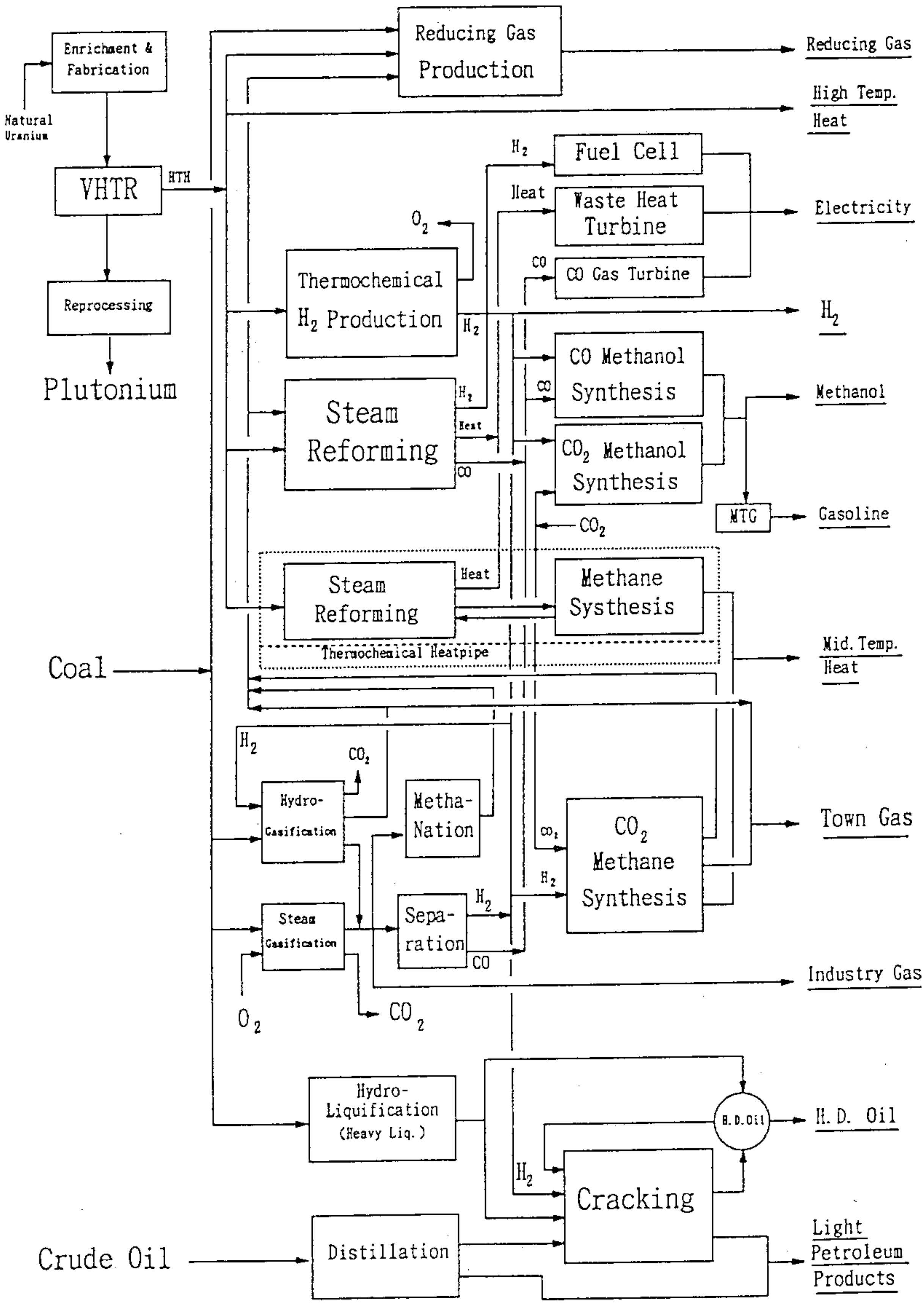


Fig.2.3 Technology Configuration of Integrated Energy System (IES)
[The Chinese Reference Energy System (Part 3)] [40,41,42,47,48]

Table 2.1 Oil Products and its Notation

Oil Products	Reference notation	
Gasoline	GSL	ZGL
Kerosene	KRS	ZKS
Liquid Petrelium Gas	LPG	ZLG
Light Distillate oil	DSL	ZDL
Heavy Distillate oil	DSH	ZDH
Naphtha	NPH	ZNH

Note: Symbols in second column are energy carriers after transportation.

Coal, coke, town gas, reducing gas, industry gas, hydrogen, methanol, biomass, biogas, solar and ship propulsion power are each represented by a single energy carrier. Heat is divided into high, medium and low temperature heat. Electricity is balanced at the following six time intervals: winter day, winter night, intermediate day, intermediate night, summer day and summer night and low temperature heat is balanced seasonally.

For the nuclear fuel cycle, the following energy carriers are defined as inTable 2.2.

Table 2.2 Energy Carriers in the NFC

Energy Carriers	Notation
Uranium	URN
Depleted uranium	UDP
Plutonium fissile	PUF
LWR fabricated fuel	LWR
LMFBR fabricated fuel	LMF
VHTR fabricated fuel	VHE
Marine LWR fabricated fuel	NSR
LWR spent fuel	LWS
LMFBR spent fuel	LMS
VHTR spent fuel	VES
Marine LWR spent fuel	NSS

The nuclear fuels are not directly utilized in demand technologies but are consumed or produced by reactors and fuel cycle technologies.

The primary energy covers the energy carriers, which are listed in left part of Fig.2.1, They are either extracted from domestic resources or imported in Chinese reference energy system. It should be noted that some of the primary energy have been mentioned under the heading of secondary energy, actually primary and secondary energy are not mutually exclusive categories. In Chinese reference energy system, primary energy carriers include: natural uranium, coal, crude oil, natural gas, biomass, biogas, geothermal, hydropower, solar and renewable energy et al.

2.3 Conversion Technology(CON)

Conversion technologies(CON) are load-dependent technologies converting primary energy into electricity and/or heat through power plants, heat plants and cogeneration plants[23,24]. A total of 29 kinds of conversion technologies are indicated in small circles in Fig. 2.1 in Chinese reference energy system. They are introduced in the reference energy system by the seasonal and diurnal load variations of electricity and heat demand, which necessitate the definition of corresponding additional variables to represent output of the electricity or heat or both for each conversion technologies.

2.4 Process Technology(PRC)

Process technology(PRC) are load-independent technologies converting one energy carrier into another[23,24]. The compiled 58 kinds of process technologies, marked in small quadrilateral in Fig.2.1 of the reference energy system, are serving two purposes:

The first is to characterize intermediate process technologies such as coal liquefaction and gasification, shown in the large dotted quadrilateral line in Fig.2.1, oil refinery, methanol and gasoline synthesis, and nuclear fuel fabrication, transportation and distribution etc.

The second use of process technologies is as dummy technologies for modeling convenience, such as to allow the model flexibility in selecting the fuel mix for multi-fuel power plants or to provide a convenient place to designate environmental emissions. The Chinese reference energy system contains 30 kinds of such dummy process technologies. As dummy process perform no work and incur no losses, we included them in class "dummy" in order to run the model quickly and let the problem easy to be solved.

2.5 Configuration of Integrated Energy System(IES)

In the configuration of Chinese reference energy system, the integrated energy system(IES) was specially configured in order to study the possibility of symbiotic use of nuclear heat and fossil fuel through hydrogen in China[40,41]. The IES subsystem has been structured schematically in Fig.2.3. In this subsystem, nuclear heat in high temperature range from VHTR is utilized in the process such as thermochemical hydrogen production, reducing gas production, methane steam reforming etc. The large waste heat is employed in electric power generation. On the other hand, the hydrogen application technologies like coal hydro-gasfication, methanol synthesis, petroleum refinery, hydrogen fuel cell and so on are also included in the IES.

3. MARKAL Database

As MARKAL model is an exogenously demand driven dynamic linear program model, while the energy demands hinge to a large extent upon national economic development, here we begin with the projection of demographic and economic development in order to set up energy demand projections and database for Chinese reference energy system.

3.1 Social and Economic Indicators

China has entered a new era of economic development characterized by reforming existing economic system and opening to the outside world since the late 1970s. Between 1980 to 1993, China' GDP growth rate averaged 9.4 percent annually[9,10,12,14]. The driving forces of China's high economic growth are dramatic increases in effective labor supply and effective capital stock as a result of economic reforms. With the rapid economic growth. China's population growth was strictly controlled and in the meantime more and more people immigrated into urban area. The social and economic situation are assumed to be continued for a certain time.

Because the development of models for economic and population projection requires extensive economic and demographic knowledge and considerable computation, such an effort is outside the purview of this study. Projecting the long-term social and economic development is an onerous task for a large country like China, especially the Chinese economic system is still in the transition towards a market-oriented economy and the historical and political factors have still momentous impacts on social and economic development.

The postulated social and economic indicators are listed in Table 3.1. The monetary units is 1980 U.S. dollars. Only a brief summary is given here to show how the numerical postulations were generated. The reference methodology can be found elsewhere[9,11, 14, 15,16].

Several Chinese population projections were reported covering the year of 2050. All of the population projection available have an implicit assumption that China will continue to implement population control policies and the future total population and its age structure depend strongly on the content and timing of these policies. Considering the reluctance of Chinese and international communities to accept current policies, we use the high variant of population projection by Tian Xueyuan, a Chinese population expert and the director of the Chinese Institute of Population in 1984, as the low population projection in our study. Chinese population projection was shown in Fig.3.1[15].

In Tian's high variant of population projection, the TFR(Total Fertility Rate) was assumed from 2.1 reduced to 1.9 from 1990 to 2000, and then increase to 2.1 during next two decades, after that time the TFR will keep replacement rate 2.1, which means that a couple just replace themselves in their live. When other demographic factors such as sex, age structure, mortality rate etc. were taken into account, the population projection was obtained shown as the low Chinese population projection in Fig.3.1[15,16]. The high Chinese population projection was obtained when we assumed the annual population growth rate as shown in Table 3.2. Low and high annual GDP growth rates are given in Table 3.1. The projections for Chinese sectoral shares in GDP and population composition are also given in Table 3.1.

Table 3.1 Social and Economic Indicators

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980U.S.$$10^9$)	675.9	1393.1	2269.1	3358.9	4514.0	5502.6	6078.3
Low Growth Rate	9.0%	7.5%	5.0%	4.0%	3.0%	2.0%	1.0%
Per Capita($/Per)	591.3	1112.7	1690.9	2360.4	3011.4	3725.5	4049.5
Share of GDP(%) (Low Growth)							
Agriculture	29.0	26.0	23.0	19.0	15.0	13.0	11.0
Industry	46.0	44.5	43.0	42.3	41.8	41.3	41.0
Service(Commercial)	20.5	24.5	28.5	33.0	37.3	39.7	41.8
Transportation	4.5	5.0	5.5	5.7	5.9	6.0	6.2
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
Urban(%)	26	32	40	45	50	55	60
Rural(%)	74	68	60	55	50	45	40
GDP(1980U.S.$$10^9$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
High Growth Rate	9.0%	8.5%	7%	5%	4%	3%	2%
Per Capita($/Per)	591.3	1210.4	2176.9	3274.4	4520.4	5722.2	6636.0
Share of GDP (%) (High Growth)							
Agriculture	29.0	24.0	19.0	14.0	10.0	7.5	6.0
Industry	46.0	45.0	44.0	43.0	42.3	41.8	41.5
Service(Commercial)	20.5	25.8	31.5	37.3	41.8	44.7	46.4
Transportation	4.5	5.2	5.5	5.7	5.9	6.0	6.1
Population(10^6)	1143	1263	1381	1495	1604	1702	1789
Urban(%)	26	34	42	50	56	62	70
Rural(%)	74	66	58	50	44	38	30

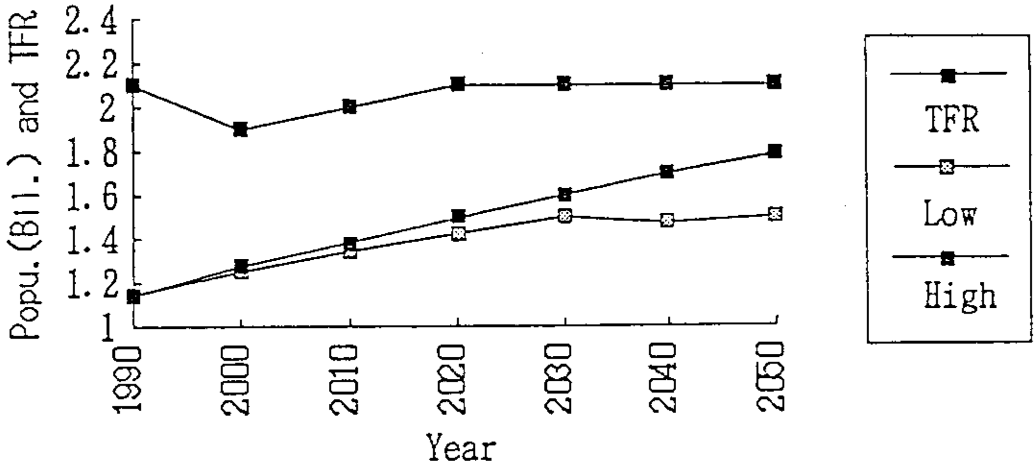


Fig.3.1 Chinese Population Projection

In the procedure of projecting sectional shares in GDP and Chinese population composition, we use an empirical approach that examines historical data from other developed countries to find an average path of economic growth and population development in the past and assume that this is the way that China will be likely to take in the near future. A lot of materials about the sectional shares in GDP and urbanization vs. GDP per capita et al, which are obtained by linear regression on historical data for sample countries as illustrated in Fig 3.3, can be found elsewhere [11,14,15,16]. The projections of China GDP development and GDP per capita for the time period from 1990 to 2050 are shown in Fig.3.2.

Table 3.2 Chinese Population Growth Rate (High)

Year	1990–2000	2000–2010	2010–2020	2020–2030	2030–2040	2040–2050
Growth Rate	1.0%	0.9%	0.8%	0.7%	0.6%	0.5%

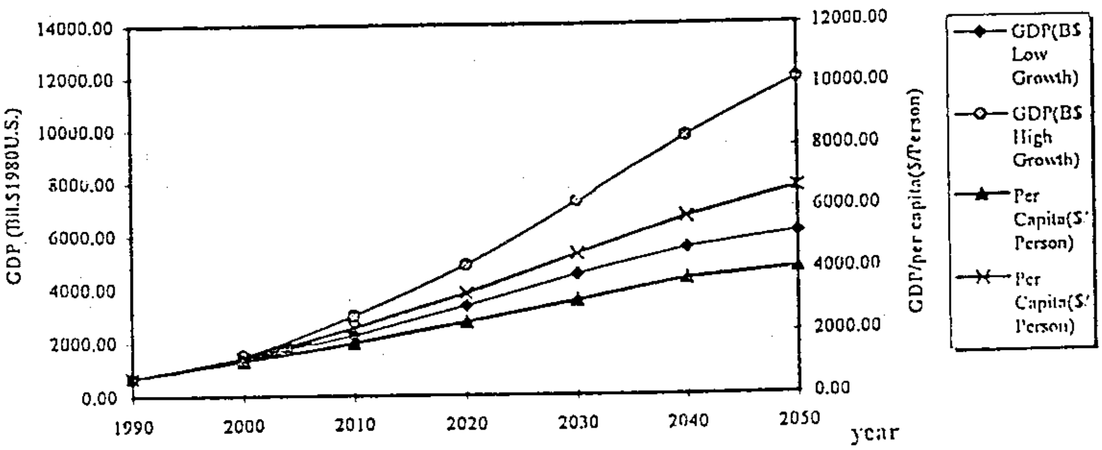


Fig.3.2 Projection of China GDP and GDP per capita

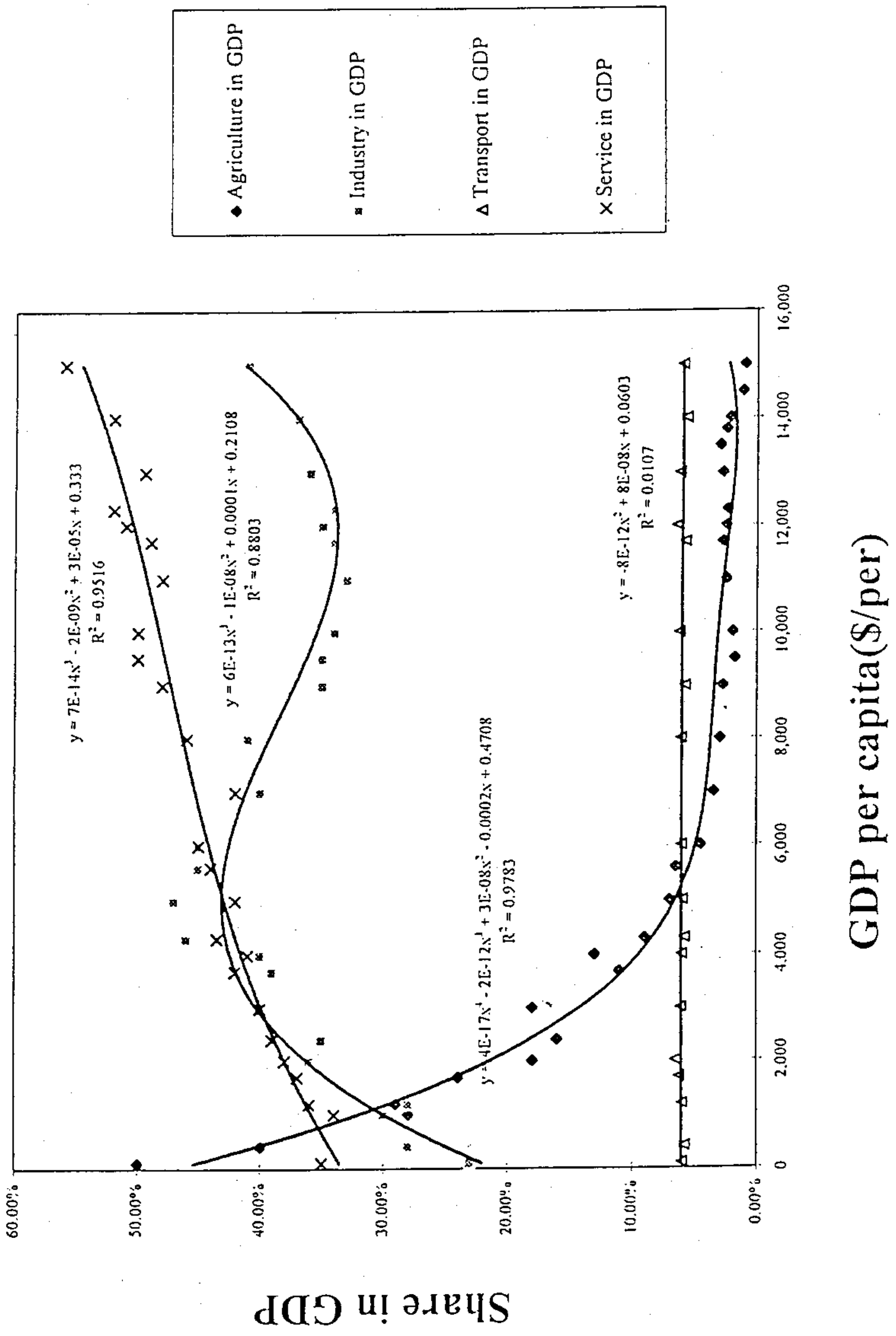


Fig.3.3 Sectoral Share in GDP for Sample Countries

3.2 Energy Resources and Supply

Although China is a poor county, with much of its population still farming for basic subsistence in rural villages, China is well blessed with energy resources. The natural resource endowments place China in a special position when planning for its future energy development. In this section, we are examining the energy supply and some import fuel prices in China.

3.2.1 Domestic Energy Resources

The main energy resources are summarized as follows:

Coal: Coal is the abundant energy source in China. According to the Ministry of Energy[1,3,4,5], in 1991, the proven resources based on the Chinese definition reached 966.7 billion tons, although proven reserves based on the World Energy Conference Definition (Proved amount in Place) were only about 290 billion tons. We use the latter in our study, i.e. the Chinese recoverable coal reserves about 204 Btce, which is listed in Table 3.3. The conversion factor is assumed to be 0.704 Kgce / kg.

Oil: Though crude oil resource was reported to be 111 Btce in 1990, recent estimates of the oil recoverable reserves vary less in China[1,3,4,5], from 3.2 billion tons to 3.4 billion tons, we take 3.4 billion tons as recoverable oil reserves in this study. That is about 4.8 Btce, which is listed in Table 3.3. The conversion factor is 1.412 kgce / kg.

Natural Gas: Natural gas resource in China is estimated to be 33.3 Trillion Cubic Meters, approximately 40 percent is oil-associated[1,3,4,5]. As of 1988 there was 866 BCM of proved natural gas reserve in China. If the conversion factor is assumed to be 1.38 kgce / m3, the proved natural gas reserve is about 1.2 Btce, listed in Table 3.3.

Domestic Biofuels: Three kinds of major biofuel resources, which included firewood, crop residuals and manure, are estimated to be about 380 Mtce in the 1980s[2,3,4,5,11]. Biofuels utilization is assumed to be decreased year by year as shown in Table 3.3.

Hydropower: As China' territory is predominantly mountainous and about 3019 rivers are identified with more than 10 MW hydropower resources, China ranks first in the world for hydropower resource amounting to 378 GW[1,3,4,5]. Hydropower utilization depends on the hydropower plant construction. High capital costs of hydropower and major resources far away from load centers etc. are main reasons in impeding hydropower exploitation in China. Now only about 12% of exploitable potential resource is utilized.

Uranium: The 1989 Survey of Energy Resources of the World Energy Conference estimated China's uranium resources at 1000-2000 thousand tons of metal uranium[1,3,4,5]. We assume the uranium reserves to be 2000 thousand tons of metal U in this study.

The upper bounds of domestic energy production capacities for each year from 1990 to 2050 are extrapolated from available materials[4,5,9,11,14]. They are also summarized in Table 3.3.

