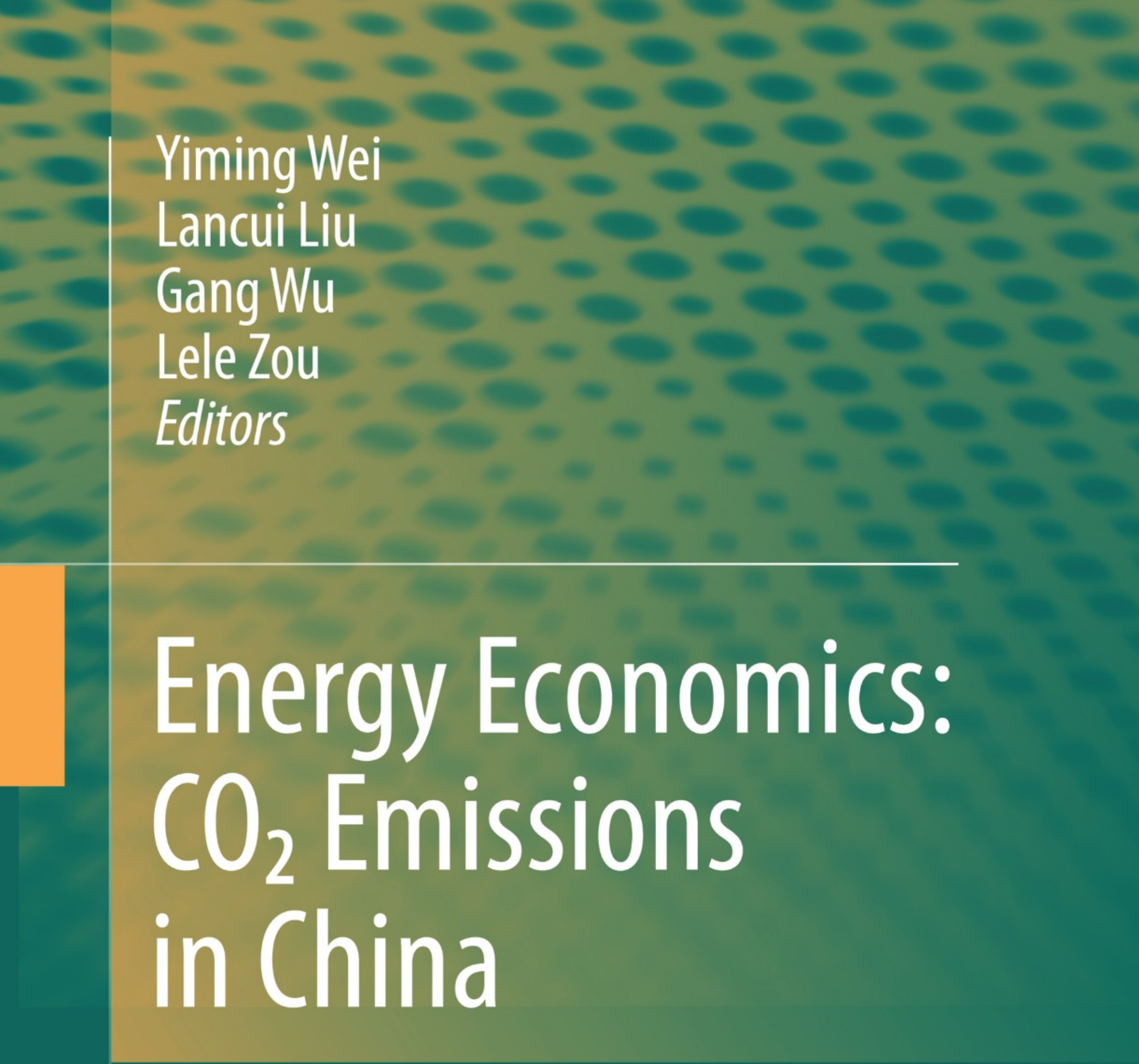

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Editors

Energy Economics: CO_2 Emissions in China

Science Press
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With 134 figures

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Preface

Energy is essential to socio-economic development in modern society. China is the largest developing country and the second largest energy producer and consumer in the world, as well as the second largest producer of CO_2 emissions after the USA. CO_2 emissions in China has become a common focus of academic communities and governments worldwide. Therefore, the study of China's CO_2 emissions is not only helpful in terms of fully implementing scientific development, but also significant in working towards the sustainable development of China and mitigating global climate change.

Beginning with energy use and CO_2 emissions, *Energy Economics*: *CO_2 Emissions in China* discusses topical issues related to the present CO_2 emissions status and its historical evolution. In addition, it analyzes CO_2 emission reduction technologies, the CO_2 market and CO_2 emissions reduction strategies and policies, in the hope of providing a reference resource for decision making in future CO_2 emission reduction and climate change resolution strategies and policies in China. The book focuses on several key issues, which are discussed further as below.

1) Energy use and CO_2 emissions

Global CO_2 emissions are increasing constantly and rapidly, resulting in a continuous rise in average temperature worldwide, and making global warming an indisputable fact. By analysing features of global energy consumption, *Energy Economics*: *CO_2 Emissions in China* examines the relationship between climate change and CO_2 emissions from an energy use perspective and describes the far-reaching impacts of global warming. This book also discusses the opportunities and challenges faced by China from the view point of CO_2 emissions reduction, within the parameters of sustainable development.

2) Characteristics of energy consumption and CO_2 emissions in China

The impacts of CO_2 emissions are global and continuous, and different countries assume different responsibilities for CO_2 emissions reduction. Understanding the history and characteristics of CO_2 emissions in different countries is helpful in working towards scientific and impartial emission reduction. The authors of *Energy Economics*: *CO_2 Emissions in China* provide a systematic analysis of China's CO_2 emissions by looking at accumulative emissions, per capita emissions, the intensity of CO_2 emissions, the evolutionary process of CO_2 emissions and end energy consumption.

3) Factors affecting CO_2 emissions at different economic development levels

To mitigate climate change, it is necessary to slow down the growth speed of greenhouse gas emissions. However, at different stages of economic development, the key determinant factors of CO_2 emissions vary greatly. Therefore, *Energy Economics*: *CO_2 Emissions in China* considers the factors that result in CO_2 emissions, which of those are decisive and the impact that different income levels have on emissions. Such points are already the subject of intense research within the scientific community.

4) Evolution characteristics of CO_2 emissions in CO_2-intensive sectors

CO_2-intensive industrial sectors are key areas of CO_2 emission reduction, and such sectors should be paid close attention when formulating emission reduction strategies. To understand the relationships between CO_2 emissions, economic growth, technical advancement and energy consumption, it is necessary to analyse the evolution of the quantity and intensity of China's CO_2 emissions in those sectors and find out the causes. The primary aim of *Energy Economics*: *CO_2 Emissions in China* here is to assist in providing scientific reference points for the formulation of future greenhouse gas emission reduction strategies.

5) The analysis of regional CO_2 emissions in China

China's CO_2 emissions are characterized not only by the growth of gross emissions, but also by the change in regional emissions. The unbalanced regional energy resource distribution and economic development in China, as well as the variation in economic development, industrial structure and energy intensity, have resulted in different levels of CO_2 emissions in different regions. Therefore, the regional comparison of regional CO_2 emissions, per capita CO_2 emissions, CO_2 emission intensity and the variation of CO_2 emissions in power generation provided by *Energy Economics*: *CO_2 Emissions in China* will help to increase current understanding and facilitate scientific decision-making in relation to reducing emissions.

6) Potential for, and impacts of, CO_2 emission reduction technologies

Technological advancement and innovation are essential ways of reducing CO_2 emissions. With efforts being made by different countries, a range of emission reduction technologies is in developing or has already been developed. Different CO_2 emission reduction technologies have different technical economic characteristics, emission reduction potential and development prospects. As *Energy Economics*: *CO_2 Emissions in China* discusses, the formulation of CO_2 emission reduction policies requires a detailed analysis on these technologies.

7) Simulation research on CO_2 emission reduction policies

Energy environmental policies will have significant impacts on CO_2 emission reduction. By introducing policies that are favourable to promote emissions reduction, the cost of emissions can play a part; for example, by regulating market behavior, production methods and consumption can be changed to decrease CO_2 emissions. The research in *Energy Economics*: *CO_2 Emissions in China* analyses two major emission reduction policies: (i) carbon taxes; and (ii) CO_2 trading; and discusses the potential impacts of different carbon tax schemes on major socio-economic indicators such as economic growth, residents' income, consumption and investment, the impacts of different tax schemes on the production and international competition capability of energy intensive sectors, and the sensitivity of different countries to the CO_2 emission trading polices of China.

8) International CO_2 trading mechanism and its impact on emission reduction

The launch of the "*Kyoto Protocol*" draft in 1997 not only meant that the greenhouse gas emission reduction goal for all countries is legally binding, but also began the process of using market mechanisms to reduce greenhouse gas emissions. Currently, global CO_2 trading schemes are taking shape and promoting CO_2 emission reduction to a large extent. For the purpose of facilitating the understanding and utilisation of international CO_2 markets, *Energy Economics*: *CO_2 Emissions in China* analyses the trading volume of international CO_2 markets, transaction values, factors influencing CO_2 trading, relationships between the CO_2 markets and energy markets, the liquidity of CO_2 markets and the social-economic impacts of CDM (clean development mechanism) projects.

9) China's CO_2 emissions prospects

What are the CO_2 emissions prospects for China? What are the effective ways to reduce emissions? What are their social-economic impacts? *Energy Economics*: *CO_2 Emissions in China* discusses such vital issues and offers corresponding policy advice on the basis of predictive analysis.

As well as the policy analysis on specific issues, *Energy Economics CO_2 Emissions in China* also discusses the model-based research approaches of each issue and the characteristics of data sources and processing. In addition to offering a reference resource for decision makers, the book also aims to encourage interactions between energy and environmental policy researchers.

Energy Economics: *CO_2 Emissions in China* is based on the second volume of the "China Energy Report" series in Chinese, biennial research reports compiled by the Center for Energy and Environmental Policy Research (CEEP), with each volume focusing on specific themes. Since its publication, the Chinese version has received positive responses from domestic and international energy-economy and management study counterparts, governmental agencies and energy-related enterprises. With the specific aim of broadening and opening up communication with international researchers, *Energy Economics*: *CO_2 Emissions in China* has now been published in English by CEEP.

The overall deployment of this project was conducted under the leader of Prfessor Yiming Wei. The authors of the chapters are as follows: Yi-Ming Wei, Gang Wu, Hua Liao and Haibo Wang (Chapter 1); Hua Liao, Gang Wu, Lancui Liu, Xiaowei Ma and Yiming Wei (Chapter 2); Lancui Liu, Ying Fan and Yiming Wei (Chapter 3); Lancui Liu and Yiming Wei (Chapter 4); Lancui Liu and Yiming Wei (Chapter 5); Yiming Wei and Lancui Liu (Chapter 6); Bin Fang, Qiaomei Liang, Yiming Wei and Lancui Liu (Chapter 7); Qiaomei Liang, Jie Guo and Yiming Wei (Chapter 8); Yuejun Zhang, Kai Wang, Yiming Wei and Lancui Liu (Chapter 9); Hua Liao, Qiaomei Liang, Gang Wu, Ying Fan and Yiming Wei (Chapter 10). Zhiyong Han, Jianling Jiao and Lele Zou participated in the research, discussion and proof-reading of certain chapters. This book is the pearl of wisdom of the CEEP.

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Xiangshan, Beijing
March 8, 2010

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Chapter 1

Energy Use and Carbon Dioxide Emissions

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Energy, as the basic element supporting economic growth, is essential for the survival and development of modern society. During the past few decades, the global economy has witnessed substantial growth. In the meantime, considerable energy have been consumed, and the resulting greenhouse gas emissions (CO_2 mainly) have given rise to global climate change, which has become one of primary element that affecting sustainable socio-economic development throughout the world.

This chapter will mainly discuss and analyze two closely related issues: energy use and CO_2 emissions.

- What are the characteristics of global energy consumption?
- What are the impacts of energy use and CO_2 emissions on climate change?
- What are the characteristics and variation trend of global CO_2 emissions?
- Which actions and measures have the international community taken to mitigate CO_2 emissions?
- What are the opportunities and challenges that China is facing during the mitigation of CO_2 emissions?

1.1 Characteristics of world energy use

1.1.1 Energy is an important driver of socio-economic development

Since the Industrial Revolution, the swift growth of world economy and the constant variation of economic structure have driven the growth of total energy demand. Besides being closely related, energy consumption and economic growth are also featured by certain extent of complexity and nonlinearity. Such relationship will differ greatly at different development stages.

In 2007, the gross global product hit USD 60 trillions (at constant PPPS dollars of 2000), and the mean annual growth rate has reached 3.0% since 1973. In 2007, the global energy consumption reached 12.2 billion toe① , with average annual growth rate hitting 2.1% when compared with the 6.128 billion toe in 1973. According to data from World Bank (2007a) and IEA (2007a), we calculated the global economic output and energy consumption, as indicated in Figure 1.1. The economic growth rate is about 1.5 times of the growth rate of energy demand, and the energy demand elasticity is about 0.7. The elasticity of energy consumption may be different from country to country, and negative values may be obtained during certain years.

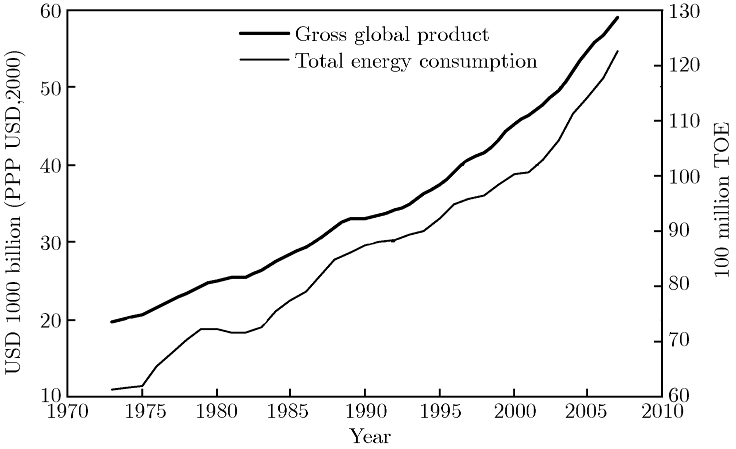

Figure 1.1 Global economic outputs and energy consumption during 1973—2007 [Data Source: World Bank (2007a), IEA (2007a) and data calculation by authors]

The GDP and energy consumption data of certain countries are given in Table 1.1. According to the data from world Bank (2007a), IEA (2007a)

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① Calculated in line with heat equivalent method, including non-commercial enegy.

and BP (2007). The energy consumption of 2006 is preliminarily calculated, as shown in Table 1.1. United States is the largest economy in the world, as well as the largest energy consumption country. During 1950—2006, its average annual GDP growth reached 3.36%, while its average annual growth of energy consumption hit 1.91%. During the period of first oil crisis, the economy declined in United States, with GDP dropping by 0.7% and energy consumption dropping by 4.9%① in 1975 compared with 1973. During the past 30 years, economic aggregate and energy consumption in developing countries have witnessed rapid growth. During 1975—2006, the GDP grew by 150% and 390% respectively in Brazil and India, with energy consumption growing by 130% and 170% respectively.

Table 1.1 GDP and energy consumption of some countries

[Unit: GDP: USD 1 billion (USD constant prices of 2000); energy consumption: 100 million toe]

Country	Year	1975	1980	1985	1990	1995	2000	2004	2006
Germany	Energy Consumption	3.17	3.60	3.61	3.56	3.42	3.44	3.48	3.48
	GDP	116.7	137.2	145.4	172.2	192.0	212.0	217.9	226.1
Russia	Energy Consumption	—	—	—	—	6.28	6.14	6.42	6.78
	GDP	—	—	—	—	94.6	102.5	129.8	147.4
France	Energy Consumption	1.69	1.94	2.06	2.27	2.41	2.58	2.75	2.76
	GDP	86.7	101.6	112.3	131.5	139.8	160.5	170.8	176.3
Canada	Energy Consumption	1.67	1.93	1.93	2.09	2.31	2.50	2.69	2.77
	GDP	40.4	48.4	55.1	63.4	69.1	84.6	93.2	98.6
US	Energy Consumption	16.61	18.12	17.81	19.28	20.88	23.04	23.26	23.16
	GDP	427.7	512.8	601.1	705.5	797.3	976.5	1070.4	1141.1
Japan	Energy Consumption	3.08	3.47	3.65	4.46	5.02	5.29	5.33	5.28
	GDP	157.7	195.5	227.6	287.7	310.1	325.4	340.5	357.1
Italy	Energy Consumption	1.24	1.32	1.31	1.48	1.61	1.73	1.84	1.83
	GDP	79.9	99.3	108.0	126.0	134.2	147.5	152.3	155.2
UK	Energy Consumption	2.02	2.01	2.04	2.12	2.23	2.33	2.34	2.32
	GDP	87.5	95.6	105.6	124.0	134.9	158.2	174.4	182.5
Brazil	Energy Consumption	0.91	1.12	1.23	1.34	1.55	1.86	2.05	2.18
	GDP	60.1	83.0	87.6	96.8	112.6	124.4	138.3	147.7
India	Energy Consumption	2.06	2.40	2.95	3.62	4.36	5.12	5.73	5.66
	GDP	68.7	80.1	104.0	140.6	181.2	240.2	307.8	367.1
China	Energy Consumption	4.84	5.99	6.94	8.67	10.52	11.23	16.09	19.02
	GDP	55.4	75.9	126.4	184.6	329.1	497.5	711.9	868.5
World	Energy Consumption	61.22	71.42	76.83	86.10	91.19	99.15	110.26	117.08
	GDP	1987.1	2409.1	2768.6	3319.7	3764.2	4533.0	5236.6	5775.8

Data Source: World Bank (2007a), IEA (2007a) and BP (2007). The energy consumption of 2006 is preliminarily calculated data (including non-commercial energy).

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① Data Source: US Bureau of Economic Analysis and US Energy Information Administration.

Along with economic development and industrialization, the energy consumption of developing countries is taking greater shares in the increment of global energy consumption. According to International Energy Agency (IEA), the global energy consumption will hit 17.721 billion toe by 2030, and the average annual growth rate will hit 1.8% during 2005—2030. Among them, the total energy consumption of OECD countries will hit 6.8 billion tons (annual growth rate: 0.8%), China will hit 3.82 billion tons (annual growth rate: 3.2%), and India will hit 1.3 billion tons (annual growth rate: 3.6%) (IEA, 2007b).

In order to meet the growing demand for energy and ensure energy supply, the energy investment will continue to grow in the future. According to IEA (2007b), by 2030, the worldwide investment on energy will reach USD 550 billion per year (2005), and the gross investment on energy in Middle East will exceed USD 1,000 billion in the future 25 years. In order to meet the new demands for energy and renovate aged infrastructures, the Europe will invest more than 1000 billions Euro in the future 20 years.

1.1.2 World energy intensity decreases continually with great difference from country to country

Affected by the economical reconstruction and technical advancements, the intensity of world energy consumption is decreasing continually, with energy efficiency increasing gradually. The acceleration rate of energy consumption falls below that of economy, and the energy consumption per unit of GDP and per unit of product yield is decreasing gradually. During 1973—2006, the world energy consumption per unit of GDP dropped by 40.0%, among which US dropped by 49.7%, Japan dropped by 39.7%, India dropped by 41.8% and China dropped by 73.0%. According to the data source from word Bank (2007), IEA (2007a) and BP (2007), the data are calculated as shown in Figure 1.2. The rapid fall of energy consumption per unit of GDP in China has played a positive role in easing the acceleration speed global energy demand and greenhouse gas emissions. Among low-income countries, Vietnam has witnessed comparatively fast drop of energy consumption per unit of GDP. However, not all developing countries nor low-income countries have experienced fast drop of energy consumption per unit of GDP. For example, the drop rate of Pakistan during 1973—2005 was 22.3%, which is far below the world average level. In Africa, the energy consumption per unit of GDP is even increasing in some countries. As a result of insufficient technological development and higher proportion of energy-intensive industries, developing countries will enjoy a higher potential of energy conservation and emission reduction. However, more appropriate development strategies will be required in order to fully exploit such potentialities.

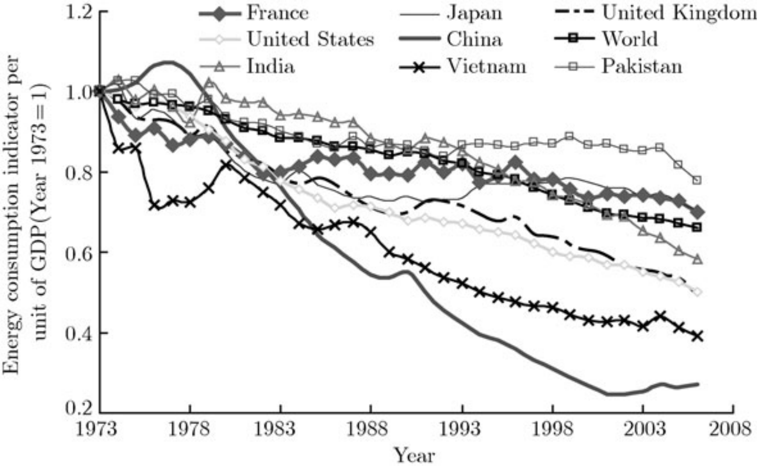

Figure 1.2 Energy intensities of the world and major countries during 1973—2006 [Data Source: World Bank (2007), IEA (2007a) and BP (2007). The energy consumption per unit of GDP (2006) is the preliminarily calculated data (including non-commercial energy)]

1.1.3 Differences of energy consumption distribution among sectors in different development phases

At different stages of economic and social development, the quantified relationship between economic growth and energy demand varies greatly, and so does the energy consumption distribution among sectors. Since developed countries have completed the industrialization process, service industry constitutes a greater proportion in national economy, and economic growth has less influence on energy demand. The energy use in transportation/ communication and domestic living sector plays a vital role in the gross increment of energy consumption. Being in the process of industrialization and urbanization, the developing countries will need to construct numerous infrastructures and require such energy-intensive products as steel and construction materials, and economic growth will contribute to the growth of energy demand. The energy consumption in industrial sector constitutes a greater proportion of energy consumption increment. Compared with 1973, the world end-use energy consumption grew by 3.62 billion toe in 2005, with 16.2% from the secondary industry, 30.3% from transportation sector and 33.7% from domestic living. The final energy use of OECD countries grew by 1.01 billion toe, with 57.0% from the transportation sector and 17.3% from domestic living. The energy consumption of secondary industry dropped by 0.94 billion tons of oil equivalent(IEA, 2007a).

Speaking of the energy type, the world final coal use reached 0.66 billion toe in 2005, 78.0% of which was consumed by the secondary industry, representing a growth rate of 20.6% when compared with 1973. The world end-use oil consumption reached 3.431 billion toe, 60.3% of which was consumed by the transportation sector, representing a growth rate of 14.9% when compared with 1973. The world final natural gas use reached 1.233 billion toe, 35.1% of which was consumed by the industrial sector, representing a drop rate of 14.9% when compared with 1973; 48.5% of which was consumed by agriculture, commerce, public service and domestic living sectors, representing a growth rate of 7.8% when compared with 1973. The final use of electric power reached 1.292 billion toe, 41.2% of which was consumed by the industrial sector, representing a drop rate of 10.1% when compared with 1973 (IEA, 2007a).

1.1.4 Fossil energy dominates world energy consumption structure

While the total energy consumption grows swiftly, the energy consumption structure is also changing. During the first Industrial Revolution, the proportion of coal in energy consumption increased rapidly, and the coal exploitation and consumption center was also the industrial center. The rapid development of automobile industry and the emergence of transnational petroleum companies have helped petroleum gradually replace the coal and become the most important primary energy in the world. Currently, the primary energy consumption in the world is dominated by such fossil fuel energy as oil, coal and natural gas, while the energy consumption of different countries or regions may vary from each other as a result of different energy reserves. When calculated by heat equivalent, the gross energy consumption of the world hit 11.434 billion toe in 2005, in which coal, petroleum, natural gas, nuclear energy, hydropower, biomass energy and other energy sources constitute 25.3%, 35.0%, 20.7%, 6.3%, 2.2%, 10.0% and 0.5% respectively. According to the data from IEA (2007a), the results of Figure 1.3 are get. Compared with 1973, the proportion of oil dropped by 11.2%, and that of natural gas and nuclear energy increased by 3.3% and 5.4% respectively (IEA, 2007a). According to IEA (2007b), under reference scenario, the consumption proportions of coal, petroleum, natural gas, nuclear energy, hydropower, biomass energy and wastes and other renewable energy will reach 28%, 32%, 22%, 5%, 2%, 9% and 2% respectively in 2030.

Excessive exploitation and consumption of fossil fuel energy has resulted in severe environmental pollution, ecological damage and the emission of greenhouse gases, and is considered as the major cause for environmental deterioration and global climate change. Fossil fuel energy, especially the coal, contain substantial sulphur, nitrogen compound and other mineral matters, which will generate such pollutants as sulfuric dioxide, oxynitride and dusts during combustion and use. Threatening human life and health, fossil fuel energy are considered as the main causes of bronchitis, pneumonia and other respiratory diseases. Sulfuric dioxide is also the major cause of acid rain, resulting in retarded growth and yield reduction of farm crops and corrosion of buildings. The coal mining process also brings about destruction to the ecological environment and underground water. Excessive greenhouses gases, such as carbon dioxide and methane, are generated during fossil fuel energy production and consumption, making "greenhouse effect" even worse.

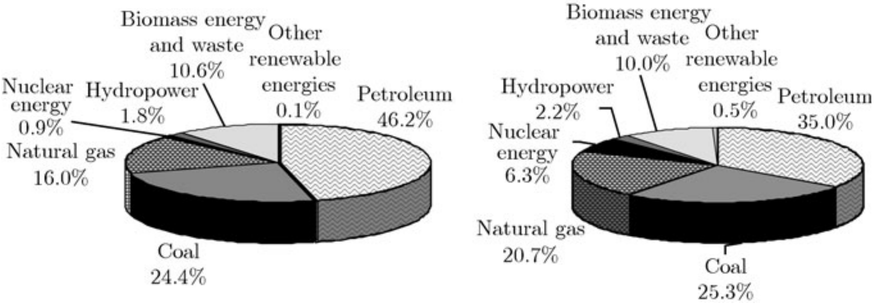

Figure 1.3 World energy consumption structure in 1973 and 2005 [Data Source: IEA (2007a)]

(Note: The left figure indicates the world energy consumption structure in 1973, and the total energy consumption was 6.128 billion TOE; the right figure indicates the world energy consumption structure in 2005, and the total energy consumption was 11.43 billion tons standard oil equivalent.)

The energy consumption structure differs from country to country (or region to region) as a result of different resource reserve, stage of economic development and energy strategy. Petroleum and natural gas consumption constitutes the largest proportion in developed countries. In 2005, the total energy consumption of OECD countries hit 5.546 billion toe, including 40.6% petroleum, 20.4% coal, 21.8% natural gas, 11.0% nuclear energy, 2.0% hydropower, 3.5% biomass energy, and 0.7% other energy sources. In countries which are in shortage of per capita petroleum resources (i.e., China, India, etc), the coal is still the dominant energy source. In Brazil and Canada, which are rich in abundant water resources, the hydropower constitutes the largest proportion. In France, the nuclear power takes up higher shares. Since fossil fuel energy is non-renewable, and owing to the fact that the combustion of fossil fuel energy will result in environmental pollution and global climate change, all countries are making positive efforts to develop new and renewable energy. The substantial rise of world crude oil price during 2004—2007 and the widespread concern on climate change speeded up this process. According to Global Wind Energy Council, new wind turbines with a total capacity of 20.1GW were installed worldwide in 2007, allowing the gross capacity of worldwide wind turbines to reach 94.1GW (GWEC, 2008).