Table 3.3 Energy Resources and Bounds on Energy Production Capacities [1,3,4,5,9,10,11,12,14,18,19,20,22]

Year	1990	2000	2010	2020	2050
Coal Recoverable Reserves		204.1	Btce	(5977298 PJ)	
Coal Annual Production Capacity(Mtce)	752	1100	1600	2368	4290
Coal Annual Production Capacity(PJ)	22034	32230	46880	69394	125697
Oil Recoverable Reserves		4.8	Btce	(141000 PJ)	
Oil Annual Production Capacity(Mtce)	164	270	400	488	657
Oil Annual Production Capacity(PJ)	4811	7911	11720	14287	19256
Proved Natural Gas		1.2	Btce	(35160 PJ)	
Natural Gas annual Production Capacity(Mtce)	23	47	85	114	154
Natural Gas Annual Production Capacity(PJ)	680	1377	2491	3347	4511
Hydropower Capacity(GW)	36	81	140	170	378
Biofuels Resources(Mtce)	380	300	250	220	180
Biofuels Resources(PJ)	11134	8790	7325	6446	5274
Uranium Resource		$2*10^6$	tons	(MU)	

Note: The price projections of domestic energy carriers are not given in this report.

3.2.2 Assumptions about International Energy Markets

The high and low assumptions of future prices of imported energy carriers, shown in Table 3.4 and Table 3.5 respectively, are based on the IEA/ETSAP common guidelines and extrapolated to 2050 in our study[34,39,40,41]. In this study no limits are imposed on the availability of imported fuels. Within the time horizon, the crude oil price is projected to increase a little more than quadruple in the high price growth, but in low price growth, just increase double. The natural gas prices are assumed to link to oil prices. The coal prices are projected to increase around double in low and high price growth in 60 years. The natural uranium price is also set as increase reflecting worldwide utilization of nuclear energy as one of measures to restrain CO_2 emissions.

Table 3.4 Import Fuel Prices (High Prices)

YEAR	1990	2000	2010	2020	2030	2040	2050
Steam Coal($/t)	39.9	49.3	56.5	64.14	71.0	77.71	84.37
Steam Coal($/GJ)	1.61	1.99	2.29	2.60	2.87	3.15	3.42
Coking Coal($/t)	58.6	72.2	82.5	93.0	103.4	111.7	120.8
Coking Coal($/GJ)	1.94	2.39	2.73	3.08	3.42	3.7	4.0
Crude Oil($/kl)	133.3	214.5	293.7	373.0	452.2	531.3	607.5
Crude Oil($/GJ)	3.74	6.03	8.25	10.48	12.7	14.92	17.06
LNG($/t)	195.4	314.9	431.5	548.1	665.1	782.1	901.5
LNG($/GJ)	3.99	6.43	8.81	11.19	13.58	15.97	18.41
Uranium Ore ($/kgU3O8)	80.7	88.8	99.2	109.7	120.1	130.4	140.6

Table 3.5 Import Fuel Prices (Low Prices)

YEAR	1990	2000	2010	2020	2030	2040	2050
Steam Coal($/t)	39.9	44.9	50.3	55.51	61.4	66.6	71.8
Steam Coal($/GJ)	1.61	1.82	2.03	2.25	2.48	2.7	2.91
Coking Coal($/t)	58.6	65.6	73.4	81.8	89.5	98.2	105.7
Coking Coal($/GJ)	1.94	2.17	2.43	2.71	2.96	3.25	3.5
Crude Oil($/kl)	133.3	167.9	205.0	241.8	278.6	315.8	352.9
Crude Oil($/GJ)	3.74	4.72	5.75	6.79	7.82	8.87	9.91
LNG($/t)	195.4	246.8	300.7	354.3	409.0	462.5	510.2
LNG($/GJ)	3.99	5.04	6.14	7.24	8.35	9.44	10.42
Uranium Ore ($/kgU3O8)	80.7	88.8	99.2	109.7	120.1	130.4	140.6

3.3 Projection of the Useful Energy Demand

There are five energy demand sectors of useful energy demands in Chinese reference energy system. Each sector includes several categories of useful energy demand, 38 demand categories are shown in the upper rows in Fig.2.2 of Section·2. Each of those categories represents a need for the useful energy in China reference energy system from 1990 to 2050. All of these energy demands, specified as input data to the model, are discrete functions of time, and the whole time period is divided into 12 intervals of five years each. The useful energy demand is projected exogenously for each interval respectively, actually representing the average annual demand over the five year period. The MARKAL Model is ultimately driven by seeking to satisfy the set of exogenously given energy demands at each of the 12 time intervals simultaneously.

Incorporating projections of useful energy demand for Chinese reference energy system is obviously imperative, but a tedious job and entails a lot of time and efforts. In our study, the projection data are treated with the Microsoft Excel in the Energy System Assessment Laboratory of Japan Atomic Energy Research Institute. The projections of useful energy demands are abbreviated in this report as follows:

3.3.1 Agriculture Sector

The following equations are used in projecting the agricultural useful energy demand AUED(s, t)(PJ):

$$AUED(s, t)\ [PJ] = AGDP(s, t)\ [\$Bil.] * AUEI(s, t)\ [MJ/\$]$$

$$AUEI(s, t) = AFEI(s, t) * AOEEC(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

AUED(s, t): Agricultural useful energy demand under the assumption(s) about the socioeconomic system development during time t(PJ).
AGDP(s, t):Agricultural GDP share under the assumption(s) out the socioeconomic system development during time t($Bil.).
AUEI(s, t): Useful energy intensity in agriculture sector under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
AFEI(s, t): Final energy intensity in agriculture sector under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
AOEEC(s, t): Overall efficiency of energy carriers in agriculture sector under the assumption(s) about the socioeconomic system development during time t.

The s in AUED(s, t)(PJ) represents the assumption of the low energy demand because of the low economic and low population growth or the assumption of the high energy demand because of the high economic and high population growth.

The projections of the agriculture useful energy demand are shown in Fig.3.4. Detailed information is given in Appendix 1 in this report.

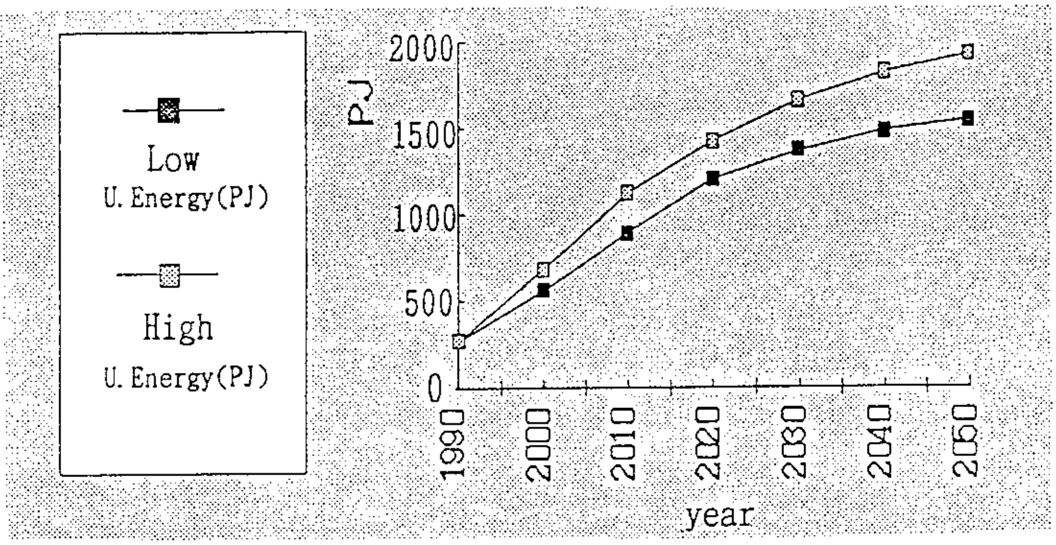


Fig.3.4 Agricultural Useful Energy Demand Projection

3.3.2 Industrial Sector

Energy demand structure in industrial sector are broken down into several categories(e.g. iron and steel, cement, paper production, chemical and other industries) with the compiled additional technological details for the MARKAL adapting to special purposes (see Section 2). The industrial energy demands, indicated either in energy units (PJ) or in output volumes, provide the basic drivers for the MARKAL model.

As the reason mentioned above, we incorporate projections of energy demands or output volumes correspondingly for the different industrial categories as follows.

By exploiting the empirical approach that through examining historical data from sample developed countries to peruse the relationships between the material output volume versus GDP per capita in the sample countries correspondingly, we can procure output volume projections in the industrial categories such as iron and steel, cement and paper production based on the assumption of GDP per capita growth for China in the time period from 1990 to 2050. For instance, according to paper output volume per capita versus. GDP per capita obtained by linear regression on historical data from some developed countries, shown in Fig. 3.5, we derived the paper production projection in China, which is shown in Table 3.6.

Table 3.6(1) Projetion of Output Volumes for Industrial Categories
(Low Demand)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
GDP/per capita(Bil.$/p)	591.34	1112.66	1690.8	2360.42	3011.37	3738.17	4049.49
Industry GDP share (%)	46.00	44.50	43.00	42.30	41.80	41.30	41.00
Industry GDP(Bil.$)	310.91	619.91	975.73	1420.80	1886.87	2272.57	2492.10
Paper Production(kg/per)	13.72	22	25	30	35	42	50
Paper Production(Mt)	15.68	27.5	33.6	42.7	52.5	61.8	75.0
Steel Production(Mt)	66	120	160	200	230	250	270
Cement Production(Mt)	210	380	800	1000	1050	1100	1150

Table 3.6(2) Projetion of Output Volumes for Industrial Categories
(High Demand)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1262	1381	1495	1603	1702	1789
GDP/per capita(Bil.$/p)	591.34	1210.37	2176.9	3274.41	4520.35	5722.22	6635.99
Industry GDP share (%)	46.00	45.00	44.00	43.00	42.30	41.80	41.50
Industry GDP(Bil.$)	310.91	687.69	1322.73	2105.62	3066.09	4071.86	4927.95
Paper Production(kg/per)	13.72	23	28	37	56	68	74
Paper Production(Mt)	15.68	29.0	38.7	55.3	89.8	115.7	132.4
Steel Production(Mt)	66	140	190	230	270	310	340
Cement Production(Mt)	210	450	1000	1100	1180	1250	1300

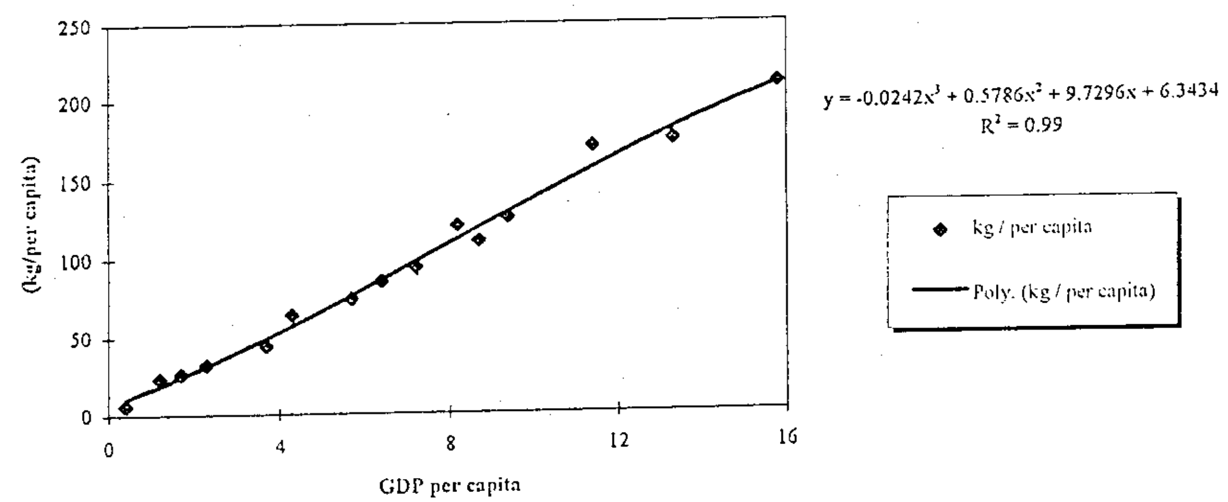


Fig.3.5 Paper Production Per Capita vs. GDP Per Capita in Selected Countries

As for chemical or other common industrial categories the following equations are used in projecting the useful energy demands IUED(i, s, t)[PJ]. In the IUED(i ,s, t), where i indicates different industrial categories such as chemical, petroleum processing, textiles, machinery & electronics and building materials etc.(listed in Appendix 2) and the s in IUED(i ,s, t) has the same meaning as that in AUED(s, t)[PJ]:

$$IUED(i, s, t) = UEI(i, s, t) * GOPV(i, s, t)$$

$$UEI(i, s, t) = FEI(i, s, t) * EECY(i, s, t)$$

$$\underline{GOPV(i, s, t)} = GOPV(i, 1990) * \{1 + [GRGOPV(i, s, t)]\}^{t-1990}$$

$$GRGOPV(i, s, t) = EGOPVG(i, s, t) * GRGDP(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

UEI(i, s, t): Useful energy intensity of industrial categories i under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
FEI(i, s, t): Final energy intensity of industrial categories i under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
EECY(i, s, t): Overall efficiency of energy carriers in industrial categories i under the assumption(s) about the socioeconomic system development during time t.(%)
GOPV(i, s, t): Gross output value in industrial categories i under the assumption(s) about the socioeconomic system development during time t. ($)
GRGOPV(i, s, t): Growth rate of gross output value in industrial categories i under the assumption(s) about the socioeconomic system development during time t.
EGOPVG(i, s, t): Elasticity of gross output value growth rate in industrial categories i versus growth rate of GDP under the assumption(s) about the socioeconomic system development during time t.

The projections of useful energy demands for some industrial categories are shown in Table 3.7 and Fig.3.6.

Table 3.7 Projections of Useful Energy Demand for Some Industrial Categories(PJ)

Year	1990	2000	2010	2020	2030	2040	2050
U.E.D in Chemical Ind.(Low)	1215	1877	2407	2876	3276	3646	3794
U.E.D in Chemical Ind.(High)	1215	1984	2877	3511	3945	4151	4162
UED for Building Materials(Low)	1111	1536	1905	2292	2687	3133	3348
UED for Building Materials(High)	1111	1600	2216	2726	3182	3526	3707
U.E.D in Other Industries(Low)**	2935	4664	6307	8145	9978	11539	12440
U.E.D in Other Industries(High)**	2935	4911	7649	10320	12929	15156	16526

Note: ** Not include the useful energy demands in the industrial categories such as iron and steel, cement and paper production.

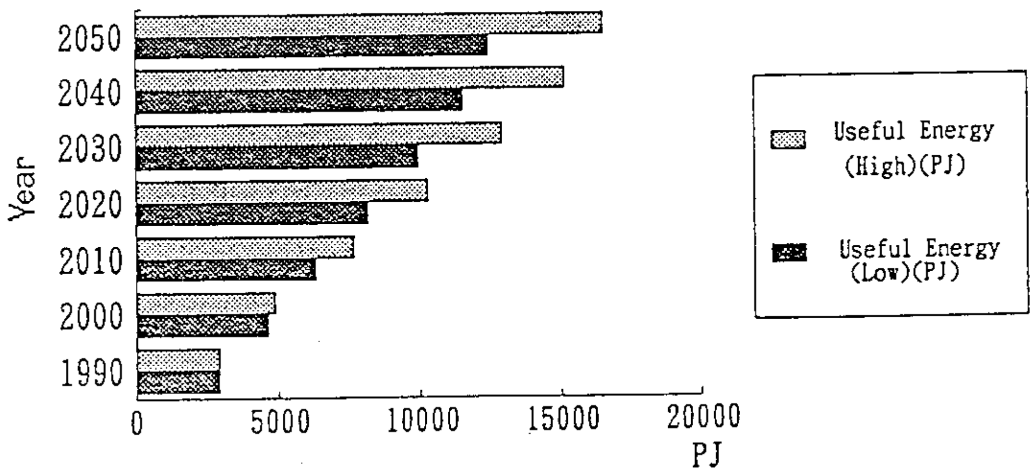


Fig.3.6 Projection of Useful Energy Demand in Other Industries

3.3.3 Commercial(Service) Sector

The following equations are used in projecting commercial(service) useful energy demand CUED(s, t)[PJ]:

$$CUED(s, t)\ [PJ] = CGDP(s, t)\ [Bil.\$] * CUEI(s, t)\ [MJ/\$]$$

$$CUEI(s, t) = CFEI(s, t) * COEEC(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

CUED(s, t): Commercial useful energy demand under the assumption(s) about the socioeconomic system development during time t(PJ).
CGDP(s, t): Commercial GDP share under the assumption(s) about the socioeconomic system development during time t($Bil.).
CUEI(s, t): Useful energy intensity in commercial sector under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
CFEI(s, t): Final energy intensity in commercial sector under the assumption(s) about the socioeconomic system development during time t.(MJ/$)
COEEC(s, t): Overall efficiencyof energy carriers in commercial sector under the assumption(s) about the socioeconomic system development during time t.

The s in CUED(s, t)(PJ) has the same meaning as in AUED(s, t)[PJ]. The projection of total commercial(service) useful energy demand CUED(s, t) is shown in Fig.3.7 and detailed information is given inAppendix 3 in this report.

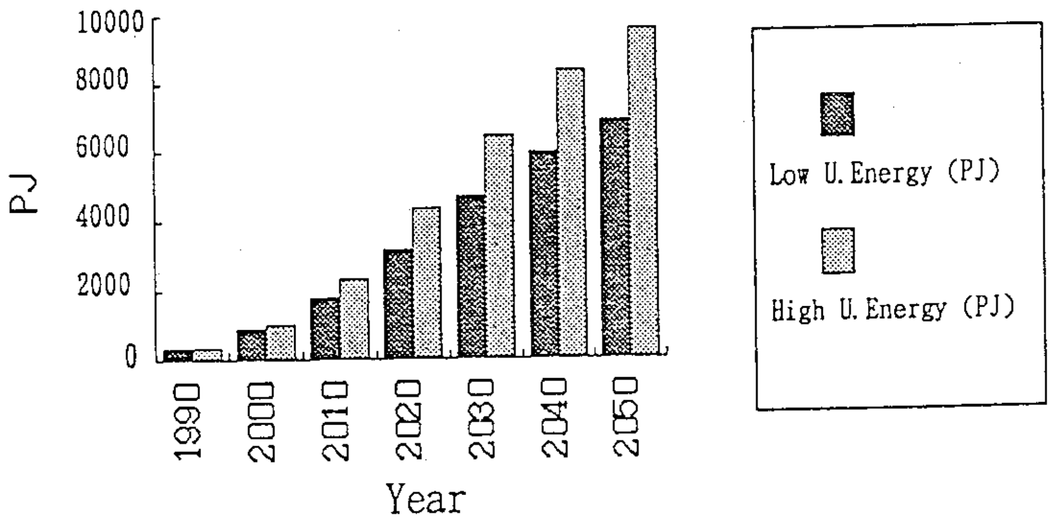


Fig.3.7 Projection of Useful Energy Demand in Commercial(Service) Sector

3.3.4 Residential Sector

1) Residential Indicators

Residential energy demands are affected by many factors such as the population size, household behaviors, appliances stock in houshould, building stock and climatic conditions etc. The behaviors of households in urban and rural areas are obviously different and the energy consumption in urban and rural places are also quite different now in China. Chinese population was classified into urban and rural population components in this research. In 1990, there are about 3.5 persons in a family in urban areas and about 84.9 million housholds in urban areas, meanwhile, about 4.8 persons in a rural family and around 176.21 million households in rural areas[2]. They are assumed to vary as illustrated in Table 3.8. for the time period from 1990 to 2050.

The projections of residential energy demands are based on energy demands in space heating, lighting and appliances, cooking and water heating etc. in urban and rural areas respectively.

Table 3.8(1) Residential Indicators(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
Urban	26%	32%	38%	45%	50%	55%	60%
Urban Population(10^6)	297	401	510	640	750	810	901
Persons per Family	3.50	3.40	3.30	3.20	3.10	3.00	2.90
Househould(Urban) 10^6	84.91	117.84	154.5	200.11	241.77	269.87	310.55
Rural	74%	68%	62%	55%	50%	45%	40%
Rural Population(10^6)	846	851	832	783	750	662	600
Persons per Family	4.80	4.50	4.30	4.10	3.90	3.70	3.50
Househould(Rural) 10^6	176.21	189.19	193.5	190.89	192.17	179.02	171.54

Table 3.8 (2) Residential Indicators(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1263	1381	1495	1604	1702	1789
Urban	26%	34%	42%	50%	56%	62%	70%
Urban Population(10^6)	297	429	580	748	898	1055	1253
Persons per Family	3.50	3.30	3.10	3.00	2.90	2.80	2.70
Househould(Urban) 10^6	84.91	130.08	187.1	249.24	309.64	376.95	463.92
Rural	74%	66%	58%	50%	44%	38%	30%
Rural Population(10^6)	846	833	801	748	706	647	537
Persons per Family	4.80	4.30	4.00	3.80	3.60	3.40	3.20
Househould(Rural) 10^6	176.21	193.8	200.2	196.8	196.	190.3	167.88

2) Rural Residential Space Heating

The following equations are used in projecting energy use RRSH(s, t) [PJ] in rural residential space heating:

$$RRSH(s, t)\ [PJ] = RHD(s, t) * TRHA(s, t) * RHR(s, t)$$

$$\text{where}\ TRHA(s, t) = RP(s, t) * RPCA(s, t) * RHD(s, t) * RHRF(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

RHD(s, t): Winter heating duration in China rural area each year(day)
TRHA(s, t): Total rural winter heating living areas (Bil.m^2)
RHR(s, t): Rural heating required ($MJ/m^2 * day$)
RP(s, t) : Rural population(10^6)
RPCA(s, t): Rural living areas per capita (m^2/per person)
RHD(s, t): Rural heating living district vs. total living areas(%)
RHRF(s, t): Rural heating rooms vs. all rooms in a rural family(%)

The s in RRSH(s, t) [PJ] represents the assumption of the low energy demand because of the low economic and low population growth or the assumption of the high energy demand because of the high economic and high population growth.

3) Urban Residential Space Heating

The following equations are used in projecting energy use URSH(s, t) [PJ] in urban residential space heating:

$$URSH(s, t)\ [PJ] = UHD(s, t) * TUHA(s, t) * UHR(s, t)$$

$$\text{where}\ TUHA(s, t) = UP(s, t) * UPCA(s, t) * UHD(s, t) * UHRF(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

UHD(s, t): Winter heating duration in China urban area each year(day)
TUHA(s, t): Total urban winter heating areas (Bil. m^2)
URHR(s, t): Urban heating required ($MJ/m^2 * day$)
UP(s, t): Urban population(10^6)
UPCA(s, t): Urban living areas per capita (m^2/per person)
UHD(s, t): Urban heating living district vs. total living areas(%)
UHRF(s, t): Urban heating rooms vs. all rooms in a urban family(%)

The s in URSH(s, t) [PJ] has the same meaning as that in RRSH(s, t) [PJ].

The projections of useful energy demands for residential space heating in rural and urban areas are listed in Appendix 4.

4)Rural Residential Energy Demand for Lighting and Appliances

The following equations are used in projecting energy use RLA(s, t) [PJ]in rural residential lighting and appliance utilization:

$$\text{RLA(s, t)(PJ)} = \sum_{MKA}[RAEU(s,t)*RSA(s,t)*RHH(s,t)*3.6*10^{-7}]$$

$$\text{where } RAEU(s, t) = RRP(s, t) *ROT(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

MKA: The main kinds of appliances and lighting.
RAEU(s, t): Lighting and appliances elec.use in rural areas(kWh/yr).
RSA(s, t): Saturation of different appliances in rural areas (Per 100 Rural HHs).
RHHS(s, t): The number of households in China rural areas.
RRP(s, t): The rated power of lighting and appliances in China rural areas(W).
ROT(s, t): Operating time of lighting and appliances in rural areas. (hrs/day).

The s in RLA(s, t) [PJ] has the same meaning as in RRSH(s, t)(PJ).

5)Urban Residential Energy Demand for Lighting and Appliances

The following equations are used in projecting energy use ULA(s, t) [PJ] in urban residential lighting and appliance utilization:

$$\text{ULA(s, t)(PJ)} = \sum_{MKA}[UAEU(s,t)*USA(s,t)*UHH(s,t)*3.6*10^{-7}]$$

$$\text{where } UAEU(s, t) = URP(s, t) * UOT(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

MKA: The main kinds of appliances and lighting.
UAEU(s, t): Lighting and appliances elec.use in urban areas(kWh/yr).
USA(s, t): Saturation of different appliances in urban areas (Per 100 urban households) .
UHHS(s, t): The number of households in China urban areas.
URP(s, t): The rated power of lighting and appliances in China urban areas(W).
UOT(s, t): Operating time of lighting and appliances in urban areas. (hrs/day)

The s in ULA(s, t) [PJ] has the same meaning as in RRSH(s, t) [PJ].The projections of useful energy demands for residential lighting and appliances in rural and urban areas are listed in Appendix 5.

6)Rural Residential Energy Demand for Cooking

The following equations are used in projecting energy use RCED(s, t) [PJ] in rural residential cooking:

$$RCED(s, t) [PJ] = RCER(s, t) * RHHS(s, t)$$

---

* 1 GW = 31.56 PJ/year

The meanings of the nomenclatures in the equations are stipulated as follows:

RCER(s, t): Energy required for cooking per household each day in rural area (MJ/Per HHs-day)
RHHS(s, t): The number of households in China rural areas.

The s in RCED(s, t) [PJ] has the same meaning as in RRSH(s, t) [PJ].

7) Urban Residential Energy Demand for Cooking

The following equations are used in projecting useful energy demands UCED(s, t) [PJ] in Urban residential cooking:

$$UCED(s, t)\ [PJ] = UCER(s, t) * UHHS(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

UCER(s, t): Energy required for cooking per household each day in urban areas(MJ/Per HHs-day).
UHHS(s, t): The number of households in China urban areas.

The s in UCED(s, t) [PJ] has the same meaning as in RRSH(s, t) [PJ]. The projections of useful energy demands for residential cooking in rural and urban areas are listed in Appendix 6.

8) Residential Water Heating

In projecting energy demand for water heating, we assumed that it is required 0.167 MJ of energy to heat 1 kilogram of water from 10 °C to 50 °C or any equivalent. The calculation equations and the explanations are retrenched here. The projections of useful energy demands for residential water heating in rural and urban areas are listed in Appendix 7.

The projections of total residential useful energy demands in rural and urban areas for the period from 1990 to 2050 are illustrated in Fig.3.8.

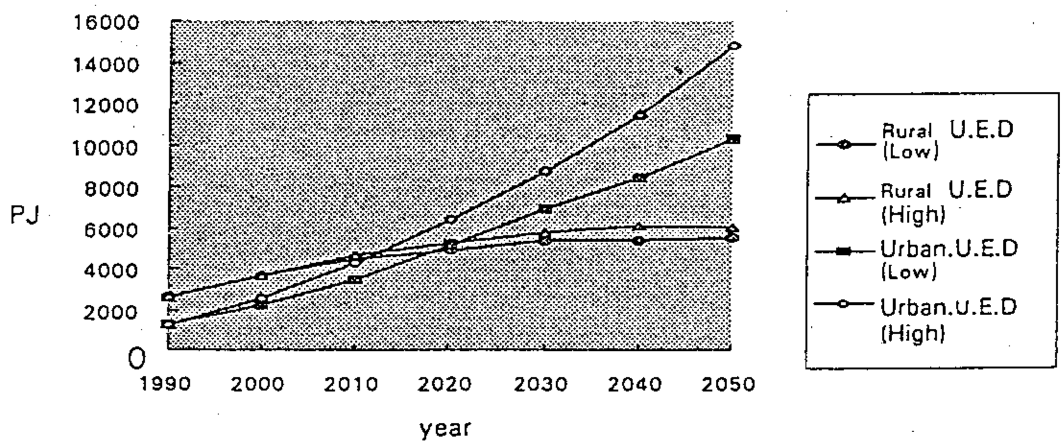


Fig.3.8 Projection of Total Residential Useful Energy Demand

3.3.5 Transportation Sector

In transportation sector, as additional transport technology details have been added in the existing database and maintained as a permanent part in the Chinese reference energy system, see Section 2 for references. The projection of freight transport turnover (Btkm) and passenger transport turnover(Btkm) are used instead of projection of transport useful energy demands.

1) Freight Transportation Turnover

The following equations are used in projecting freight transportation turnover FTT(s, t) [Btkm] in time t in transportation sector:

$$FTT(s, t)\ [Btkm] = FTT(1990) * [1+GRFT(s, t)]^{t-1990}$$

$$\text{where}\quad GRFT(s, t) = EFTG(s, t) * GGR(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

FTT(1990): Freight transportation turnover in 1990(Btkm).
GRFT(s, t): Annual growth rate of freight turnover in time t.
GGR(s, t): China GDP annual growth rate in time t.
EFTG(s, t): Elasticity of freight transport turnover vs. GDP in time t.

The s in FTT(s, t) [Btkm] has the same meaning as that in AUED(s, t) [PJ]. The projections of freight transportation are illustrated in Fig.3.9.

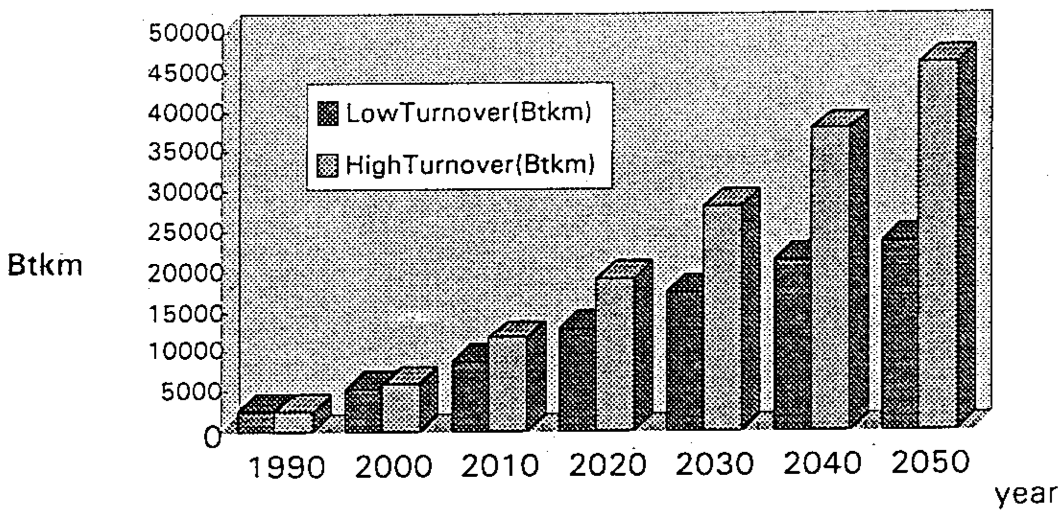


Fig.3.9 Freight Transportation Projection

2) Passenger Transportation Turnover

The following equations are used in projecting passenger transportation turnover PTT(s, t) [Bpkm] in time t in transportation sector:

$$PTT(s, t)\ [Bpkm] = POPU(s, t) * PTTP(1990) * [1+GRPTP(s, t)]^{t-1990}$$

$$\text{where}\quad GRPTP(s, t) = EPT(s, t) * GRGP(s, t)$$

The meanings of the nomenclatures in the equations are stipulated as follows:

PTTP(1990): Passenger turnover per capita in 1990(Bpkm / per capita).
POPU(s, t): China population in time t.
GRPTP(s, t): Annual growth rate of passenger turnover per capita in time t.
GRGP(s, t): Annual growth rate of GDP per capita in time t.
EFT(s, t): Elasticity of passenger transport turnover vs. GDP in time t..

The s in PTT(s, t) [Bpkm] has the same meaning as that in AUED(s, t) [PJ]. The projections of freight transportation are illustrated in Fig.3.10.

Detailed data about the projections of freight and passenger transportation turnover are given in Appendix 8.

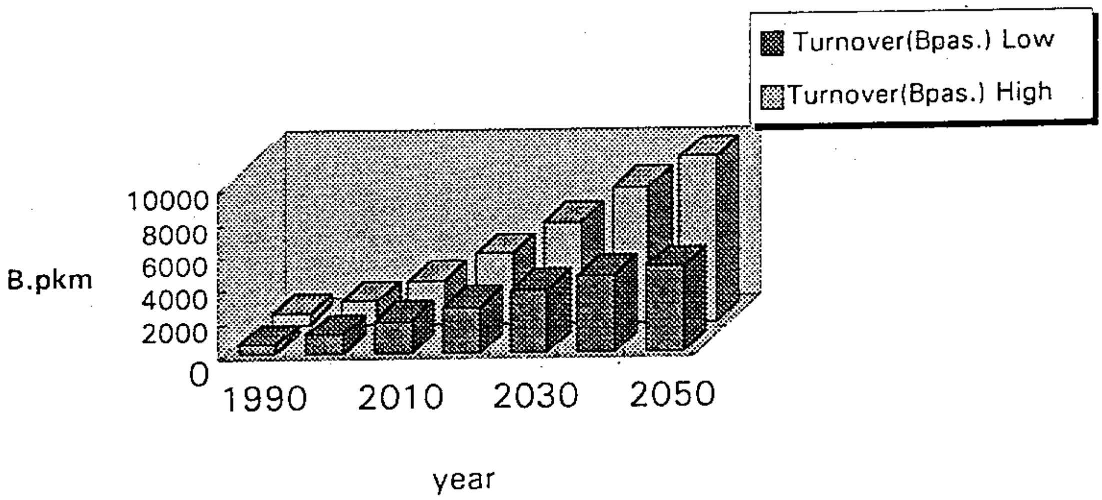


Fig.3.10 Passenger Turnover Projection

3.4 Characteristic Data of Technologies

In order to provide energy services to meet the useful energy demands that we have projected, various kinds of energy facilities and equipment should be installed in China energy system. These facilities, equipment and devices, which we assumed practically in commission or prospective in actual energy system, are classified by making use of the concept "technology". Through assigning the essential characteristics to the technologies, China energy system is delineated by activities of energy production, conversion and consumption of these technologies. Characteristic data for technologies are very substantial in MARKAL database.

3.4.1 Characterization of technologies

Characterization of each technology in Chinese reference energy system is a herculean task for energy-environment system analysis. In our study, the characteristic data are based on the database which have been arranged in the past studies of the ETSAP, especially that in Energy System Assessment Laboratory of JAERI. In view of the characteristics of the energy system in China, many data such as technological efficiencies and costs etc. are revised. The common characteristics of the technologies concerned in our study are concisely described in the following.

Availability factor: The fraction of the nominal output capacity which can actually be available for a technology operation during a year. Seasonal variations are also taken into account. For conversion and process technologies, the availability factor usually sets an upper limit to the annual output of the installed capacity. For conversion technologies, fraction of forced outage is given externally. Actually seasonal and diurnal output are determined by allocating scheduled outage for six time intervals during a year. In case of demand devices it defines the annual output, i.e. it is the load factor.

Efficiency: The total net energy output divided by the input.

Outputs and inputs: The fractional outputs and inputs of different energy carriers going through a technology.

Investment cost: The total capital investment cost, including interest during construction, discounted to the start of commercial operation year.

Fixed operating and maintenance cost: The annual cost incurred per unit of installed capacity, irrespective of its output.

Variable operating and maintenance cost: The annual cost incurred per unit of output.

Lifetime: For simplicity and comparison purposes, the nominal values of 20 or 30 years have frequently been adopted for similar classes of technology, an approach which is in keeping with the standard cost-benefit method of economic comparison.

In order to assess technology's contribution to the energy and economic system, the above depicted technology characteristics together with upper and lower bounds and environmentally related data etc. are required in MARKAL model.

Characteristic data for technologies are not given in this report. The upper bounds for availability of some main power generation capacity were presented below.

3.4.2 Bounds on Implementations of Technologies

For many technologies in Chinese reference energy system, it is important to specify bounds or constraints on extents or levels of their market penetrations and implementations in accordance with realistic investment behavior. If without any constraints, the MARKAL model might make very sudden switches among technologies that may be economically sound but unrealistic actually for a variety of other reasons. In truth, we defined the upper and lower bounds on the installed capacity of a technology or on its growth rate, and in several cases both options together have been presumed. As for technologies with residual capacities, the data about their retention and phase-outs in the system has been provided in this study. It should be made clear that lots of technology bounds are based on personal judgment as short of abundant data.

The upper bounds for availability of some main power generation capacity were given in Table 3.9[2,3,4,5,12,14,18,20].

Table 3.9 Upper Bounds for Availability of Power Generation Capacity(GW) [2,3,4,5,12,14,18,20]

Year	1990	2000	2010	2020	2050
LWR Power Plant (E21)	2.1	7	35	70	130
LMF Power Plant (E26)				1	5
LWR Cogeneration (E63)			0.2	3	10
Coal Steam ELEC (E01)	80	145	180	210	320
Advanced Coal Steam ELEC (E06)	3	20	70	100	160
Coal Steam Cogeneration (E61)	15.5	30	60	90	160
Oil Steam ELEC (E13)	10.2	12	28	40	50
Gas Steam ELEC (E82)	4	7	10	12	20
Hydropower Plant (E31)	36	75	140	170	360
Geothermal Power (E33)		1.42	2	2.5	6
Solar Power (E4C)		1	5	8	20
Hydrogen Fuel Cell (E91)		1	5	10	30
Other Renewable ELEC (E38)		2	8	20	40

4. Scenarios and Cases

The energy system evolution could not be divorced from socioeconomic development. They are generally interacting with each other. In order to study the China energy system development and CO_2 emission abatement strategies, two scenarios and several cases were examined according to the different projections for the socioeconomic development in China from 1990 to 2050.

4.1 Scenarios

Scenarios are defined according to the assumptions for the socioeconomic development in China. The basic assumptions for two main scenarios are summarized in Table 4.1.

Table 4.1 Basic Assumptions for Scenarios

Item	Scenario HL	Scenario LH
Population development	High projection: (see Section 3.1) From 1.14 billion in 1990 to 1.79 billion in 2050	Low projection: (see Section 3.1) From 1.14 billion in 1990 to 1.50 billion in 2050
Annual growth rate of GDP	High projection: (see Section 3.1) 1990 ~ 2000: 8.5 %, 2000 ~ 2010: 7 %, 2010 ~ 2020: 5 %, 2020 ~ 2030: 4 %, 2030 ~ 2040: 3 %, 2040 ~ 2050: 2 %	Low projection: (see Section 3.1) 1990 ~ 2000: 7.5 %, 2000 ~ 2010: 5 %, 2010 ~ 2020: 4 %, 2020 ~ 2030: 3 %, 2030 ~ 2040: 2 %, 2040 ~ 2050: 1 %
Useful energy demand	High projection: (see Section 3.3) AUED(high, t), IUED(high, t), CUED(high, t), FTT(high, t), PTT(high, t) and high residential energy demands etc.	Low projection: (see Section 3.3) AUED(low, t), IUED(low, t), CUED(low, t), FTT(low, t), PTT(low, t) and low residential energy demands etc.
Import price projection of oil and natural gas[*1]	Low projection: (see Section 3.2) Import oil price from 3.74 $/GJ in 1990 to 9.91 $/GJ in 2050. Import natural gas price from 3.99 $/GJ in 1990 to 10.42 $/GJ in 2050	High projection: (see Section 3.2) Import oil price from 3.74 $/GJ in 1990 to 17.06 $/GJ in 2050. Import natural gas price from 3.99 $/GJ in 1990 to 18.41 $/GJ in 2050

4.2 Cases

For each scenario, several analysis cases based on scenario baseline case are investigated with the MARKAL Model. Before introducing the definitions of concerned cases, we briefly describe the objective function in MARKAL model.

MARKAL has the capability of phasing out technologies before the end of their lifetime(i.e. some installed capacities can be idle in the lifetime), if alternatives become more attractive, salvaging the investment costs etc. at the end of the study time period in order to avoid terminal effects and selecting desirable mix of energy carriers and technologies to satisfy the projected energy demands from the view point of total discounted energy system cost [23,24,42,43,45,]. In reality, criteria other than the total energy cost are also considered in MARKAL. The obvious way is to use an objective function which includes other terms than cost. If we denote by C the total cost objective function, the concern for reducing CO_2 emission or for reducing dependence on foreign oil etc. can

[*1] Same price projections of domestic energy supply for each scenario were considered but not given in this report.

be expressed by adding to C the CO_2 emission S_c or the net oil import S_o, multiplied by some weighting factor λ_c or λ_o.

The new objective function would be:

$$F = C + \lambda_C * S_C$$

or

$$F = C + \lambda_O * S_O$$

and they can be minimized by the model just as readily as C alone. The λ_c and λ_o are interpreted as the marginal cost of reducing CO_2 emissions or net import oil in MARKAL model. The objective function in our study is given in broad outline as follows:

ESLOPE(N)(K) = EPRICE(N) * PRICE + ESLCDE(N) * ENVCDE + SSL(N)(K) * SECURITY

Where, PRICE: Total discounted system cost; ENVCDE: Total CO_2 emissions; SECURITY: Cumulated net import oil; ESLCDE(N): Weight of CO_2 emissions relative to the system cost and can be interpreted as the marginal costs of total emission reduction; SSL(N)(K): Weight of cumulated net import oil relative to the system cost and can be interpreted as the marginal costs of net import oil.

The definitions of the main cases for scenario HL, each headed by a shorthand notation to identify itself, are described as follows. The definitions of cases for scenario LH are alike and left out here.

1) HLBC

This is the baseline case for scenario HL of the high energy demands combined with the low oil and natural gas import prices that have been given in Section 3. In this case, the discounted system cost is employed as an objective function without any external constraint such as restrictions on CO_2 emissions or surcharges for them etc.

2) HLT(N)

In this case group, surcharges, which are imposed on CO_2 emissions as the introduction of CO_2 tax regimes, are increasing with time starting from 1995 to 2050 as shown in Table 4.2. The surcharges are discounted back to the reference year as well as investment cost and maintenance fee et al. The sum of the discounted system cost and the surcharges multiplied by weighting factor are employed in the objective function for optimizing the Chinese reference energy system. For all other input data the baseline case data set is used.

Table 4.2 Surcharges on CO_2 Emissions (1980US k$ / ton CO_2)

Year	1995	2000	2005	2010	2015	2020	2025	2050
HLT1	0.02	0.04	0.06	0.09	0.13	0.17	0.21	0.41
HLT2	0.02	0.03	0.04	0.06	0.09	0.12	0.16	0.36

3) HLC(M)

In the CO_2 emission mitigation cases HLC1 and HLC2, the discounted system costs are minimized with external CO_2 emission constraints, i.e. annual CO_2 emissions are 5.5 and 7.0 tons CO_2 per capita permitted separately during the planning horizon. The other respects are assumed to be exactly like that in the baseline case HLBC.

4) HLS(K)

We use combined objective function $C + \lambda_o * S_o$ in these three cases, Where λ_o is the marginal cost of reducing the net oil import, i.e.1 $ / GJ, 4 $ / GJ and 8 $ / GJ in the case HLS1, HLS2 and HLS3, respectively. For all other input data the baseline case HLBC data set is used. In addition, the impacts emerging from the absence of import oil and natural gas are also studied in this case group.

5) HLNM, HLNE and HLSY

The effects are investigated provided that no nuclear power plant were constructed after 2010 because of serious accident or some political reasons in the nuclear moratorium case (HLNM). In the nuclear enhancement case (HLNE), on the other hand, we suppose another 100 GW nuclear power capacity were introduced during the time period from 2020 to 2050 and the effects is assessed. The role of IES with fossil-nuclear symbiotic system or biomass- nuclear symbiotic system is examined in the symbiotic use case (HLSY).

The contour of the relationship among scenarios, cases and socioenergy system is in the shape of a tree, shown in Fig.4.1, in which the socioenergy system likened to be the trunk is ramifying from the scenario "crotch" to many case "branches".