Owing to the fluctuation of primary energy consumption structure and driven by technological advancements and increase of environmental awareness, the end-use energy consumption structure is improving constantly. In 2005, the world final energy use hit 7.912 billion toe, in which petroleum, natural gas, electric power, coal, biomass energy and other energy sources constitute 43.4%, 15.6%, 16.3%, 8.3%, 12.9% and 3.5% respectively. Compared with 1973, the proportion of electric power grew by 7%, and the level of electrification improves gradually. The final energy use in OECD countries is now featured by environmental protection and low carbon. In 2005, the final energy use hit 3.853 billion toe, in which the petroleum, natural gas, electric power, coal, biomass energy and other energy sources constitute 51.9%, 19.2%, 20.0%, 3.3%, 3.5% and 2.1% respectively. Compared with 1973, the proportion of electric power increased by 8.6% (IEA, 2007a).

During recent years, the climbing oil price has compelled all countries to increase the proportion of renewable energy, so as to guarantee energy supply security, enhance energy self-sufficiency rate and reduce energy supply risks. The governments of some western US states have planned to increase the proportion of renewable energy power to 10% of gross power generation in the next 10—20 years. EU has issued the proposal in early 2007 to increase the proportion of renewable energy consumption to 20% of total energy consumption and to increase the proportion of renewable energy power to 30% of gross power output by 2020. In 2005, India announced to increase the proportion of renewable energy power from 5% to 25% of gross power output by 2030. According to IEA (2007a), by 2030, the proportion of renewable energy consumption will hit 10% of world energy consumption.

Transnational energy companies are increasing their investments on renewable energy and transforming into integrative energy enterprises. Ever since 2000, Shell Oil has invested USD 1 billion on renewable energy, and the gross investment of Petroleo Brasileiro on reproducible fuel will exceed USD 0.3 billion during 2007—2011.

1.1.5 Uneven energy consumption

Despite the huge volume of world energy consumption, the energy consumption is uneven among countries and regions, with developed countries consuming the majority of energy. In 2006, the energy consumption of OECD countries hit 5.55 billion toe, accounting for 47% of world consumption. United States is the largest developed country in the world, as well as the largest energy consumption country. In 2006, the gross energy consumption of United States hit 2.32 billion toe, accounting for 20% of world energy consumption. The per capita energy consumption of United States hits 7.9 toe, which is 4.4 times of world average. Even in Japan which is famed for higher energy efficiency ratio, the per capita energy consumption still hits 4.1 toe.

As the largest developing country in the world, China is currently in the process of industrialization and urbanization, with the economy volume and energy consumption growing rapidly. In 2006, the gross energy consumption hit 1.9 billion toe, accounting for 16% of world energy consumption. The per capita energy consumption of China is 1.3 ton of standard oil equivalent, which is only 73% of world average and 16% of the per capita energy consumption in United States. Based on the data from world Bank (2007), IEA (2007a) and BP (2007), the results are shown in Figure 1.4.

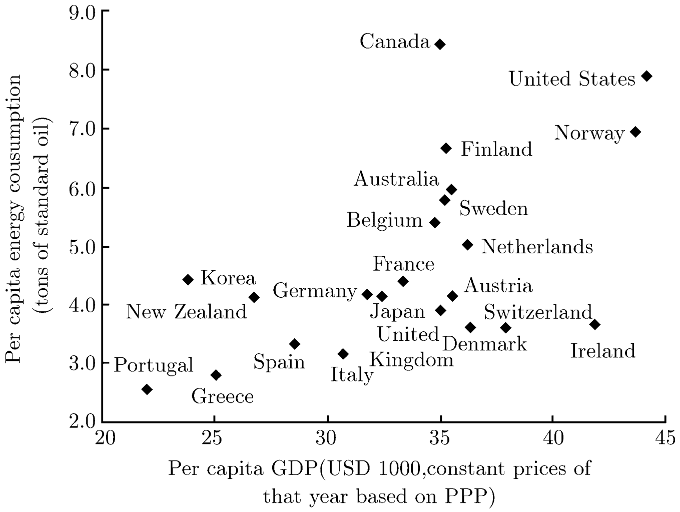

Figure 1.4 Energy consumption per capita of OECD countries in 2006
[Data Source: World Bank (2007), IEA (2007a) and BP (2007)]

1.2 Fossil energy use and climate change

1.2.1 Global warming directly threats the human environment

The fact of global climate change has been highly concerned by the international community. The Second Assessment Report of IPCC states that: ever since the late 19th century, the global average surface temperature has increased by 0.3—0.6°C. The temperature rise is especially obvious in Northern Europe, East Asia, South Africa, North American and Australia (increase by 0.8%—1.0% on average). During the past 100 years, the global sea level has also risen by 10—25cm (IPCC, 1995a).

According to the Third Assessment Report of IPCC, the global average surface temperature has risen by 0.6°C (0.4—0.8°C) during 1901—2000. During the past 50 years, the global average surface temperature increases by 0.13°C every 10 years. The speed of global warming has been doubled when compared with the past 100 years (IPCC, 2001).

According to the Fourth Assessment Report of IPCC, 1995—2006 are the warmest 12 years since 1850. During 1906—2005, the global average surface temperature has risen by 0.74°C (0.56—0.92°C), which is far above the 0.6°C indicated in the Third Assessment Report. Asia is featured by the quickest temperature rise, the speed of which even exceeds 1°C during recent years (IPCC, 2007).

The impacts of climate change are multi-scaled, all-inclusive and multi-leveled. Firstly, climate change will have a strong impact on the living environment. The global climate change has changed the natural ecosystem of many regions, such as the extinction of species, the migration of plants, insects, birds and fishes to high-latitude and high-altitude areas, etc. The global warming will not only result in the rise of global surface temperature, meltdown of polar ice and rise of sea level, but also cause a series of severe problems, such as the change of climate pattern, frequent incurrence of storm, flood, Elnino, warming and drying. The global warming will bring about more climate damages and economic losses. Ever since the mid 20th century, the occurrence rate of weather anomalies has been increasing constantly from over 10 times in 1950s/1960s to over 70 times in 1990s (by 6 times). The economic losses have also increased year by year from USD 4 billion in 1950s to USD 50 billion in 1990s.

Secondly, the climate change had a strong impact on the survival and development of human society.

On one hand, climate change will have direct influence on different aspects of social economy to different extents. The agriculture is the most sensitive sector to climate change: ① Increase of uncertainties in agricultural production and greater output fluctuation; ② Fluctuation of agricultural production structure and layout and greater change of crop growing system; ③ Change of agricultural production conditions and substantial increase in agricultural costs and investments. Peasants are the most vulnerable group under climate change. The incomes of a majority of peasant population are relatively low, while the climate change will worsen their living environment. The temperature rise may bring about the increase in the yield of crops in certain mid-latitude zones. However, a majority of tropical zones, subtropical zones and mid-latitude zones will suffer from crop failure, which will bring about considerable impacts on world agriculture production. The climate change will also impose notable influence on industrial production. For example, extreme temperature, fresh gale, rainstorm, extreme humidity, snow and poor visibility will directly affect the efficiency and quality of industrial production and increase energy consumption, especially for such sectors as energy, building, mining, transportation, foodstuff and petrochemical engineering. Meanwhile, the climate change may also cause the spread of "heat" related diseases and infectious diseases.

On the other hand, the indirect influence caused by climate change could be even worse. The shortage of water resource, agricultural production and rise of sea level etc., all these could result in strained international relations and regional conflicts.

In conclusion, while climate warming is threatening the human being, it has stronger influence on developing countries than developed countries. Being weak in economic foundation and underdeveloped in technological attainment, developing countries have weak capacity to respond to climate change and disasters, and they have to pay direct and considerable costs. Although Africa is featured by the lowest greenhouse gas emissions, it suffers the most from the climate change caused by human activities. If the air temperature rises by 2°C, the agricultural output of Africa will drop by 5%—10%, and at least 40—60 million people will be threatened by malaria (Stern, 2006). For African people who are still in poverty, this will mean a greater scale of famine. Africa has to suffer from more natural disasters caused by climate change, and the level of poverty could be even worse.

1.2.2 Industrial production is the major cause of global climate change

Besides natural factors, the global warming results mainly from human activities, and this point of view is underpinned by more and more scientific research outputs. According to the Third Assessment Report of IPCC, the probability that global warming results from human activities reaches 66%, while this figure was raised to 90% in the Fourth Assessment Report of IPCC.

Since the industrial revolution in 1750, the modern production and life style of human has resulted in the excessive emission of greenhouse gases, especially the rapid increase of CO_2 emissions. The concentration of CO_2, CH_4 and N_xO contained in the atmospheric layer increases substantially, and has currently exceeded the concentration value obtained from the pre-industrial ice core record. The CO_2 concentration value has increased from the pre-industrial value of 280ppm① to 379ppm in 2005, the CH_4 concentration value has increased from the pre-industrial value of 715ppb② to 1774ppb in 2005, and the N_xO concentration value has increased from the pre-industrial value of 270ppb to 319ppb in 2005 (IPCC, 2007).

According to the research findings, the global surface temperature is closely related to the CO_2 concentration level in the atmosphere. Based on the data from Marland (2007), the results are calculated and shown in Figure 1.5.

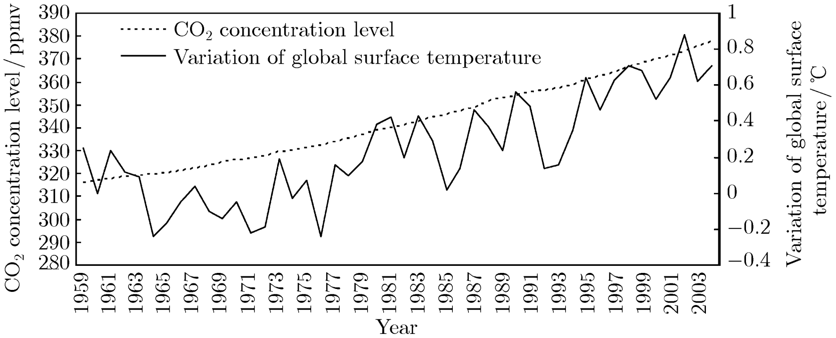

Figure 1.5 Changes of CO_2 concentration and temperature during 1959—2004 [Data Source: Marland (2007)]

According to the statistical data of IPCC (2007), as a result of excessive use of fossil energy after industrial revolution, the greenhouse gas emissions caused by human production and living activities account for over 90% of the gross greenhouse gas emissions of the world, while five major greenhouse gas emission sectors (energy supply, industry, forestry, agriculture and transportation) are mainly fossil fuel energy intensive sectors. In 2004, the greenhouse gas emissions of the energy supply, industry and transportation sectors constituted 58.4% of total emissions of the world, which is to say, human production and life style have contributed to 60% of global greenhouse gas emissions. The results of Figure 1.6 are calculated based on the data from IPCC (2007). Therefore, human activities are the main source of greenhouse gas emissions, as well as one of the major reasons causing global warming.

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① $1ppm=1 \times 10^{-6}$.

② $1ppb=1 \times 10^{-9}$.

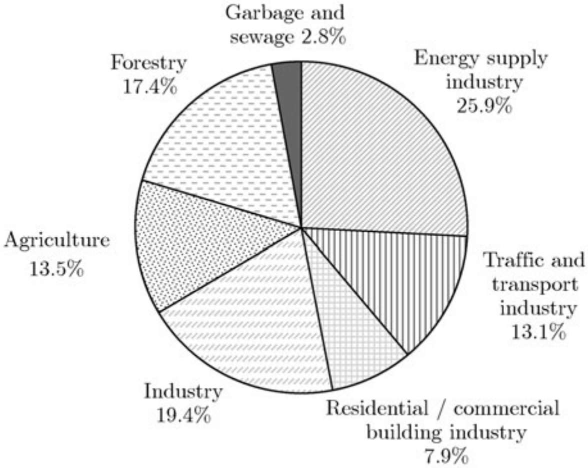

Figure 1.6 Global GHG emissions shares of different sectors in 2004
[Data Source: IPCC (2007)]

1.2.3 CO_2 emissions caused by fossil fuels combustion are the main sources of greenhouse gases

The global climate change is mainly caused by the excessive emissions of greenhouse gases, while CO_2 is the primary greenhouse gas. According to the statistical data of EDGAR (2007), in 2004, the CO_2 emissions accounted for 76.7% of global greenhouse gas emissions. Therein, the CO_2 emissions caused by fossil energy consumption accounted for 56.6% of global greenhouse gas emissions, the CO_2 emissions caused by forest cutting and organism death accounted for 17.3% and CO_2 emissions from other sources only accounted for 2.8%. The CH_4 emissions accounted for 14.3% of total greenhouse gas emissions, while the nitrous oxide accounted for 7.9% and the fluoride and other greenhouse gases accounted for 1.1%. The results of Figure 1.7 are calculated based on the data from IPCC (2007). We can conclude that the fossil fuel energy consumption is the main source of CO_2 emissions (73.79%). How to mitigate CO_2 emissions caused by fossil fuel energy consumption is the key to reduce global greenhouse gas emissions. Currently, some countries are making efforts to study CO_2 capture and storage technologies in order to reduce CO_2 emissions caused by fossil fuel energy consumption. This technology is capable of capturing 90% carbon dioxide emitted during the power generation using fossil fuel energy. However, it has not been commercialized as a result of cost problem.

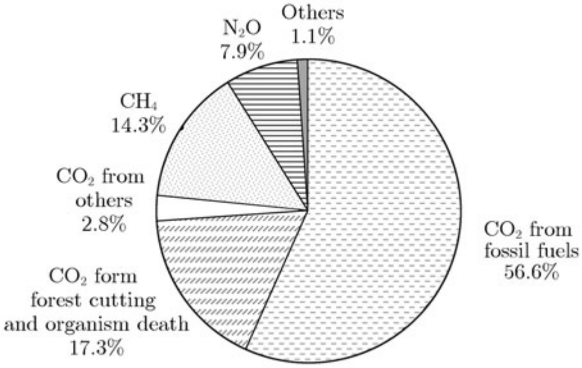

Figure 1.7 Global GHG emissions in 2004

[Data Source: IPCC (2007)]

1.3 Basic characteristics of world CO_2 emissions

1.3.1 CO_2 emissions increase continually

Compared with the agricultural society, the world economy has been growing at a high speed since the industrial revolution. The proportion of industry and transportation sectors in economy grows continually for long periods, with fossil fuel consumption increases rapidly. This has resulted in the sharp rise of CO_2 emissions. In 1850, the global CO_2 emissions only reached 54 million tons, which increased to 7.910 billion tons in 2004. Generally speaking, the global CO_2 emissions have been increasing steadily and constantly. The results of Figure 1.8 are calculated based on the data from IPCC (2007).

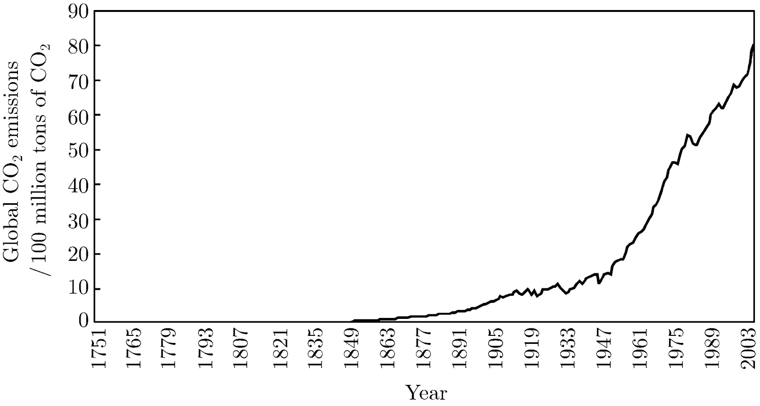

Figure 1.8 Global CO_2 emissions during the year of 1751—2004

[Data Source: IPCC (2007)]

1.3.2 Electricity, industry and transportation sectors account for 60%—70% emissions of total CO_2 emissions

Since the global fossil fuel consumption focus mainly on industry, electricity and transportation sectors, the global CO_2 emissions during 1970—2004 are mainly from electricity, industry (exclusive of cement industry) and transportation sectors, which accounted for 63.09%—72.96% of global CO_2 emissions, while CO_2 emissions of the electric power and transportation sectors are growing rapidly. The results of Figure 1.9 are calculated based on the data from IPCC (2007). Since these two sectors are energy intensive sectors, they are featured by high CO_2 emission intensity. Therefore, many industrial countries are gradually transforming their energy consumption structure and upgrading from fossil fuel clean energy, so as to decrease their dependence on fossil fuels and promote the R&D and application of emission reduction technologies. Positive effects have also been made to explore and promote CO_2 capture and storage technology to decrease CO_2 emissions caused by fossil fuel energy consumption and to slow down the speed of global warming. However, owing to the restrictions in resource characteristics and technological level and along with the improvement of electrification level and economic development of developing countries, the electricity, industry and transportation sectors will still be the primary CO_2 emission sectors during recent years.

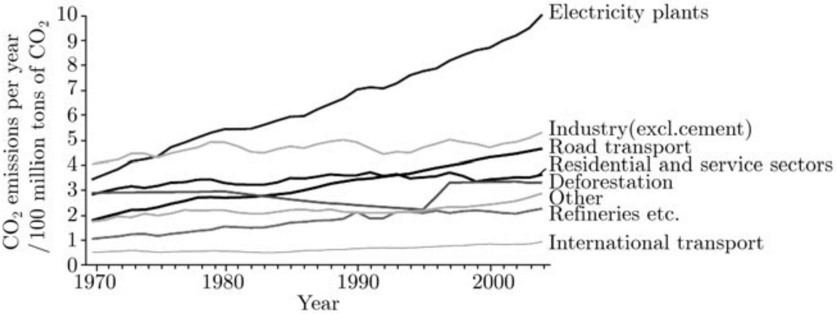

Figure 1.9 Global CO_2 emissions of different sectors during 1970—2004

[Data Source: IPCC (2007)]

1.3.3 Industrialized countries account for 80% of world accumulated CO_2 emissions

The invention of steam engine had allowed the coal to replace fuel wood and become primary energy source of industrial countries, and substantial amount of CO_2 was emitted during the combustion of coal. Along with the proceeding of industrialization process, the invention of internal combustion engine had enabled the petroleum to gradually replace the coal and become the most important energy of industrial countries. Especially after the Second World War, the booming development of industry and economy in industrial countries has also brought the rapid growth of fossil fuel energy consumption and CO_2 emissions. The results of Figure 1.10 are calculated based on the data from IPCC (2007).

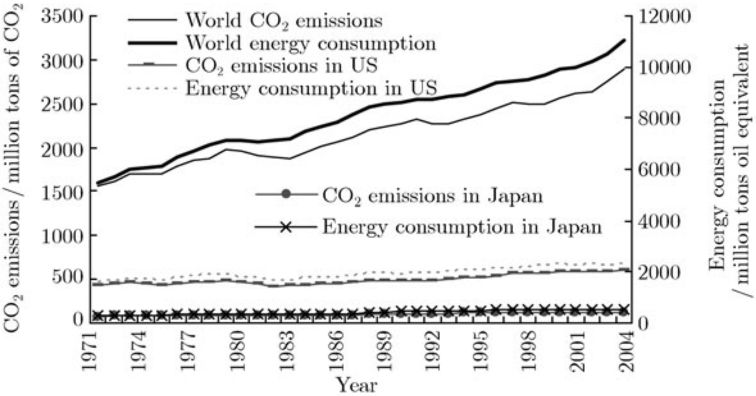

Figure 1.10 World and major industrialized countries' energy consumption and CO_2 emissions during 1971—2004
[Data Source: IPCC (2007)]

In recent years, technological advancement has enabled clean energy to take up an increasingly higher share in the energy consumption structure of industrial countries, while the shares of such fossil fuel energy energies as coal are dropping gradually. Nonetheless, fossil fuel energy consumption and CO_2 emissions are still concentrated in industrial countries. Therefore, either in the past or at present, the industrial countries are the primary sources of CO_2 emissions. During 1900—2004, 80% of world accumulated CO_2 emissions are from industrial countries, while US, Central Europe and Western Europe accounted for 58.98% of world accumulated emissions. The historical accumulated CO_2 emissions of United States accounted for 28.03% of world accumulated emissions, which is 3.5 times of that of China. Africa is featured by the lowest accumulated CO_2 emissions (2.56% only). In 2004, the CO_2 emissions of industrial countries accounted for 70% of the total CO_2 emissions of the world. As the No.1 emission country in the world, US accounted for 21% of the total emissions. The results of Figure 1.11 and Figure 1.12 are calculated based on the data from IPCC (2007).

Since developing countries are lagged in the industrialization process, their historical fossil fuel consumption is very limited, and the historical

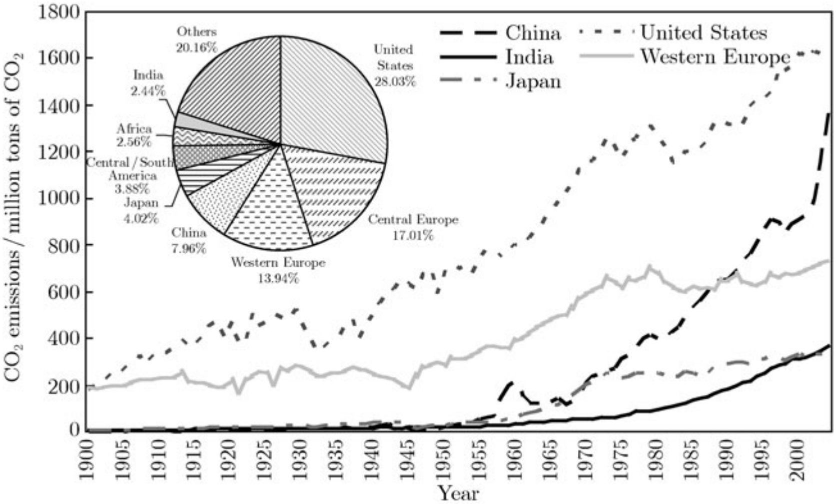

Figure 1.11 World major regions and countries' CO_2 emissions and their shares during 1900—2004

[Data Source: IPCC (2007)]

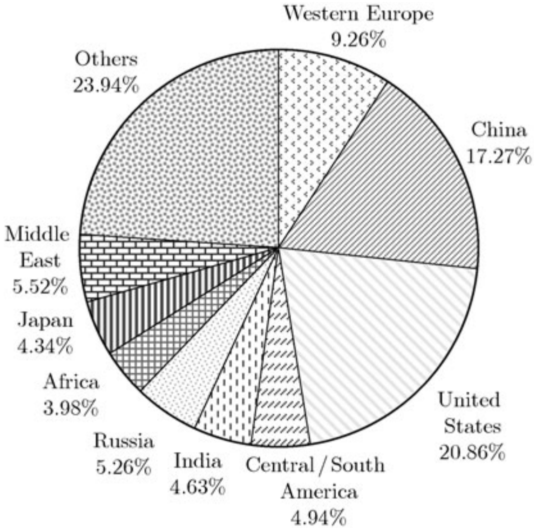

Figure 1.12 World major regions and countries' CO_2 emissions shares in 2004

[Data Source: IPCC (2007)]

accumulated CO_2 emissions are particularly low (about 20% of the total emissions of the world, as indicated in Figure 1.11). During recent years, the industry and economy of some developing countries have experienced rapid growth, and the fossil fuel consumption and CO_2 emissions have also increased quickly. However, either the per capita emissions or the gross CO_2

emissions are far lower than developed countries. In 2004, the CO_2 emissions of developing countries only accounted for 30% of total emissions of the world. Therefore, the CO_2 emissions of developing countries can be classified into survival-oriented emissions at the early stage of the industrialization process. In the future, the energy consumption and CO_2 emissions of developing countries will be prone to grow instantly, which is a necessary trend of the industrialization process.

1.4 CO_2 emissions mitigation and sustainable development

1.4.1 CO_2 emissions and socio-economic development

According to the development history of different countries, the economic development level is the most important factor associated with CO_2 emissions. Although the differences in the carbon content of energy may result in different CO_2 emissions under the same energy consumption, the comprehensive carbon intensity of energy is determined by the energy supply structure, which is hard to change in the short run. For example, the energy supply structure of China is dominated by coal, and such a structure cannot be transformed into an oil and gas and renewable energy dominated structure easily. Therefore, the variation of CO_2 emissions in different countries is closely related to the level of economic development, and CO_2 emissions will generally grow along with the growth of real GDP per capita. Based on the data from CDIAC (2007) and SIMA (2007), the data are calculated and shown in Figure 1.13.

In order to further analyze the relationship between CO_2 emissions and economic development at different stages of economic development, we have studied the variation of relationship between CO_2 emissions and real GDP per capita of world average, typical developed countries (US and Japan) and typical developing countries (China and India). For this purpose, we have analyzed the figures about CO_2 emissions and real GDP per capita (year 2000, USD) of world, United States, Japan, India and China (1978—2004) during 1960—2004 (CDIAC, 2007; SIMA, 2007).

According to the variance in trend of worldwide CO_2 emissions and real GDP per capita, they have obvious linear relationship, with correlation coefficient hitting 0.98, and the increase of CO_2 emissions is directly influenced. As indicated in Figure 1.13, CO_2 emissions grow with the increase of real GDP per capita. During 1960—2004, the world CO_2 emissions dropped by four times. The declines of real GDP per capita during 1973—1975, 1979—1983 and 1990—1993 have resulted in the corresponding drop of CO_2 emissions.

The three stages are the periods of three world oil crises. The upsurge of oil price has caused considerably adverse impacts and resulted in the decline of real GDP per capita. Meanwhile, the energy consumption was also severely affected by the high oil price and the depressed economy, resulting in the drop of CO_2 emissions. In addition, the world CO_2 emissions also dropped during 1997—1999, but the real GDP per capita didn't decline. This is because the CO_2 emissions dropped substantially in China during this period.

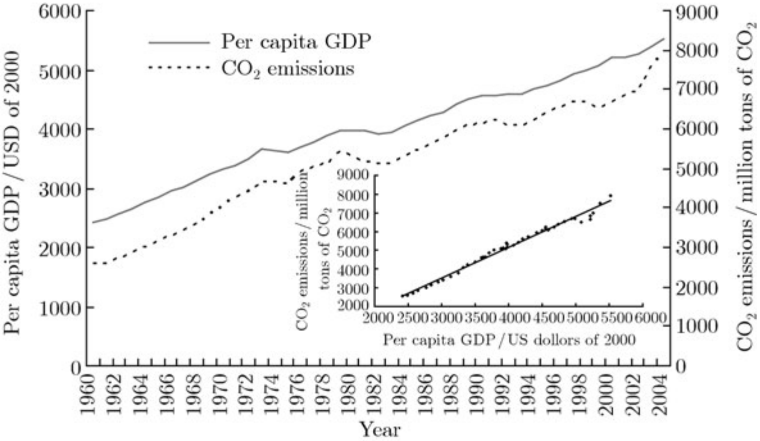

Figure 1.13 A comparison between world CO_2 emissions and real GDP per capita [Data Source: CDIAC (2007) and SIMA (2007)]

The CO_2 emissions and real GDP per capita of United States and Japan are represented by non-linear relationship. The economic growth is the primary driver of CO_2 emissions, which fluctuates along with the growth of real GDP per capita. During 1960—2004, the CO_2 emissions in United States and Japan dropped during 1973—1975, 1979—1982 and 1989—1992 respectively (three world oil crises), while the real GDP per capita of both countries declined accordingly. Since United States and Japan are major petroleum importing countries, the oil crises have severely influenced the economy and energy consumption of both countries, resulting the concurrent drop of real GDP per capita and CO_2 emissions of both countries. Based on the data from CDIAC (2007) and SIMA (2007), the data are calculated and shown in Figure 1.14 and Figure 1.15.

Because China has become a net oil importer only since 1996, the three world oil crises had little impacts on the economy and energy consumption of China. Therefore, China's real GDP per capita keeps growing swiftly, and CO_2 emissions dropped sharply only during 1996—2000. Based on the data from CDIAC (2007) and SIMA (2007), the data are calculated and shown in

Figure 1.16. In general, if the existing energy structure and energy intensity maintain unchanged, the economic growth of China will still be the primary driver of CO_2 emissions (non-linear relationship). Although China's real GDP per capita has experienced a rapid growth during 1996—2000, China's energy intensity dropped sharply in the corresponding period, resulting in the decrease of total energy consumption by 6.19%. Therefore, CO_2 emissions dropped substantially as well by 17.12%. Since 2002, China's real GDP per capita and CO_2 emissions have been growing quickly.

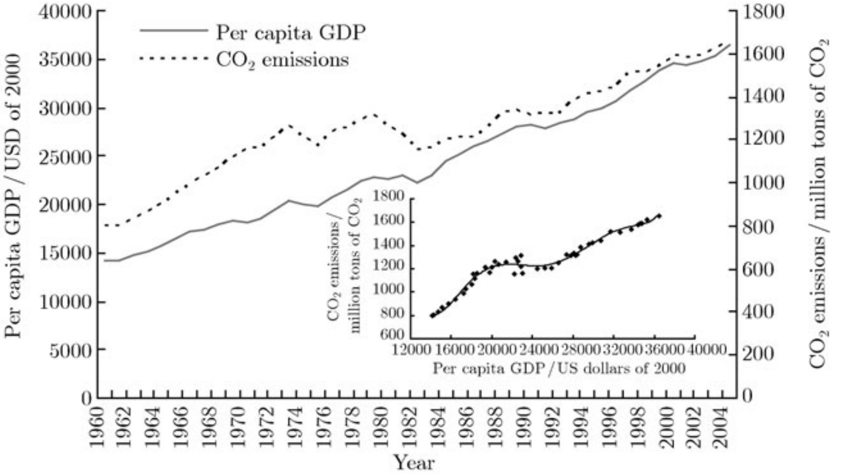

Figure 1.14 A comparison between CO_2 emissions and real GDP per capita in the United States

[Data Source: CDIAC (2007) and SIMA (2007)]

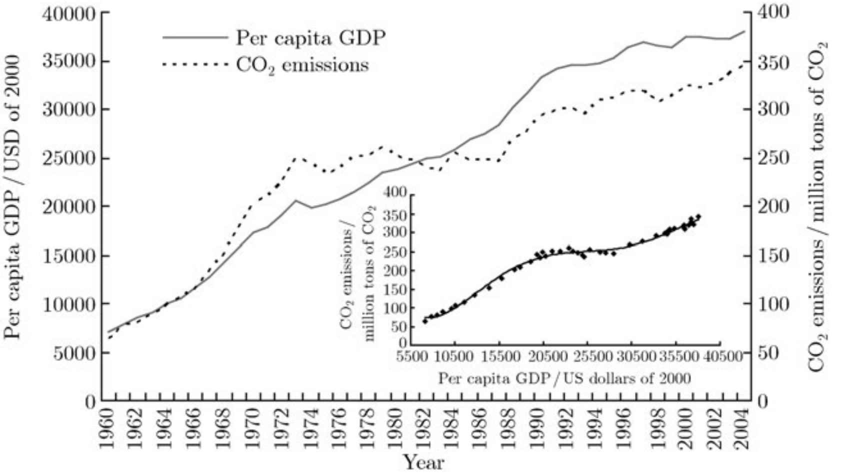

Figure 1.15 A comparison between CO_2 emissions and real GDP per capita in Japan

[Data Source: CDIAC (2007) and SIMA (2007)]

During 1960—2004, the CO_2 emissions and real GDP per capita of India has indicated a logarithmic relationship. Since the oil import volume of India is on the low side, and its energy consumption is mainly dominated by coal and renewable energy, the economic development and energy consumption of India wasn't affected by three world oil crises. However, with the booming of economy, the CO_2 emissions in India grow quickly. Based on the data form CDIAC (2007) and SIMA (2007), the data are calculated and shown in Figure 1.17.

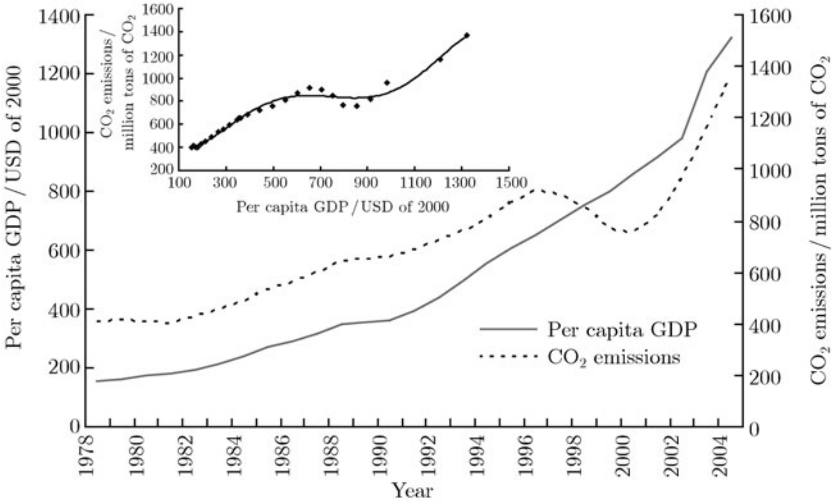

Figure 1.16 A comparison between CO_2 emissions and real GDP per capita in China [Data Source: CDIAC (2007) and SIMA (2007)]

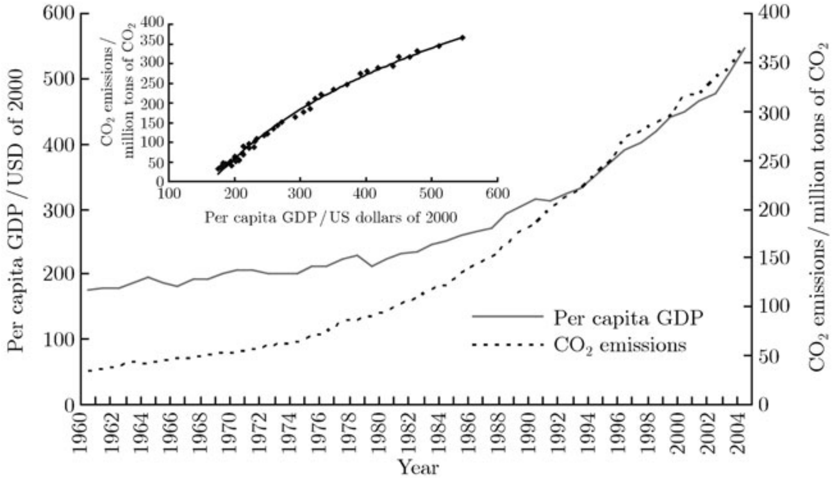

Figure 1.17 A comparison between CO_2 emissions and real GDP per capita in India [Data Source: CDIAC (2007) and SIMA (2007)]

Based on the historical data of CO_2 emissions and real GDP per capita of the world and some representative countries, our research indicates:

CO_2 emissions and economic development are positively correlated. The CO_2 emissions and real GDP per capita of world are featured by linear relationship, while United States, Japan and China are featured by non-linear relationship and India is featured by logarithmic relationship. Therefore, both in developing countries and developed countries, CO_2 emissions and economic development are closely related, and CO_2 emissions will increase along with the growth of economic aggregate. Hence, in future years, the global CO_2 emissions will increase along with the proceeding of industrialization process in different countries. This will be a great challenge for the smooth accomplishment of emission reduction goal indicated in "*Kyoto Protocol*" and the formulation of future emission reduction framework.

It is extremely hard to reduce the absolute emission of greenhouse gases on a global scale in the near future. Since CO_2 emissions and economic growth are positively correlated, it will be a difficult choice for any country to slow down economic growth in order to decrease CO_2 emissions, especially for developing countries which are weak in economic foundation. Therefore, it is an important consideration of the CO_2 emission reduction strategy to take what steps and approaches to implement such strategy in order to achieve the best balance between slow-down and adaptation, between socio-economic development and emission reduction, between economic growth and environmental protection, and between contemporary interests and interests of our future generations.

1.4.2 CO_2 emissions mitigation has become one of the new elements of sustainable development

As the major driver of global climate change, greenhouse gases as CO_2 will have global and long-term influences, and are closely related to economic development and energy consumption. Therefore, CO_2 emission reduction is not only a scientific problem and an environmental problem, but also a historical problem, energy problem, economic problem and political issue.

Climate change and CO_2 emission reduction have drawn the attention of all circles in the world. In order to mitigate climate warming and avoid its disastrous impacts on human being, "*UN Framework Convention on Climate Change*" (hereafter referred to as "*Convention*") was concluded at the UN Conference on Environment and Development held in June 1992 in Rio de Janeiro, Brazil. This Convention took effect as of March 21, 1994. Up to June 2007, 191 countries and regions have signed on the Convention, indicating that an important move has been made by the residents of global village to protect the ecological environment of the world. The Convention is composed of Preface and 26 chapters, and is considered as the first international convention aimed to control CO_2 emissions in order to address the adverse impacts on human economy and society caused by global warming. It is also a fundamental framework of international cooperation on global climate change. This Convention adopts the equity principle and the common but differentiated responsibilities principle insisted by "Group of Seventy-seven and China". The "commitment" of emission monitoring is only applicable to developed countries, which, as the major countries of greenhouse gas emissions, shall take measures to restrict greenhouse gas emissions and finance developing countries to fulfill their obligations under the Convention. The Convention has developed a mechanism through which the developing countries can be provided with funds and technologies to fulfill their obligations under the Convention. The purpose of this convention is to control the emissions of CO_2, methane and other greenhouse gases and maintain greenhouse gas concentration within the range in which the climate system will not be affected.

An annual conference attended by all contracting parties is required by the Convention. The third Conference of the Parties (COP3) held in Tokyo, Japan on December 11, 1997 and approved the "*Kyoto Protocol*", which took effect as of Feb 16, 2005 and put forward legally binding CO_2 emission reduction goals for developed countries for the first time, while the "*Kyoto Mechanism*" oriented by joint implementation (JI), emissions trading (ET) and clean development mechanism (CDM) was also introduced. "*Kyoto Protocol*" stipulates that 1990 shall be the baseline year for CO_2, CH_4 and N_2O emissions, while 1995 shall be the baseline year for HFC, PFC and SF_6 emissions. The first commitment period will be 2008—2012, during which the CO_2 emissions of developed countries shall be reduced by 5.2% on the average (Japan −6%, United States −7%, European Union −8%, Canada −6%, Russia 0%, Australia +8%, New Zealand 0% and Sweden +1%). Developing countries are encovraged to propose the detailed plans to decrease the absorption strength of absorption sources and enhance the energy efficiency use.

"*Kyoto Protocol*" is not only an international environmental convention, but also an international CO_2 emissions trading agreement. The implementation of "*Kyoto Protocol*" will involve the fulfillment of emission reduction goal of respective countries, international CO_2 emissions trading and clean development mechanism, and will certainly have far-reaching influence on worldwide economic development, environmental change and political configuration.

Up to December 2007, 13 COPs have been held. The subject of each COP mainly focuses on what obligations should developed countries and developing countries assume in order to mitigate global warming, and how to develop a feasible emission reduction framework to allow emission reduction. However, owing to the disputes on interests and obligations, many specific problems have not been addressed yet. Currently, developing countries are not obliged to assume the direct obligation of greenhouse gas emission reduction, while developed countries keep exerting pressure on developing countries and request such developing countries as China, India and Brazil to participate in CO_2 emission reduction as early as possible. It can be foreseen that China will be confronted with tougher negotiation on greenhouse gas emission reduction in the future. In particular, it has become an urgent need for Chinese scientists to study and answer all scientific problems involved in the negotiation and to provide decision-making and theoretical reference for the government.

However, in order to mitigate global warming, it is not enough to promote emission reduction merely during 2008—2012. Comparatively speaking, greenhouse gas emission reduction at the post-Kyoto age is even more important.

1.4.3 Challenges and opportunities of CO_2 emission abatement for China

China is confronted with both challenges and opportunities during the mitigation of CO_2 emissions.

Firstly, earth is the common homeland of human being. The climate warming is exerting adverse influences on China, and it is our common wish to mitigate climate change through emission reduction.

Secondly, we have paid huge environmental costs during the economic development in the past years. The mitigation of CO_2 emissions accords with our political goal of energy conservation and emission reduction. It is necessary for us to take related measures to improve and optimize the energy structure and economic structure, develop low-carbon technologies and take initiative in the new round of international competition.

Thirdly, along with the exacerbation of global warming trend, the negotiation on the greenhouse gas emission reduction at “Post-Kyoto” age has been kicked off already. Many developed countries insisted that developing countries shall share a certain part of emission reduction obligations. China, as the largest developing country and second largest CO_2 emission country, will be faced with greater emission reduction pressure at the "Post-Kyoto" age. The "Bali Road Map" developed in the end of 2007 requests that both developing countries and developed countries shall take "measurable, verifiable and reportable" actions on greenhouse gas emission reduction.

Fourthly, China is still faced with the severe challenge of future CO_2 emissions. To compulsorily restrict CO_2 emissions will certainly slow down economic growth and urbanization process. How to find out a way of low-carbon energy development while still maintaining sufficient development space remains a major challenge to China in the future years.

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Chapter 2

Analysis of Energy Consumption and CO_2 Emissions in China

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Global warming is closely related to human activities, especially the excessive consumption of fossil fuels. Therefore, in order to mitigate global warming and reduce its disastrous impacts on human society, the greenhouse gas (GHG) emissions such as CO_2 must be reduced. The impacts of CO_2 emissions are global and constant. Since the development history varies from country to country, we must correctly recognize the CO_2 emission situations in different countries in order to make the "common but differentiated responsibilities" clear for different countries.

Therefore, this chapter will analyze the characteristics of the CO_2 emissions of China in terms of historical accumulated emission, per capita emission, CO_2 emission intensity, development stage and end use. It will provide scientific and detailed supportive information for the correct understanding of China's CO_2 emissions, differentiation of China's responsibilities in CO_2 emissions and the negotiation of global GHG emission reduction.

This chapter has analyzed and discussed the following issues:

- Compared with developed countries, what are the characteristics of China's gross CO_2 emissions and historical accumulated emissions?
- Comparing the current stage with the corresponding stage of economic growth of developed countries, what are China's per capita CO_2 emissions?
- What is the difference of the variation in CO_2 emission intensity between China and developed countries at the same development stage?
- Which factors have affected CO_2 emissions and the emission intensity from China's primary energy consumption? What is the impact of each factor?

2.1 Characteristics of energy consumption in China

2.1.1 Huge energy consumption with high growth rate

Since the founding of People's Republic of China, especially the reform and opening up, China's economy and gross energy consumption have been growing rapidly. As indicated in Table 2.1, the GDP grows from RMB 0.38 trillion in 1953 to RMB 1.53 trillion in 1978, and further to RMB 22.76 trillion in 2007 (at constant prices of 2005). The annual growth rate during 1953—1978 and 1979—2007 reached 5.8% and 9.75% respectively. The energy consumption grows from 54 *million tons of coal equivalent* (Mtce) in 1953 to 571 Mtce in 1978 and further to 2655 Mtce in 2007. The annual growth rate during 1953—1978 and 1979—2008 reached 9.9% and 5.4% respectively.

In 2007, China's gross energy consumption increased by 7.8% over the previous year. The coal consumption was 2.58 billion tons, up 7.9%; crude oil 340 million tons, up 6.3%; natural gas 67.3 billion cubic meters, up 19.9%; and electric power 3,263.2 billion kWh, up 14.1%, in which the hydropower consumption was 482.88 billion kWh (increasing by 10.8%) and the nuclear power consumption was 62.6 billion kWh (increasing by 14.1%) (China Electricity Council, 2008; National Bureau of Statistics, 2008). In 2007, the energy consumption per unit of GDP decreased by 3.23% over the previous year.

The rapidly growing energy consumption has also brought about considerable pressure on China's energy supply. China became a net importer of petroleum products once again in 1993, and ever since 1997, China's energy self-reliance rate has been below 100%. China's net oil imports have been increasing rapidly since 2000, together with the quick rise of foreign dependency rate. In 2007, the net import of crude oil hit 159.28 million tons, and that of petroleum products hit 18.29 million tons. The foreign dependency

Table 2.1 Economic outputs and energy consumption in China during 1953—2007

Year	Total energy consumption	GDP	Energy consumption per unit of GDP	Year	Total energy consumption	GDP	Energy consumption per unit of GDP	Year	Total energy consumption	GDP	Energy consumption per unit of GDP
1953	0.54	0.38	1.44	1972	3.73	1.08	3.45	1991	10.38	4.71	2.20
1954	0.62	0.39	1.59	1973	3.91	1.16	3.36	1992	10.92	5.38	2.03
1955	0.70	0.42	1.67	1974	4.01	1.19	3.37	1993	11.60	6.13	1.89
1956	0.88	0.48	1.83	1975	4.54	1.29	3.51	1994	12.27	6.93	1.77
1957	0.96	0.50	1.91	1976	4.78	1.27	3.75	1995	13.12	7.69	1.71
1958	1.76	0.61	2.87	1977	5.24	1.37	3.82	1996	13.89	8.46	1.64
1959	2.39	0.67	3.59	1978	5.71	1.53	3.73	1997	13.78	9.25	1.49
1960	3.02	0.66	4.54	1979	5.86	1.65	3.56	1998	13.22	9.97	1.33
1961	2.04	0.48	4.22	1980	6.03	1.78	3.39	1999	13.38	10.73	1.25
1962	1.65	0.46	3.63	1981	5.94	1.87	3.18	2000	13.86	11.64	1.19
1963	1.56	0.50	3.10	1982	6.21	2.04	3.05	2001	14.32	12.60	1.14
1964	1.66	0.59	2.80	1983	6.60	2.26	2.92	2002	15.18	13.75	1.10
1965	1.89	0.70	2.72	1984	7.09	2.60	2.72	2003	17.50	15.13	1.16
1966	2.03	0.77	2.63	1985	7.67	2.95	2.60	2004	20.32	16.65	1.22
1967	1.83	0.73	2.53	1986	8.09	3.22	2.51	2005	22.47	18.39	1.22
1968	1.84	0.70	2.64	1987	8.66	3.59	2.41	2006	24.63	20.52	1.20
1969	2.27	0.81	2.79	1988	9.30	3.99	2.33	2007	26.55	22.97	1.16
1970	2.93	0.97	3.01	1989	9.69	4.15	2.33				
1971	3.45	1.04	3.32	1990	9.87	4.31	2.29				

Sources: prepared and calculated according to "*Comprehensive Statistical Data and Materials on 55 Years of New China*" (Department of Comprehensive Statistics, National Bureau of Statistics, 2005), "*China Statistical Yearbook 2007*" (National Bureau of Statistics, 2007a), "*Statistical Communique of the People's Republic of China on the 2007 National Economic and Social Development*" (National Bureau of Statistics, 2008) and "*Announcement of National Bureau of Statistics on the Final Verification Result of 2006 GDP Data and the Preliminary Verification Result of 2007 GDP Data*" (National Bureau of Statistics, 2008). The energy consumption is calculated in line with the coal consumption of power generation, with the magnitude of value being the constant prices of 2005. The units for total energy consumption, GDP and energy consumption per unit of GDP are: 100 Mtce, RMB 100 million and 100 Mtce/RMB 100 million.

rate of petroleum reached almost 50%① . It is expected that China's net oil imports will keep growing. Owing to the increase of domestic demands and adjustment of foreign trade policies, China will gradually transform from a major coal exporter into a net importer. According to the customs statistics, in 2007, China's net export of coal hit 2.15 million tons, and that of charred coal hit 15.3 million tons. The drop of energy self-reliance rate and the rapid rise of net oil imports have endangered the national security of China.

Compared with developed countries, China's future energy needs will keep growing at a high speed. If the average annual acceleration rate of economic growth should reach 7.5% and that of energy consumption should reach 3.5%, then the gross energy consumption will exceed 4 billion tce by year 2020. If China's future per capita energy consumption reach the level of Japan, which is famed for its outstanding energy efficiency, the annual energy needs of China, with an estimated population of 1.45 billion, will exceed 8.5 billion tce. If China's future per capita energy consumption reach the level of United States, the annual energy needs of China will exceed 16 billion tce. Such a huge but uncertain energy need prospect will become a great challenge to China's economic and social development. The great uncertainty of energy demand can also be our historical opportunity. If effective measures are taken, the energy efficiency can be improved substantially, and a lower per capita energy consumption level may be accomplished by China.

2.1.2 Low carbon energy grows fast in recent years while small in proportion

Currently, the Chinese government is making great efforts to develop renewable energy. According to the "Middle- and Long-term Planning of Renewable Energy Development", the proportion of high-quality clean renewable energy in the energy structure shall be increased gradually, so that the renewable energy consumption can reach 10% of gross energy consumption by 2010 and 15% by 2020. During the past two years, renewable energy have witnessed booming development in China. In 2007, China's wind power generation has accomplished a breakthrough over the previous year. According to Global Wind Energy Council (GWEC, 2008), the capacity of newly installed wind turbines in China hit 3,450MW in 2007, increasing by 156% or 605MW over the previous year, ranking No.5 in the world. On Nov 8, 2007, the first offshore wind farm of China was put into production in the oil field of Bohai, marking the beginning of effective offshore wind energy use (China

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① Source: "*Customs Statistics Express*" and "*Statistical Communique of the People's Republic of China on the 2007 National Economic and Social Development*".

Electricity Council, 2008).

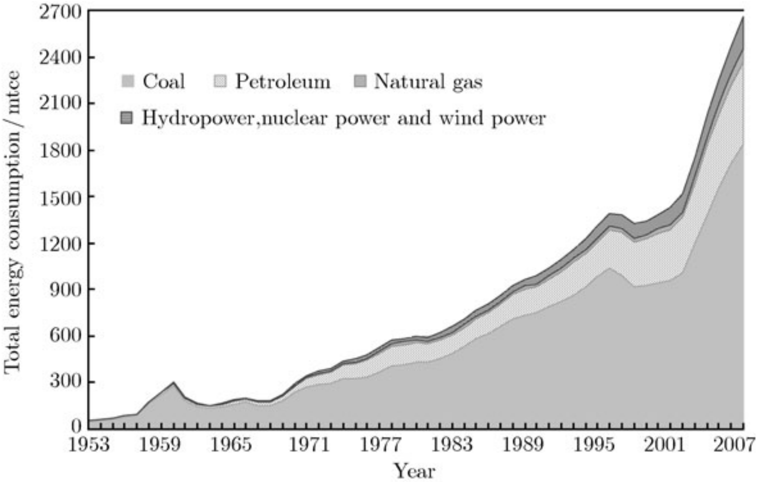

Figure 2.1 China's energy consumption and its structure during 1953—2007 [Data Sources: prepared and calculated in line with "*Comprehensive Statistical Data and Materials on* 50 *Years of New China*" (Department of Comprehensive Statistics, National Bureau of Statistics, 2005), "*China Statistical Yearbook* 2007" (National Bureau of Statistics, 2007a) and "*Statistical Communiqué of the People's Republic of China on the 2007 National Economic and Social Development*" (National Bureau of Statistics, 2008)]

Restricted by resource endowments, coal takes up the greatest share of primary energy consumption. Data in Figure 2.1 are prepared and calculated in line with "Comprehensive Statistical Data and Materials on 50 Years of New China", "China Statistical Yearbook (2007)" and " Statistical Communique of the People's Republic of China on the 2007 National Economic and Social Development", in the initial period of China, China's coal consumption constitutes over 90% of primary energy consumption. Along with the development of China's petroleum and natural gas industry and hydropower industry, the proportion of coal consumption dropped gradually. Since 1978, the proportion of hydropower consumption has been increasing gradually in China's primary energy consumption structure from 3.4% in 1978 to 7.4% in 2007. Currently, China has developed the energy production and consumption structure "based by coal and featured by diverse development". The considerable proportion of coal in gross energy consumption has brought about severe environmental pollution and great pressure on the mitigation of GHG emissions.

2.1.3 Big difference in energy structure with certain potential

No matter in terms of the primary energy supply structure, the final energy structure or the energy consumption distribution among sectors, China differs a lot from developed countries. This might be attributable to resource reserves or the development stage. Figure 2.2, China's energy flow chart of 2006, is drawn in line with China's energy balance sheet (standard electrothermal equivalent) and indicates the energy production, imports/exports, processing/transformation and final energy use flows of China, as well as the aforementioned three structures.

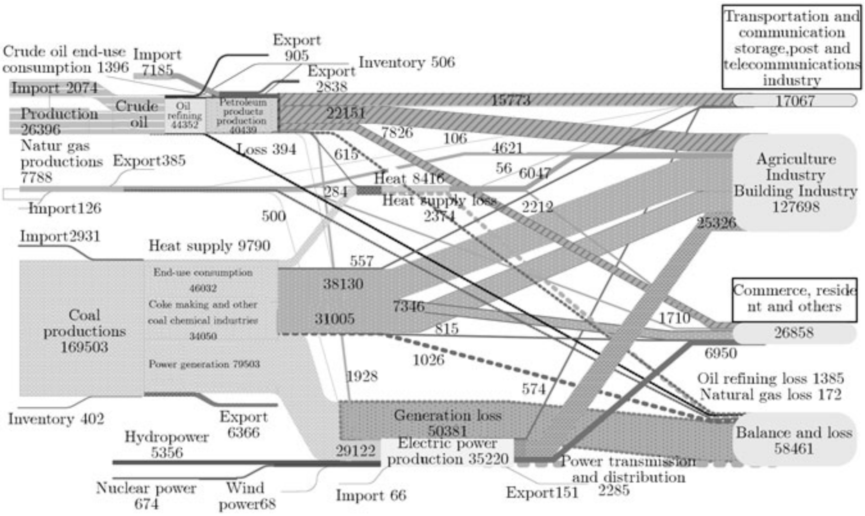

Figure 2.2 China's energy flow in 2005

[Note: (1) drawn in line with electrothermal equivalent method; (2) the import volume includes the fueling volume of Chinese ships and aircrafts in overseas countries; the export volume includes the fueling volume of foreign ships and aircrafts in China. Unit: 10,000 tce]

In 2005, China's total energy supplies hit 2329.96 Mtce (electrothermal equivalent), with foreign dependence rate reaching 8.8%. The energy processing/trans- formation losses hit 635.34 Mtce, and the total final energy use hit 1716.22 Mtce. In respect of final energy use, the industrial sector constituted 69%, the transportation, storage, postal and telecommunications services sector constituted 9.9%, and the domestic consumptions of urban and rural residents constituted 6.2% and 3.9% respectively. In OECD countries, the energy consumption of industrial sector accounts for 22% of final energy use, while the resident consumption accounts for 19% (exclusive of the energy consumption from the private transport of residents). Since China is currently in the process of industrialization, the energy consumption of industrial sector will maintain at a high level for a long period in the future, but downward adjustment is still possible.

Since 1980, the proportion of coal in the final energy use has been declining continuously from 62.0% to 26.8% in 2006, and the proportion of coal used for power generation has been increasing constantly from 20.2% to 47.3%. In 2006, the coal supply volume of China hit 2,357.81 million tons, including 1187.64 million tons for thermal power generation, 145.61 million tons for heat supply, 52.79 million tons lost in the preparation by washing, 12.57 million tons for gas making, and 2.21 million tons for coal product processing. The total volume of coal used for final energy use hit 616.84 million tons and that used for the domestic consumption of residents hit 83.86 million tons. The drop in the proportion of coal in final energy use has facilitated the transition towards clean energy, and will help improve the efficiency of comprehensive coal utilization and improve the environmental performance, which will also facilitate large-scale and centralized CO_2 emission reduction activities. Despite such a drop, there is still a big gap between China and developed countries. In OECD countries, 73% of coal is used for power generation, 11% used for final energy use and only 1% is used for resident consumption.

China is also a major country of coke production, consumption and exportation. In 2006, 374.5 million tons of coal was used for coke making. With coke making efficiency reaching 97.77%, 294.62 million tons of coke and 52.1 billion cubic meters of coke-oven gas were generated, as well as 4.58 million tons of other coke products and 0.24 million tons of other coal gases. In 2006, the export volume of coke hit 14.47 million tons. China is also a major country of iron and steel production, with the total output of steel products reaching 568.94 million tons in 2007 (National Bureau of Statistics, 2008), and about 85% of coke were used in the iron and steel industry. With the slowdown of iron and steel consumption in the future, the growth of coke demand will slow down as well.