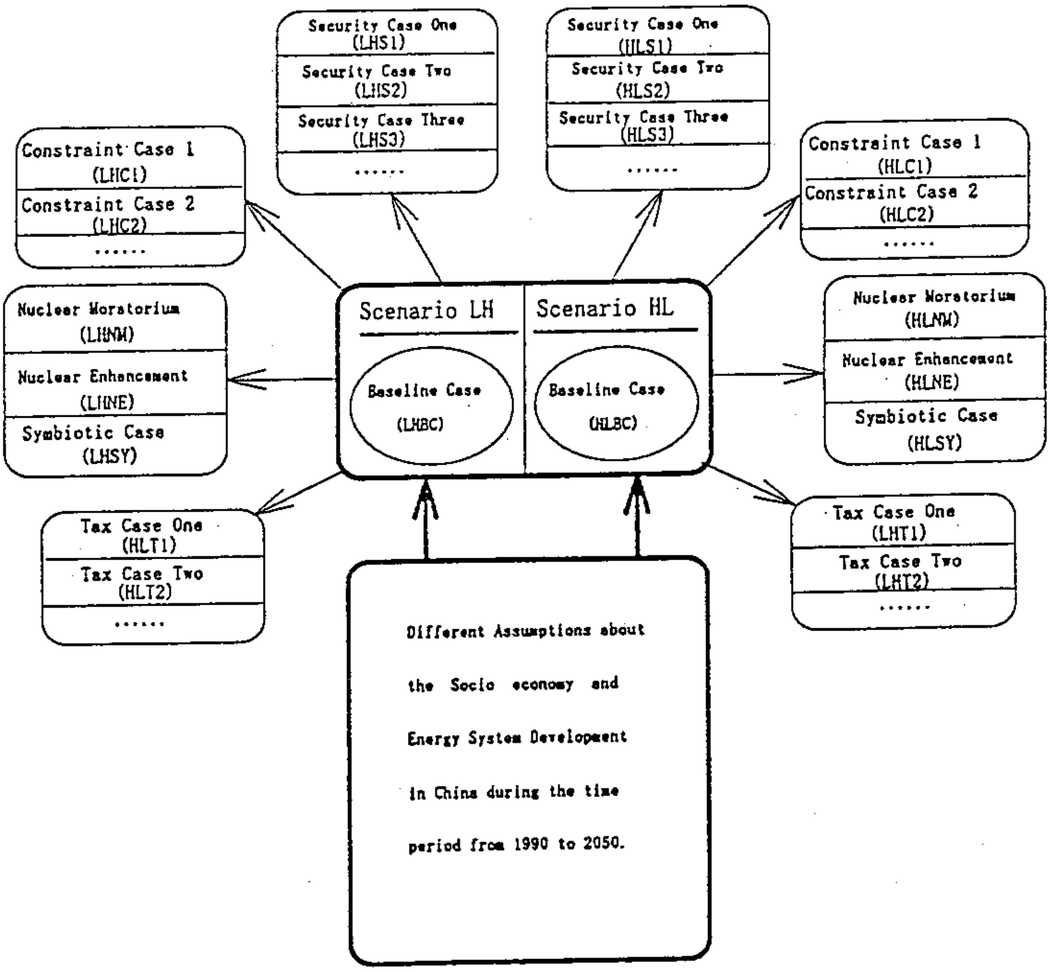


Fig. 4.1 Relationship among Socioeconomy, Scenarios and Cases

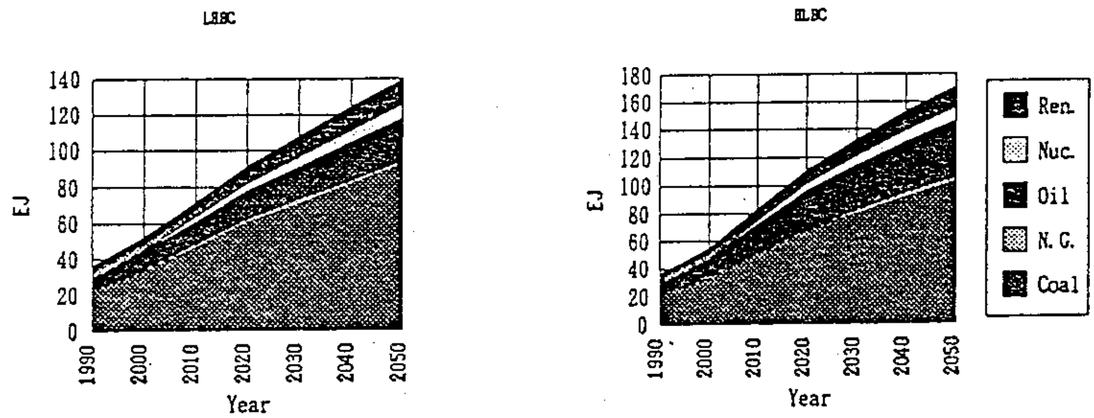
5. Analytical Results

A tremendous volume of output results were generated by running MARKAL with the established database. In the following results are summarized with the discussion for some important issues, which are related to primary energy demand, final energy consumption, CO_2 emission reduction and economic impacts etc..

5.1 Primary Energy

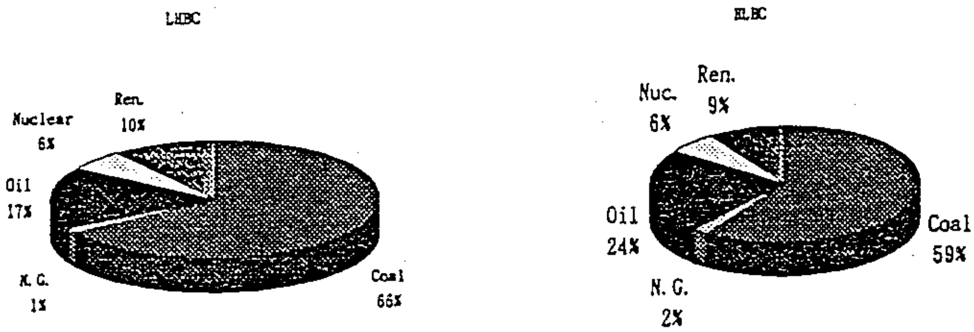
5.1.1 Total Primary Energy Supply

The total primary energy supply each year from 1990 to 2050 are illustrated in Fig 5.1 for baseline case LHBC and case HLBC. The annual primary energy supply is about 170 EJ in 2050 in case HLBC, much higher than 140 EJ in 2050 in case LHBC.



Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 5.1 Total Primary Energy Supply in Baseline Cases



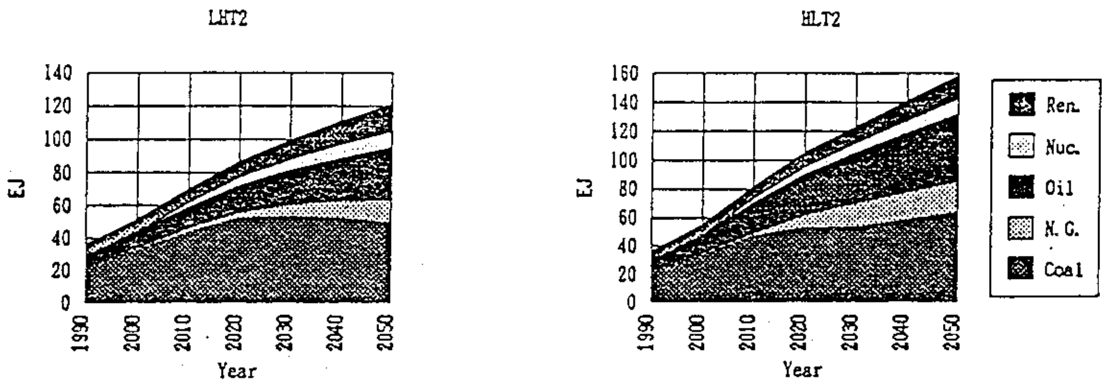
Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 5.2 Pattern of Primary Energy in 2050 in Baseline Cases

From the patterns of total primary energy demands in the baseline case LHBC and case HLBC, we can see the nuclear energy gradually becomes one type of the main primary energy in China. Nuclear power accounts for about 6% of the total primary energy in 2050 in both baseline cases. The patterns of primary energy in 2050 are shown in Fig.5.2.

5.1.2 Share of Primary Energy Supply

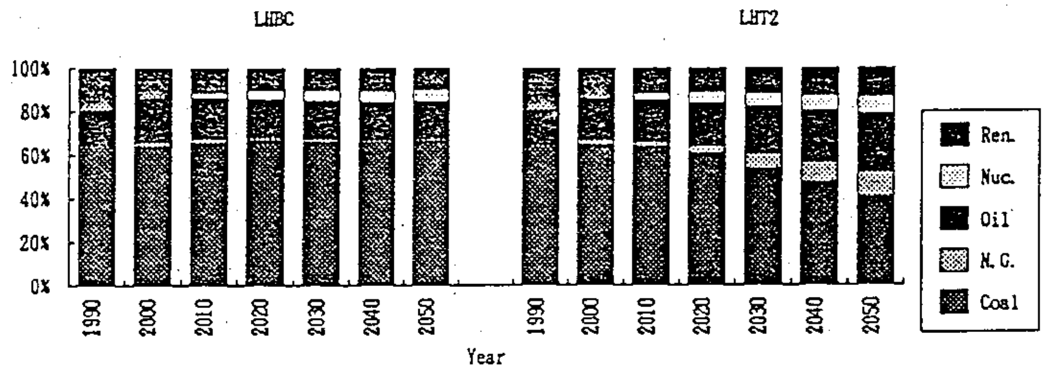
When surcharges or restrictions are imposed on CO_2 emissions, the patterns of primary energy supply are changed as in case HLT2 and case LHT2, which are shown in Fig.5.3.



Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

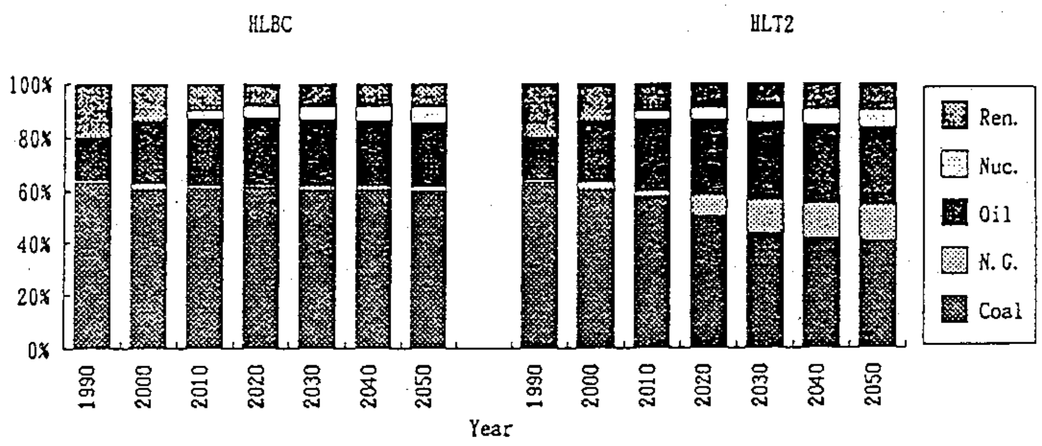
Fig 5.3 Pattern of Primary Energy Supply in CO_2 Tax Cases

In cases HLT2 and LHT2, the share of each primary energy source changes from that of their corresponding baseline cases, as shown in Fig.5.4. and Fig.5.5. Share of coal in primary energy is decreasing, while the share of natural gas and oil is increasing in CO_2 tax cases. As the domestic biofuels are included in renewable energy and assumed to decrease from 11134 PJ in 1990 to 5274 PJ in 2050, the share of renewable energy declines in these cases.



Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 5.4 Share of Primary Energy Supply in Scenario LH

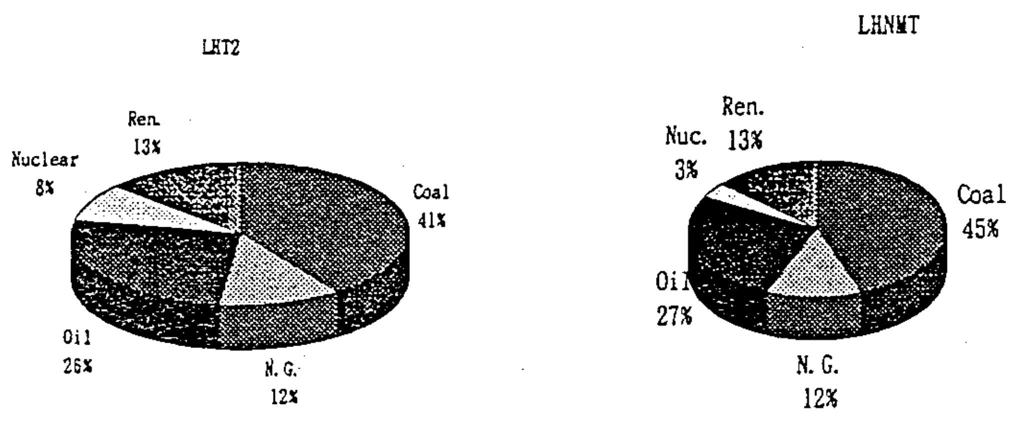


Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 5.5 Share of Primary Energy Supply in Scenario HL

5.1.3 Sensitivity Analysis

In sensitivity case LHNMT, where the nuclear moratorium is assumed to happen in China after 2010 and the surcharges on CO_2 emissions are assumed to be the same as in case LHT2, the structure of primary energy supply in 2050 changes from that of case LHT2 as shown in Fig.5.6. Another 5.4 EJ of coal and about 1 EJ of natural gas and oil will be used instead of nuclear energy in 2050.



Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 5.6 Share of Primary Energy in 2050 in Case LHT2 and LHNMT

5.1.4 Cost–Security Trade–off

The trade–off relationships between the total discounted cost and the total cumulated net oil import for scenario HL and scenario LH are shown in Fig.5.7. These two figures have demonstrated the general feature that if surcharges or constraints on CO_2 emission become tighter, the cost of the energy system obtained as a solution must always ascend. In comparison with patterns of the trade–off for the two scenarios, the 'marginal costs of security', which are given as the negative slope of the trade off curves, are increasing quickly in scenario HL, since scenario HL is more sensitive to import oil.

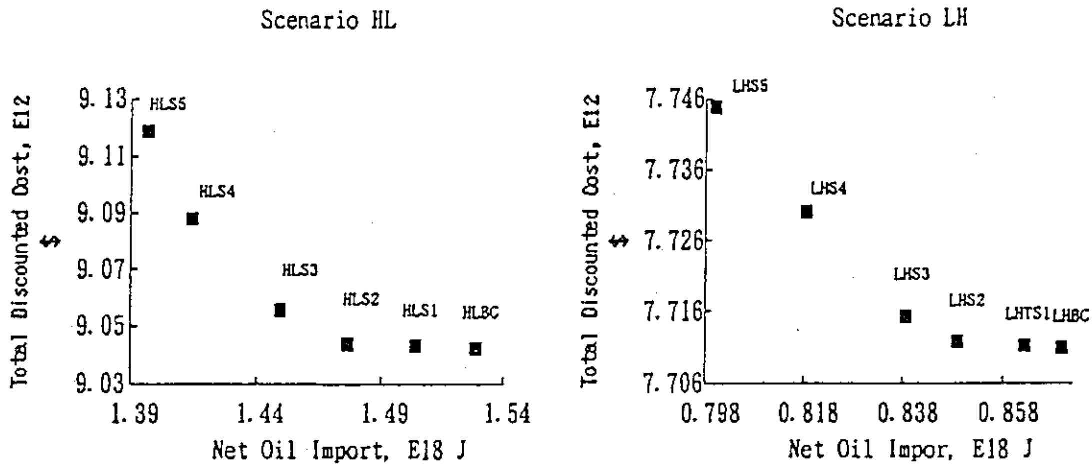
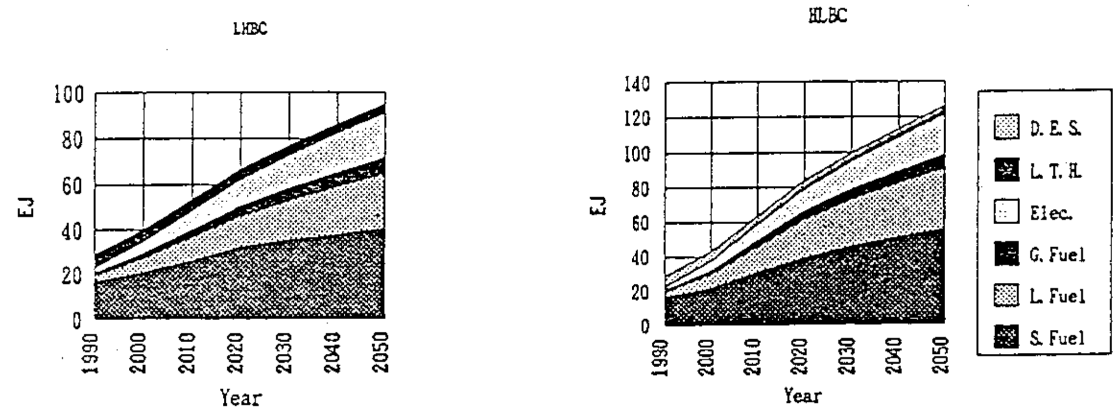


Fig 5.7 The Cost–Security Trade–off

5.2 Final Energy

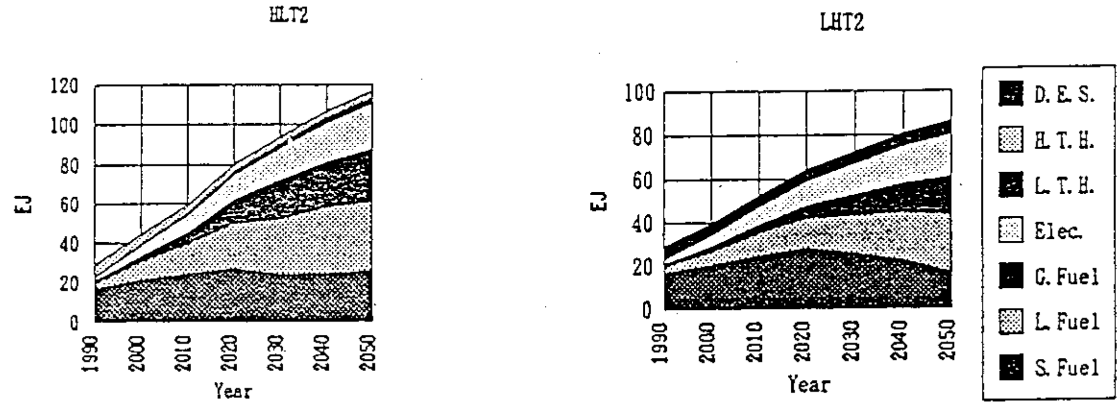
5.2.1 Final Energy Demand by Energy Types

Energy types in final energy demand for baseline case LHBC and case HLBC are illustrated in Fig. 5. 8.When CO_2 surcharges are introduced as in case LHT2 and case HLT2, the patterns of energy types in final energy demands have varied as shown in Fig. 5.8 and Fig.5.9.



D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

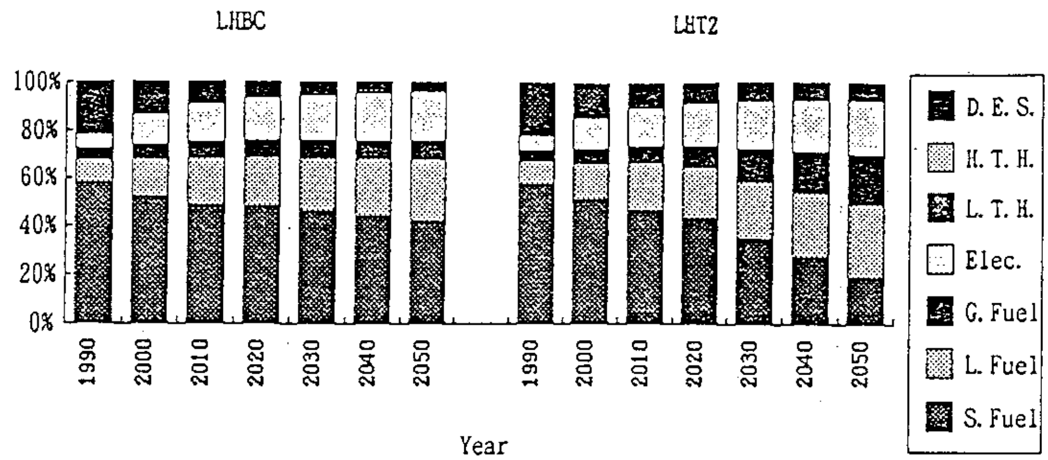
Fig 5.8 Energy Types of Final Energy Demand in Baseline Cases



D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

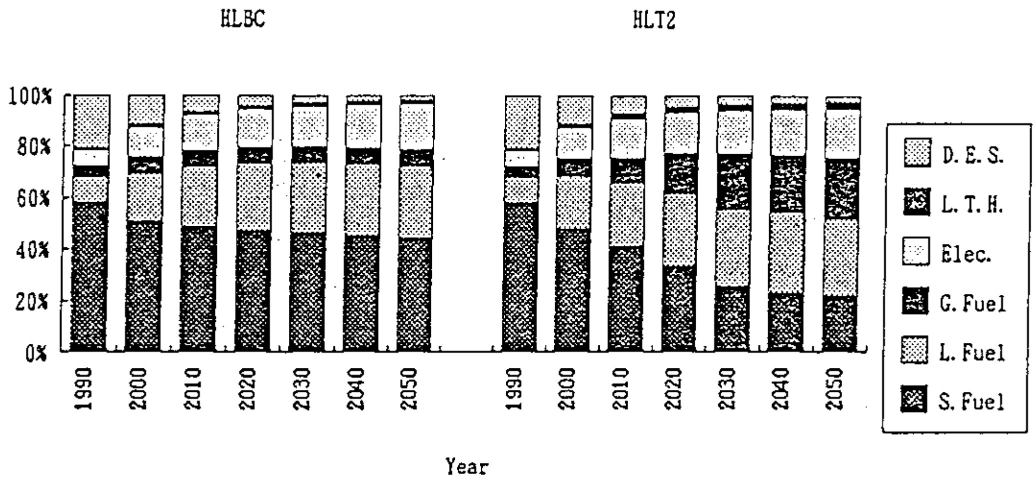
Fig 5.9 Types of Final Energy Demand in CO_2 Tax Cases

The share of final energy demands by energy types in case HLT2 and case LHT2 is different from those of their corresponding baseline cases, as shown in Fig.5.10 and Fig.5.11.