In 2006, China's crude oil consumption hit 322.49 million tons, including 310.46 million tons for oil refining. With efficiency reaching 96.86%, the oil refining process has generated 55.95 million tons of gasoline, 9.75 tons of kerosene, 117.62 million tons of diesel oil, 17.85 million tons of fuel oil, 17.45 million tons of LPG, 9.83 million tons of refinery gas, and 69.22 million tons of other petroleum products. As for the final energy use, a majority of oil products were consumed by the industry and transportation sectors (37.6% and 34.2% respectively), while the domestic consumption of residents (including the consumption from the private transport of residents) accounted for 6.3%. There is a big gap between China and developed countries. In OECD countries, about 63% of petroleum is consumed by the transportation sector (including the consumption from the private transport of residents). Along with the improvement of the consumption level of Chinese residents, private cars are owned by more and more people, and the oil consumption from residents' transportation needs is taking up greater shares. In 2006, 9.28

million tons of fuel oil was used for power generation in China, accounting for 35.9% of its gross fuel oil consumption.

In China, natural gas accounts for a limited proportion in energy production and consumption. In 2006, the proportion of natural gas in final energy use was 3.2%, while this proportion could be 15.6% in OECD countries. Among the 56.6 billion cubic meters of natural gas supply volume of China in 2006, 3.76 billion cubic meters were used for power generation, 2.13 billion cubic meters were used for heat supply, and 48.4 billion cubic meters were used for end-use consumption. 34.6 trillion cubic meters were consumed by industrial sectors (8.65 trillion cubic meters were used as the raw material to produce synthetic ammonia), and 10.26 trillion cubic meters were used for the domestic consumption of residents (urban residents mainly). Since the natural gas is a low-carbon and clean energy source, the increase in the proportion of natural gas in energy supply structure is of great significance for China to mitigate CO_2 emissions and improve environmental performance. On Feb 22, 2008, China started up its Second West-East Pipeline project, with total length reaching 9,102 kilometers. To be completed in 2011, this project will be able to supply 30 billion cubic meters of natural gas per year. In OECD countries, natural gas constitutes 20% of the power generation fuels. Owing to the limited reserves of China, the natural gas cannot be used for large-scale power generation.

There is still great potential for China to optimize its energy structure. By developing renewable energy and speeding up the development and introduction of natural gases, China's energy supply structure can be further optimized. The promotion of coal-electricity conversion and the increase of electricity's proportion in final energy use will help further optimize the final energy use structure, enhance the energy efficiency and improve environmental performance. The sector distribution structure of energy consumption can also be optimized by actively guiding industrial structure adjustment and promoting the development of low-energy industries.

2.1.4 Low energy efficiency and big differences among regions

Despite the notable achievements in energy conservation, the energy efficiency is still on the low side in China. Since 1978, as a result of technical progress and economic structure shifting, China has made remarkable progress in energy efficiency improvement. In 2007, China's energy consumption per RMB 10,000 of GDP was 1.16 tce, decreasing by 68.6% over year 1978. Data in Figure 2.3 are prepared and calculated in line with "Comprehensive Statistical Data and Materials on 50 Years of New China", "China Statistical Yearbook (2007)" and "Statistical Communique of the People's Republic of China on the 2007 National Economic and Social Development". Major energy intensive products have witnessed the sharp drop of energy consumption per unit production. The data are collected from Energy Research Institute of National Development and Reform Commission (2006) and Shown in Table 2.2, the comprehensive energy consumption of steel has

Table 2.2 Energy consumption per product of major energy intensive products in China during 1980—2005

Key unit consumption indicator	Unit	1980	1990	2000	2005
Comprehensive energy consumption of steel	kce/ton	2039	1611	898	741
Comprehensive energy consumption of copper smelting	kce/ton	2028	1705	1277	780
Comprehensive power consumption of aluminum ingot	kWh/ton	20342	16316	15480	14622
Comprehensive energy consumption of lead smelting	kce/ton	830	920	721	630
Comprehensive energy consumption of electrolytic zinc	kce/ton	—	2437	2307	1997
Comprehensive energy consumption of cement	kce/ton	207	185	172	149
Comprehensive energy consumption of plate glass	kce/ton	32	35	30	22
Comprehensive energy consumption of synthetic ammonia (large-scale)	kce/ton	1431	1343	1327	1300
Comprehensive energy consumption of synthetic ammonia (medium-scale)	kce/ton	2439	2176	1892	1860
Comprehensive energy consumption of synthetic ammonia (small-scale)	kce/ton	3021	2263	1801	1760
Sodium hydroxide (dissepiment)	kce/ton	1870	1660	1563	1460
Sodium hydroxide (ion film)	kce/ton	—	—	1090	1050
Sodium hydroxide (ammonia-soda process)	kce/ton	571	613	468	450
Sodium hydroxide (Hou's process)	kce/ton	450	391	313	307
Comprehensive energy consumption of oil refining	koe(kg oil equivalent)/ton	129	103	83	73
Comprehensive energy consumption of ethene	koe (kg oil equivalent)/ton	—	1121	787	690

Data Source: Energy Research Institute of National Development and Reform Commission (2006).

dropped from 2039kce/ton(kg coal equivalent) in 1980 to 741kce/ton in 2005.

Despite all the achievements made by China in energy conservation, China's energy efficiency is still on the low side when compared with that of developed countries. There is still good potential for China to improve its industrial structure and energy consumption per unit of product. According to the statistics of IEA (2006c), China's energy consumptions per unit of such energy intensive products as ordinary steel, cement and synthetic ammonia are 50%, 60% and 33% higher than that of the most developed countries. Even if China's energy efficiency reaches the level of developed countries, there is still room for improving it.

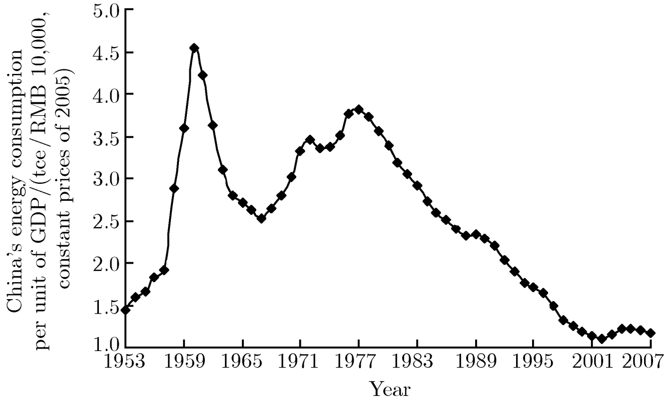

Figure 2.3 China's energy consumption per unit of GDP during 1953—2007
[Data Sources: prepared and calculated in line with "*Comprehensive Statistical Data and Materials on* 50 *Years of New China*" (Department of Comprehensive Statistics, National Bureau of Statistics, 2005), "*China Statistical Yearbook* 2007" (National Bureau of Statistics, 2007a) and "*Statistical Communiqué of the People's Republic of China on the* 2007 *National Economic and Social Development*" (National Bureau of Statistics, 2008)]

Despite the tense situation of energy conservation, energy intensive industries keep expanding rapidly. Restricted by development stage, technological level and incentive mechanism, China is currently faced with tense situations of energy conservation: investment-driven economic growth, quick urbanization, resident consumption structure at the upgrading stage, booming demands for high energy consuming goods, difficult drop of the proportion of energy intensive industries; extensive growth of foreign trade, and huge export volume of energy-intensive products; the mechanism with the energy conservation awareness of the market subjects is yet to develop, the information channel of energy conservation is not clear enough, and the government's administration and service related to energy conservation remains to be improved; insufficient technology innovation and promotion of energy conservation, and weak conservation awareness of the entire society.

Since 2002, China's economy has entered into a new growth period. The capital investments grow quickly, the heavy chemical industries are increasing their shares, and energy intensive industries such as iron and steel, building materials and electrolytic aluminum expand rapidly etc., all these have resulted in the booming growth of energy consumption, which has even exceeded the speed of economic growth. The energy consumption per unit of GDP kept growing during 2003—2005. Since 2006, the central government has further strengthened energy conservation efforts and stipulated the goal of reducing energy consumption per unit of GDP by 20% during the "11th Five-year Period (2006—2010)".

As the largest energy consuming sector in China, the iron and steel industry took up 18.9% of the energy consumption of all industrial sectors in 2002, and it has increased to 24.4% in 2006. During 2002—2006, about 83% of the energy consumption increment of industrial sectors came from coal, petroleum processing, chemical engineering, construction materials, iron and steel, non-ferrous metal and electricity sectors, with iron and steel sector accounting for 32.6%. Characterized by high energy consumption per value added, data in Table 2.3 are prepared and calculated in line with China Statistical Yearbook (2007), these seven sectors are key industries which shall be subject to energy conservation and consumption reduction. Besides keeping relying on technical progress, energy conservation and consumption reduction initiatives shall pay more attention to the importance of optimizing and adjusting industrial structure.

However, in 2007, no matter from the perspective of the output growth rate of energy intensive products, the value-added growth rate of energy intensive industries, or the capital investment acceleration of energy intensive industries, China's industrial structure is still featured by energy intensive development, with a significant part of energy conservation achieved by technical progress and the added value raise of products offset by the change of industrial structure. This fact can be proved by the newly disclosed data of electricity consumption. In 2007, the gross power consumption of China increased by 14.42%, in which the growth rate of primary industry, secondary industry and tertiary industry and urban/rural residents were 5.19%, 15.66%, 12.08% and 10.55% respectively. As for power consumption in industry, the light industry and heavy industry hit 450.2 billion kWh and 2006.4 billion kWh respectively, 9.81% and 17.34% (China Electricity Council, 2008). 72.50% of the increase came from the heavy industry.

China is a country featured by unbalanced regional development. The energy efficiency and its improvement potential vary from region to region.

Table 2.3 Energy consumption per value added of different industries in 2006

Industry	Energy consumption per unit of value added	Industry	Energy consumption per unit of value added
All industries	1.92	Chemical feedstock and chemical products	4.59
Coal exploitation and washing	1.89	Medicine	0.64
Petroleum and natural gas exploitation	0.61	Chemical fiber	2.36
Ferrous mineral mining and dressing	1.89	Rubber products	1.65
Non-ferrous mineral mining and dressing	1.06	Plastic products	0.93
Non-metallic mineral mining and dressing	2.37	Non-metallic mineral products	5.46
Non-staple foodstuff processing	0.62	Ferrous metal smelting and processing	6.11
Foodstuff production	0.86	Non-ferrous smelting and processing	2.70
Beverage production	0.66	Metal products	1.16
Tobacco	0.10	General-purpose equipments	0.61
Textile	1.45	Specialized equipments	0.59
Costume, shoes and hat production	0.34	Transport and communication equipments	0.43
Leather, fur, feather and related products	0.30	Electrical machinery and equipments	0.29
Furniture production	0.29	Instrumentation and cultural/office machinery	0.24
Papermaking and paper products	2.48	Handicraft and others	1.83
Printing and duplication of recording media	0.53	Electricity/heat production and supply	2.52
Culture, education and sports products	0.43	Fuel gas production and supply	3.37
Petroleum processing, coke making and nuclear fuel	5.34	Water production and supply	2.38

Note: (1) Data Sources: prepared and calculated in line with "*China Statistical Yearbook 2007*" (National Bureau of Statistics, 2007a); (2) The industry sector includes all industries. The unit of energy consumption per unit of value added is: RMB 10,000/tce, current year's prices.

Generally, the energy consumption per unit of GDP is more or less correlated to the level of economic development. As indicated in Figure 2.4 (data in Figure 2.4 are prepared and calculated in line with China Statistical Yearbook (2007)), the regions with higher economic development level (expressed in GDP per capita) are always featured by low energy consumption per unit of GDP. The correlation coefficient between them is −0.58. In 2006, Beijing boasted the highest energy efficiency, with energy consumption per unit of GDP hitting 0.760 tce/RMB 10,000, while Ningxia had the lowest energy efficiency (4.099 tce/RMB 10,000). Regions with great energy conservation potential mainly include: Shandong, Henan, Hebei, Liaoning, Sichuan, Hubei, Hunan, Heilongjiang, Shanxi and Inner Mongolia. Although Ningxia, Guizhou and Qinghai have high energy consumption per unit of GDP, their GDP and energy consumption take up minor shares in China, and the potential of energy conservation is relatively small.

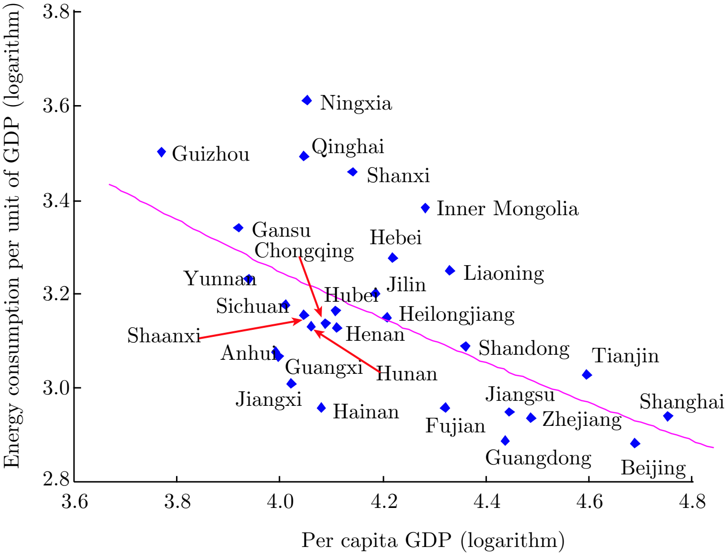

Figure 2.4 Regional energy consumption per unit of GDP and GDP per capita in 2006 [Data Source: China Statistical Yearbook (2007)]

For regions with higher energy consumption per unit of GDP, the cost of energy conservation is relatively smaller. Appropriate financial, tax and industrial policies shall be adopted to encourage the transformation of advanced energy-saving technologies into regions with low energy efficiency, so as to allow advanced regions to guide backward regions and to optimize regional industrial layout. It will be of far reaching importance for promoting balanced development among regions, shortening the gaps between regions and saving more energy resources with less costs.

2.2 Overview of CO_2 emissions in China

Owing to its limited energy reserves, China is one of a few countries with coal being the major subject of energy consumption. Since the economic reform and opening-up in 1978, China's economy has witnessed booming development. The rapid economic development and the energy consumption structure dominated by coal have determined the characteristics of China's CO_2 emissions. The data of gross CO_2 emissions as analyzed in this chapter are from CDIAC. CO_2 emissions are mainly caused by solid fuel, liquid fuel, gas fuel and cement production (CDIAC, 2007).

2.2.1 CO_2 emissions grow fast while accumulated emission is lower than that of major developed countries

Owing to the rapid growth of economy and energy consumption, the CO_2 emissions caused by the use of fossil fuels and cement production grow quickly. According to the statistical data of CDIAC (2007), China's energy consumption and CO_2 emissions increase rapidly after the reform and opening-up. Despite the year-over-year decrease during 1996—1999, the energy consumption and CO_2 emissions rebounded suddenly and have been growing rapidly since 2000. In 2004, China's CO_2 emissions caused by fossil fuel consumption hit 1.37 billion tons (right behind US). During 1970—1996, China's CO_2 emissions grew at a speed of 5.3% per year. The fossil fuel consumption and cement production in 1996 have resulted in the increase of CO_2 emissions by 39% over 1990. The main reason was the growth in coal consumption in 1996, which increased by 38% over 1990. Generally, China's CO_2 emissions grew rapidly during 1970—2004, though the CO_2 emissions did drop during 1996—1999 as a result of the decline in the energy consumption. Since 2002, China's CO_2 emissions have been increasing rapidly.

(1) China's CO_2 emissions are mainly represented by the increase of emissions caused by solid fuel consumption.

As one of a few countries with coal being the major source of energy consumption, 98.7% of China's CO_2 emissions in 1950 were caused by coal consumption. With the decrease of the proportion of coal in energy consumption structure and the development of clean coal technology, the CO_2 emissions caused by coal consumption dropped to 71.9% in 2004. Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.5. CO_2 emissions caused by the use of liquid fuel accounted for less than 18%, with proportion increasing gradually. CO_2 emissions caused by the use of gas fuel accounted for less than 2% as a result of the fact that the natural gas takes up little shares in China's energy consumption structure. CO_2 emissions caused by cement production is increasing quickly year by year, and hit 9.65% in 2004 as a result of China's infrastructure construction needs during recent years.

However, according to Figure 2.6, based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.6, we can find out that the share of China's CO_2 emissions in the world of the cement industry is increasing year after year, and hit 44.27% in 2004. That's because China's cement production grows quickly and has been ranking top in the world since 1990. However, China has been exporting 1.3% of its cement products since 1994. China's CO_2 emissions per unit of cement produced are apparently higher than that of developed countries.

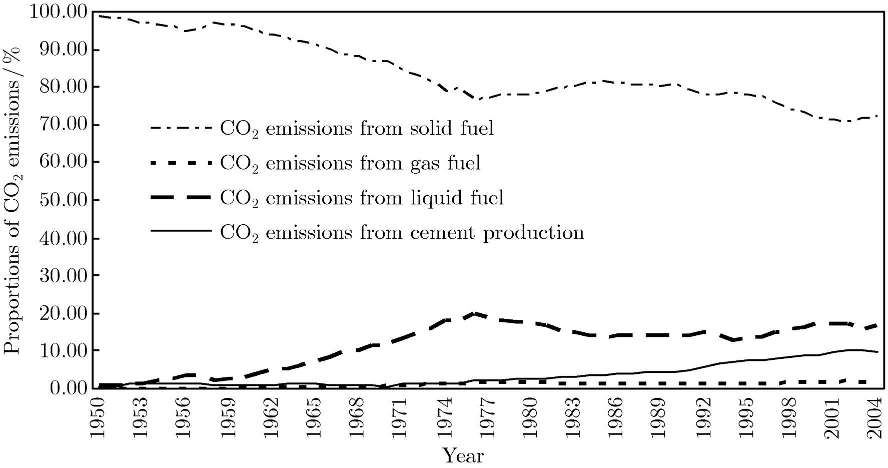

Figure 2.5 China's CO_2 emission sources during 1950—2004
[Data Source: CDIAC (2007)]

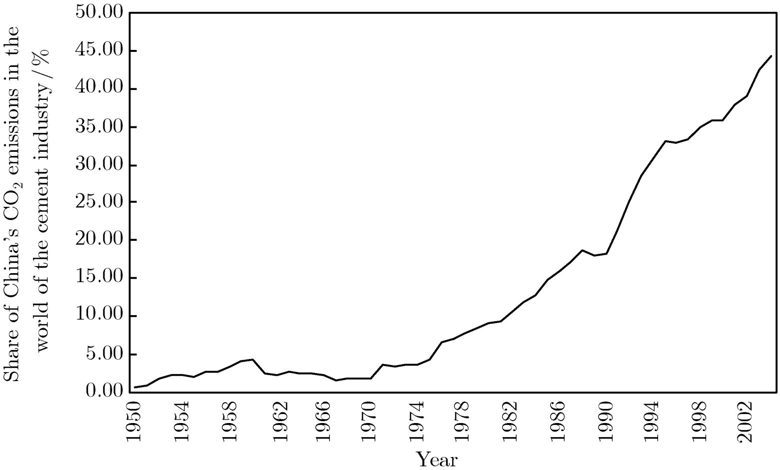

Figure 2.6 Share of China's CO_2 emissions in the world of the cement industry
[Data Source: CDIAC (2007)]

(2) The share of China's CO_2 emissions in the world increases year by year, while the growth rate is apparently lower than that of developed countries at the same stage of economic development.

The quick growth of China's CO_2 emissions has resulted in the gradual growth of the share of China's CO_2 emissions in the world. Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.7. In 2000, China's CO_2 emissions hit 910.82 million tons of carbon, accounting for 13.05% of worldwide CO_2 emissions and 56.01% of CO_2 emissions of United States. The CO_2 emissions of United States hit 1626.14 million tons of carbon, accounting for 23.29% of worldwide CO_2 emissions. In 2004, the CO_2 emissions of China reached 1366.55 million tons of carbon, accounting for 17.28% of worldwide CO_2 emissions and 82.82% of that of United States. The CO_2 emission of United States hit 1650.02 million tons of carbon in 2004, accounting for 20.86% of worldwide CO_2 emissions of the same year.

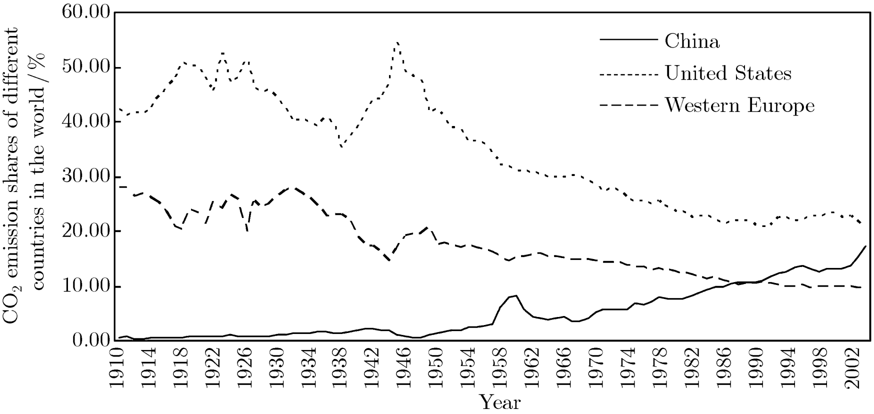

Figure 2.7 Shares of China, US, West Europe's CO_2 emissions in the world during 1910—2004

[Data Source: CDIAC (2007)]

Despite the gradual increase in the share of China's CO_2 emissions in the world since 1960, the historical CO_2 emissions of United States accounted for over 40% of worldwide emissions during 1910—1950, and a share of 20% was achieved by Western Europe during 1910—1940, indicating that economic development will certainly result in more CO_2 emissions. Currently, China can be classified into a country with survival-oriented CO_2 emissions.

(3) The historical accumulated CO_2 emissions of China are apparently lower than that of major developed countries.

Since global warming is mainly caused by the rise of greenhouse gas concentration in the atmospheric layer, it is necessary to analyze China's CO_2 emissions from the aspect of historical accumulated emissions.

The accumulated CO_2 emissions of China are not as high as some industrial countries. During 1900—2004, the accumulated CO_2 emissions accounted for 7.96% of worldwide emissions. Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.8. This proportion is apparently lower than that of United States, Western Europe and Central Europe. The United States has the greatest accumulated CO_2 emissions (28.03%), followed by Central Europe (17.01%) and Western Europe (13.94%). China's accumulated CO_2 emissions are only 28.39% of that of United States. Therefore, despite the notable CO_2 emissions and its rapid growth speed, China's historical accumulated CO_2 emissions are apparently lower than major industrial countries.

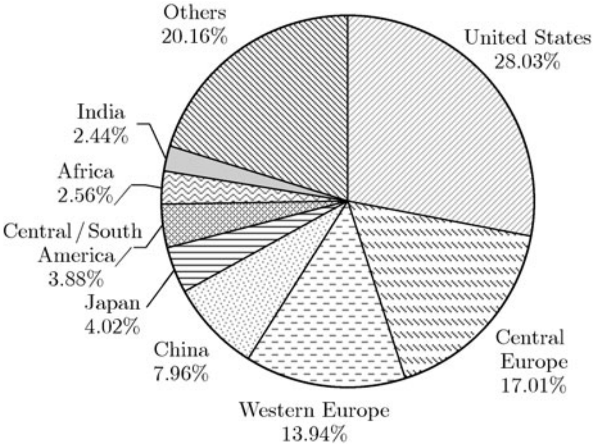

Figure 2.8 Shares of accumulated CO_2 emissions of major countries and regions [Data Source: CDIAC (2007)]

(4) The contribution of China's CO_2 emissions to the increase of world emissions is lower than major developed countries.

Figure 2.9 (Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.9) indicates that: Since 1970, the contribution of China's CO_2 emissions to the increase of worldwide CO_2 emissions has been increasing year by year, with growth rate during 2000—2004 exceeding 40%, which is higher than that of United States and Western Europe. However, in the historical perspective, United States and Western Europe were the major contributors to the increase of worldwide CO_2 emissions during 1800—1950. Despite the decrease during 1800—1900, the contribution of Western Europe to the increase of worldwide CO_2 emissions remained above 20%. The contribution of United States grew gradually during 1800—1920, and the contribution rate even exceeded 100% during 1910—1920, indicating that CO_2 emissions can be closely correlated to the stage of economic growth.

Owing to the unbalanced economic development among different countries, we cannot analyze the features of CO_2 emissions of a certain country merely from the current emission level. Therefore, in order to compare the CO_2 emission levels of different countries in a scientific and objective way, we have compared the contribution of different countries to the increase of worldwide CO_2 emissions at the same stage of economic development. Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.10. At the same stage of economic development when GDP per capita was between USD 500—3500 (USD of 1990), major industrial countries (especially the US) were at their early stage of industrialization process and the economy development relied on huge energy consumption and high CO_2 emission. At this stage, the CO_2 emission increase of United States to the worldwide increase accounted for 32%, Western Europe accounted for 22%, and China accounted for 14%, indicating that the contribution of China to the increase of worldwide CO_2 emissions is lower than major developed countries.

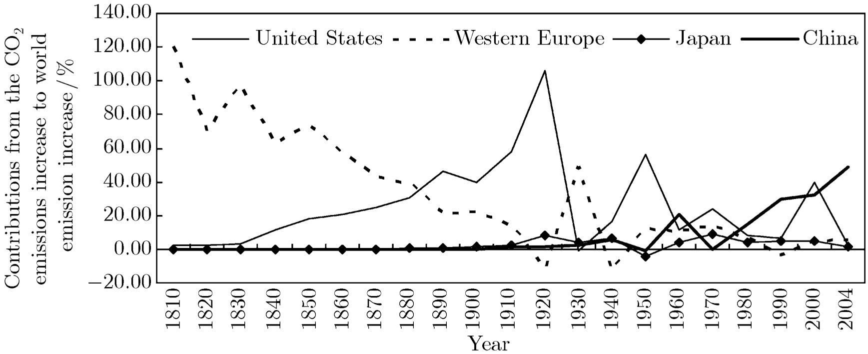

Figure 2.9 Contributions from the CO_2 emissions increase of major regions and countries to world emission increase in each decade from 1800 to 2004 [Data Source: CDIAC (2007)]

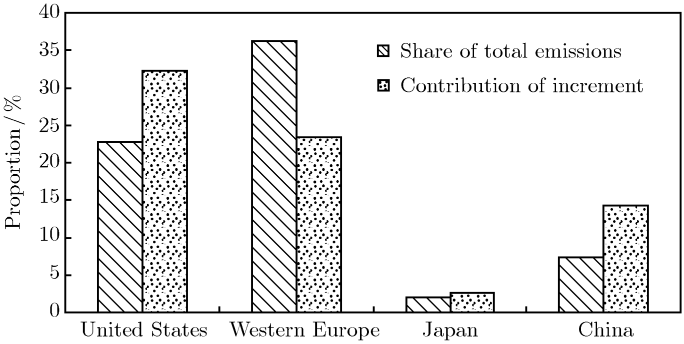

Figure 2.10 Shares of major regions and countries' CO_2 emissions in the world with their GDP per capita between USD 500—3500 [Data Source: CDIAC (2007)]

2.2.2 CO_2 emissions per capita is lower than the level in developed countries and worldwide average

The current per capita CO_2 emissions of China are apparently lower than that of major developed countries and world average. Despite the considerable gross emissions, the per capita emissions of China are always lower than world average. In 2000, the per capita CO_2 emissions of China were only 0.72 ton, which was only 62.61% of world average (1.15 tons per capita), 12.50% of that of United States (5.76 tons per capita), 27.59% of that of Japan (2.61 tons per capita) and 41.38% of that of Western Europe (1.74 tons per capita). In 2004, the per capita CO_2 emissions of China increased to 1.05 ton, which was only 84.6% of world average (1.24 tons per capita), 18.68% of that of United States (5.62 tons per capita), 39.03% of that of Japan (2.69 tons per capita) and 56.45% of that of Western Europe (1.86 tons per capita). As indicated in Figure 2.11 (Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.11), during 1960—2004, the per capita CO_2 emissions of both the world and major countries and regions were increasing gradually, while Japan was featured by the quickest growth of per capita CO_2 emissions (6.62%), followed by China (5.06%). The growth rate of world per-capita CO_2 emissions was about 1.02% during this period. Therefore, along with the instant development of economy, China's needs on fossil fuels and per capita CO_2 emissions will also grow instantly. However, the per capita CO_2 emissions of China will still be far lower than that of United States, Japan, Western Europe and other developed countries.

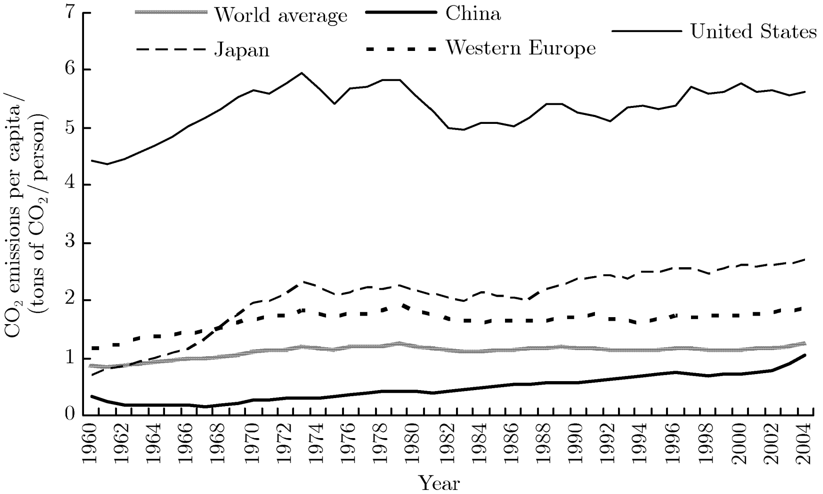

Figure 2.11 CO_2 emissions per capita of the major regions and countries during 1960—2004

[Data Source: CDIAC (2007)]

The CO_2 emissions per capita of China are apparently lower than those of major developed countries at the same stage of economic development. Since different countries are featured by different sizes, populations and economic development levels, it is unfair to simply compare the total CO_2 emissions of each country. In order to reflect the CO_2 emission level of each country in a scientific and objective way, we have compared the per capita CO_2 emissions of countries at the same stage of economic growth. As indicated in Figure 2.12 (Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.12), at the early stage of industrialization in major industrial countries, the economic development was always coupled with high energy consumption and high CO_2 emissions, especially in the United States. Through calculation, it has occurred to us that: At the same stage when GDP per capita was between USD 500—3500 (USD of 1990), the per capita CO_2 emissions grew quickly in all countries, while US was with the quickest growth speed, about 2 times of that in Western Europe, Japan and China. At the same development stage, the per capita CO_2 emissions of China equal to that of Japan and were slightly lower than that of Western Europe. The CO_2 emissions of United States accounted for 22.85% of worldwide emissions during 1820—1896; the CO_2 emissions of Western Europe accounted for 36.19% during 1820—1923; the CO_2 emissions of China accounted for 7.37% during 1903—2001. Therefore, at the same stage of economic development, either the accumulated CO_2 emissions or the share of China in worldwide CO_2

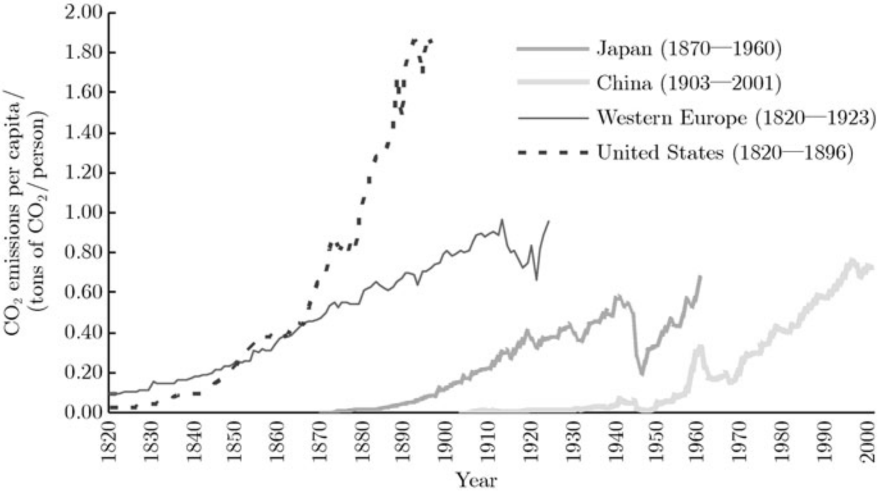

Figure 2.12 CO_2 emissions per capita of different regions and countries with their GDP per capita between USD 500—3500
(The GDP per capita is expressed in USD of 1990)
[Data Source: CDIAC (2007) and Maddison (2005)]

emissions were all on the low side. Therefore, like the CO_2 emissions at the early development stage of industrial countries, the current CO_2 emissions of China can be classified as survival-oriented emissions. Furthermore, compared with the CO_2 emissions of other industrial countries at the same development stage, China's CO_2 emissions are far lower than that in United States, Western Europe and other industrial countries. Based on the data from CDIAC (2007), the results are calculated and shown in Figure 2.12.

2.2.3 CO_2 emission intensity is higher than world average while decreases fast

The CO_2 emission intensity refers to the CO_2 emissions per unit of GDP. In 1960, China's CO_2 emission intensity was 3.02kg CO_2/USD (USD of 2000), which was 8.71 times of the world average of 0.35kg CO_2/USD. In 1978, China's CO_2 emission intensity was 2.56kg CO_2/USD, 8.25 times of the world average of 0.31kg CO_2/USD. In 2004, it was 0.79kg CO_2/USD, 3.43 times of the world average of 0.23kg CO_2/USD. Based on the data from CDIAC (2007) and Maddison (2005), the results are calculated and shown in Figure 2.13. Although China's CO_2 emission intensity is far higher than that of US and Japan, it has been dropping quickly and constantly. However, the CO_2 emission intensity increased during 1967—1972 and 1974—1977 which was the result of extremely low GDP growth during these two periods (only 3%, or even negative growth for several years). Since the reform and opening-up, the CO_2 emission intensity of China has been dropping instantly and reached

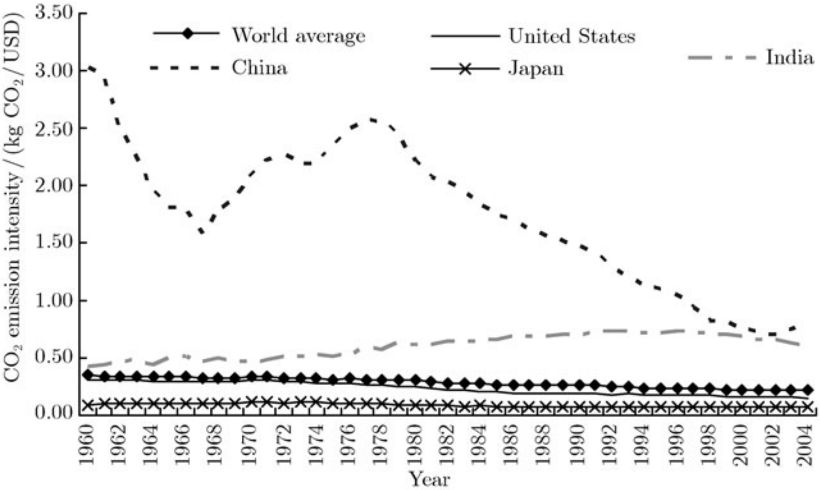

Figure 2.13 CO_2 emission intensities of major countries during 1960—2004

the historical lowest point in 2002 (about 0.69kg CO_2/USD, very close to that of India at the same stage). However, China's CO_2 emission intensity kept growing during 2002—2004 as a result of the quick growth of CO_2 emissions. The average growth rate of CO_2 emissions hit 13.69% during 2002—2004, while the world average was 3.61% only during this period.

Nonetheless, when compared with that of developed countries at the same stage of economic development, the CO_2 emission intensity of China was still on the low side: ① the CO_2 emission intensity of China kept dropping, while that of developed countries kept rising; ② the CO_2 emission intensity of China was lower than that of United States, United Kingdom, Germany and Canada at the same stage of economic development. Based on the data from CDIAC (2007) and Maddison (2005), the results are calculated and shown in Figure 2.14.

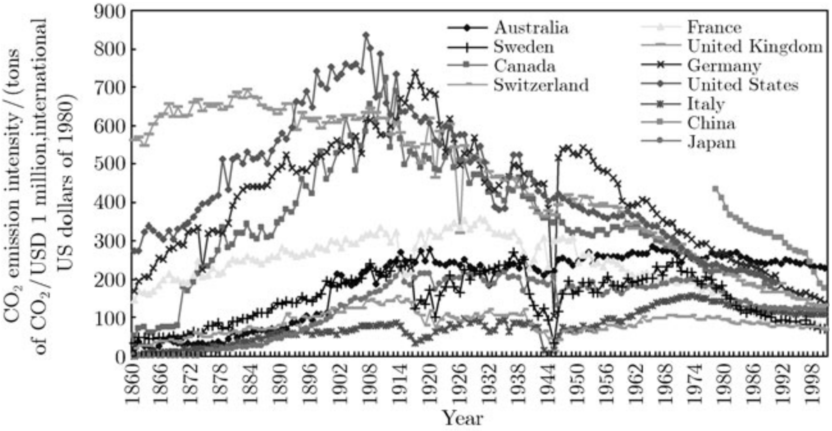

Figure 2.14 Comparison of CO_2 emission intensities of different countries

(Data Sources: the GDP per capita is expressed at constant PPPS dollars of 2000 and the data are from Maddison, 2005; the data of CO_2 emissions are from CDIAC)

2.3 Study on characteristics of CO_2 emissions from primary energy consumption in China

2.3.1 CO_2 emissions and its intensity during 1980—2005

Since the reform and opening-up in 1978, China's economy has been growing rapidly, and the average annual growth of China's GDP was 9.84% during 1980—2005. Along with economic development, the primary energy consumption of China also grew from 603 Mtce in 1980 to 2247 Mtce in 2005, with energy consumption increasing by 272.64%. In the meantime, CO_2 emissions increased apparently from 4.0271 million tons in 1980 to 1.439 billion tons in 2005, growing by 257.43%. The average annual growth of CO_2 emissions was lower than 9% during 1980—2002 but were 16.79%, 15.76% and 9.95% respectively in 2002, 2004 and 2005.

The CO_2 emission intensity kept dropping during 1980—2002 by 68.93% but increased by 11.17% during 2002—2005. Based on the data from China Statistical Yearbook (1990) and China Statistical Yearbook (2006), the results are calculated and shown in Figure 2.15.

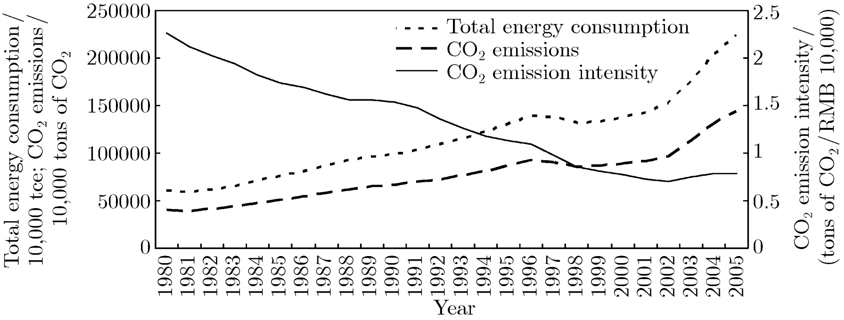

Figure 2.15 Changes of the primary energy consumption, CO_2 emissions, and CO_2 emission intensity of China in 1980—2005

[Data Source: China Statistical Yearbook (1990; 2006)]

Despite the rebound of CO_2 emission intensity from primary energy consumption of China during 2002—2005, the track of variation in CO_2 emission intensity of China is opposite to that of developed countries at the same stage of economic development (as indicated in Figure 2.14). Calculated in line with the Purchasing Power Parity (PPP) of 1990, the GDP per capita of China was USD 1067—3425 during 1980—2000, and was similar to that in developed countries from 1870 to the First World War Therefore, the cause for such variations and whether such decline trend can be maintained in the future remain to a major concern. This section utilizes the Log-Mean Divisia Index (LMDI) method to quantitatively study the cause for the change of CO_2 emissions in China.

Currently, there are many research findings about CO_2 emissions, including quite a few on CO_2 emissions of developed countries and limited research on that of developing countries.

Davis et al. (2003) have analyzed the causes for the decline of energy intensity and CO_2 emission intensity of United States during 1996—2000. It is believed that the adjustment of energy structure is not the leading cause, which, instead, shall be the weather variations. Greening et al. have applied Divisia Index Decomposition method to analyze the CO_2 emission intensity of the material production sector (1971—1991), the freight transport sector (1971—1993), the resident end service sector (1970—1993) and the private transport sector (1970—1993) of 10 OECD countries (Denmark, Finland, France, West Germany, Italy, Japan, Norway, Swedish, United Kingdom and United States). It is considered that the drop of energy intensity of the material production sector is the leading cause for the drop of CO_2 emission intensity, which might have also been influenced by other factors such as energy price (Greening et al., 1998). The increase of CO_2 emission intensity of the freight transport sector is mainly resulted from the transformation of traffic pattern into the CO_2 intensive, while such measures as fuel price and automobile tax cannot effectively decrease energy consumption (Greening et al., 1999). In the resident and service sector, the final energy use structure, fuel structure for power generation and energy intensity will have different impacts on the decrease of CO_2 emission intensity, but the mode of final energy use will have the opposite effect on the decrease of CO_2 emission intensity (Greening et al., 2001). The drop of energy intensity in the private transport sector will have a major impact on the decrease of CO_2 emission intensity. However, it is not enough to merely rely on policies aimed to decrease the energy intensity to reduce CO_2 emissions (Greening, 2004).

In fact, the study on the change of CO_2 emissions in developing countries will be of greater significance and provide detailed decision-making references to help optimize the energy structure and industrial structure, avoid the development path of “resolution only after pollution” incurred in developed countries and mitigate global climate change.

Zhang (2003) has applied the non-residual Laspeyres method to analyze the change of energy consumption of China’s industrial sectors during 1990—1997. The research findings indicate that 87.8% of energy conservation achieved by the industrial sectors during 1990—1997 was resulted from the decline of real energy intensity, which took place in ferrous metal sector, chemical sector, non-metallic mineral sector and mechanical manufacturing sector. Wu et al. (2006) have adopted the LMDI method to study the change of CO_2 emissions in China during 1980—2002 from the aspects of supply and demand. They believed that: before 1996, the economic development, energy structure and energy intensity of the energy demand side drove the change of China’s CO_2 emissions, while the industrial structure adjustment and energy efficiency promotion have played limited roles. The final energy use and the enhancement of energy efficiency during 1996—2000 are considered as the major causes for the drop of China’s CO_2 emissions. In accordance with the data of respective Chinese provinces, Wu et al. (2005)

have adopted a new three-layer decomposition method to study the "sudden drop" of China's CO_2 emissions during 1996—1999. The research findings indicate that: the decline speed of energy intensity in the industrial sectors and the slow falling of labor productivity are the decisive factors of the drop of CO_2 emissions from fossil fuel consumption. Wang et al. (2005) has used LMDI method to study the change of CO_2 emissions of China during 1957—2000, and the findings indicate that: theoretically, China's CO_2 emissions decreased by 2.466 billion tons during 1957—2000, 95% of which were resulted from the drop of energy intensity, and only 1.6% and 3.2% were caused by the adjustment of fossil fuel energy structure and the consumption of renewable energy. In accordance with the conditions of 2582 large- and medium-sized energy-intensive enterprises of China, Fisher-Vanden et al. (2004) have adopted Divisia method to analyze the impacts of the changes in energy price, R&D input, pattern of ownership and industrial structure on the drop of energy consumption during 1997—1999. It was believed that 50% of energy consumption and variation in intensity were resulted from the increase in the energy efficiency of enterprises, while the variation of relative price and R&D inputs were key factors in the drop of energy intensity of enterprises. Fan et al. (2007) has studied the changes of primary energy consumption and the intensity of CO_2 emissions of the final energy use of material production sectors, and found out that the drop of energy intensity was the major cause for the decline of China's CO_2 emission intensity.

2.3.2 Method for studying CO_2 emission change

In respect of the research method, many decomposition methods are now being used by researchers, research institutes and policy makers to analyze energy consumption and CO_2 emissions. Each method has the corresponding assumption, which will have direct influence on the decomposition result (Greening et al., 1998). Ang (2004) has pointed out that the Laspeyres decomposition method is easy to understand, while Divisia decomposition method is more scientific. Therefore, in this section, we will adopt LMDI method to study the change of CO_2 emissions of China's primary energy consumption and the change of CO_2 emission intensity.

1) Decomposition of CO_2 emission intensity of primary energy consumption

The CO_2 emission intensity of primary energy consumption can be decomposed into energy consumption structure, energy intensity and CO_2 emission coefficients of different energy, as indicated in Formula (2.1).

$$G_t \equiv \frac{C_t}{Y_t} = \frac{C_t}{E_t}\frac{E_t}{Y_t} = I_t\frac{C_t}{E_t} = I_t\sum_{i=1}^{n}\frac{C_{it}}{E_{it}}\frac{E_{it}}{E_t} = I_t\sum_{i=1}^{n}e_{it}R_{it} \tag{2.1}$$

2) Decomposition of CO_2 emissions from primary energy consumption

The CO_2 emissions from primary energy consumption can be decomposed into population, GDP per capita, energy intensity and energy consumption structure, as indicated in Formula (2.2).

$$C_t = \sum_{i=1}^{n} C_{it} = \sum_{i=1}^{n} P_t \times \frac{\mathrm{GDP}_t}{P_t} \times \frac{E_t}{\mathrm{GDP}_t} \times \frac{E_{it}}{E_t} \tag{2.2}$$

Here, G_t refers to CO_2 intensity of primary energy consumption; Y_t refers to GDP; C_t refers to CO_2 emissions of primary energy consumption; E_t refers to primary energy consumption; I_t refers to energy intensity; E_{it} refers to the i kind of primary energy consumption; e_{it} refers to share of the i kind of primary energy consumption; R_{it} refers to CO_2 emission coefficient of the i kind of primary energy consumption; P_t refers to population; C_{it} refers to CO_2 emissions from the i kind of primary energy consumption.

The primary energy include coal, petroleum, natural gas and hydropower. Since hydropower takes up a minor share (7.8% in 2002) and brings about no CO_2 emissions, the primary energy as mentioned herein shall include coal, petroleum and natural gas. The primary energy consumption data are derived from "*China Statistical Yearbook* 1990" and "*China Statistical Yearbook* 2006". The GDP data of 1980—2005 are expressed at constant prices of 2005. The constant price GDP of 2005 was calculated in line with the GDP indicators of three major industries indicated at comparable prices in "*China Statistical Yearbook* 2006". The population data are derived from "*China Statistical Yearbook* 2006".

2.3.3 Structure decomposition analysis on CO_2 emission intensity

In accordance with Formula (2.1), we can use the LMDI method to analyze the change of CO_2 emission intensity of primary energy consumption.

Compared with 1980, the CO_2 emission intensity of China's primary energy consumption dropped by 1.4838 tons/RMB 10,000 in 2005. Data are calculated according to China Statistical Yearbook (1990) and (2006) and shown in Figure 2.16. The primary energy intensity decreased by 64.20% during 1980—2005, resulting in the drop of CO_2 emission intensity by 1.4491 tons/RMB 10,000. The variation of primary energy consumption structure was mainly represented by the change of coal proportion, which dropped from 72.20% in 1980 to 68.9% in 2005. This also means the increase of low-carbon energy consumption. Therefore, the variation of primary energy consumption structure has also facilitated the drop of emission intensity, but the impact was limited (only 0.0347 tons/RMB 10,000). It can be observed that the continual improvement of China's energy efficiency and the low-carbon energy oriented development of primary energy consumption structure have more or less slowed down the growth of CO_2 emissions.

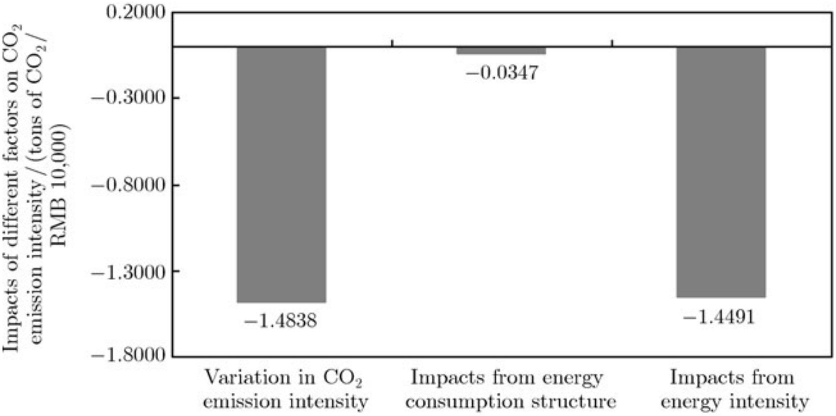

Figure 2.16 Impacts from energy structure and energy intensity on CO_2 emission intensity of primary energy consumption in 1980—2005

[Data Source: China Statistical Yearbook (1990; 2006)]

However, the changes of primary energy intensity and primary energy consumption structure might not be able to facilitate the drop of CO_2 emission intensity, which can be told from the variation track of CO_2 emission intensity of China's primary energy consumption during 1980—2005. Data are calculated according to China Statistical Yearbook (1990) and (2006) and shown in Figure 2.17. Such a variation was mainly caused by the change of energy intensity. The drops in CO_2 emission intensity during 1980—1988, 1989—2002 and 2004—2005 were mainly caused by the decline of energy intensity, which contributed over 75% to the drop. The impact of the change of energy intensity on the CO_2 emission intensity was 0.0025 tons/RMB 10,000 during 1988—1989, offsetting partially the impact of primary energy consumption structure on CO_2 emission intensity, which only dropped by 0.0006 tons/RMB 10,000. The changes of primary energy intensity during 2002—2003 and 2003—2004 have helped increase CO_2 emission intensity by 0.0388 tons/RMB 10,000 and 0.0410 tons/RMB 10,000 respectively, while the impact of primary energy consumption structure has increased and decreased CO_2 emission intensity by 0.0095 tons/RMB 10,000 and 0.0025 tons/RMB 10,000 respectively. Generally speaking, the CO_2 emission intensity of China's primary energy consumption has increased by 0.0819 tons/RMB 10,000 during 2002—2004. The rebound in energy intensity during 2004—2005 has resulted in minor rebound of China's CO_2 emission intensity during 2002—2005.

Therefore, the future decline in the CO_2 emission intensity of China's primary energy consumption shall be achieved by further reducing its energy intensity and adjusting the proportion of coal consumption in energy consumption structure. If only the decrease of energy intensity is emphasized while the adjustment of primary energy consumption structure is neglected, the impact of primary energy consumption structure on CO_2 emission intensity might partially offset the contribution of energy intensity to the drop. According to the experiences of developed countries, China has great potential to decrease energy intensity and improve energy structure. Therefore, China's CO_2 emission intensity will certainly keep declining in the future.

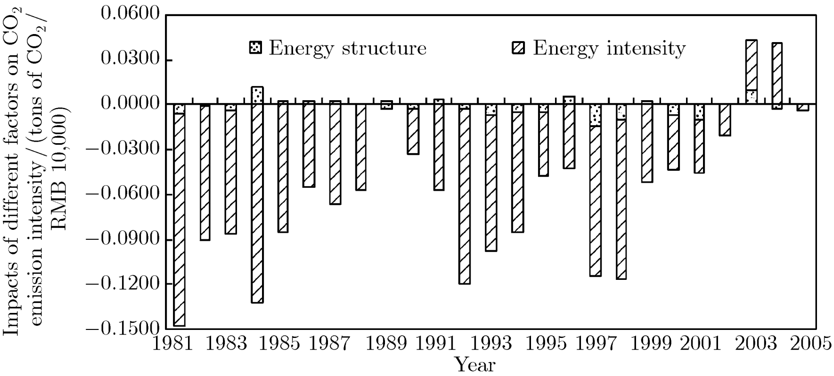

Figure 2.17 Impacts from China's energy structure and primary energy intensity on CO_2 emission intensity of primary energy consumption in 1980—2005

[Data Source: China Statistical Yearbook (1990; 2006)]

2.3.4 Structure decomposition analysis on CO_2 emissions

In the previous section, we have analyzed the change of CO_2 emission intensity of China's primary energy consumption. How about the change of CO_2 emissions of China's primary energy consumption? How are the impacts of major factors? In accordance with Formula 2.2, this section has adopted the LMDI method to make related analysis.

Compared with 1980, CO_2 emissions of China's primary energy consumption increased by 1.037 billion tons in 2005. Data are calculated according to China Statistical Yearbook (2006) and shown in Figure 2.18. During 1980—2005, China's population grew by 35.84%, resulting in the increase of CO_2 emissions by 194 million tons. China's GDP per capita grew by 6.81 times, resulting in the increase of CO_2 emissions by 1.566 billion tons. The GDP per capita is the major factor of the increase in CO_2 emissions. The primary energy intensity of China was reduced by 64.20% in 2005 over 1980, resulting in the decrease of CO_2 emissions by 692 million tons. The proportion of coal in the primary energy consumption of 2005 has reduced from 72.20% in 1980 to 68.9% in 2005, resulting in the decrease of CO_2 emissions of primary energy consumption by 31 million tons.

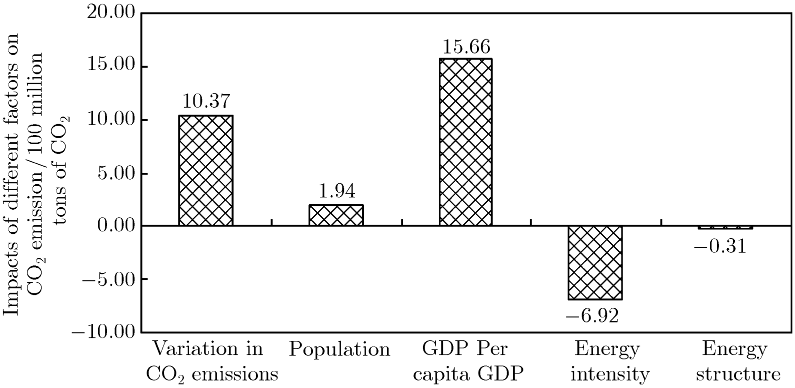

Figure 2.18 Impacts from population, GDP per capita, primary energy intensity, and energy consumption structure on CO_2 emissions

[Data Source: China Statistical Yearbook (1990; 2006)]

Figure 2.19 indicates the changes of CO_2 emissions of China's primary energy consumption during 1980—2005, as well as the impacts of different factors. In Figure 2.19 (Data are calculated according to China Statistical Yearbook (2006) and shown in Figure 2.19), it is observed that: the growth of GDP per capita is the major cause for the increase of CO_2 emissions from China's primary energy consumption, and the growth of population has also contributed to the increase of CO_2 emissions, with impact following GDP per capita. The change of energy intensity is the most important factor to mitigate CO_2 emissions of China's primary energy consumption. The impact of energy intensity has helped reduce CO_2 emissions during 1980—1988, 1989—2002 and 2004—2005, and can completely offset the impact of population on CO_2 emissions or 39% of the impact of GDP per capita on CO_2 emissions (only 5.1% during 2004—2005), or even 100% of such impact during 1996—1998. During 1988—1989, 2002—2003 and 2003—2004, the rebounds of energy intensity by 0.016%, 4.78% and 5.50% respectively have helped increase CO_2 emissions by 1.0248 million tons, 48.8642 million tons and 65.1885 million tons respectively. Since GDP per capita and energy intensity have increased CO_2 emissions during 2002—2004, the growth of

CO_2 emissions during this period was apparently higher than other years.

The primary energy consumption structure has smaller impact on CO_2 emissions, and no apparent rule of variation can be found (as indicated in Figure 2.19).

Therefore, the above analysis indicates that: The economic development (population growth and increase of GDP per capita) is the utmost factor determining the increase of China's CO_2 emissions, while the decline of energy intensity can more or less mitigate such increase. Therefore, the mitigation of CO_2 emissions cannot be achieved by slowing down economic growth but through the control of population, adjustment of economic structure, promotion of technical advancements, enhancement of energy efficiency and adjustment of energy consumption structure.