D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

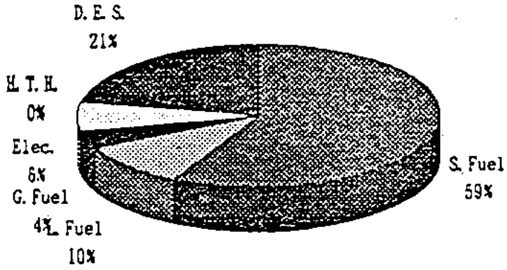
Fig 5.10 Share of Energy Types in Final Energy Comsuption(LH)



D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

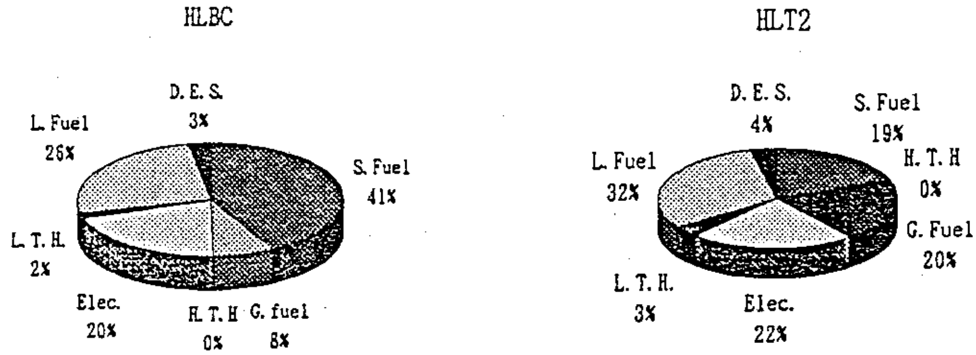
Fig 5.11 Share of Energy Types in Final Energy Comsuption(HL)

In CO_2 tax case LHT2 and case HLT2, the share of solid fuels is decreasing from 59% in 1990 to 19% in 2050, while the share of gas fuels is increasing quickly from 4% in 1990 to 20% in 2050. The shares of final energy types in 1990 are given in Fig.5.12. The share of energy types in final energy demands in 2050 for case HLT2 as compared with its corresponding baseline case HLBC is shown in Fig.5.13. As decentralized energy supply mainly comes from domestic biofuels, its share in final energy supply decreases in each mentioned case.



D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

Fig.5.12 Share of Final Energy Types in 1990



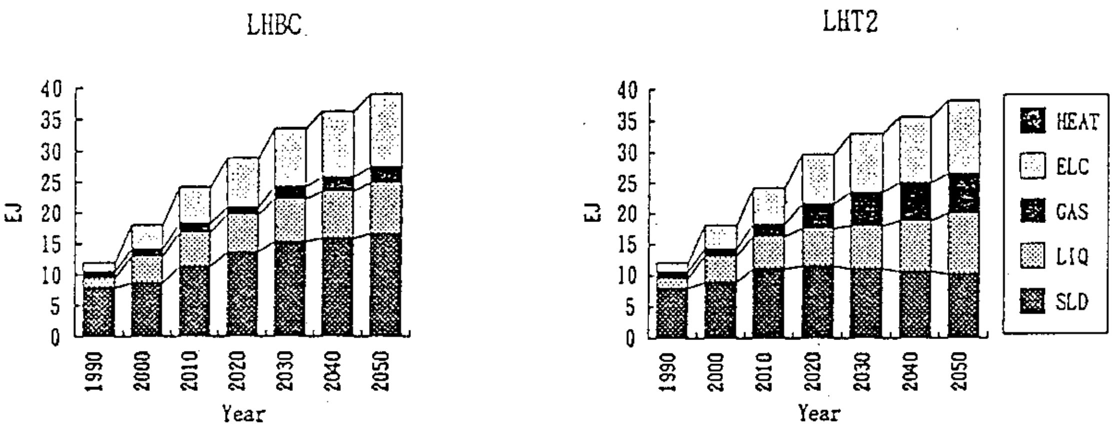
D.E.S.: Decentralized energy supply(mainly come from domestic biofuels utilization); L.T.H.: Low temperature heat; H.T.H.: High temperature heat; Elec.: Electricity; G.fuel: Gas fuel; L.fuel: Liquid fuel; S.fuel: Solid fuel.

Fig.5.13 Share of Final Energy Types in 2050

5.2.2 Fuel Mix in Demand Sectors

1) Industrial Fuel Mix

Fig.5.14 shows the fuel mix in industrial sector for case LHBC and case LHT2. In industrial sector, the shares of electricity consumption are increasing remarkably, i.e. from 13% in 1990 to 30% in 2050 in both case LHBC and case LHT2. But in case LHT2, the absolute level of electricity consumption increase 4 PJ more in 2050. When shifting from case LHBC to case LHT2, gaseous fuel consumption obviously increase to substitute solid fuel use in industrial sector.

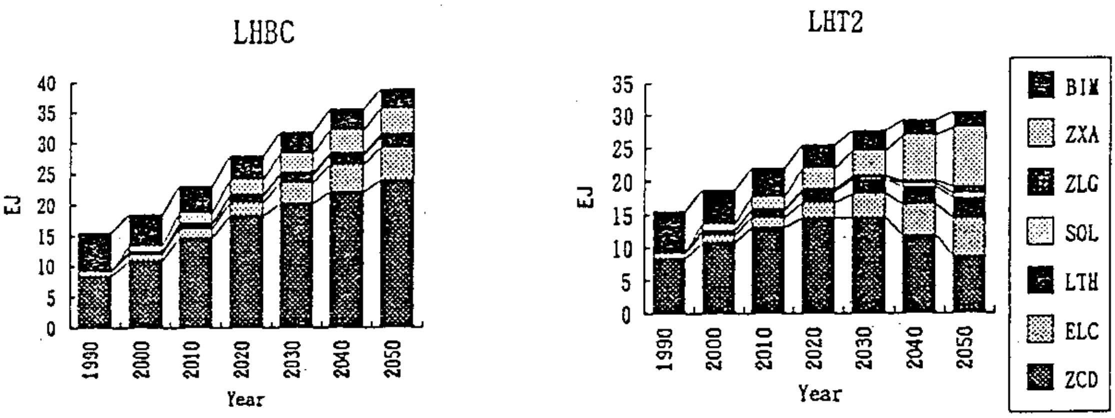


ELC: Electricity; GAS: Gas fuel; LIQ: Liquid fuel; SLD: Solid fuel.

Fig.5.14 Industrial Fuel Mix

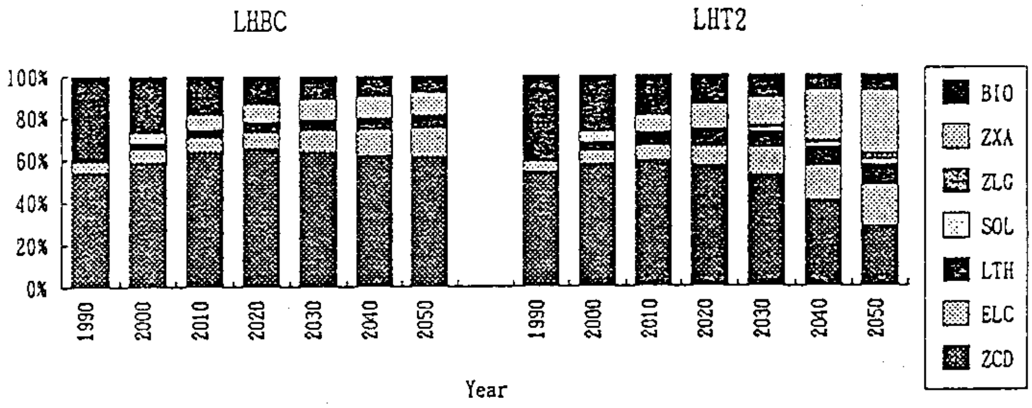
2) Fuel Mix in Residential and Commercial Sector

The fuel mix in residential and commercial sector for case LHBC and case LHT2 is shown in Fig.5.15. In residential and commercial sector, the biofuel consumption descends while the demands of electricity, consumer gas, and low temperature heat are expanded in both cases and direct coal use has strong market penetration in case LHBC. When shifting from case LHBC to case LHT2, the increasing consumption of direct coal will decline after 2020 and substituted by electricity, consumer gas, and low temperature heat in LHT2 case. The shares of fuel types in case LHBC and case LHT2 are illustrated in Fig.5.16.



BIO: Domestic biofuels; ZXA: Consumer gas; ZLG: Liquid petroleum gas; SOL: Solar energy; LTH: Low temperature heat; ELC: Electricity; ZCD: Coal.

Fig.5.15 Fuel Mix in Residential and Commercial Sector

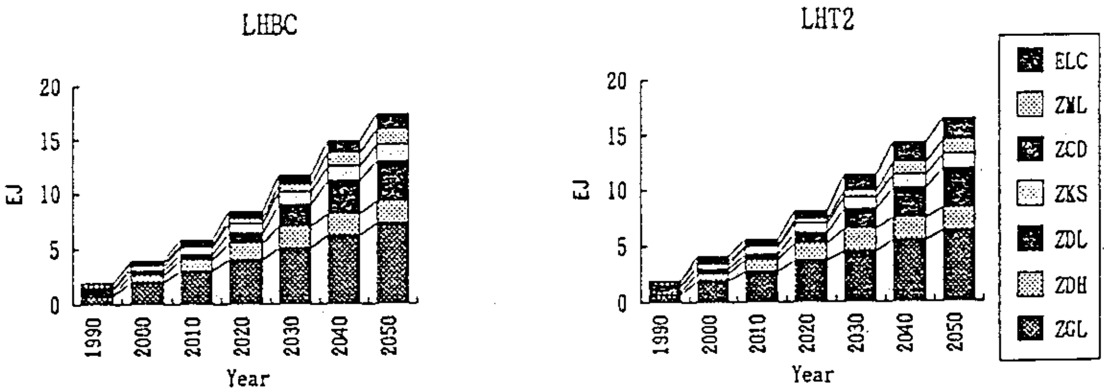


BIO: Domestic biofuels; ZXA: Consumer gas; ZLG: Liquid petroleum gas; SOL: Solar energy; LTH: Low temperature heat; ELC: Electricity; ZCD: Coal.

Fig.5.16 Share of Fuels in Residential and Commercial Sector

3) Fuel Mix in Transportation Sector

The fuel mix in transportation sector for case LHBC and case LHT2 is shown in Fig.5.17. The shares of fuels in the transportation sector in 1990 are: gasoline about 37%, coal about 24%, light distillate oil about 23%, heavy distillate oil about 10%, kerosene about 5% and the electricity takes a scanty of 1%. At present transportation sector depends on oil products and coal. However, share of coal in fuel mix will significantly decline from around 20% now to 0% in 2020, and transportation sector will depend heavily on gasoline and light distillate oil in near future. In 2050 electricity is expected to take 8% and 12% of the total energy consumption in transportation sector in case LHBC and case LHT2 respectively and it will gradually become one of the important energy types in transportation sector in China.



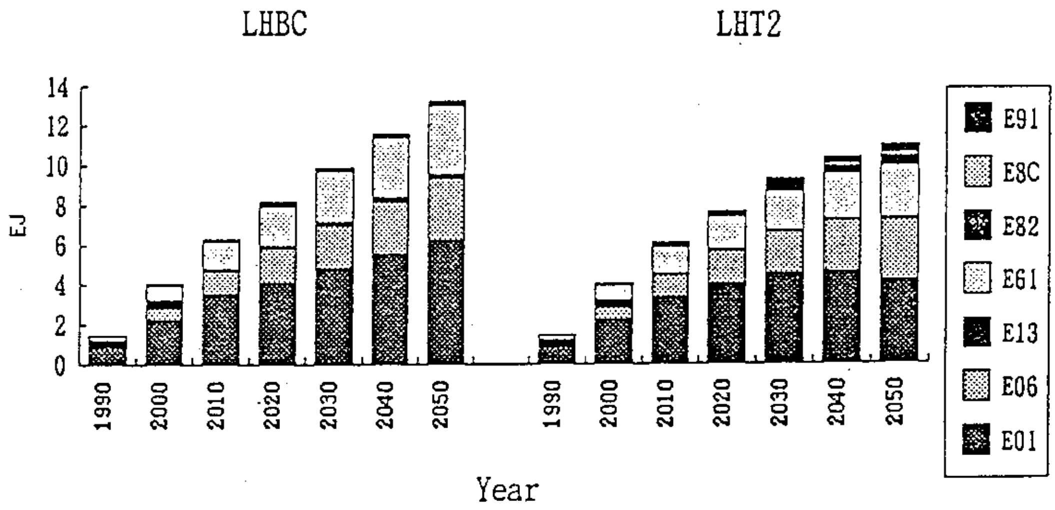
ZML: Methanol; ZXA: Consumer gas; ZGL: Gasoline; ZKS: Kerosene; ZDL: Light distillate oil; ZDH: Heavy distillate oil; ELC: Electricity; ZCD: Coal.

Fig.5.17 Fuel Mix in Transportation Sector

5.2.3 Electricity Generation

1) Generation by Technologies

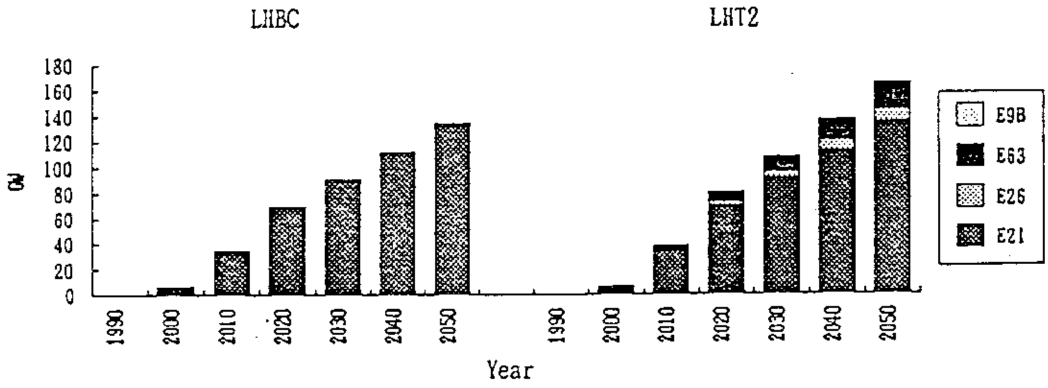
Fig.5.18 shows electricity generation by fossil fuel power plants in case LHBC and case LHT2. The most striking feature is that electricity generation from fossil fuel power plants relies heavily on coal burning power plants. Around 50% of the total electricity will be generated from coal burning power plants in 2050 in baseline case LHBC, another 50% of electricity generation in 2050 mainly coming from hydropower and nuclear power etc. When CO_2 tax regime is introduced in the energy system as in case LHT2, the amount of electricity generated from fossil fuel power plants increases slowly to 10.8 EJ in 2050, much smaller than 13.8 EJ in 2050 in case LHBC.



E01: Concentional coal steam power plants; E06: Coal IGCC power plants; E61: Coal steam cogeneration: E13: Oil steam electric plants; E82: Gas steam power plants; E8C: LNG combustion cycle plants; E91: Hydrogen fuel cell.

Fig.5.18 Electricity Generated from Fossil Fuel Power Plants

When surcharges or restrictions are imposed on CO_2 emission , electricity generation depends further on nuclear and renewable power generation. Fig.5.19 show us the total installed capacity of nuclear power plants is increasing faster in case LHT2 compared with that in case LHBC. Nuclear power plants such as LWR power plant(E21), LMFBR power plant(E26), LWR cogeneration(E63), VHTR steam turbine(E9B) are all coming into play in case LHT2.

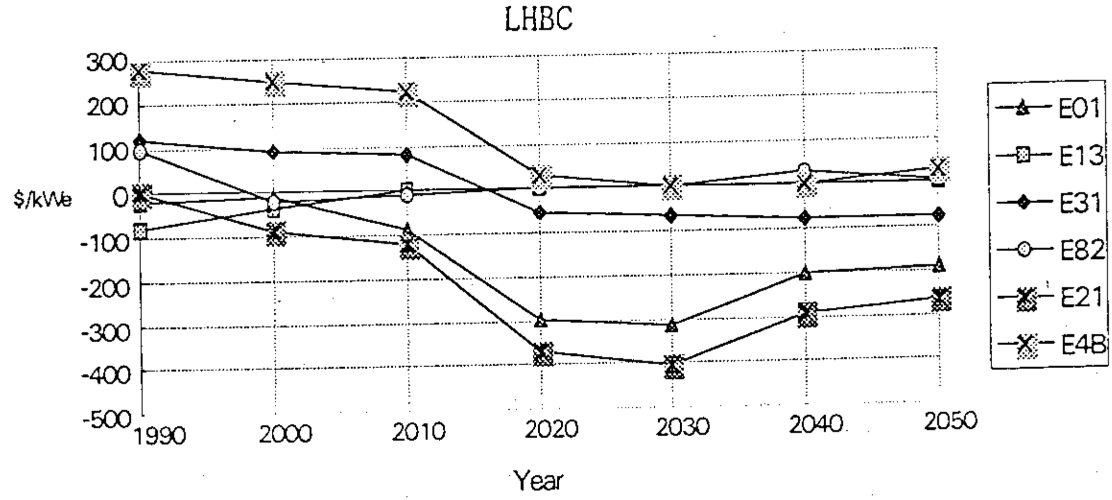


LWR power plant(E21), LMF power plant(E26), LWR cogeneration(E63), VHTR steam turbine(E9B)

Fig.5.19 Installed Capicity of Nuclear Power Plants

2) Reduced Cost of Technologies

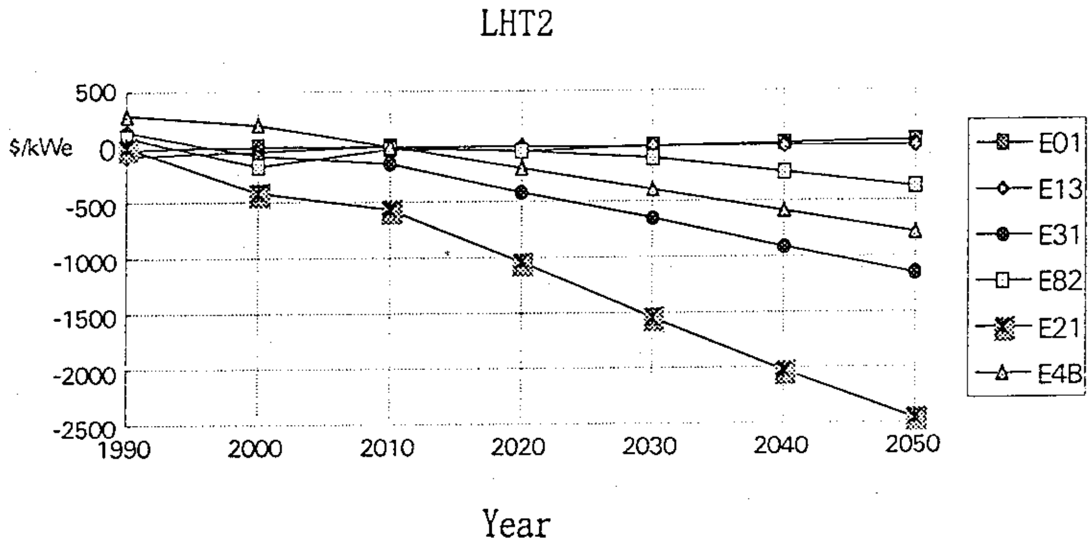
In linear programming problems, reduced costs represent sensitivity of an objective function to the values of variables. Here, reduced costs of installed capacity i.e. the change of discounted system cost per unit of capacity added, are considered as a measure of the competitiveness of electric power technologies in the energy system. Reduced costs for electric power technologies are changing with time in energy system as illustrated in Fig.5.20. The reduced cost of solar photovoltaic cell(E4B) is more than 200 $/kWe until 2010 in case LHBC. This means that solar photovoltaic cell does not compete with other electric power technologies until 2020. In baseline case LHBC, the more competent technologies are nuclear power technology(E21) and the conventional coal−firing power technologies(E01) after 2000.



E01: Concentional coal steam power plants; E13: Oil steam electric plants; E82: Gas steam power plants; E21: LWR power plant; E31: Hydroelectric power. E4B: Solar photovoltaic cell

Fig.5.20 Reduced Costs of Electric Power Technologies(LHBC)

Reduced costs will change when surcharges on CO_2 emission are introduced as in case LHT2, which are shown in Fig.5.21. The competent technologies shift to those CO_2 less-emitting technologies such as nuclear power technologies(E21), hydropower technologies(E31) and solar power technologies(E4B) .