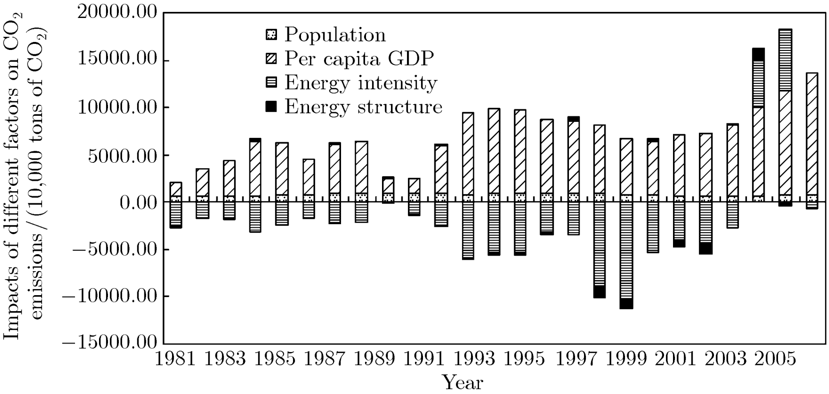

Figure 2.19 Impacts of population, GDP per capita, energy structure and energy intensity on China's CO_2 emissions

[Data Source: China Statistical Yearbook (2006)]

In summary, this section has adopted LMDI method to analyze the changes of CO_2 emission intensity and gross CO_2 emissions of China's primary energy consumption, and the result shows that: the drop of CO_2 emission intensity of China's primary energy consumption during 1980—2002 mainly resulted from the decline of energy intensity, while the increase of CO_2 emission intensity during 2003—2004 was mainly caused by the rebound of energy intensity. Despite the drop of CO_2 emission intensity, CO_2 emissions from primary energy consumption demonstrated the trend of growth, which was mainly caused by the increase of GDP per capita and population growth. The energy intensity reduction during 1980—2002 has mitigated the increment speed of CO_2 emissions but increased CO_2 emissions during 2002—2005, making the acceleration of CO_2 emissions apparently higher than other years.

Therefore, despite the potential drop of China's CO_2 emission intensity in the future, the economic development will certainly be accompanied by the increase of CO_2 emissions. The keys to mitigate the increase of CO_2 emissions shall be the reduction of energy intensity, decrease of the proportion of high-carbon energy in energy consumption structure, increase of low-carbon energy consumption and the control of population growth.

2.4 Conclusion

This chapter first analyzes the characteristics of China's CO_2 emissions, and then analyzes the impacts of China's urban/rural residents and export trade on CO_2 emissions. The research findings indicate that:

(1) China's historical accumulated CO_2 emissions are on the low side, and the per capita CO_2 emissions are even lower, but the growspeed of CO_2 emission is quick.

China's CO_2 emissions grew rapidly during 1960—2004, though the CO_2 emission did drop during 1996—1999 as a result of the decline in the energy consumption. Since 2002, China's CO_2 emissions have been increasing rapidly. However, the accumulated CO_2 emissions of China are not as high as those of some industrial countries. During 1900—2004, the accumulated CO_2 emissions of China accounted for 7.96% of worldwide emissions and only 28.39% of that of United States.

Despite the notable total CO_2 emissions, the per capita emissions of China are on the low side. In 2000, the per capita CO_2 emissions of China was only 0.72 ton, which was only 62.61% of world average (1.15 tons per capita), 12.50% that of United States (5.76 tons per capita), 27.59% that of Japan (2.61 tons per capita) and 41.38% of that of Western Europe (1.74 tons per capita). In 2004, the per capita CO_2 emissions of China increased to 1.05 ton, which was only 84.6% of world average (1.24 tons per capita), 18.68% that of United States (5.62 tons per capita), 39.03% that of Japan (2.69 tons per capita) and 56.45% that of Western Europe (1.86 tons per capita).

Through calculation, it has occurred to us that: At the same stage when GDP per capita was between USD 500—3500 (USD of 1990), the per capita CO_2 emissions grew quickly in all countries, while US was featured by the quickest growth rate, about 2 times that of Western Europe, Japan and China. At the same development stage, the per capita CO_2 emissions of China equal to that of Japan and were slightly lower than that of Western Europe. Therefore, like the CO_2 emissions at the early development stage of industrial countries, the current CO_2 emissions of China can be classified as survival-oriented emissions. Furthermore, compared with the CO_2 emissions of other industrial countries at the same development stage, China's CO_2 emissions are far lower than United States, Western Europe and other industrial countries.

(2) The drop of CO_2 emission intensity of China's primary energy consumption during 1980—2002 mainly resulted from the decline of energy intensity, while the increase of CO_2 emission intensity during 2003—2004 was mainly caused by the rebound of energy intensity. Despite the drop of CO_2 emission intensity, CO_2 emissions from primary energy consumption demonstrated the trend of growth.

The increase in CO_2 emissions was mainly caused by the increase of GDP per capita and population growth. The reduction of energy intensity during 1980—2002 has mitigated the increment speed of CO_2 emissions but increased CO_2 emissions during 2002—2005, making the acceleration of CO_2 emissions apparently higher than other years. Therefore, despite the potential drop of China's CO_2 emission intensity in the future, the economic development will certainly be accompanied by the increase of CO_2 emissions. The keys to mitigate such an increase shall be the reduction of energy intensity, decrease of the proportion of coal in primary energy consumption structure, and control of population growth.

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Chapter 3

Study on Impact Factors of CO_2 Emissions under Different Economic Development Levels

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Global warming has now become an undisputed fact. With the deep research and analysis on this phenomenon, scientists believe that the great concentration of greenhouse gases including CO_2 contributes to global temperature rise (IPCC, 1995b). Therefore, it has become the inescapable responsibility of countries from all over the world to control the increase of the emission of greenhouse gases including CO_2 in order to mitigate climate change. To effectively curb the rapid increase of CO_2 emissions, it is particularly important to study the impact factors of CO_2 emissions. Since those impact factors are directly related to the measures, policies and strategies on CO_2 emissions, they have come into the focus of scholars from various countries. Therefore, this chapter carries out researches on following questions:

- Which factors have impacts on CO_2 emissions?
- How do CO_2 emissions vary under different income levels?
- How do population, economy and technology affect CO_2 emissions?
- How do population structure and urbanization level affect CO_2 emissions?
- How do the impacts of population, economy and technology differ on

CO_2 emissions from countries with different income levels, the world as a whole and China?

3.1 Population, economy, technology and CO_2 emissions

CO_2 emissions of a country are jointly determined by its technical level, affluence, energy structure, economic structure, population constitution, etc. But the impacts of these factors on CO_2 emissions are different. According to traditional viewpoints, the increase of CO_2 emissions was due primarily to the growing energy consumption, without population and technology taken into account (Shi, 2003). However, some researchers believed that population, economy and technology were all key factors to determine CO_2 emissions (Cole et al., 1997; Engleman, 1994; Meyerson, 1998; Schmalensee et al., 1998; YE Yong, 1996). These determinative factors made different contributions to CO_2 emissions in different countries (Shi, 2003). What kind of relationships on earth exists between different economic conditions, population structures, technical levels and CO_2 emissions in different countries?

In order to solve the problems above, scholars at home and abroad have carried out numerous studies. With the help of STIRPAT Model, Dieta and Rosa (1997), York et al. (2003), and Shi (2003) studied the relationship between CO_2 emissions and population. Dieta and Rosa (1997) and York et al. (2003) believed that the elasticity of emissions with respect to population change is nearly 1; while Shi (2003) argued this elasticity varying between 1.41 and 1.65. However, these researches were based on the average values of overall CO_2 emissions and population from a number of countries without detailed analysis on specific countries. Thus, the results lack of guidance for the CO_2 emission reduction strategies of various countries. Fan et al. (2006), Wei Yiming et al. (2006), and Liu Lancui (2006) analyzed the impacts of population, economy and technology on the CO_2 emissions in China, of the world, high income countries, upper middle income countries, lower middle income countries and low income countries during 1975—2000. They found that the impacts were different.

3.1.1 Change of CO_2 emissions

During 1975—2003, overall CO_2 emissions in high income countries, low income countries, upper middle income countries, lower middle income countries, as well as China and the world all show an increasing trend. During this period, CO_2 emissions of the whole world rose by 58.24% in total; although there was some decrease in 1980s, the overall CO_2 emissions in high income countries also rose by 37.92% during 1975—2003; while in upper middle income countries, CO_2 emissions increased by 39.71% during 1975—1988, but decreased by 17.94% during 1988—2003; in lower middle income countries, CO_2 emissions surged by 141.78%; CO_2 emissions of low income countries were apparently less than high income and middle income countries, but with a greater increase rate of 190.85%; though there was a drop of 17.00% in China's CO_2 emissions during 1996—2000, its overall trend was climbing with an increase of 1.63 times, based on the data from SIMA of WB (2004), the results are calculated and shown in Figure 3.1 below.

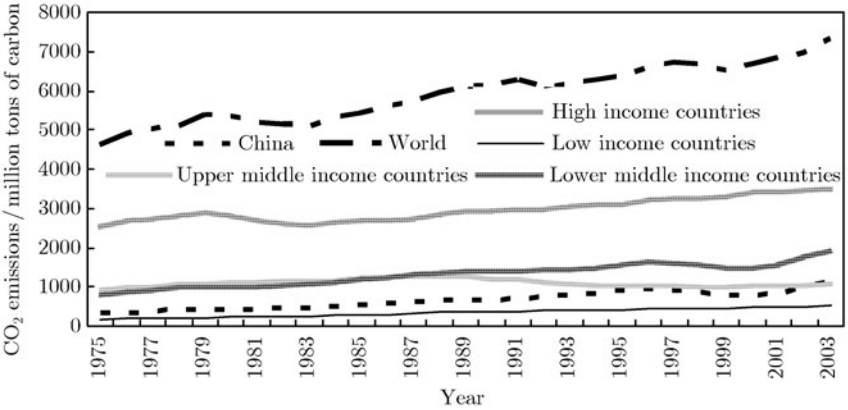

Figure 3.1 CO_2 emissions of countries with different income levels

[Data Source: SIMA of WB (2004)]

3.1.2 Change of population

Upper middle income countries have the least total population in the world. During 1975—2003, overall populations in the world, high income countries, low income countries, upper middle income countries, lower middle income

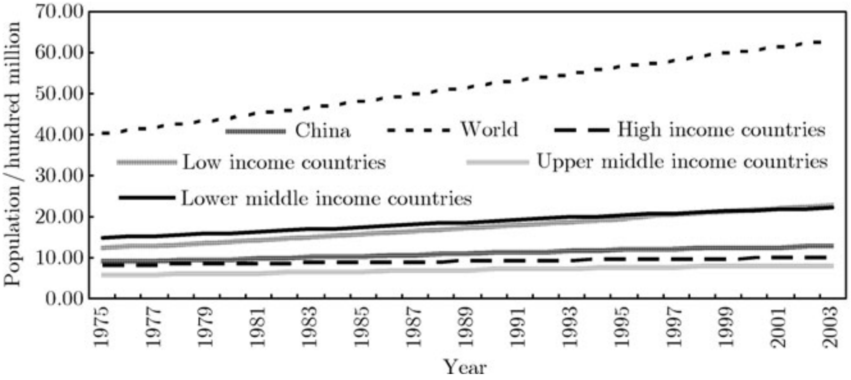

Figure 3.2 Populations of countries with different income levels

[Data Source: SIMA of WB (2004)]

countries and China were on the rise. The world population had a linear growth of 55.24%; the population in high income countries had a slower growth of 23.30%; there was a faster population growth of 44.73% and 50.39% in upper middle income countries and lower middle income countries, respectively; the population growth of low income countries reached the fastest rate of 87.38%; while in China, the growth was by 40.59%, based on the data from SIMA of WB (2004), the results are calculated and shown in Figure 3.2.

3.1.3 Change of GDP per capita

During 1975—2003, there was a continuous increase of real GDP per capita (all in constant 2000 dollars herein) in the world, high income countries, low income countries, upper middle income countries, lower middle income countries and China, based on the data from SIMA of WB (2004), the results are calculated and shown in Figure 3.3. Among them, the real GDP per capita of lower middle income countries recorded the fastest growth. To be specific, the average real GDP per capita of the world rose by 48.80%; the percentages were 79.97%, 33.59%, 208.81% and 74.61% for high income countries, upper middle income countries, lower middle income countries and low income countries respectively; while that of China showed an increase of over six times.

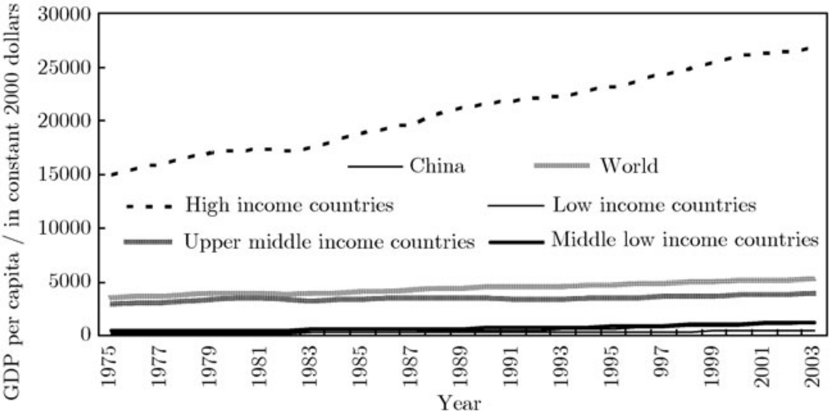

Figure 3.3 Real GDP per capita of countries with different income levels

[Data Source: SIMA of WB (2004)]

3.1.4 Change of energy intensity

High income countries have the lowest energy intensities. During 1975—2003, there was a trend of energy intensity decline in the world, high income countries, low income countries, upper middle income countries, lower middle income countries and China, based on the data from SIMA of WB (2004), the results are calculated and shown in Figure 3.4. During 1975—2003, there was a continuous decline of overall energy intensity in the world, but with a low decrease of only 25.47%; the energy intensity of high income countries dropped by 29.39%; while the percentages were 29.12%, 50.30% and 29.73% in upper middle income countries, lower middle income countries and low income countries respectively. There was a dramatic drop of 75.57% on China's energy intensity.

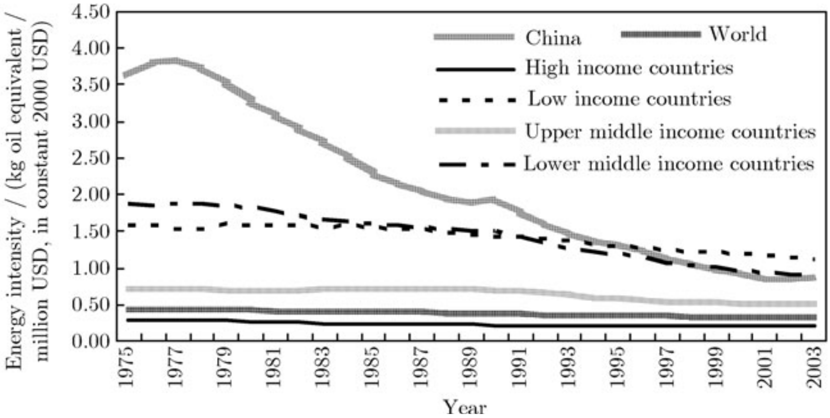

Figure 3.4 Energy intensities of countries with different income levels

[Data Source: SIMA of WB (2004)]

The analysis above shows that the growth rate of overall CO_2 emissions, population and real GDP per capita of the world is apparently higher than the decrease rate of energy consumption per unit of GDP, while the growth of population and GDP per capita surpasses that of CO_2 emissions. In high income countries, the increase of real GDP per capita outdistanced the population growth, the decrease of energy consumption per unit of GDP and the increase of CO_2 emissions. In upper middle income countries, the growth of population and GDP per capita exceeded that of CO_2 emissions while the decrease of energy consumption per unit of GDP also exceeded it. In lower middle income countries, the increase of real GDP per capita was apparently higher than that of CO_2 emissions, while population growth and the energy consumption decrease per unit of GDP were slower than the increase of CO_2 emissions. In low income countries, the increase of CO_2 emissions exceeded the growth of population and real GDP per capita as well as the decrease of energy consumption per unit of GDP. The increase of real GDP outdistanced that of CO_2 emissions in China. It is evident that the relationships between the variance in impact factors and the increase of CO_2 emissions are different in different countries. In that way, how do these factors affect CO_2 emissions on earth and to what extent can they explain the growth of CO_2 emissions?

Therefore, with the method of Partial Least Squares, we have established the STIRPAT Model and conducted an overall quantitative analysis on historical data of high income countries, upper middle income countries, lower middle income countries, low income countries, the world and China during 1975—2003. Results show that for the past twenty years, the impacts of population, in particular the 15—64 year-old population, on CO_2 emissions were comparatively large in both high income countries and low income countries. While the impacts of real GDP per capita and energy intensity on CO_2 emissions were large in upper middle income countries, showing that further optimization of economic structure and the increase of energy conservation efforts should be made in high income countries. These findings have proved different impacts of population, economy and technology on CO_2 emissions of countries with different development levels. Therefore, decision makers should take all of those factors into full account when they develop long-term strategies on CO_2 emission reduction.

3.2 Method for analysis

3.2.1 STIRPAT Model

Ehrlich and Holden (1971; 1972) were the first to put forward that the establishment of "$I = PAT$" equation helps to reflect the impacts of population on environmental pressure. The equation combines environmental impact (I) and population size (P), affluence per capita (A) and technological levels of environmental damage (T), known as "$I = PAT$". It is a well-recognized equation that analyzes the environmental impact of population and is still under wide-spread use for analyzing the determinative factors of environmental change (York et al., 2002).

However, the "$I = PAT$" model is limited to some extent, in that it analyzes a problem by changing a factor while keeping others still, resulting in the proportionate impacts on the dependent variable. In order to overcome this, scholars analyzed the non-proportional impacts of population on the environment by establishing a stochastic model. On the basis of $I = PAT$, York et al. (2003) set up the STIRPAT (i.e., Stochastic Impacts by Regression on Population, Affluence, and Technology) Model:

$$I_i = aP_i^b A_i^c T_i^d e_i \tag{3.1}$$

The model keeps the multiplication structure of "$I = PAT$" Model, taking the three major factors of population (P), per capita affluence (A) and technology (T) as the determinative factors for the change of emissions. After taking logarithms for the model, Formula (3.1) turns into:

$$\ln I_{it} = a + b\,(\ln P_{it}) + c\,(\ln A_{it}) + d\,(\ln T_{it}) + e_{it} \tag{3.2}$$

Here, suffixes i and t refer to countries and years respectively; P represents population; A stands for affluence per capita; T stands for technology or the energy efficiency of economic activities; and the dependent variable I stands for CO_2 emissions.

Factors P and A are decomposable (Dieta and Rosa, 1994), so is T (York et al. 2003). Therefore, in order to analyze the impacts of population structure and urbanization level on CO_2 emissions, the percentage of population aged 15—64 and the percentage of the population living in the urban areas are introduced into the model, thus Formula (3.2) is changed to Formula (3.3):

$$\ln I_t = a + b_1\,(\ln P_t) + b_2\,(\ln U_t) + b_3\,(\ln L_t) + c\,(\ln A_t) + d\,(\ln T_t) + e_t \tag{3.3}$$

Here, U and L stand for the percentage of population aged 15—64 and of the population living in the urban areas respectively.

3.2.2 Data sources

According to STIRPAT Model introduced by York et al. (2003), we adopt the data of population, real GDP per capita and energy consumption per unit of GDP(namely the energy intensity) during 1975—2003 to analyze their impacts on CO_2 emissions.

Affluence is represented by real GDP per capita (in constant 2000 dollars). Technology is by energy intensity. The less the energy consumption per unit of GDP is, the higher the energy efficiency of economy activities is and the less CO_2 emission are produced in economic activities. Population is decomposed to two variables: the percentage of population aged 15—64 and the proportion of population living in urban areas. Normally, the higher the percentages of population between ages of 15 and 64 and of urbanization are, the more energy consumption there is, but, at the same time, the higher the awareness of environmental protection and technology are. Table 3.1 shows the definitions of variables used herein.

The data used in this study are all from the Statistical Information Management and Analysis (SIMA) database of the World Bank (2004). In conformance with other studies, we express the unit of CO_2 emissions as the unit of carbon. The conversion ratio is a unit of carbon to 3.664 units of CO_2 emissions (Engleman, 1998).

Table 3.1 Definition of variables in the model

Variable	Definition	Unit
CO_2 emissions	CO_2 emissions from fossil fuel burning and cement production	kton C (Thousand tons of carbon)
GDP per capita	Real GDP per capita	Constant 2000 USD
Total population	Total population	Person
Energy intensity	Energy consumption per unit of GDP	kg of oil equivalent per USD million (PPP, 2000)
Urbanization level	Proportion of urban population in total population	%
Proportion of population aged 15—64	The proportion of population aged 15—64 in total population	%

In order to contrast the effects of population, affluence and technology on CO_2 emissions at different development levels, this study analyzes the world, high income countries, upper middle income countries, lower middle income countries and low income countries on an overall basis instead of sample analysis on each of them. In 1995, the World Bank's definitions of the income levels were: low income countries refer to 59 countries with GNP per capita of $765 or less, lower-middle income countries refer to 54 countries with GNP per capita between $766 and $3035, upper-middle income countries refer to 40 countries with GNP per capita between $3036 and $9385, and the high income countries refer to 59 countries with GNP per capita above $9386 (World Bank, 2004). Country names are detailed in the official website of the World bank. The population of high income, upper middle income, lower middle income and low income countries are the aggregates of countries of each category. The world total population is the total of countries in the above four categories with different income levels.The CO_2 emissions and populations at different income levels are their respective aggregates of all countries at different income levels. GDP per capita at different income levels are their average GDP per capita, and energy intensity, urbanization, population aged 15—64 at different income levels are their average in each category. These data are directive from SIMA database of the World Bank.

3.3 Impact analysis of population, economy and technology on CO_2 emissions

The correlation coefficients between CO_2 emissions, population and technology are all high in China, the world, high income countries, upper middle income countries, lower middle income countries and low income countries, as shown in Tables 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7. We find considerable multi-collinearity among data after calculating the VIF (Variance Inflation

Factor). Thus, the establishment of a regression model with OLS (Ordinary Least Squares) will result in bigger standard errors in parameter estimation of regression coefficients, wider variables in confidence intervals, lower stability of estimated values, and failure to pass the coefficient test or to get correct estimated values of coefficients, etc.(Yi Danhui, 2002).

Table 3.2 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology in China

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.96576	1		
Technology	–0.95114	–0.99763	1	
Population	0.97626	0.99242	–0.98893	1

Table 3.3 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology in high income countries

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.92071	1		
Technology	–0.81698	–0.97206	1	
Population	0.91465	0.99467	–0.97645	1

Table 3.4 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology in upper middle income countries

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.08683	1		
Technology	0.47949	–0.81860	1	
Population	–0.05860	0.87699	–0.84231	1

Table 3.5 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology in lower middle income countries

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.94838	1		
Technology	–0.91159	–0.99354	1	
Population	0.97322	0.98516	–0.96866	1

Table 3.6 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology in low income countries

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.94095	1		
Technology	–0.72280	–0.90312	1	
Population	0.98915	0.97371	–0.79264	1

Table 3.7 Correlation coefficients between CO_2 emissions, population, real GDP per capita and technology of the world

Variable	CO_2 emissions	Real GDP per capita	Technology	Population
CO_2 emissions	1			
Real GDP per capita	0.98789	1		
Technology	–0.83920	–0.89092	1	
Population	0.97639	0.99118	–0.89626	1

In order to avoid multi-collinearity among a number of variables of the model, a regression relation is established between population, economy, technology and CO_2 emissions with the method of PLS (Partial Least Squares). The model result is achieved with the use of software SAS V8 as shown in Table 3.8.

Table 3.8 Impacts of population, capital, technology on CO_2 emissions in 1975—2003

Variable	High income countries	Upper middle income countries	Lower middle income countries	Low income countries	World	China
C	–2.63	2.77	5.29	2.03	5.03	–10.03
GDP per capita	1.33	0.91	0.07	0.20	0.42	0.89
Total population	0.31	0.34	0.31	0.43	0.30	0.87
Technology	0.93	1.39	0.22	0.27	0.26	1.50
Urbanization level/%	0.48	0.60	0.24	0.44	0.30	0.61
Proportion of population aged 15—64	–0.35	–0.64	0.57	0.15	0.21	0.10
Model indicator:						
A	3	4	3	3	4	4
PRESS	0.1553	0.2179	0.1725	0.1119	0.1444	0.1419
Prob	0.29	1	0.24	1	1	1
Explanation on population variance of major components on independent variables/%	99.9056	99.9944	99.8969	99.90	99.9981	99.9894
Explanation on population variance of major components on dependent variables/%	98.4291	96.5897	98.1946	99.05	98.5873	98.6175
R^2	0.94	0.89	0.95	0.93	0.95	0.93

We can see from the regression coefficient symbols in Table 3.8 that during the past 20 years, the effect of population, economy and technology on CO_2 emissions accords with the viewpoints of most scholars represented by Bidsall (1992), in another word, larger population will certainly result in greater energy demand in industry, electric power and transport, except that those effects (i.e. negative impacts) of the proportion of population aged 15—64 on CO_2 emissions in high income countries and upper middle income countries which coincides with the viewpoint of Simon (1980).

Meanwhile, in order to better demonstrate the explanation capability of each independent variable to dependent variables, we take into account the indicator of VIP (variable importance in projection): VIP shows the importance of every independent variable when explaining the dependent variable. If a predictor has a relatively small VIP value ((Wold, 1995) considering those less than 0.8 to be "small"), it will not provide much help to the explanation of dependent variables then it is a prime candidate for deletion. It can be expressed as the following formula:

$$\mathrm{VIP}_j = \sqrt{\frac{p}{Rd\,(Y; t_1, \cdots, t_m)} \sum_{h=1}^{m} Rd\,(Y; t_h)\, w_{hj}^2} \tag{3.4}$$

Here, VIP_j is the VIP of x_j; p is the number of independent variables, $Rd(Y; t_1, \cdots, t_m) = \sum_{h=1}^{m} Rd\,(Y; t_h)$ is the accumulative explanation capability; $t_1, \cdots, t_m$ are components extracted in the variable X; w_{hj} is No. j component of w_h which is measured by the marginal contribution of x_j for constitution t_h, and for any $h = 1, 2, \cdots, m$,

$$\sum_{j}^{p} w_{hj}^2 = w_h' w_h = 1$$

Figures 3.5 to 3.11 show the VIP of population, urbanization, the percentage aged 15—64, real GDP per capita, and energy consumption per unit of GDP are greater than 0.8, which means each independent variable plays an important role in explaining the growth of CO_2 emissions.

(1) During the period of 1975—2000, the impact of population on emissions is the greatest at the upper-middle income level, followed by the low income level, and is the least at the lower middle income level. Thus, for emissions abatement, it is important for the upper middle income countries to mitigate the growth of population and optimize people's production and living style.

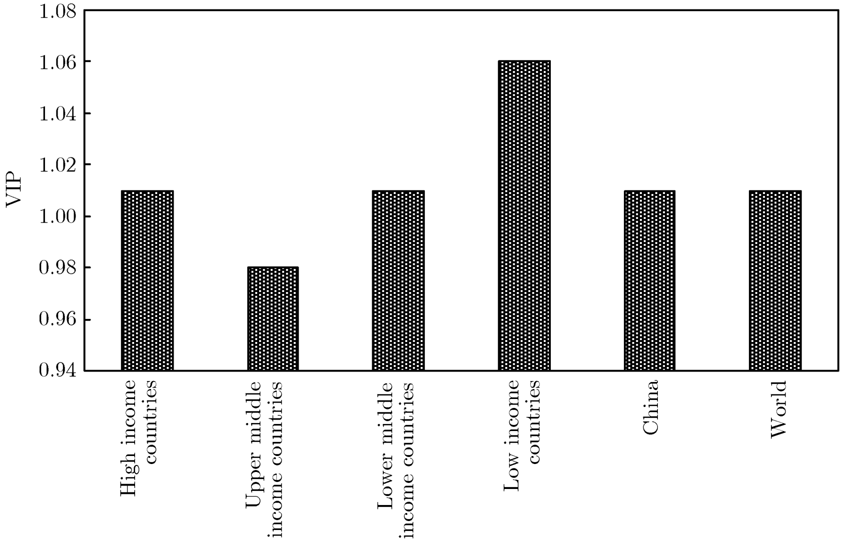

Figure 3.5 The VIP of population

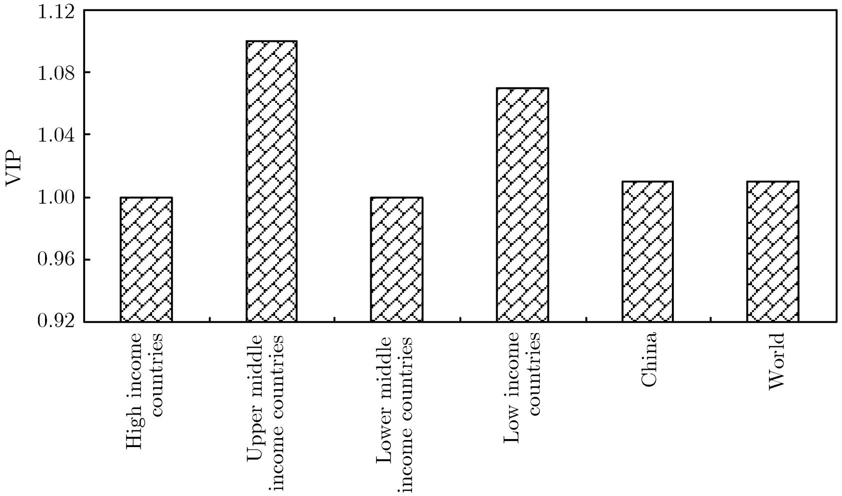

Figure 3.6 The VIP of urbanization

(2) The effect of urbanization on emissions is different from that of population. It is the greatest at the upper middle income level followed by the low income level, and is the least in the lower middle income level. This shows that higher urbanization further increases energy consumption per capita and CO_2 emissions with low energy efficiency, energy saving technology and awareness of environmental protection. Therefore, for the countries at the upper-middle income level, urbanization should make efforts in guiding the

way of energy consumption in urban life and advocate energy-saving during the process of urbanization.

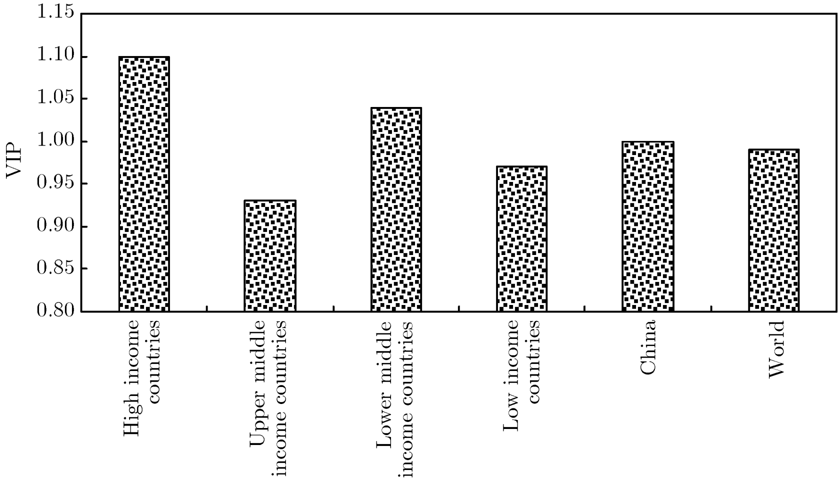

Figure 3.7 The VIP of the percentage of population of aged 15—64

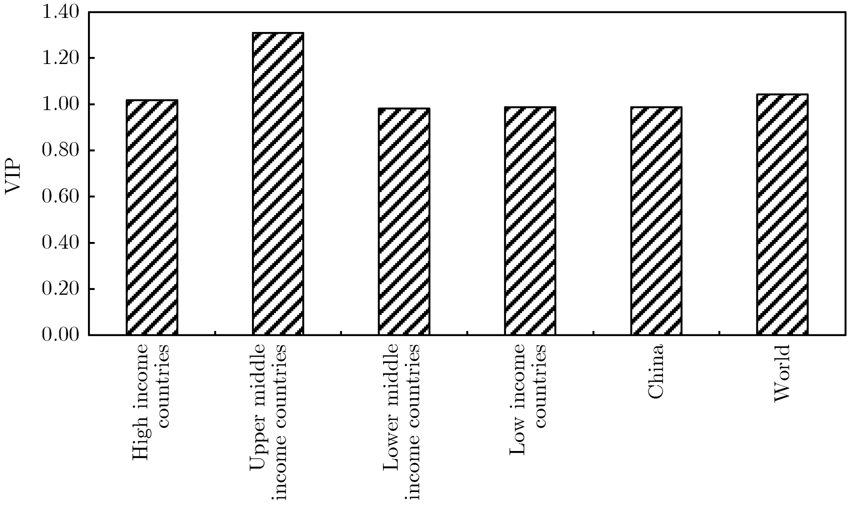

Figure 3.8 VIP value of real GDP per capita

(3) The effect on emissions of the population aged 15—64 is the greatest, and its effect is the greatest and negative, at the high income level, while it is still great but positive at the lower middle income level. Because of the high awareness of environmental protection, energy efficiency and energy-saving technology in high income countries, the increase of labor force favors the abatement of CO_2 emissions. This illustrates that the role of population on

CO_2 emissions is not only constrained by impersonal conditions, but also affected by subjective awareness; that is to say, the human behavior can greatly affect CO_2 emissions.

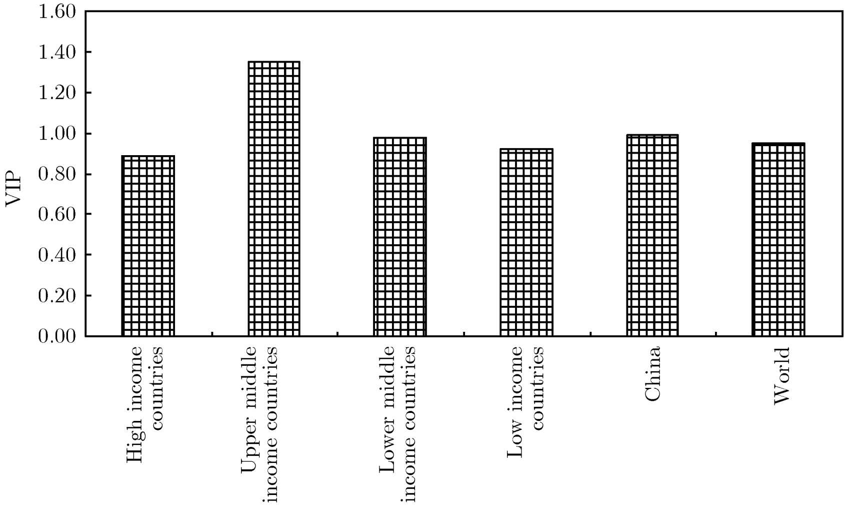

Figure 3.9 The VIP of energy consumption per unit of GDP

(4) The impact of real GDP per capita is the greatest at the upper middle income level, followed by the worldwide level, while that in the lower middle income level is the least, which shows us that CO_2 emissions per unit GDP in the high income countries are lower than those in the middle income countries. This accords with the fact that developed countries have some advantages in energy efficiency, economic structure, energy-consuming structure, energy technology and so forth. For the countries at the upper middle income level, due to their economic structure, product structure and some other reasons, higher GDP per capita can induce more energy consumption and more CO_2 emissions.

(5) The effect of energy intensity is the greatest for the upper middle income countries, and is similar in other income levels. Because of more advanced energy utilization technology and higher energy efficiency, the achievement of high income countries are not very obvious in cutting CO_2 emissions by enhancing their energy efficiency. And low income countries have much difficulty in improving their energy efficiency to a large extent and have a high cost of CO_2 emission reduction by increasing their energy efficiency because of their irrational economic structure and energy consumption structure. However, for the upper middle income countries, in spite of increased energy consumption, and relatively low energy efficiency and energy technol-

ogy utilization level, the effect of abating CO_2 emissions will be obvious and the emission reduction costs will be lower through decreasing energy intensity due to the optimization of economic and energy structures.

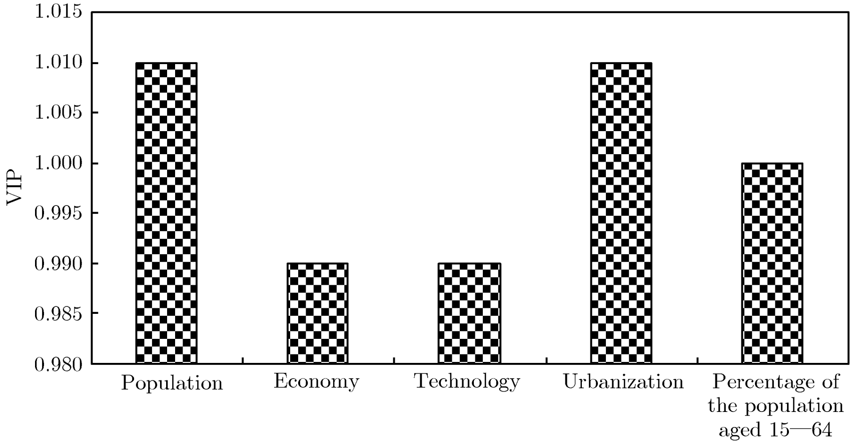

Figure 3.10 VIP value of China's population, real GDP per capita, and energy consumption per unit of GDP

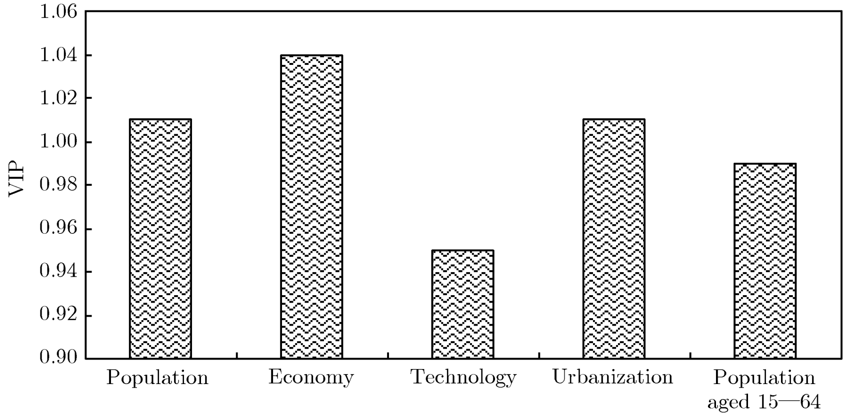

Figure 3.11 VIP value of world population, GDP per capita, and energy consumption per unit of GDP

(6) For China, population has the greatest impact on CO_2 emissions, followed by urbanization, the percentage of population aged 15–64, GDP per capita and energy intensity, as shown in Figure 3.10. This shows that population and the labor force's production and living styles have the greatest effect on emissions. As a lower-middle income country, China could reduce emissions greatly by decreasing energy intensity. In addition, without high energy efficiency, energy-saving technology and public awareness of environmental protection, higher urbanization essentially increases CO_2 emissions.

Thereafter, the optimal strategy at present for mitigating China's CO_2 emissions is: controlling the growth of population, changing the labor force's production and lifestyles, and improving energy efficiency.

(7) At the global level, GDP per capita has the greatest impact on emissions, followed by population, and the impact of energy intensity is the least, as shown in Figure 3.11. Thus it seems that global CO_2 emission reduction depends on the improvement of energy efficiency, CO_2 reduction technologies and utilization of renewable energy, etc., because of the continuous growth of economic development and urbanization worldwide, and the population increase in most countries. However, on the one hand, economic development at present stage and a long period of time into the future will surely cause the increase of CO_2 emissions, so nearly all countries in the world believe it's certain for CO_2 emission mitigation to bring about negative effects on economic development. On the other hand, climate change is a long-existing global phenomenon while the countries that implement CO_2 emission reduction measures need to assume the cost. So they are slow and non-active in taking actions of greenhouse emission reduction plans. Therefore, it will be a long way to go in greenhouse emission reduction on a global scale.

3.4 Conclusion

Through the quantitative analysis of the impact of population, real GDP per capita and energy efficiency of China and countries at different incomes levels in the world on CO_2 emissions, we can find that:

(1) Population has a great impact on CO_2 emissions. Especially the percentage of population aged 15—64 has negative effects in high income countries and upper middle income countries which coincides with that of Boserupian, i.e. technological progress is derived from the external pressure of environment (Boserup, 1981). Countries of other categories are positively affected, which confirms with Malthusian's point of view, i.e. population growth increases CO_2 emissions (Malthus, 1798). This shows that human's awareness of environmental protection and effects of environmental improvement vary with income levels, technical levels and economic conditions. When income per capita reaches a higher level, the humankind will seek the optimization of energy consumption structure, CO_2 emission reduction and thus the improvement of living environment by means of science and technology. Therefore, decision makers should take into account the role of production and lifestyles in CO_2 emission reduction under different income levels when they develop long-range strategies on CO_2 emission reduction.

(2) The growth of real GDP per capita has a decreasing impact on CO_2 emissions with the rise of economic development levels.

(3) The effects of CO_2 emission reduction by increasing energy efficiency are limited by national economic development levels and energy consumption structures. In high income countries, low income countries and upper middle income countries, energy intensity has small impacts on CO_2 emissions. While in lower middle income countries, impacts are comparatively large.

(4) The impact of urbanization on CO_2 emissions is limited by national economic development level, energy consumption structure, energy consumption per capita, urban-rural disparity, etc.

Research findings of STIRPAT Model have fully proved that the population, economy and technology of countries at different development levels have different impacts on CO_2 emissions. Therefore, decision makers should fully consider such impacts together with the actual conditions when they develop long-term strategies on CO_2 emission reduction. For the CO_2 emission reduction of China, some conclusions are as follows:

① As the second largest country of CO_2 emissions and a lower middle income country, economic development is more important than CO_2 emission reduction for China. During its development towards a upper middle income country, China's optimization of economic structure and product mix may slow down the increase of CO_2 emissions. However, there will be certain difficulties in maintaining the current decline rate of energy intensity. Further decline of energy intensity still needs the guidance of policies in the future.

② China has the biggest population in the world, and it is of high importance to provide guidance on lifestyle of citizens when it develops towards a high income country. Currently, more and more high incomers and those highly educated consumers conduct irrational and excessive consumption behaviors, which will undoubtedly put forward a high demand on energy supply while increasing the pressure on energy security and CO_2 emission reduction.

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Chapter 4

Evolution Characteristics of CO_2 Emissions in Carbon-intensive Sectors in China

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China is the second largest country of CO_2 emissions in the world next to the United States. As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), the Chinese government announced its approval of the "*Kyoto Protocol*" in August—September 2002. Although China has no obligation of quantified emissions reduction in 2008—2012 as a non-Annex I country, its greenhouse gas emissions and carbon sink must be monitored and reported to the member countries. In addition, China must take measures to slow down the net increase of greenhouse gas emissions in the future. To mitigate global climate change by reducing greenhouse gas emissions has raised attentions of many scientists and a number of international organizations. They attach great importance to the establishment of quantified targets of emission reduction to influence relevant international policies. Therefore, it is only a matter of time for China to commit emission reduction in the future framework of greenhouse gas emission reduction. So it is necessary to analyze China's CO_2 emissions and its variable characteristics in different perspectives so as to reach a more comprehensive and scientific recognition of the internal relations among economic development, technological progress, energy consumption and CO_2 emissions and provide a detailed scientific basis for China's preparation of greenhouse emission reduction strategies in the future.

In this chapter, we adopt LMDI method to study the change of China's CO_2 emissions and its evolution rules. A series of researches have been carried out as follows:

- What are the CO_2 emissions in China's electricity sector which acts as the main fuel transformation sector?
- How are the CO_2 emissions and CO_2 emission intensity of China's material production sectors changing? Which factors have the major influence?
- How is CO_2 emissions of China's industrial sector variating?

4.1 Study on Characteristics of CO_2 emissions change in electricity sector

With rapid economic growth, China's energy consumption, especially electricity consumption is swiftly increasing. During 1980—2005, the elasticity coefficient of China's electricity consumption was apparently higher than that of energy consumption. Electricity consumption doubled each decade during 1980—2000, and increased even more rapidly during 2000—2005 by doubling in only five years, based on the data from China Statistical Yearbook (2005), the results are calculated and shown in Figure 4.1. What's more, 75% of China's electricity comes from thermal power, and coal-fired power generation increases year after year. During 1991—2005, the proportion of coal-fired power in thermal power generation reached between 90%—96% which embedded with great CO_2 emissions.

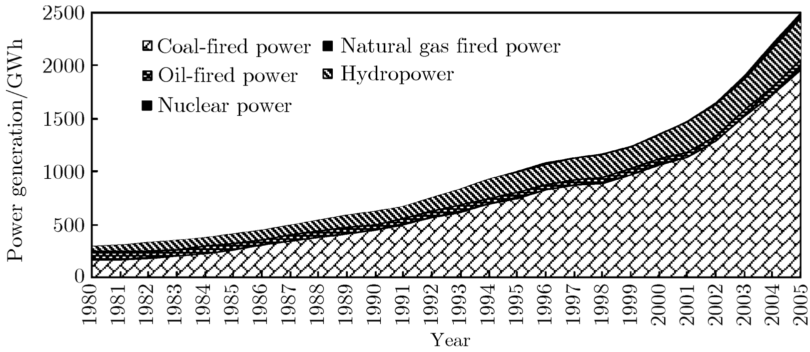


Figure 4.1 China's electricity generation in 1980—2005

[Data Source: China Electricity Yearbook (2005)]

4.1.1 Current status of CO_2 emissions in electricity sector

During 1980—2005, the CO_2 emissions of China's power generation rose rapidly. It increased 5.57 times in 2005 over 1980. Meanwhile, the proportion of CO_2 emissions from power sector in total CO_2 emissions from fossil fuels was increasing every year, from 21.07% in 1980 to 38.73% in 2005, based on the data from China Statistical Yearbook (2005), the results are calculated and shown in Figure 4.2. The proportion of CO_2 emissions from coal-fired power generation in that of power generation was also climbing each year, from 79% in 1980 to 97% in 2005.

The increase of CO_2 emissions from power generation has played a major role in boosting the increase of CO_2 emissions from fossil fuel use in China, based on the data from China Statistical Yearbook (2005), the results are calculated and shown in Figure 4.2. During 1980—2005, the increase of CO_2 emissions from power sector had an average contribution of 49.86% to the increase of total CO_2 emissions from fossil fuels in China. Though there was some decrease of CO_2 emissions from the power sector and the total CO_2 emissions from fossil fuels in 1981, 1985, 1997 and 1998 compared to 1980, 1984, 1996 and 1997 respectively, its contribution to the total CO_2 emission reduction in fossil fuels was only 3.02%, –0.14%, –19.95% and 1.15% respectively. During 1998—1999 and 2000—2001, the percentage of contribution of CO_2 emissions from power sector to the total CO_2 emission increase in fossil fuels was as high as 114.79% and 124.36% respectively.

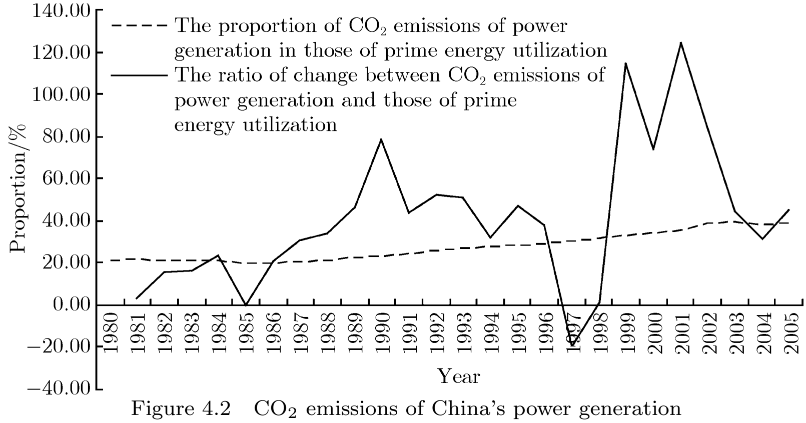


Figure 4.2 CO_2 emissions of China's power generation

[Data Source: China Electricity Yearbook (2007)]

Currently, there is little analysis on CO_2 emissions of power sectors. Early researchers include Shrestha and Timilsina who studied the characteristics of CO_2 dioxide, nitrogen oxide and sulfur dioxide emission change of the power sectors in some Asian countries with the Divisia decomposition method from the aspect of supply side (Shrestha and Timilsina, 1996; 1997; 1998). Recently, Nag and Parikh (2005) studied the change of CO_2 emission coefficient of power sector of India from the angle of demand side, and predicted the change of CO_2 emissions per unit of end use power. Steenholf (2007) studied the baseline of China's power sector from the aspect of demand side. Zhang et al. (2005) made an analysis on the CO_2 emissions of power sectors of Guangdong Province, Liaoning Province and Hubei Province of China. Therefore, it is necessary to analyze the change of CO_2 emissions from China's power generation and supply and determine the factors that have boosted the change of CO_2 emission coefficient of China's power sector. Through the above analysis, not only can the change of CO_2 emission coefficient be traced, but also an effective strategy can be developed for the alleviation of CO_2 emission increase of power sector.

4.1.2 Method for analyzing CO_2 emission change in electricity sector

1) The decomposition of CO_2 emission coefficient from power generation

With regard to power generation, CO_2 emission coefficient of the power sector can be decomposed into the CO_2 emission coefficient of different power fuels, the energy consumption of different power structure, and the power structure.

$$\frac{E_t}{Q_t} = \sum_i \frac{E_{it}}{Q_{it}} \frac{Q_{it}}{Q_t} = \sum_i \frac{c_{it}F_{it}}{Q_{it}} \frac{Q_{it}}{Q_t} = \sum_i c_{it} f_{it} g_{it} \tag{4.1}$$

Here, E_t refers to CO_2 emissions from power generation in year t; Q_t refers to power generation including thermal power, hydropower and nuclear power in year t; E_{it} refers to CO_2 emissions during the process of power generation by fuel i in year t; Q_{it} refers to power generation by fuel i; c_{it} refers to CO_2 emission coefficient of fuel i in year t; F_{it} refers to consumption of fuel i for power generation; g_{it} refers to power structure; f_{it} refers to energy consumption for power generation.

2) The decomposition of CO_2 emission coefficient of electricity consumption

With regard to electricity consumption, the CO_2 emissions per unit is influenced by the main factors of the power end use, energy consumption of power generation, power generation fuel structure, thermal power share, electricity consumption during power generation, the loss of power transmission and distribution, etc.

$$\frac{E_t}{C_t} = \frac{E_t}{G_{\text{thermal},t}} \frac{G_{\text{thermal},t}}{G_{\text{power},t}} \frac{G_{\text{power},t}}{G_{\text{net},t}} \frac{G_{\text{net},t}}{C_t} \tag{4.2}$$

$$\frac{E_t}{G_{\text{thermal},t}} = \sum_i c_{i,t} \frac{F_{i,t}}{\sum F_{i,t}} \frac{\sum F_{i,t}}{G_{\text{thermal},t}} \tag{4.3}$$

Here, E_t refers to CO_2 emissions during power generation; C_t refers to electricity consumption; $G_{\text{thermal},t}$ refers to total thermal power generation; $G_{\text{power},t}$ refers to total power generation; $G_{\text{net},t}$ refers to net power generation, i.e. total power generated minus (-) electricity consumption during power generation; $c_{i,t}$ refers to CO_2 emission coefficient of fuel i.

Therefore,

$$e_t = \sum_i c_{i,t} \cdot fm_t \cdot ei_t \cdot gm_t \cdot aux_t \cdot sm_t \tag{4.4}$$

Here, $\dfrac{E}{C} = e$, for CO_2 emission coefficient of electricity consumption; $\dfrac{\sum_i F_i}{G_{\text{thermal}}} = ei$, for the impact of energy consumption of thermal power generation; $\dfrac{G_{\text{power}}}{G_{\text{net}}} = aux$, for the impact of self-consumptionof power plants; $\dfrac{F_i}{\sum_i F_i} = fm$, for structural impact of power generation fuels; $\dfrac{G_{\text{thermal}}}{G_{\text{power}}} = gm$, for the impact of thermal power share; and $\dfrac{G_{\text{net}}}{C} = sm$, for the impact of power transmission and distribution loss.

Power fuels include raw coal, cleaned coal, other washed coal, crude oil, diesel oil, kerosene, gasoline, fuel oil, LPG, dry refinery gas, other petroleum products, natural gas, etc. The data comes from "*China Energy Statistical Yearbook*": 1989, 1991, 1991—1996, 1997—1999, 2004, 2005 and 2006. Power transmission and distribution losses are sourced from "*China Statistical Yearbook 2005*". The power consumption rates of power plants are derived from China Electricity Yearbook (www.chinapower.com.cn, 2007; SPInet, 2007). Data of coal, petroleum, natural gas and hydro-power generation is derived from the database of World Bank (SIMA, 2007).

4.1.3 Structure decomposition analysis of CO_2 emissions coefficient in electricity production

A trend of fluctuation and decline of overall CO_2 emission coefficient was unfolded in China's power generation and electricity consumption. In 1980 and 2005, the CO_2 emission coefficient of power generation was 282.18g carbon/kWh and 222.95g carbon/kWh respectively with a decrease of 20.99%. The CO_2 emission coefficient of electricity consumption decreased from 328.97g carbon/kWh in 1980 to 253.93g carbon/kWh with a decrease of 22.81%, based on the data from China Electricity Yearbook (2007), the results are calculated and shown in Figure 4.3. That CO_2 emission coefficient of electricity consumption is higher than that of power generation is because electricity consumption does not include power transmission and distribution loss and the self consumption of power plants. The ratio between the two rises higher and higher every year, indicating that China's power transmission and distribution loss and the self consumption of power plants account less and less in power generation. The proportion of electricity consumption in power generation is slightly raised from 86% to 88%.

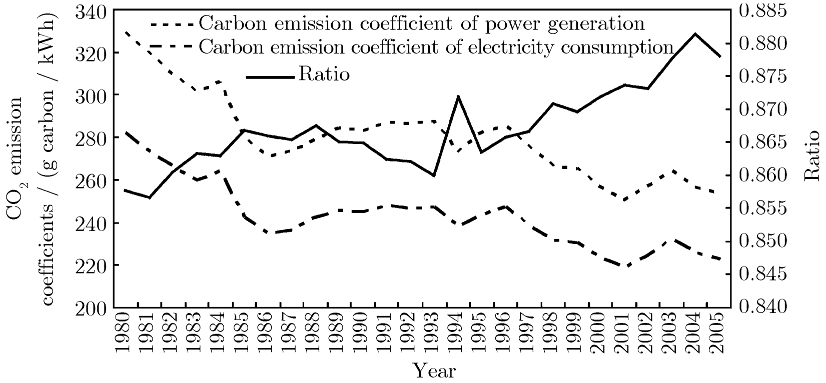


Figure 4.3 Change of CO2 emission coefficients of China's power generation and consumption during 1980—2005

[Data Source: China Electricity Yearbook (2007)]

Research findings on CO2 emission coefficient of power generation show that the decline of it in China is mainly caused by the degradation of power generation intensity, based on the data from China Electricity Yearbook (2007), the results are calculated and shown in Figure 4.4. China's CO2

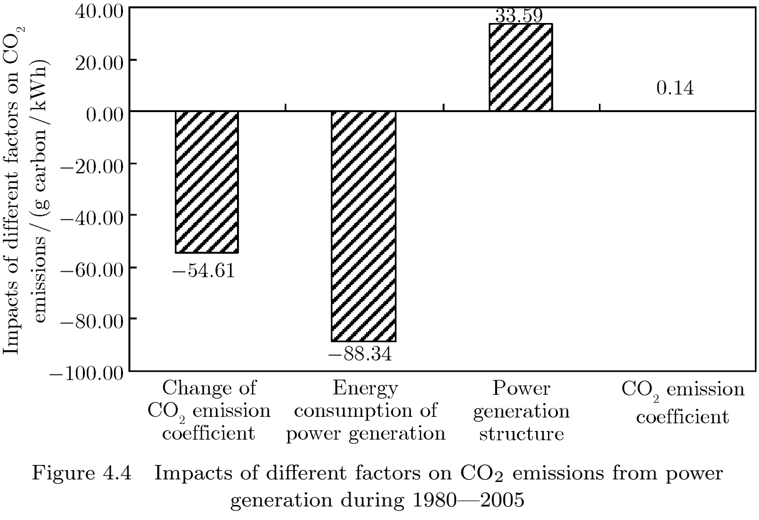


Figure 4.4 Impacts of different factors on CO2 emissions from power generation during 1980—2005

[Data Source: China Electricity Yearbook (2007)] emission coefficient of power generation was 54.61g carbon/kWh lower in 2005 than in 1980, a drop of 19.37%. The decrease of gross energy consumption rate of power generation, especially gross coal consumption rate, led to 88.34g carbon/kWh reduced. However, neither the change of CO_2 emission coefficient of power fuels nor power generation structure was conducive to the decline of carbon emission coefficient of power generation, where power generation structure is the major factor to prevent CO_2 emission coefficient of electricity from descending, offsetting partial impacts of gross energy consumption rate decline of power generation and increasing the emission intensity of electricity by 33.58g carbon/kWh and 0.14g carbon/kWh respectively.