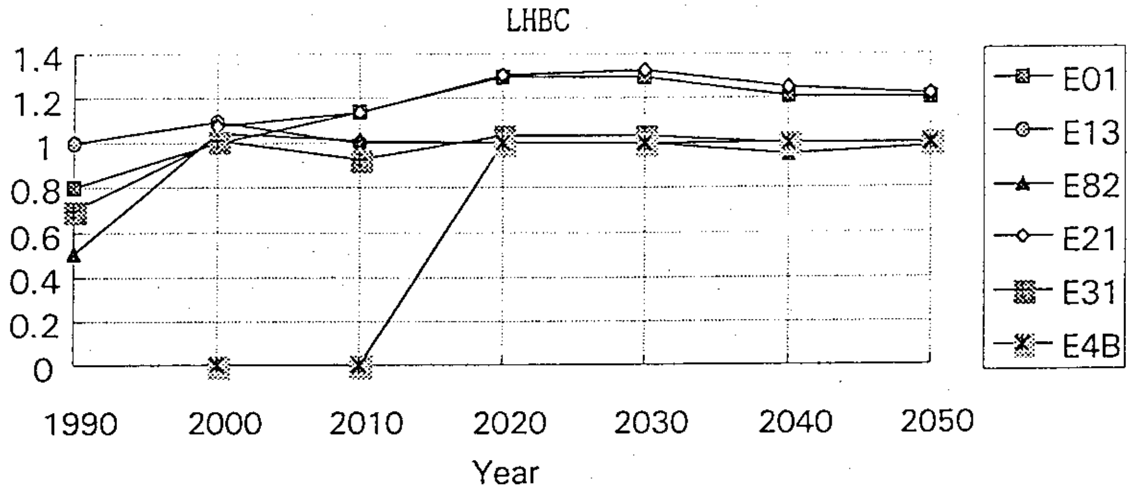


E01: Concentional coal steam power plants; E13: Oil steam electric plants; E82: Gas steam power plants; E21: LWR power plant; E31: Hydroelectric power. E4B: Solar photovoltaic cell

Fig.5.21 Reduced Costs of Power Technologies (LHT2)

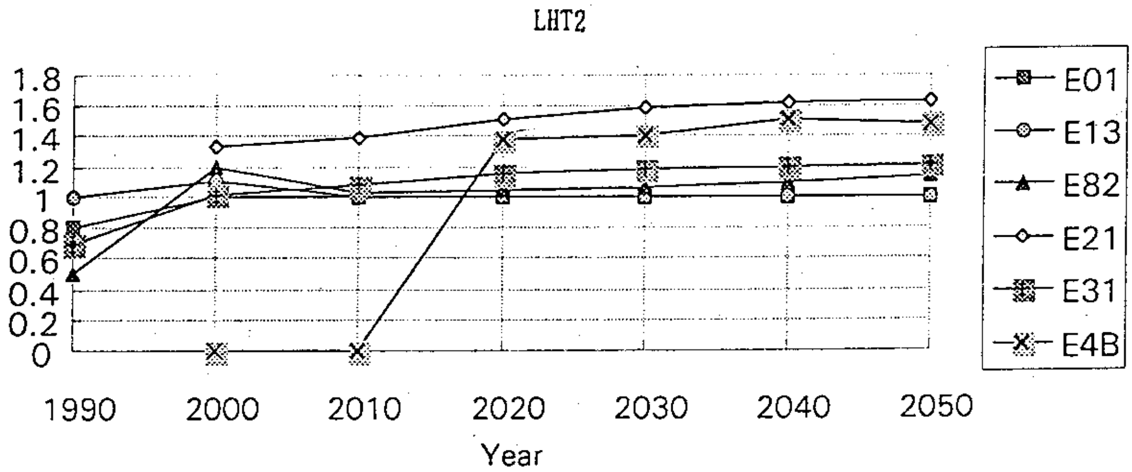
3) Benefit/Cost of Technologies

As another measure to show relative compititiveness of technologies, a benefit/cost ratio can be utilized. This is defined as value outflow divided by the sum of value inflow and value added by a technology.The benefit/cost ratios for some power technologies in case LHBC and case LHT2 are shown in Fig.5.22. In the baseline case LHBC, the benefit/cost ratios of the nuclear power technology (E21) and the conventional coal-firing power technologies(E01) are larger than 1 after 2000. This shows the strong compititiveness of these two technologies. The benefit/cost ratio of solar photovoltaic cell(E4B) is 0 until 2020 in case LHBC. This means that solar photovoltaic cell does not compete with other electric power technologies until 2020, which are consistent with the result obtained by making use of their reduced costs. When shifting to CO_2 tax case LHT2, the benefit/cost ratios of those CO_2 less-emitting technologies such as nuclear power technologies(E21), hydropower technologies(E31) and solar power technologies(E4B) are all larger than 1. (as shown in Fig. 5. 23)



E01: Concentional coal steam power plants; E13: Oil steam electric plants; E82: Gas steam power plants; E21: LWR power plant; E31: Hydroelectric power. E4B: Solar photovoltaic cell

Fig. 5. 22 Banefit/Cost Ratios for Power Generation Technologies in Case LHBC



E01: Concentional coal steam power plants; E13: Oil steam electric plants; E82: Gas steam power plants; E21: LWR power plant; E31: Hydroelectric power. E4B: Solar photovoltaic cell

Fig. 5. 23 Banefit/Cost Ratios for Power Generation Technologies in Case LHT2

5.3 Options of CO_2 Emission Reduction

5.3.1 CO_2 Emission in Selected Cases

Annual CO_2 emissions in selected cases of scenario LH are delineated in Fig.5.24. Even when the total accumulated amount of CO_2 emission was minimized as in case LHME, the annual CO_2 emission is still increasing over the whole time period. When carbon tax is levied on CO_2 emissions as in case LHT2, the annual CO_2 emission will decrease in comparison with that in baseline case LHBC. In case LHT2, after 2030 CO_2 emission reduction can nearly be stabilized. The annual CO_2 emissions will be larger when nuclear moratorium occurs in energy system as in case LHNMT, compared with the annual CO_2 emissions in case LHT2, where the same carbon tax is levied on CO_2 emissions. The difference of annual CO_2 emissions is about 560 million ton CO_2 emission / year in 2050.

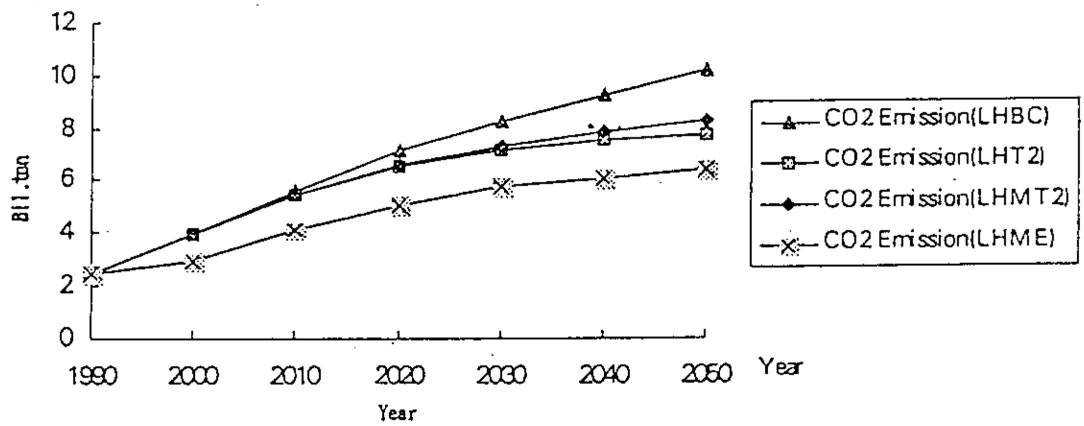
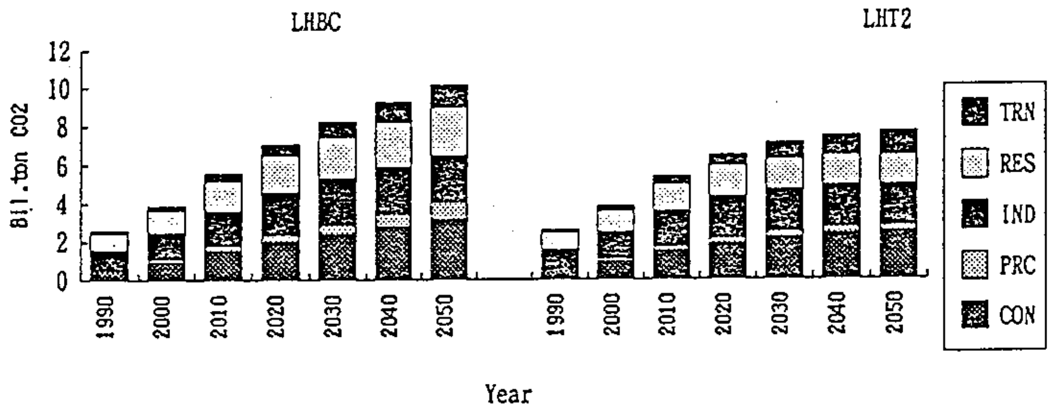


Fig.5.24. Annual Carbon Dioxide Emissions for Selected Cases in Scenario LH

5.3.2 Sectoral CO_2 Emissions

The the total annual CO_2 emissions and sectoral emissions in case LHBC and LHT2 are shown in Fig.5.25. It is noteworthy that CO_2 emission reduction in residential sector makes the biggest contribution to CO_2 emission abatement from a long-term point of view when surcharges imposed on CO_2 emission as in case LHT2. The reason is that fuel consumption in residential sector switches from the dominant direct use of coal and biomass in case LHBC to substantial employment of electricity, consumer gas and low temperature heat in this sector in case LHT2 as shown in Fig.5.15.



TRN: Transportation sector; RES: Residential sector; IND: Industrial sector; PRC : Process sector; CON: Conversion sector.

Fig. 5. 25 Carbon Dioxide Emission from Sectors

5.3.3 Disaggregation of CO_2 Emission

The annual CO_2 emission from China energy system can be expressed by the following four indicators, i.e. 1) Per capita GDP; 2) Primary energy intensity of GDP; 3) Fossil fuel use in primary energy supply; 4) CO_2 emission factor defined as CO_2 emissions per unit of fossil fuel consumption. The carbon dioxide emissions can be calculated from the following formula proposed by professor Kaya[39,40,41]:

$$\frac{CO_2}{Per\ \ Capita} = \frac{CO_2}{Fossil\ \ Energy} \times \frac{Fossil\ \ Energy}{Primary\ \ Energy} \times \frac{Primary\ \ Energy}{GDP} \times \frac{GDP}{Per\ \ Capita}$$

The reduction of CO_2 emissions can be attributed to the change of indicators in right side of the above equation. According to this formula, the results are summarized for baseline cases and carbon tax cases as shown in Table 5.1 to Table 5.4

The data about the growth rates of primary energy / GDP in these tables reflect the decreasing trend of energy intensity in selected cases, which means the efficiency of the energy supply system as well as the efficiency of end-users of energy will improve with time. In both scenario HL and scenario LH, emission surcharges or constraints drive the energy system to use its energy resource more efficiently and meanwhile to employ more non-fossil energy sources. The data in Table 5.1 and Table 5.2 show that the differences of fossil fuel use in primary energy supply and CO_2 emissions per unit of fossil fuel consumption between baseline cases of scenario HL and scenario LH are not so large. The primary energy / GDP decrease much faster in scenario HL, but the higher growth rate of GDP per capita in the baseline case of scenario HL is the overwhelming factor that results in higher CO_2 emission per capita in comparison with the situation in the baseline case of scenario LH. Comparing annual growth rates of CO_2 emissions / per capita in case HLT2 and case LHT2, we can know that it is much more difficult to reduce CO_2 emission in scenario HL than that in scenario LH by imposing taxes on CO_2 emissions.

Table 5.1 Disaggregation of Per Capita CO_2 Emissions
(HLBC)

Year	1990	2000	2010	2020	2030	2050
GDP(Bil.$ 1980 USA)	675.09	1528.20	3006.20	4896.80	7248.40	11874.00
Annual Growth Rate of GDP(%)		8.50	7.00	5.00	4.00	2.00
Primary Energy (PJ)	35998	55784	83401	111023	130401	168603
Primary Energy / GDP(MJ/$)	53.32	36.50	27.74	22.67	17.99	14.20
Annual Growth Rate(%)		-3.72	-2.71	-2.00	-2.29	-1.18
Fossil Energy (PJ)	28780	47736	72550	96739	112532	143287
Fossil Energy / Primary Energy	0.7995	0.8557	0.8699	0.8713	0.8630	0.8498
Annual Growth Rate(%)		0.68	0.16	0.02	-0.10	-0.08
CO_2 Emission (kton CO_2)	2500075	4277963	6547652	8649670	10083688	12450610
CO_2 Emission / Fossil Energy	86.87	89.62	90.25	89.41	89.61	86.89
Annual Growth Rate(%)		0.31	0.07	-0.09	0.02	-0.15
Annual Growth Rate of CO_2 Emission Per Capita(%)		5.78	4.53	2.93	1.64	0.59

Table 5.2 Disaggregation of Per Capita CO_2 Emissions (LHBC)

Year	1990	2000	2010	2020	2030	2050
GDP(Bil.$1980 USA)	675.09	1393.10	2269.10	3358.90	4514.00	6078.30
Annual Growth Rate of GDP(%)		7.50	5.00	4.00	3.00	1.00
Primary Energy (PJ)	35998	52256	71510	89878	105997	138069
Primary Energy / GDP (MJ/$)	53.32	37.51	31.51	26.76	23.48	22.72
Annual Growth Rate(%)		-3.46	-1.73	-1.62	-1.30	-0.17
Fossil Energy (PJ)	28780.0	44224.0	61369.00	76440.00	89400.0	115999
Fossil Energy / Primary Energy	0.7995	0.8463	0.8582	0.8505	0.8434	0.8402
Annual Growth Rate(%)		0.57	0.14	-0.09	-0.08	-0.02
CO_2 Emission (kton CO_2)	2500075	3964223	5592407	7085761	8222439	10139762
CO_2 Emission / Fossil Energy	86.87	89.64	91.13	92.70	91.97	87.41
Annual Growth Rate(%)		0.31	0.16	0.17	-0.08	-0.25
Annual Growth Rate of CO_2 Emission Per Capita(%)		4.93	3.58	2.46	1.54	0.56

Table 5.3 Disaggregation of Per Capita CO_2 Emissions (HLT2)

Year	1990	2000	2010	2020	2030	2050
GDP(Bil.$1980 USA)	675.09	1528.20	3006.20	4896.80	7248.40	11874.00
Annual Growth Rate of GDP(%)		8.50	7.00	5.00	4.00	2.00
Primary Energy(PJ)	35998	53946	81041	104764	123300	158645
Primary Energy / GDP(MJ/$)	53.32	35.30	26.96	21.39	17.01	13.36
Annual Growth Rate(%)		-4.04	-2.66	-2.28	-2.27	-1.20
Fossil Energy(PJ)	28780.00	45866.29	70107.86	90230.84	105086.9	132696
Fossil Energy / Primary Energy	0.7995	0.8502	0.8651	0.8613	0.8523	0.8364
Annual Growth Rate(%)		0.62	0.17	-0.04	-0.10	-0.09
CO_2 Emission (kton CO_2)	2500075	4214925	6297394	7807462	8738597	10514669
CO_2 Emission / Fossil Energy	86.87	91.90	89.82	86.53	83.16	79.24
Annual Growth Rate(%)		0.56	-0.23	-0.37	-0.40	-0.24
Annual Growth Rate of CO_2 Emission Per Capita(%)		5.64	4.29	2.30	1.23	0.46

Table 5.4 Disaggregation of Per Capita CO_2 Emissions (LHT2)

Year	1990	2000	2010	2020	2030	2050
GDP(Bil.$1980USA.)	675.09	1393.10	2269.10	3358.90	4514.00	6078.30
Growth Rate of GDP(%)		7.50	5.00	4.00	3.00	1.00
Primary Energy (PJ)	35998	50530	69045	86252	99272	121044
Primary Energy / GDP(MJ/$)	53.32	36.27	30.43	25.68	21.99	19.91
Annual Growth Rate(%)		-3.78	-1.74	-1.68	-1.54	-0.50
Fossil Energy (PJ)	28780.00	42489.00	58363.00	71780.60	81079.03	95025
Fossil Energy / Primary Energy	0.7995	0.8409	0.8453	0.8322	0.8167	0.7850
Annual Growth Rate(%)		0.51	0.05	-0.16	-0.19	-0.20
CO_2 Emission (kton CO_2)	2500075	3916878	5384502	6506675	7089895	7669804
CO_2 Emission / Fossil Energy	86.87	92.19	92.26	90.65	87.44	80.71
Annual Growth Rate(%)		0.60	0.01	-0.18	-0.36	-0.40
Annual Growth Rate of CO_2 Emission Per Capita(%)		4.82	3.32	1.99	0.92	-0.09

6. Concluding Summary

Potential of CO_2 emission reduction and the role of energy technologies have been analyzed for the energy system of China in the time period from 1990 to 2050. The MARKAL model has been used in order to optimize the energy system and to determine optimum sets of energy carriers and technologies in the system. The outline of the reference energy system, scenarios and cases, and analytical results are summarized in the following.

1) Chinese Reference Energy System

The reference energy system was established based on the framework of MARKAL model for China energy system. The time period for this study is from 1990 to 2050. About 79 kinds of energy carriers, 135 kinds of demand technologies, 29 kinds of conversion technologies and 58 kinds of process technologies that have been in active service or might come to the fore in China were configured in the database for the reference energy system.

2) Scenarios and cases

Two scenarios were set up on the assumptions about socioeconomic development and the import fuel prices. The basic assumptions for scenarios are shown in Table6.1.The useful energy demands were projected for both scenario assumptions.

Table6. 1 Basic Assumptions for Scenarios

Item	Scenario HL	Scenario LH
Population development	High projection: From 1.14 billion in 1990 to 1.79 billion in 2050	Low projection: From 1.14 billion in 1990 to 1.50 billion in 2050
Annual growth rate of GDP	High projection: 1990～2000: 8.5 %, 2000～2010: 7 %, 2010～2020: 5 %, 2020～2030: 4 %, 2030～2040: 3 %, 2040～2050: 2 %	Low projection: 1990～2000: 7.5 %, 2000～2010: 5 %, 2010～2020: 4 %, 2020～2030: 3 %, 2030～2040: 2 %, 2040～2050: 1 %
Useful energy demand	High projection: AUED(high, t), IUED(high, t), CUED(high, t), FTT(high, t), PTT(high, t) and high residential energy demands etc.	Low projection: AUED(low, t), IUED(low, t), CUED(low, t), FTT(low, t), PTT(low, t) and low residential energy demands etc.
Import price projection of oil and natural gas	Low projection: Import oil price from 3.74 \$/GJ in 1990 to 9.91 \$/GJ in 2050. Import natural gas price from 3.99 \$/GJ in 1990 to 10.42 \$/GJ in 2050	High projection: Import oil price from 3.74 \$/GJ in 1990 to 17.06 \$/GJ in 2050. Import natural gas price from 3.99 \$/GJ in 1990 to 18.41 \$/GJ in 2050

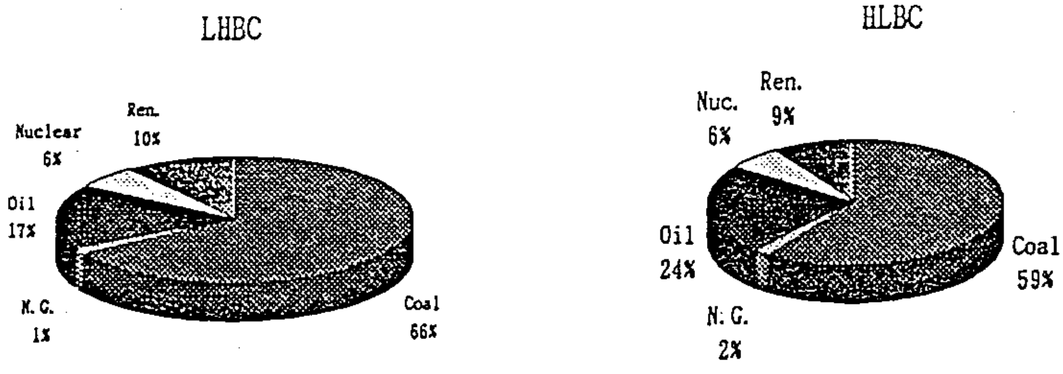
The cases analyzed are as follows: ❶ Baseline Case (minimizing total discounted system cost), ❷ CO_2 Emission Tax Cases(minimizing total discounted system cost under constraint of exogenous given marginal prices on CO_2 emissions), ❸ Security Cases (minimizing total discounted system cost with a surcharge on import oil) and ❹ Nuclear Moratorium Case (provided that no more nuclear power plants were constructed after 2010).

3) Analytical Results

Applying the MARKAL model with the established database, the optimal results were obtained for several scenarios and cases. The results are summarized as follows:

① Baseline Cases:

The energy demands are much higher in scenario HL, about 170 EJ of primary energy will be consumed in 2050 in the baseline case HLBC, much more than 140 EJ of primary energy in 2050 in the baseline case LHBC. The patterns of primary energy consumption in 2050 in baseline cases are shown in Fig.6.1.



Ren.: Renewable energy(included domestic biofuels). Nuc.: Nuclear energy.
Oil. : Crude oil. N.G.: Natural gas.

Fig 6.1. Pattern of Primary Energy in 2050 in Baseline Cases

In baseline case HLBC, the annual CO_2 emissions reach 12.45 Bil.ton in 2050, 5 times than that in 1990, while the annual CO_2 emissions will be 10.14 Billion ton in 2050 in baseline LHBC, 4 times than that in 1990. Detailed analyses on the disaggregations of CO_2 emissions by Kaya Formula show: The energy intensity (primary energy / GDP) decrease much faster in scenario HL, but the higher growth rate of GDP per capita is the overwhelming factor that results in higher CO_2 emission per capita in the baseline case of scenario HL in comparison with the situation in the baseline case of scenario LH.

② CO_2 Emission Reduction

Annual CO_2 emissions in selected cases of scenario LH are delineated in Fig.6.2. Even when the total accumulated amount of CO_2 emission was minimized as in case LHME, the annual CO_2 emission is still increasing over the whole time period. When carbon tax is levied on CO_2 emissions as in case LHT2, the annual CO_2 emission will decrease in comparison with that in baseline case LHBC. In case LHT2, after 2030 CO_2 emission reduction can nearly be stabilized.

CO_2 emission reduction in residential sector makes the biggest contribution to CO_2 emission abatement from a long-term point of view when carbon tax imposed on CO_2 emission as in case LHT2. The reason is that fuel consumption in residential sector switches from the dominant direct use of coal and biomass in case LHBC to substantial employment of electricity, consumer gas and low temperature heat in this sector in case LHT2.

The annual CO_2 emissions will be larger when nuclear moratorium occurs in energy system as in case LHNMT, compared with the annual CO_2 emissions in case LHT2, where the same carbon tax is levied on CO_2 emissions. The difference of annual CO_2 emissions is about 560 million ton CO_2 emission / year in 2050.

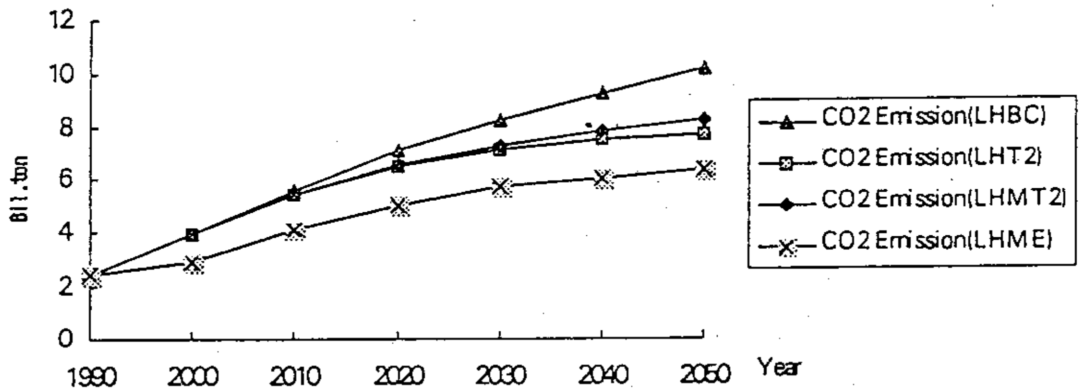


Fig.6.2 Annual CO_2 Emission for Selected Cases in Scenario LH

③ Roles of Technology

CO_2 emissions reduction depends largely on new or advanced technologies particularly in the field of electricity generation. In addition to combined cycle technologies for fossil-fired electric power generation, nuclear and renewable energy technologies are important. The benefit/cost ratios of electric power technologies clearly indicate this, i.e. when carbon tax is imposed on CO_2 emission, the competent power generation technologies shift to those CO_2 less-emitting technologies such as nuclear power, hydropower and solar photovoltaic. In particular, nuclear power shows significant potential in saving fossil energy resources and reducing CO_2 emissions..

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Appendix 1

Projection of Agricultral Useful Energy Demand

Agricultural Eergy Demand(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
GDP(1980U.S Bil.$)	676	1393	2269	3359	4514	5503	6078
Agri.GDP Share	29%	26%	23%	19%	16%	13%	11%
Agri.GDP(Bil.$)	196.0	362.19	521.90	638.19	722.25	687.82	668.61
E.Intensity(MJ/$)(F)	3.9	4.1	4.3	4.5	4.7	4.9	5.1
Overall Efficiency	35%	38%	40%	41%	42%	46%	48%
E.Intensity(MJ/$)(U)	1.37	1.56	1.72	1.85	1.97	2.25	2.45
Low U.Energy(PJ)	**268**	**564**	**898**	**1177**	**1426**	**1550**	**1637**

Agriculture Eergy Demand(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1263	1381	1495	1604	1702	1789
GDP(1980U.S Bil.$)	676	1528	3006	4897	7248	9741	11875
Agri.GDP Share	29%	25%	19%	14%	10%	7.50%	6.00%
Agri.GDP(Bil.$)	196.0	382.05	571.18	661.07	724.84	730.60	712.47
E.Intensity(MJ/$)(F)	3.9	4.4	4.6	4.9	5.1	5.3	5.5
Overall Efficiency	35%	41%	43%	44%	45%	47%	49%
E.Intensity(MJ/$)(U)	1.37	1.80	1.98	2.16	2.30	2.49	2.70
High U.Energy(PJ)	**268**	**689**	**1130**	**1425**	**1664**	**1820**	**1920**

Appendix 2

Useful Energy Projection for Industrial Categories

1) Projection of Usefull Energy Demand in Excavation Industry(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	39.17	29.15	23.91	21.22	19.60	18.64	18.27
Efficiency of E.Carriers	41.05%	42.29%	43.15%	43.58%	43.89%	44.11%	44.28%
U. E. Intensity(MJ/$)	16.08	12.33	10.32	9.25	8.60	8.22	8.09
Elasticity(GOPV/GDP)	1.10	1.00	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	9.50%	7.50%	5.00%	4.00%	2.85%	1.80%	0.85%
GOPV in Excav.(Bil. $)	48.25	99.46	162.00	239.80	317.60	379.63	413.16
Proj. of U.E.Demand(PJ)	776	1226	1671	2218	2731	3122	3343

Projection of Usefull Energy Demand in Excavation Industry(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	39.17	27.77	21.07	17.28	14.89	13.22	11.97
Efficiency of E.Carriers	41.05%	42.72%	44.02%	44.90%	45.36%	45.67%	45.90%
U. E. Intensity(MJ/$)	16.08	11.86	9.27	7.76	6.75	6.04	5.49
Elasticity(GOPV/GDP)	1.10	1.00	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	9.50%	8.50%	7.00%	5.00%	3.80%	2.70%	1.70%
GOPV in Excav.(Bil. $)	48.25	109.10	214.62	349.59	507.61	662.58	784.21
Proj. of U.E.Demand(PJ)	776	1294	1990	2713	3429	4000	4307

2) Projection of Usefull Energy Demand in Food, Beverages & Tobacco(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	11.61	8.64	7.09	6.29	5.81	5.52	5.42
Efficiency of E.Carriers	35.95%	37.04%	37.79%	38.17%	38.44%	38.63%	38.78%
U. E. Intensity(MJ/$)	4.17	3.20	2.68	2.40	2.23	2.13	2.10
Elasticity(GOPV/GDP)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.68%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
GOPV in F.B.&T.(Bil. $)	87.37	180.08	293.32	434.20	583.52	711.31	785.73
Proj. of U.E.Demand(PJ)	365	576	785	1042	1303	1518	1650

Projection of Usefull Energy Demand in Food, Beverages & Tobacco(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	11.61	8.23	6.24	5.12	4.41	3.92	3.55
Efficiency of E.Carriers	35.95%	37.41%	38.55%	39.33%	39.72%	40.00%	40.20%
U. E. Intensity(MJ/$)	4.17	3.08	2.41	2.01	1.75	1.57	1.43
Elasticity(GOPV/GDP)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.68%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
GOPV in F.B.&T.(Bil. $)	87.37	197.55	388.61	633.00	936.99	1259.24	1534.93
Proj. of U.E.Demand(PJ)	365	608	935	1275	1643	1973	2188

3) Projection of Usefull Energy Demand in Textiles Industry(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	9.20	6.85	5.62	4.99	4.60	4.38	4.29
Efficiency of E.Carriers	39.99%	41.12%	41.95%	42.37%	42.67%	42.89%	43.06%
U. E. Intensity(MJ/$)	3.68	2.82	2.36	2.11	1.96	1.88	1.85
Elasticity(GOPV/GDP)	0.98	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.07%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
GOPV in Textiles(Bil. $)	103.20	212.70	346.45	512.84	689.20	840.14	928.04
Proj. of U.E.Demand(PJ)	380	599	816	1084	1354	1578	1716

Projection of Usefull Energy Demand in Textiles Industry(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	9.20	6.52	4.95	4.06	3.50	3.11	2.81
Efficiency of E.Carriers	39.99%	41.62%	42.88%	43.75%	44.19%	44.50%	44.72%
U. E. Intensity(MJ/$)	3.68	2.72	2.12	1.78	1.55	1.38	1.26
Elasticity(GOPV/GDP)	0.98	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.07%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
GOPV in Textiles(Bil. $)	103.20	233.33	458.99	747.65	1106.6	1487.31	1812.9
Proj. of U.E.Demand(PJ)	380	634	974	1328	1711	2055	2279

4) Projection of Usefull Energy Demand in Elec, Steam & Hot Water(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	25.42	18.92	15.83	14.05	12.97	12.34	12.10
Efficiency of E.Carriers	55.90%	57.60%	58.77%	59.36%	59.77%	60.07%	60.31%
U. E. Intensity(MJ/$)	14.21	10.90	9.30	8.34	7.75	7.41	7.30
Elasticity(GOPV/GDP)	1.08	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.15%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
GOPV in E.S.&H.W(Bil. $)	23.10	47.61	77.54	114.79	154.26	188.04	207.72
Proj. of U.E.Demand(PJ)	328	519	721	957	1196	1394	1515

Projection of Usefull Energy Demand in Electricity, Steam & Hot Water(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	25.42	17.85	13.54	11.11	9.57	8.50	7.69
Efficiency of E.Carriers	55.90%	58.18%	59.83%	61.04%	61.65%	62.09%	62.40%
U. E. Intensity(MJ/$)	14.21	10.39	8.10	6.78	5.90	5.27	4.80
Elasticity(GOPV/GDP)	1.08	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.15%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
GOPV in E.S.&H.W(Bil. $)	23.10	52.22	102.73	167.34	247.70	332.90	405.78
Proj. of U.E.Demand(PJ)	328	542	832	1135	1462	1756	1947

5) Projection of Usefull Energy Demand in Petroleum Processing(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	23.18	17.25	14.15	12.56	11.60	11.03	10.82
Efficiency of E.Carriers	33.53%	34.55%	35.25%	35.60%	35.85%	36.03%	36.17%
U. E. Intensity(MJ/$)	7.77	5.96	4.99	4.47	4.16	3.98	3.91
Elasticity(GOPV/GDP)	1.17	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.96%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
GOPV in Petroleum(Bil.$)	18.68	38.50	62.71	92.83	124.75	152.07	167.98
Proj. of U.E.Demand(PJ)	145	229	313	415	519	605	657

Projection of Usefull Energy Demand in Petroleum Processing(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	23.18	16.43	12.59	10.33	8.90	7.90	7.15
Efficiency of E.Carriers	33.53%	34.89%	35.95%	36.68%	37.05%	37.31%	37.50%
U. E. Intensity(MJ/$)	7.77	5.73	4.53	3.79	3.30	2.95	2.68
Elasticity(GOPV/GDP)	1.17	1.00	1.00	1.00	1.00	1.00	1.00
A. G. Rate of GOPV	9.96%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
GOPV in Petroleum(Bil.$)	18.68	42.23	83.08	135.33	200.31	269.21	328.15
Proj. of U.E.Demand(PJ)	145	242	376	513	661	793	880

6) Projection of Usefull Energy Demand in Chemical Industry(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	63.76	49.81	41.67	36.99	34.15	32.49	31.85
Efficiency of E.Carriers	37.18%	38.23%	38.93%	39.32%	39.60%	39.79%	39.95%
U. E. Intensity(MJ/$)	23.71	19.05	16.22	14.54	13.52	12.93	12.73
Elasticity(GOPV/GDP)	1.40	1.00	0.90	0.80	0.70	0.60	0.50
A. G. Rate of GOPV	12.73%	7.50%	4.50%	3.20%	2.10%	1.20%	0.50%
GOPV in Chemistry(Bil.$)	48.29	99.53	154.56	211.79	260.70	293.73	308.76
Proj. of U.E.Demand(PJ)	1145	1896	2507	3080	3526	3798	3929

Projection of Usefull Energy Demand in Chemical Industry(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	63.76	47.45	37.80	31.62	27.25	24.18	21.89
Efficiency of E.Carriers	37.18%	38.50%	39.59%	40.39%	40.80%	41.09%	41.29%
U. E. Intensity(MJ/$)	23.71	18.27	14.96	12.77	11.12	9.94	9.04
Elasticity(GOPV/GDP)	1.40	1.00	0.90	0.80	0.70	0.60	0.50
A. G. Rate of GOPV	12.73%	8.50%	6.30%	4.00%	2.80%	1.80%	1.00%
GOPV in Chemistry(Bil.$)	48.29	109.18	201.13	297.72	392.41	469.05	518.11
Proj. of U.E.Demand(PJ)	1145	1994	3010	3803	4362	4660	4683

7) Projection of Usefull Energy Demand in Buiding Materials(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	67.29	51.05	41.07	35.39	32.03	30.48	29.87
Efficiency of E.Carriers	32.41%	33.40%	34.07%	34.42%	34.66%	34.83%	34.97%
U. E. Intensity(MJ/$)	21.81	17.05	13.99	12.18	11.10	10.62	10.45
Elasticity(GOPV/GDP)	1.43	1.00	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	13.41%	7.50%	5.00%	4.00%	2.85%	1.80%	0.85%
GOPV in B. Mater.(Bil.$)	44.44	91.59	149.19	220.84	292.49	349.62	380.50
Proj. of U.E.Demand(PJ)	969	1562	2088	2690	3248	3711	3975

Projection of Usefull Energy Demand in Building Materials(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	67.29	48.63	37.62	30.86	26.59	23.60	21.37
Efficiency of E.Carriers	32.41%	33.67%	34.62%	35.32%	35.68%	35.89%	36.03%
U. E. Intensity(MJ/$)	21.81	16.37	13.03	10.90	9.49	8.47	7.70
Elasticity(GOPV/GDP)	1.43	1.00	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	13.41%	8.50%	7.00%	5.00%	3.80%	2.70%	1.70%
GOPV in B. Mater.(Bil.$)	44.44	100.48	197.65	321.95	467.48	610.20	722.21
Proj. of U.E.Demand(PJ)	969	1645	2575	3510	4435	5169	5561

8) Projection of Usefull Energy Demand in Nonferrous Metals Smelting(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	33.55	26.21	21.93	19.46	17.97	17.10	16.76
Efficiency of E.Carriers	45.74%	47.13%	48.08%	48.56%	48.90%	49.15%	49.34%
U. E. Intensity(MJ/$)	15.35	12.35	10.54	9.45	8.79	8.40	8.27
Elasticity(GOPV/GDP)	1.36	1.00	0.90	0.80	0.70	0.60	0.50
A. G. Rate of GOPV	11.69%	7.50%	4.50%	3.20%	2.10%	1.20%	0.50%
GOPV in N.M.Smel.(Bil.$)	16.69	34.39	53.41	73.19	90.09	101.51	106.70
Proj. of U.E.Demand(PJ)	256	425	563	692	792	853	882

Projection of Usefull Energy Demand in Nonferrous Metals Smelting(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	33.55	24.25	18.94	15.85	13.66	12.12	10.97
Efficiency of E.Carriers	45.74%	47.41%	48.75%	49.74%	50.24%	50.59%	50.84%
U. E. Intensity(MJ/$)	15.35	11.50	9.24	7.88	6.86	6.13	5.58
Elasticity(GOPV/GDP)	1.36	1.00	0.90	0.80	0.70	0.60	0.50
A. G. Rate of GOPV	11.69%	8.50%	6.30%	4.00%	2.80%	1.80%	1.00%
GOPV in N.M.Smel.(Bil.$)	16.69	37.73	69.51	102.88	135.61	162.09	179.05
Proj. of U.E.Demand(PJ)	256	434	642	811	930	994	999

9) Projection of Usefull Energy Demand in Metal Products(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	9.25	7.02	5.76	5.11	4.72	4.49	4.40
Efficiency of E.Carriers	40.49%	41.72%	42.56%	42.99%	43.29%	43.51%	43.68%
U. E. Intensity(MJ/$)	3.74	2.93	2.45	2.20	2.04	1.95	1.92
Elasticity(GOPV/GDP)	1.82	1.20	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	16.71%	9.00%	5.00%	4.00%	2.85%	1.80%	0.85%
GOPV in M.Prod.(Bil.$)	27.06	64.07	104.36	154.47	204.59	244.55	266.15
Proj. of U.E.Demand(PJ)	101	188	256	339	418	478	511

Projection of Usefull Energy Demand in Metal Products(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	9.25	6.56	5.02	4.12	3.55	3.15	2.85
Efficiency of E.Carriers	40.49%	41.72%	42.77%	43.55%	43.99%	44.30%	44.52%
U. E. Intensity(MJ/$)	3.74	2.74	2.15	1.79	1.56	1.40	1.27
Elasticity(GOPV/GDP)	1.82	1.20	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	16.71%	10.20%	7.00%	5.00%	3.80%	2.70%	1.70%
GOPV in M.Prod.(Bil.$)	27.06	71.48	140.61	229.04	332.57	434.10	513.78
Proj. of U.E.Demand(PJ)	101	196	302	411	519	606	653

10) Projection of Usefull Energy Demand in Machinary & Electronics(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980 U.S. Bil.$)	675.90	1393.1	2269.1	3358.9	4514.0	5502.60	6078.3
A. G. Rate of GDP	9.00%	7.50%	5.00%	4.00%	3.00%	2.00%	1.00%
F. E. Intensity(MJ/$)	7.88	6.16	5.20	4.71	4.48	4.35	4.31
Efficiency of E.Carriers	38.76%	39.94%	40.74%	41.15%	41.52%	41.86%	42.19%
U. E. Intensity(MJ/$)	3.06	2.46	2.12	1.94	1.86	1.82	1.82
Elasticity(GOPV/GDP)	1.45	1.10	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	13.82%	8.25%	5.00%	4.00%	2.85%	1.80%	0.85%
GOPV in M. & E.(Bil. $)	197.22	435.77	709.79	1050.6	1391.5	1663.37	1810.2
Proj. of U.E.Demand(PJ)	603	1072	1505	2037	2590	3028	3289

Projection of Usefull Energy Demand in Machinary & Electronics(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(80 U.S. Bil.$)	675.9	1528.2	3006.2	4896.8	7248.4	9741.3	11874
A. G. Rate of GDP	9.00%	8.50%	7.00%	5.00%	4.00%	3.00%	2.00%
F. E. Intensity(MJ/$)	7.88	5.59	4.37	3.69	3.65	3.47	3.37
Efficiency of E.Carriers	38.76%	39.74%	40.3%	40.74%	41.03%	41.19%	41.28%
U. E. Intensity(MJ/$)	3.06	2.22	1.76	1.50	1.50	1.43	1.39
Elasticity(GOPV/GDP)	1.45	1.10	1.00	1.00	0.95	0.90	0.85
A. G. Rate of GOPV	13.82%	9.35%	7.00%	5.00%	3.80%	2.70%	1.70%
GOPV in M. & E.(Bil. $)	197.22	482.11	948.39	1544.8	2243.1	2927.91	3465.3
Proj. of U.E.Demand(PJ)	603	1071	1671	2322	3362	4191	4824

Appendix 3

Projection of Commercial Useful Energy Demand

Service Eergy Demand(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
GDP(1980U.S Bil.$)	675.90	1393.05	2269.1	3358.87	4514.04	5502.59	6078.29
Service GDP Share	20.50%	24.50%	28.50%	33.00%	37.30%	39.70%	41.80%
Service GDP(B$)	138.56	341.30	646.70	1108.43	1683.74	2184.53	2540.72
E.Intensity(MJ/$)(F)	6.1	5.8	5.5	5.2	4.9	4.7	4.5
Overall Efficiency	42%	46%	51%	55%	57%	58%	60%
E.Intensity(MJ/$)(U)	2.56	2.67	2.81	2.86	2.79	2.73	2.70
Low U.Energy (PJ)	355	911	1814	3170	4703	5955	6860
Lighting and Appli.(PJ)	47	102	221	434	777	1266	1874
Space heating(PJ)	189	308	502	744	1101	1479	1803
Water heating(PJ)	95	449	991	1813	2532	2732	2476
Air Condition(PJ)	24	51	101	180	293	478	707

Service Eergy Demand(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1263	1381	1495	1604	1702	1789
GDP(1980U.S Bil.$)	676	1528	3006	4897	7248	9741	11875
Service GDP Share	20.50%	25.80%	31.50%	37.30%	41.80%	44.70%	46.40%
Service GDP(B$)	138.56	394.28	946.95	1826.50	3029.84	4354.35	5509.80
E.Intensity(MJ/$)(F)	6.1	5.5	4.7	4.2	3.6	3.2	2.8
Overall Efficiency	42.00%	48.00%	52.50%	57.00%	59.00%	60.00%	62.00%
E.Intensity(MJ/$)(U)	2.56	2.64	2.47	2.39	2.12	1.92	1.74
U.Energy (PJ) High	355	1041	2337	4373	6435	8360	9565
Lighting and Appli.(PJ)	47	123	291	627	1234	2011	2976
Space heating(PJ)	189	339	552	818	1210	1626	1982
Water heating(PJ)	95	518	1348	2614	3374	3618	3121
Air Condition(PJ)	24	61	145	314	617	1105	1485

Residential Indicators

Residential Indicators(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143	1252	1342	1423	1499	1477	1501
Urban Share	26.00%	32.00%	38.00%	45.00%	50.00%	55.00%	60.00%
Urban Population(10^6)	297.18	400.64	509.96	640.35	749.50	812.35	900.60
Persons per Family	3.5	3.4	3.3	3.2	3.1	3	2.9
Househould(Urban) 10^6	84.91	117.84	154.53	200.11	241.77	270.78	310.55
Rural Share	74.00%	68.00%	62.00%	55.00%	50.00%	45.00%	40.00%
Rural Population(10^6)	845.82	851.36	832.04	782.65	749.50	664.65	600.40
Persons per Family	4.8	4.5	4.3	4.1	3.9	3.7	3.5
Househould(Rural) 10^6	176.21	189.19	193.50	190.89	192.18	179.64	171.54

Residential Indicators(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Population(10^6)	1143.00	1262.58	1380.93	1495.47	1603.51	1702.36	1789.42
Urban Share	26.00%	34.00%	42.00%	50.00%	56.00%	62.00%	70.00%
Urban Population(10^6)	297.18	429.28	579.99	747.73	897.97	1055.46	1252.59
Persons per Family	3.5	3.3	3.1	3	2.9	2.8	2.7
Househould(Urban) 10^6	84.91	130.08	187.09	249.24	309.64	376.95	463.92
Rural Share	74.00%	66.00%	58.00%	50.00%	44.00%	38.00%	30.00%
Rural Population(10^6)	845.82	833.30	800.94	747.73	705.54	646.90	536.83
Persons per Family	4.8	4.3	4	3.8	3.6	3.4	3.2
Househould(Rural) 10^6	176.21	193.79	200.23	196.77	195.98	190.26	167.76

Appendix 4

Projection of Useful Energy Demand for Space Heating

Rural Residential Energy Demand - Space Heating(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(10^6)	845.82	851.36	832.04	782.65	749.50	664.65	600.40
Per Capita Area(m^2)	17.83	19	20	21	22	23	24
Heating Area	40.00%	42.50%	45.00%	47.50%	50.00%	52.50%	55.00%
Heating Rooms	15.00%	21.00%	22.50%	23.50%	26.00%	29.00%	32.00%
Heating Area(B.m^2)	90.49	144.37	168.49	183.46	214.36	232.74	253.61
Heating Duration(day)	120	120	120	120	120	120	120
Heating required(MJ/m^2 *day)	5.86	5.7	5.6	5.5	5.4	5.3	5.2
S.Heat Useful Energy (PJ)	636.30	987.49	1132.24	1210.86	1389.03	1480.25	1582.52

Rural Residential Energy Demand - Space Heating(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(10^6)	845.82	833.30	800.94	747.73	705.54	646.90	536.83
Per Capita Area(m^2)	17.83	20	21.5	23	24.5	26	27.5
Heating Area	40.00%	42.50%	45.00%	47.50%	50.00%	52.50%	55.00%
Heating Rooms	15.00%	21.00%	25.00%	28.00%	30.00%	32.00%	35.00%
Heating Area(B.m^2)	6.03	7.08	7.75	8.17	8.64	8.83	8.12
Heating Duration(day)	120	125	125	125	130	135	140
Heating required(MJ/m^2*day)	5.8	5.4	5.2	5.1	4.7	4.5	4.5
S.Heat Useful Energy (PJ)	629.78	1004.03	1259.23	1458.16	1584.25	1716.58	1790.35

Urban Residential Energy Demand - Space Heating(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(10^6)	297.18	400.64	509.96	640.35	749.50	812.35	900.60
Per Capita Area(m^2)	6.7	6.5	7.2	8	8.7	9.3	9.8
Heating Area Population(%)	45.00%	47.00%	49.00%	51.00%	54.00%	57.00%	58.00%
Heating Rooms	60.00%	75.00%	90.00%	100.00%	100.00%	100.00%	100.00%
Heating Area(B.m^2)	0.54	0.92	1.62	2.61	3.52	4.31	5.12
Heating Duration(day)	120	120	120	120	120	120	120
Heating required(MJ/m^2*day)	5.86	5.7	5.6	5.5	5.4	5.3	5.1
S.Heat Useful Energy (PJ)	378.04	627.89	1088.12	1724.33	2281.71	2738.79	3132.83

Urban Residential Energy Demand - Space Heating(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(10^6)	297.18	429.28	579.99	747.73	897.97	1055.46	1252.59
Per capita Area(m^2)	6.7	8	9	10	10.5	11	11.2
Heating Area Population(%)	45.00%	49.00%	52.00%	54.00%	56.00%	58.00%	59.00%
Heating Rooms	60.00%	75.00%	90.00%	100.00%	100.00%	100.00%	100.00%
Heating Area(B.m^2)	0.54	1.26	2.44	4.04	5.28	6.73	8.28
Heating Duration(day)	120	125	125	125	130	135	140
Heating required(MJ/m^2*day)	5.86	5.6	5.25	5	4.8	4.5	4.2
S.Heat Useful Energy (PJ)	378.04	883.45	1603.17	2523.60	3294.74	4090.82	4866.96

Appendix 5

Projection of Useful Energy Demand for Lighting and Appliances

Rural Residential Energy Demand - Lighting and Appliances(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural householud(*10^6)	176.21	189.19	193.50	190.89	192.18	179.64	171.54
Lighting Elec. Use(kWh/year)	58.00	64.07	70.77	78.18	86.35	95.39	105.37
Saturation(per 100 Rural HH)	70.00	80.00	90.00	100.00	100.00	100.00	100.00
Lighting Useful Energy(PJ)	25.76	34.91	44.37	53.73	59.75	61.69	65.08
Refri. Elec. Use(kWh/year)	400.00	400.00	400.00	400.00	400.00	400.00	400.00
Saturation(per 100 Rural HH)	1.20	5.00	10.00	17.00	25.00	34.00	45.00
Refri. Useful Energy(PJ)	3.05	13.62	27.87	46.74	69.19	87.96	111.17
Color TV Elec. Use(kWh / year)	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Saturation(per 100 Rural HH)	4.70	10.00	20.00	35.00	50.00	65.00	80.00
Color TV Useful Energy(PJ)	3.28	7.49	15.33	26.46	38.06	46.24	54.35
B&W TV Elec. Use(kWh/year)	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Saturation(per 100 Rural HH)	39.70	45.00	50.00	35.00	30.00	25.00	20.00
B&W TV Useful Energy(PJ)	11.08	13.49	15.33	10.58	9.13	7.11	5.44
Fan Elec. Use(kWh/year)	26.00	28.00	30.00	33.00	36.00	38.00	40.00
Saturation(per 100 Rural HH)	41.40	50.00	60.00	70.00	80.00	90.00	100.00
Fan TV Useful Energy(PJ)	6.83	9.54	12.54	15.88	19.93	22.12	24.71
Air Conditioner							
Annual Elec.Use(kWh/year)	750.00	750.00	750.00	750.00	750.00	750.00	750.00
Saturation(per 100 HHs)	0.01	0.03	0.06	0.12	0.24	0.50	1.00
U.E.(PJ, Low Demand)	0.05	0.15	0.31	0.62	1.25	2.43	4.63
L&A. U. E.(PJ) Low Growth	50.04	79.21	115.75	154.01	197.31	227.56	265.38

Rural Residential Energy Demand - Lighting and Appliances(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural householud(*10^6)	176.21	193.79	200.23	196.77	195.98	190.26	167.76
Lighting Elec. Use(kWh/year)	58.00	67.31	78.12	90.66	105.21	122.10	141.71
Saturation(per 100 Rural HH)	70.00	80.00	90.00	100.00	100.00	100.00	100.00
Lighting Useful Energy(PJ)	25.76	37.57	50.69	64.23	74.24	83.65	85.59
Refri. Elec. Use(kWh/year)	400.00	400.00	400.00	400.00	400.00	400.00	400.00
Saturation(per 100 Rural HH)	1.20	8.00	16.00	25.00	35.00	45.00	55.00
Refri. Useful Energy(PJ)	3.05	22.33	46.14	70.85	98.79	123.31	132.88
Color TV Elec. Use(kWh/year)	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Saturation(per 100 Rural HH)	4.70	15.00	30	45.00	60.00	75.00	90.00
Color TV Useful Energy(PJ)	3.28	11.51	23.79	35.07	46.57	56.52	59.80
B&W TV Elec. Use(kWh/year)	44.00	44.00	44.00	44.00	44.00	44.00	44.00
Saturation(per 100 Rural HH)	39.70	50.00	35.00	20.00	15.00	10.00	10.00
B&W TV Useful Energy(PJ)	11.08	15.35	11.10	6.23	4.66	3.01	2.66
Fan Elec. Use(kWh/year)	26.00	28.00	30.00	33.00	36.00	38.00	40.00
Saturation(per 100 Rural HH)	41.40	50.00	60.00	70.00	80.00	90.00	100.00
Fan TV Useful Energy(PJ)	6.83	9.54	12.54	15.88	19.93	22.12	24.71
Air Conditioner							
Annual Elec.Use(kWh/year)	750.00	750.00	750.00	750.00	750.00	750.00	750.00
Saturation(per 100 HHs)	0.01	0.05	0.10	0.25	0.60	1.20	2.50
U.E.(PJ, High Demand)	0.05	0.26	0.52	1.29	3.11	5.82	11.58
L&A. Useful E.(High) PJ	50.04	96.56	144.78	193.54	247.30	294.42	317.21

Urban Residential Energy Demand - Lighting and Appliances(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Household(*10^6)	84.91	117.84	154.53	200.11	241.77	270.78	310.55
Lighting Elec. Use(kWh/year)	88.00	92.50	97.23	102.20	107.43	112.92	118.70
Saturation(per 100 Rural HH)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Lighting Useful Energy(PJ)	26.90	39.24	54.10	73.64	93.52	110.09	132.72
Refri. Elec. Use(kWh/year)	400.00	400.00	400.00	400.00	400.00	400.00	400.00
Saturation(per 100 Rural HH)	42.30	50.00	58.00	65.00	71.00	76.00	80.00
Refri. Useful Energy(PJ)	51.73	84.85	129.08	187.33	247.22	296.38	357.80
Color TV Elec. Use(kWh/year)	82.00	82.00	82.00	82.00	82.00	82.00	82.00
Saturation(per 100 Rural HH)	59.00	68.00	76.00	85.00	91.00	96.00	100.00
Color TV Useful Energy(PJ)	14.79	23.66	34.67	50.22	64.96	76.75	91.69
B&W TV Elec. Use(kWh/year)	32.00	32.00	32.00	32.00	32.00	32.00	32.00
Saturation(per 100 Rural HH)	52.40	45.00	35.00	28.00	20.00	12.00	5.00
B&W TV Useful Energy(PJ)	5.13	6.11	6.23	6.46	5.57	3.74	1.79
Fan Elec. Use(kWh/year)	33.00	33.00	33.00	33.00	33.00	33.00	33.00
Saturation(per 100 Rural HH)	135.00	130.00	125.00	120.00	110.00	100.00	90.00
Fan TV Useful Energy(PJ)	13.62	18.20	22.95	28.53	31.60	32.17	33.21
Air Conditioner							
Annual Elec. Use(kWh/year)	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Saturation(per 100 Rural HH)	0.10	0.25	0.50	1.00	3.00	5.00	6.00
A. C. U.E.(PJ) Low Growth	0.28	0.95	2.50	6.48	23.50	43.87	60.38
L.&A Useful E.(Low) PJ	112.44	173.02	249.54	352.65	466.37	563.01	677.58

Urban Residential Energy Demand - Lighting and Appliances(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Household(10^6)	84.91	130.08	187.09	249.24	309.64	376.95	463.92
Lighting Elec. Use(kWh/year)	88.00	95.30	103.20	111.76	121.03	131.07	141.94
Saturation(per 100 Rural HH)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Lighting Useful Energy(PJ)	26.98	44.76	69.71	100.57	135.31	178.38	237.74
Refri. Elec. Use(kWh/year)	400.00	400.00	400.00	400.00	400.00	400.00	400.00
Saturation(per 100 Rural HH)	42.30	53.00	60.00	68.00	76.00	84.00	90.00
Refri. Useful Energy(PJ)	51.73	99.29	161.67	244.09	338.92	456.02	601.32
Color TV Elec. Use(kWh/year)	82.00	82.00	82.00	82.00	82.00	82.00	82.00
Saturation(per 100 Rural HH)	59.00	70.00	80.00	90.00	100.00	105.00	110.00
Color TV Useful Energy(PJ)	14.79	26.88	44.19	66.23	91.42	116.85	150.66
B&W TV Elec. Use(kWh/year)	32.00	32.00	32.00	32.00	32.00	32.00	32.00
Saturation(per 100 Rural HH)	52.40	40.00	25.00	10.00	5.00	2.00	1.00
B&W TV Useful Energy(PJ)	5.13	6.00	5.39	2.87	1.78	0.87	0.53
Fan Elec. Use(kWh/year)	33.00	33.00	33.00	33.00	33.00	33.00	33.00
Saturation(per 100 Rural HH)	135.00	130.00	125.00	120.00	110.00	100.00	90.00
Fan TV Useful Energy(PJ)	13.62	20.09	27.79	35.54	40.47	44.79	49.61
Air Conditioner							
Annual Elec. Use(kWh/year)	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Saturation(per 100 Rural HH)	0.10	0.30	0.70	2.00	5.00	7.00	9.00
A. C. U.E.(PJ) Low Growth	0.28	1.26	4.24	16.15	50.17	85.50	135.30
L.&A Useful E.(Low) PJ	112.51	198.29	312.99	465.45	658.06	882.41	1175.17

Appendix 6

Projection of Useful Energy Demand for Cooking

Rural Residential Energy Demand - Cooking(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(*10^6)	845.82	851.36	832.04	782.65	749.50	664.65	600.40
Rural househould(*10^6)	176.21	189.19	193.50	190.89	192.18	179.64	171.54
Heat required(MJ/house-day)	10.5	10.3	10.1	9.9	9.7	9.5	9.3
C.Heat Useful Energy(PJ)	675.33	711.26	713.33	689.78	680.41	622.88	582.30

Rural Residential Energy Demand - Cooking(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(*10^6)	845.82	833.30	800.94	747.73	705.54	646.90	536.83
Rural househould(*10^6)	176.21	193.79	200.23	196.77	195.98	190.26	167.76
Heat required(MJ/house-day)	10.5	10.3	10.1	9.9	9.7	9.5	9.3
C.Heat Useful Energy(PJ)	675.33	728.56	738.17	711.04	693.88	659.74	569.45

Urban Residential Energy Demand - Cooking(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(*10^6)	297.18	400.64	509.96	640.35	749.50	812.35	900.60
Urban househould(*10^6)	84.91	117.84	154.53	200.11	241.77	270.78	310.55
Heat required(MJ/house-day)	10.5	10.3	10.1	9.9	9.7	9.5	9.3
C.Heat Useful Energy(PJ)	325.41	443.00	569.69	723.10	856.00	938.94	1054.17

Urban Residential Energy Demand - Cooking(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(*10^6)	297.18	429.28	579.99	747.73	897.97	1055.46	1252.59
Urban househould(*10^6)	84.91	130.08	187.09	249.24	309.64	376.95	463.92
Heat required(MJ/house-day)	10.5	10.3	10.1	9.9	9.7	9.5	9.3
C.Heat Useful Energy(PJ)	325.41	489.05	689.72	900.65	1096.29	1307.08	1574.79

Appendix 7

Projection of Useful Energy Demand for Space Water Heating

Rural Residential Energy Demand - Water Heating(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(*10^6)	845.82	851.36	832.04	782.65	749.50	664.65	600.40
Rural househould(*10^6)	176.21	189.19	193.50	190.89	192.18	179.64	171.54
Face Washing (times/person-day)	2	2	2	2	2	2	2
Liters/time	3	4	5	5	5	6	6
Liters/person-year	2190	2920	3650	3650	3650	4380	4380
Facing Useful Energy(PJ)	332.68	446.48	545.44	513.06	491.33	522.85	472.30
Bathing (times/person-day)	0.2	0.35	0.5	0.6	0.65	0.7	0.75
Liters/time	30	45	60	65	70	75	80
Liters/person-year	2190	5748.75	10950	14235	16607.5	19162.5	21900
Bathing Useful Energy(PJ)	332.68	879.01	1636.31	2000.93	2235.54	2287.45	2361.52
Cloth Washing (Liters/Household-3day)	3	4	5	5	6	6	6
liters/household-year	365.00	486.67	608.33	608.33	730.00	730.00	730.00
CW.Useful Energy(PJ)	11.55	16.54	21.14	20.86	25.20	23.55	22.49
Utensil washing Liters /Househould-day)	8	10	12	14	16	18	20
liters/household-year	2920	3650	4380	5110	5840	6570	7300
UW.Useful Energy(PJ)	92.41	124.02	152.21	175.19	201.57	211.96	224.91
W. Heating(PJ,Low Growth)	769.33	1466.05	2355.10	2710.03	2953.63	3045.81	3081.22

Rural Residential Energy Demand - Water Heating(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Rural Population(*10^6)	845.82	833.30	800.94	747.73	705.54	646.90	536.83
Rural househould(*10^6)	176.21	193.79	200.23	196.77	195.98	190.26	167.76
Face Washing (times/person-day)	2	2	2	2	2	2	2
Liters/time	3	4	5	5	5	5	7
Liters/person-year	2190	2920	3650	3650	3650	3650	5110
Facing Useful Energy(PJ)	332.68	437.01	525.05	490.17	462.51	424.07	492.68
Bathing (times/person-day)	0.2	0.35	0.5	0.6	0.7	0.8	0.9
Liters/time	30	45	60	65	70	75	80
Liters/person-year	2190	5748.75	10950	14235	17885	21900	26280
Bathing Useful Energy(PJ)	332.68	860.37	1575.14	1911.66	2266.31	2544.40	2533.76
Cloth Washing (Liters/Household-3day)	3	4	5	5	6	6	6
liters/household-year	365.00	486.67	608.33	608.33	730.00	730.00	730.00
CW.Useful Energy(PJ)	11.55	16.94	21.88	21.50	25.70	24.95	21.99
Utensil washing Liters /Househould-day)	8	10	12	14	16	18	20
liters/household-year	2920	3650	4380	5110	5840	6570	7300
UW.Useful Energy(PJ)	92.41	127.04	157.51	180.59	205.56	224.51	219.94
W. Heating(PJ,High Growth)	769.33	1441.36	2279.58	2603.92	2960.08	3217.92	3268.37

Urban Residential Energy Demand - Water Heating(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(*10^6)	297.18	400.64	509.96	640.35	749.50	812.35	900.60
Urban househould(*10^6)	84.91	117.84	154.53	200.11	241.77	270.78	310.55
Face Washing	2	2	2	2	2	2	2
(times/person-day)							
Liters/time	3	4	5	5	5	6	7
Liters/person-year	2190	2920	3650	3650	3650	4380	5110
Facing Useful Energy(PJ)	116.89	210.11	334.30	419.78	491.33	639.03	826.53
Bathing	0.2	0.4	0.5	0.6	0.67	0.7	0.7
(times/person-day)							
Liters/time	50.00	60.00	65.00	70.00	75.00	78.00	79.00
Liters/person-year	3650.00	8760.00	11862.50	15330.00	18341.25	19929.00	20184.50
Bathing Useful Energy(PJ)	194.81	630.33	1086.47	1763.06	2468.92	2907.60	3264.80
Cloth Washing	3	4	5	5	6	6	6
(Liters/Household-3day)							
liters/household-year	365.00	486.67	608.33	608.33	730.00	730.00	730.00
CW.Useful Energy(PJ)	5.57	10.30	16.88	21.86	31.70	35.50	40.72
Utensil washing	8	10	12	14	16	18	20
Liters /Househould-day)							
liters/household-year	2920	3650	4380	5110	5840	6570	7300
UW.Useful Energy(PJ)	44.53	77.25	121.56	183.65	253.59	319.52	407.16
W.Heating(PJ,Low Growth)	361.80	927.98	1559.22	2388.35	3245.53	3901.65	4539.20

Urban Residential Energy Demand - Water Heating(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
Urban Population(*10^6)	297.18	429.28	579.99	747.73	897.97	1055.46	1252.59
Urban househould(*10^6)	84.91	130.08	187.09	249.24	309.64	376.95	463.92
Face Washing	2	2	2	2	2	2	2
(times/person-day)							
Liters/time	3	5	5	5	5	6	6
Liters/person-year	2190	3650	3650	3650	3650	4380	4380
Facing Useful Energy(PJ)	116.89	281.41	380.21	490.17	588.65	830.28	985.35
Bathing	0.2	0.5	0.6	0.65	0.68	0.7	0.7
(times/person-day)							
Liters/time	50	60	65	72	78	79	80
Liters/person-year	3650	10950	14235	17082	19359.6	20184.5	20440
Bathing Useful Energy(PJ)	194.81	844.23	1482.81	2293.99	3122.21	3826.20	4598.30
Cloth Washing	3	5	5	5	6	6	6
(Liters/Household-3day)							
Liters/household-year	365.00	608.33	608.33	608.33	730.00	730.00	730.00
CW.Useful Energy(PJ)	5.57	14.21	20.44	27.23	40.60	49.42	60.82
Utensil washing	8	10	12	14	16	18	19
Liters /Househould-day)							
Liters/household-year	2920	3650	4380	5110	5840	6570	6935
UW.Useful Energy(PJ)	44.53	85.28	147.18	228.75	324.77	444.79	577.83
W.Heating(High Growth)	361.80	1225.12	2030.63	3040.14	4076.23	5150.69	6222.30

Appendix 8

Projection of Turnover for Freight and Passenger Transportation

Transportation Turnover-Freight(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980U.S.B$)	675.90	1393.05	2269.1	3358.87	4514.04	5502.59	6078.29
Growth Rate	9.2	7.5	5	4	3	2	1
Elasticity	0.95	1	1	1	1	1	1
Growth Rate(%) (Turnover)	8.74	7.5	5	4	3	2	1
Low Turnover(Btkm)	2621	5401.5	8798.4	13024	17503	21336	23568

Transportation Turnover-Freight(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980U.S.B$)	676	1528	3006	4897	7248	9741	11875
Growth Rate	9.2	8.5	7	5	4	3	2
Elasticity	0.95	1	1	1	1	1	1
Growth Rate(%) (Turnover)	8.74	8.5	7	5	4	3	2
High Turnover(Btkm)	2621	5925.5	11656	18987	28105	37771	46043

Transpotation Turnover-Passenger(Low Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980U.S.B$)	675.90	1393.0	2269.1	3358.87	4514.04	5502.59	6078.29
GDP / per capita($/cap)	5.91	11.13	16.91	23.60	30.11	37.38	40.49
Growth Rate (GDP per capita)		6.53%	4.27%	3.39%	2.47%	2.19%	0.80%
Elasticity		1	1	1	1	1	1
Growth Rate(%) (Turnover/per capita)		6.53	4.27	3.39	2.47	2.19	0.80
Turnover/per capita (pkm/per capita)	491.00	923.86	1403.9	1959.90	2500.40	3103.88	3362.37
Population(10^6)	1143	1252	1342	1423	1499	1472	1501
Low Turnover(Bpkm)	561	1157	1884	2789	3748	4569	5047

Transpotation Turnover-Passenger(High Growth)

Year	1990	2000	2010	2020	2030	2040	2050
GDP(1980U.S.B$)	676	1528	3006	4897	7248	9741	11875
GDP / per capita($/cap)	5.91	12.10	21.77	32.74	45.20	57.22	66.36
Growth Rate (GDP per capita)		7.43%	6.05%	4.17%	3.28%	2.39%	1.49%
Elasticity		1	1	1	1	1	1
Growth Rate(%) (Turnover/per capita)		7.43	6.05	4.17	3.28	2.39	1.49
Turnover/per capita (pkm/per capita)	491.00	1005.0	1807.5	2718.81	3753.34	4751.27	5509.99
Population(10^6)	1143	1262.6	1380.9	1495.47	1603.51	1702.36	1789.42
High Turnover(Bpkm)	561	1269	2496	4066	6019	8088	9860