It can be seen from the change of CO_2 emission coefficient of power generation during 1980—2005 that the decreasing energy consumption of power generation does not necessarily mean the descending of CO_2 emission coefficient of power generation, but the change of power generation structure has certain impacts on such change, based on the data from SIMA of World Bank (2007), the results are calculated and shown in Figure 4.5. During 1983—1984, 1986—1987, 1990—1991, 1995—1996 and 2000—2001, the changes of CO_2 emission coefficient were mainly caused by structural change of power generation. During 1983—1984, 1986—1987, 1990—1991 and 1995—1996, the decreases of energy consumption of power generation led to the decreases of CO_2 emission coefficient of power generation by 4.3752g carbon/kWh, 1.0658g carbon/kWh, 4.1403g carbon/kWh and 2.1675g carbon/kWh respectively. However, the change of power structure led to the increase of CO_2 emission intensity by 8.4858g carbon/kWh, 3.2021g carbon/kWh, 6.6793g carbon/kWh and 5.5203g carbon/kWh respectively. Due to the little impact brought by the change of CO_2 emission coefficient of power fuels, CO_2 emission coefficient of

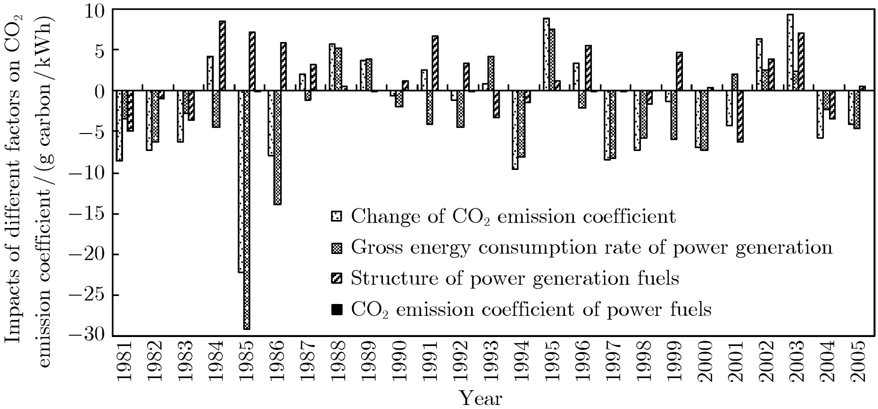


Figure 4.5 Impacts of different factors on CO_2 emission coefficient of power generation

[Data Source: SIMA of World Bank (2007)] power generation actually increased by 4.1563g carbon/kWh, 2.0989g carbon/kWh, 2.5029g carbon/kWh and 3.3069g carbon/kWh in 1983—1984, 1986—1987, 1990—1991 and 1995—1996 respectively. During 2000—2001, the increase of gross energy consumption rate of power generation led to the rise of its CO_2 emission coefficient by 1.9734g carbon/kWh. But the share of thermal power in power generation decreased by 2.4% (among which coal-fired power share decreased by 2.1%) during the same period, resulting in the drop of CO_2 emission coefficient of electricity by 6.3080g carbon/kWh. In fact, the CO_2 emission coefficient of power generation declined by 4.3314g carbon/kWh during 2000—2001.

Therefore, in order to slow down the growth of CO_2 emissions from power generation or decrease its CO_2 emission coefficient, it is important to enhance power generation technology, reduce gross coal consumption for power generation, as well as the proportion of thermal power especially that of coal-fired power, and raise the proportion of power generation with renewable energy. Otherwise, the impact of descending gross energy consumption rate of power generation on CO_2 emission coefficient will be weakened or even be offset completely.

4.1.4 Structure decomposition analysis of CO_2 emissions coefficient in electricity consumption

Section 4.1.3 has analysed the change of CO_2 emission coefficient of power generation. During power generation, though, there is some power loss during its transmission to meet the power demand. So, it is necessary to analyze the change of CO_2 emission coefficient of electricity in respect of electricity end use. Therefore, based on Formula (4.4), we adopt LMDI method to make a quantitative analysis.

In 1980—2005, the decline of CO_2 emission coefficient of China's electricity consumption is mainly caused by the decrease of gross energy consumption rate of power generation and transmission and distribution loss, based on the data from China Electricity Yearbook (2007), the results are calculated and shown in Figure 4.6. China's CO_2 emission coefficient of power consumption was 75.04g carbon/kWh in 2005, 22.81% lower than 1980. The decrease of gross energy consumption rate of power generation caused the drop of CO_2 emission coefficient by 83.35g carbon/kWh, the drop of electricity consumption in power plants contributed 1.59g carbon/kWh decrease, and power transmission and distribution loss brought it down 4.32g carbon/kWh. However, thermal power structure, thermal power share and CO_2 emission coefficients of power fuels go against the decline of CO_2 emission coefficient of electricity consumption, resulting in the increase of CO_2 emission coefficient by 11.43g carbon/kWh, 2.62g carbon/kWh and 0.16g carbon/kWh respectively.

Figure 4.7 (Data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook as shown in Figure 4.7) reflects the change of impacts of different factors on CO_2 emission coefficient of electricity consumption during 1980—2005. Gross energy consumption rate of

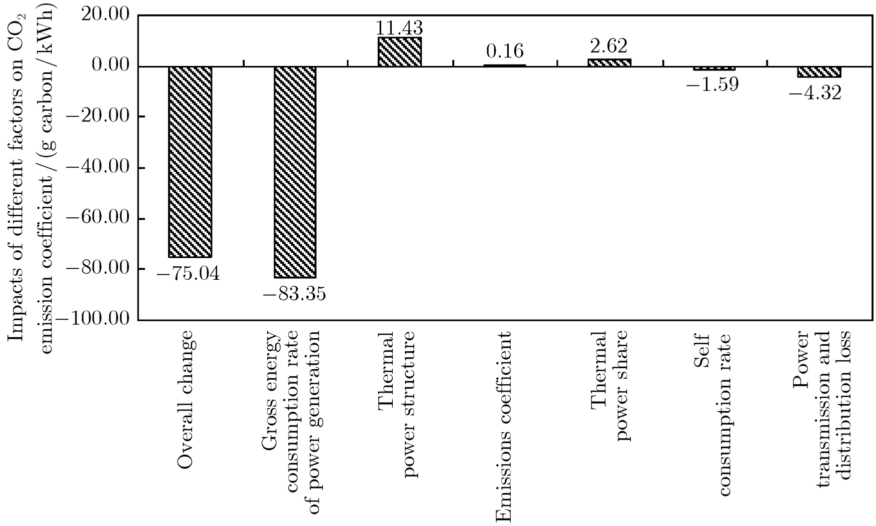


Figure 4.6 Impacts of different factors on CO_2 emission coefficient of power supply

[Data Source: China Electricity Yearbook (2007)]

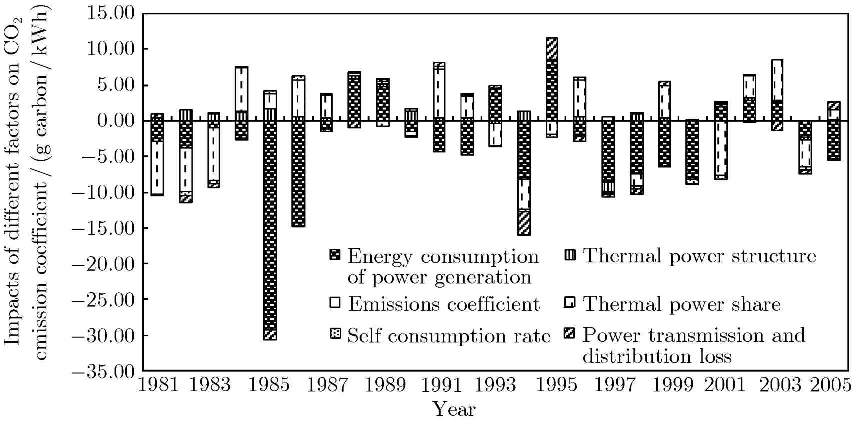


Figure 4.7 Change of CO_2 emission coefficient of power consumption of China in 1980—2005

[Data Source: China Statistical Yearbook]

power generation and thermal power share had larger impacts on the CO_2 emission coefficient, which is different from the above analysis.

From Figure 4.7, it is observed that:

(1) There is an obvious rule of impacts of thermal power structure on CO_2 emission coefficient of electricity consumption. In another word, apart from 1992—1993, 1994—1995, 1996—1997, and 2003—2004, CO_2 emission coefficient was distinctly increased in other years. It indicates that there is an increasing trend of coal-fired power share in China's thermal power structure, which is detrimental to the decrease of CO_2 emission coefficient.

(2) The impact of self consumption of power plants caused the increase of CO_2 emission coefficient during 1983—1992. But with the decrease of self consumption, CO_2 emission coefficient was lowered during 1996—2005. It shows that current descending self-use rate of electricity of power plants is favorable to the decrease of CO_2 emission coefficient.

(3) The share CO_2 of thermal power in power structure has a larger impact on CO_2 emission coefficient. During 1980—1984, 1986—1987, 1990—1991, 1995—1996, and 2000—2004, thermal power share had a decisive impact on the change of CO_2 emission coefficient of power consumption, with an average contribution rate of 104.09%. With the decrease of thermal power share during 1980—1983, 1988—1990, 1992—1995, 1997—1998, 2000—2001, and 2003—2004, its impact on CO_2 emission coefficient was lowered by 44.60g carbon/kWh. But in other years, CO_2 emission coefficient increased 47.22g carbon/kWh with the increase of thermal power share.

(4) Gross energy consumption rate of power generation also has a large impact on CO_2 emission coefficient. During 1985—1986, 1987—1990, 1991—1995, 1996—2000, and 2004—2005, gross energy consumption rate of power generation had a decisive impact on the change of CO_2 emission coefficient of electricity consumption, with an average contribution rate of 189.93%. In 1980—1987, 1989—1992, 1993—1994, 1995—2000, and 2003—2005, the decrease of gross energy consumption rate of power generation, especially the decrease of gross energy consumption rate of coal-fired power, data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook as shown in Figure 4.8, brought down the CO_2 emission coefficient of electricity consumption by 114.67g carbon/kWh, among which the decrease of gross energy consumption rate of coal-fired power contributed 103.80g carbon/kWh. But in other years, CO_2 emission coefficient increased 31.33g carbon/kWh with the increase of gross energy consumption rate of power generation(due to the increase of gross energy consumption rate of

coal-fired power, as shown in Figure 4.8), among which the increase of gross energy consumption rate of coal-fired power contributed 29.30g carbon/kWh. Therefore, it is of great importance for China to lower its gross energy consumption rate of power generation, especially that of coal-fired power in order to alleviate its CO_2 emissions.

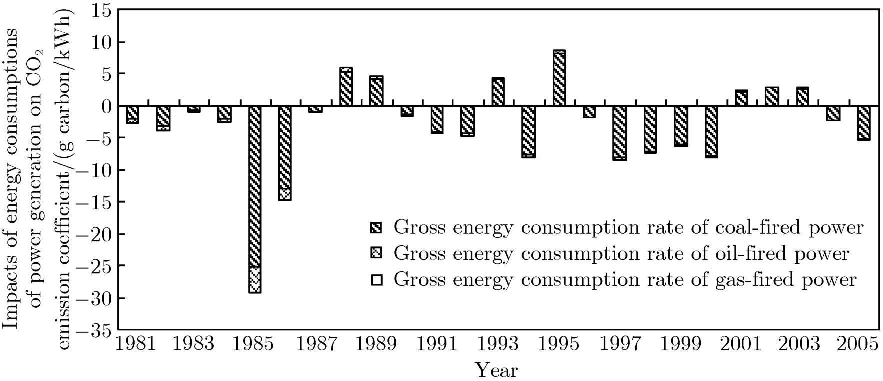


Figure 4.8 Impacts of different energy consumptions of power generation on CO_2 emission coefficient

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

(5) The CO_2 emission coefficient of power fuels has the least impact on that of electricity consumption. The impact of power transmission and distribution loss on CO_2 emission coefficient is reduced by 11.69g carbon/kWh during 1981—1988, 1989—1990, 1993—1994, 1995—1998, 1999—2000 and 2002—2004. But in other years, it increased by 7.37g carbon/kWh. Therefore, it is favorable to alleviate CO_2 emissions by cutting the loss of power transmission and distribution.

In spite of its descending trend of CO_2 emission coefficient of power generation and consumption in 1980—2005, China is still higher than some developed countries with regard to the CO_2 emissions of power generation per kilowatt-hour, data are prepared and calculated from SIMA of World Bank (2007) and shown in Figure 4.9. According to the data of IEA, the CO_2 emissions of power and heat per kilowatt-hour were 771g CO_2 in Chinese mainland, which was higher than the average level of the world and OECD countries and ranked the 22nd in the world.

Therefore, CO_2 emissions induced by great electricity demand will be higher in the future. If the growth rate of China's electricity demand is lower or close to its GDP growth rate, i.e. 5% or 8%, during 2005—2020, when its CO_2 emission coefficient reaches the average level of the world, OECD countries, non-OECD countries, Annex I countries, non-Annex I countries, US, Germany, and UK, i.e., China's CO_2 emission coefficient is reduced by 38.71%, 42.87%, 34.19%, 47.03%, 22.20%, 29.66%, 38.96% and 42.14% respectively (China's CO_2 emission coefficient of electricity was lowered by 20.99% during 1980—2005), China's CO_2 emissions of power generation will exceed 660 million and 930 million tons of carbon in 2020, data are prepared and calculated from SIMA of World Bank (2007) and Shown in Table 4.1, which will be higher than the emissions reduced by OECD countries in 2004 compared with 1990. Therefore, it will become the fundamental measures for the mitigation of China's CO_2 emissions from power generation and consumption by improving its economic growth and increasing its electricity utilization efficiency.

Table 4.1 CO_2 emissions of electricity consumption in China 2020

CO_2 emission coefficient level	5%/10,000 ton CO_2	8%/10,000 ton carbon
World	70845	108100
OECD countries	66037	100764
Non-OECD countries	76077	116084
Annex I countries	61229	93428
Non-Annex I countries	89935	137229
US	81309	124067
Germany	70562	107669
UK	66886	102059

Data Source: SIMA of World Bank (2007).

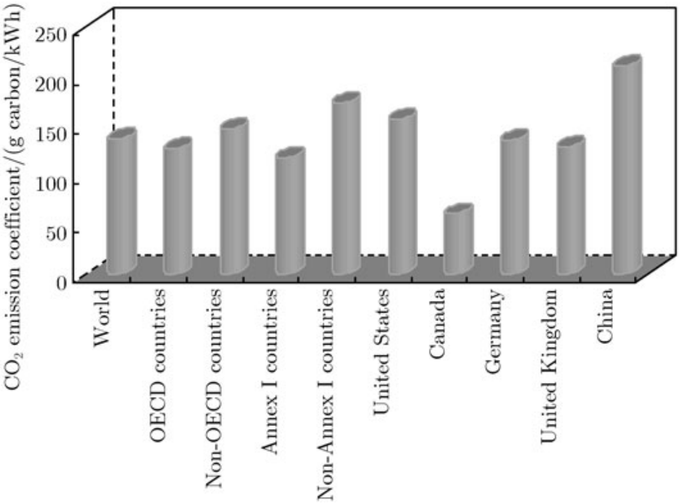


Figure 4.9 International comparison of the CO_2 emission coefficient of power and heat [Data Source: SIMA of World Bank (2007)]

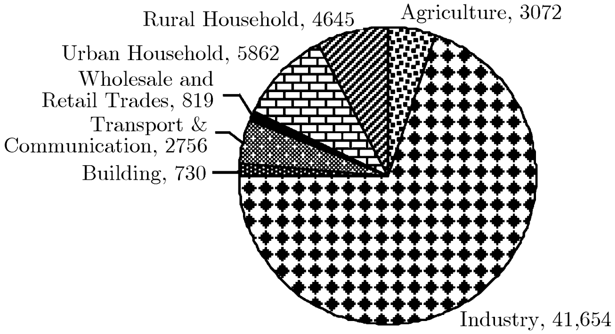
Through the above analysis, we come to the following conclusions: Power industry is the major production sector of CO_2 emissions in China. There was a rapid increase of CO_2 emissions from power generation during 1980—2005 in China. The CO_2 emissions from power generation accounted for 38.73% of total CO_2 emissions from fossil fuels in 2005. Furthermore, the increase of CO_2 emissions from power generation has a promoting role in the rise of total CO_2 emissions from fossil fuel utilization in China. During 1980—2005, the increase of CO_2 emissions of power sector had an average contribution of 49.86% to the increase of total CO_2 emissions from fossil fuel utilization in China. During 1998—1999 and 2000—2001, it was as high as 114.79% and 124.36% respectively. Therefore, it is an effective way to slow down the increase of CO_2 emissions by reducing the growth rate of CO_2 emissions from power generation in China.

Due to its high CO_2 emission coefficient of electricity, China must, on one hand, reduce its coal consumption of power generation by improving its power generation technology, while further lowering the proportion of thermal power especially that of coal-fired power, to decrease the CO_2 emission coefficient of power generation and consumption. On the other hand, because of the huge demand of electricity power in the future, it is necessary for China to mitigate the increase of CO_2 emissions from power generation and consumption by transforming its economic growth and increasing its electricity utilization efficiency.

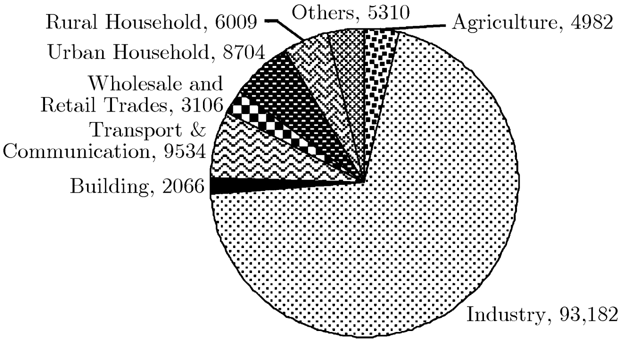
4.2 Study on characteristics of CO_2 emission change from final energy use

CO_2 emissions from the final energy use by material production sectors (Agriculture, Industry, Construction, Transport, Inventory and Post, Information Transmission, Computer Services and Software, Wholesale and Retail Trades, Hotels and Catering Services) are the greatest in amount, which were 490.32 million tons of carbon in 1990, accounting for 82.35% and 112.9 thousand tons of carbon in 2005, accounting for 84.93%, based on the data from China Energy Statistical Yearbook (1991) and (2006), the results are calculated and shown in Figure 4.10.

It can be seen from Figure 4.11 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.11) that the CO_2 emissions from material production sectors of China demonstrated an apparent growth trend during 1980—2005. CO_2 emissions increased by 118.25%, 264.83% and 485.88% from primary industry, secondary industry and tertiary industry respectively. The CO_2 emissions from secondary industry are apparently higher than those from primary industry or tertiary industry, indicating that the CO_2 emissions of China's material production sectors are mainly from secondary industry, occupying around 85%.



(a) In 1990 (10,000 ton carbon)



(b) In 2005 (10,000 ton carbon)

Figure 4.10 Sectional CO_2 emissions of China in 1990 and 2005

[Data Source: China Energy Statistical Yearbook (1991; 2006)]

Meanwhile, with technological progress and the increase of energy utilization efficiency, CO_2 emission intensity of material production sectors demonstrated a decline trend during 1980—2002. There was a drop of 77.94% in CO_2 emission intensity of secondary industry, which was more than that of primary industry at 35.39% or tertiary industry at 60.92%. However, CO_2 emission intensity rebounded by 5.17%, 12.80% and 11.16% respectively for primary industry, secondary industry and tertiary industry during 2002—2005. Furthermore, CO_2 emission intensity of secondary industry is apparently higher than that of primary industry and tertiary industry. In 2005, CO_2 emission intensity of those three industries was 1.09 tons of carbon/10,000RMB, 0.22 tons of carbon/10,000RMB and 0.17 tons of carbon/10,000RMB respectively. It shows that the decrease of CO_2 emission intensity of material production sectors of China is mainly caused by the decrease of CO_2 emission intensity of secondary industry.

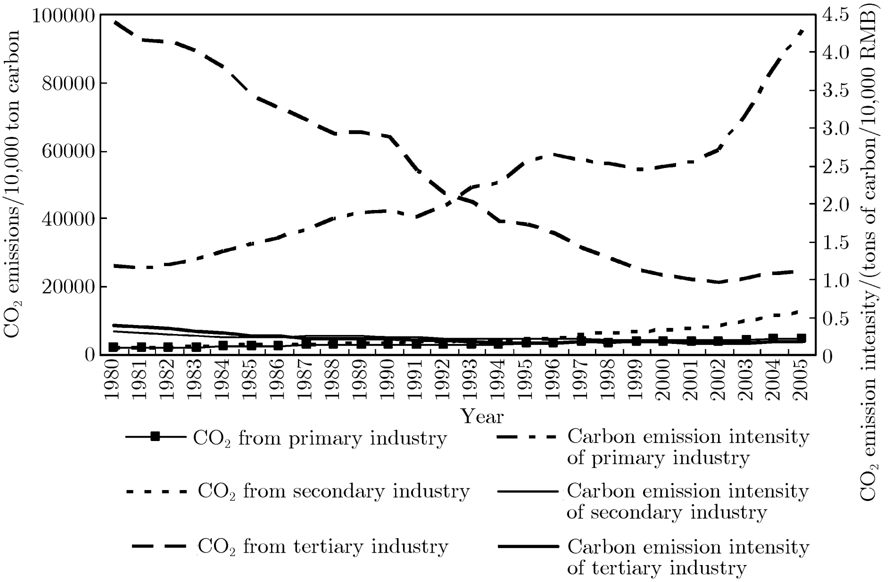


Figure 4.11 Changes of CO_2 emissions and its intensity of material production sectors in China in 1980—2005

[Data Source: China Energy Statistical Yearbook]

Therefore, with regard to the final energy use, this section has made an analysis on the change of CO_2 emissions and CO_2 emission intensity of the final energy use of China's material production sectors in the hope of finding impacts of China's industry structure, energy intensity, emission intensity and the structure of final energy use on CO_2 emissions and CO_2 emission intensity.

4.2.1 Method for analysis

Formula (4.5) is the decomposition of CO_2 emission intensity of the final energy use of material production sectors:

$$G_t = \frac{C_t}{Y_t} = \sum_{i=1}^{m}\sum_{j=1}^{n}\frac{C_{ijt}}{E_{ijt}}\frac{E_{ijt}}{E_{it}}\frac{E_{it}}{Y_{it}}\frac{Y_{it}}{Y_t} = \sum_{i=1}^{m}\sum_{j=1}^{n}R_{ijt}e_{ijt}I_{it}y_{it} \tag{4.5}$$

Formula (4.6) is the decomposition of CO_2 emissions of the final energy use of material production sectors:

$$C_t = \sum_{i=1}^{m}\sum_{j=1}^{n}C_{ijt} = \sum_{i=1}^{m}\sum_{j=1}^{n}Y_t\frac{Y_{it}}{Y_t}\frac{E_{it}}{Y_{it}}\frac{E_{ijt}}{E_{it}}\frac{C_{ijt}}{E_{ijt}} \tag{4.6}$$

Here, G_t represents the CO_2 emission intensity of the final energy use of material production sectors; Y_t refers to total value added of material production sectors, namely Agriculture, Industry, Construction Industry, Transportation, Inventory and Post, Wholesale and Retail Trades, Hotels and Catering Services; C_t refers to the CO_2 emissions from the final energy use of material production sectors; C_{ijt} refers to CO_2 emissions from energy consumption of category j energy of sector i; E_{ijt} refers to energy consumption of category j energy of sector i; E_{it} refers to final energy use of sector i; Y_{it} refers to value added of sector i; I_{it} refers to energy intensity of sector i; e_{ijt} refers to proportion of category j energy in the final energy use of sector i; R_{ijt} refers to CO_2 emission coefficient of category j energy consumption of sector i; y_{it} is proportion of the value added of sector i; m is the category of final energy use, including raw coal, cleaned coal, other washed coal, coke, coke oven gas, other coal gas, other coking products, crude oil, diesel oil, kerosene, gasoline, fuel oil, LPG, dry refinery gas, other petroleum products, natural gas, heat, power, etc.; n is Material production sectors, including primary industry (Agriculture), secondary industry (Industry and Construction), and tertiary industry (Transport, Storage and Post, Wholesale and Retail Trades, Hotels and Catering Services).

Data of coal products, petroleum products, natural gas, power and heat are derived from "*China Energy Statistical Yearbook*": 1989, 1991, 1991—1996, 1997—1999, 2004, 2005 and 2006. Data of power transmission and distribution losses are collected from "*China Statistical Yearbook 2005*". Material production sectors refer to primary industry, secondary industry and some tertiary industry sectors (transportation and communication, warehousing, post and telecommunication, wholesale and retail trade, catering industry, etc). Their value added are calculated on the basis of the indicators of comparable prices and presented at constant 2005 prices.

Since the time range considered is limited to 1980—2005, we assume that the CO_2 emission coefficients of different kinds of energy (coal, oil, natural gas, etc.) are constant. As a matter of fact, all these CO_2 emission coefficients have changed, but limited to subtle change which is negligible during our analysis of macro-change. But the change of CO_2 emission coefficient of electricity is available. Due to the change of power generation fuel structure (coal, oil, natural gas, water power, nuclear energy, etc.) and the technological progress from year to year, there have been significant changes in the CO_2 emission coefficients of power and heat.

4.2.2 CO_2 emission intensity in material production sector

On the basis of Formula (4.5) and by means of LMDI method, we made a computational analysis on the change of CO_2 emission intensity of the final energy use of China's material production sectors during 1980—2005.

During 1980—2005, the decline of energy intensity resulted in the decrease of CO_2 emission intensity of material production sectors by 1.39 tons of carbon/10,000RMB, the change of industry structure brought an increase of 0.24 tons of carbon/10,000RMB, the change of the structure of final energy use contributed 0.15 tons of carbon/10,000RMB, and 0.04 tons of carbon/10,000RMB were reduced by the change of CO_2 emission coefficient. As a result, the CO_2 emission intensity of China's material production sectors decreased by 1.03 tons of carbon/10,000RMB during 1980—2005, as shown in Table 4.2.

Table 4.2 Impacts of different factors on material production sectors' CO_2 emissions in 1980—2005

Time/year	CO_2 emission intensity	Impact of industry structure	Impact of energy intensity	Impact of energy consumption structure	Impact of CO_2 emission coefficient
1980—1985	–0.4239	–0.0611	–0.3701	0.0317	–0.0244
1985—1990	–0.1346	0.0592	–0.2352	0.0333	0.0081
1990—1995	–0.2543	0.1838	–0.4808	0.0474	–0.0047
1995—2000	–0.2611	0.0317	–0.3039	0.0245	–0.0133
2000—2002	–0.0427	0.0030	–0.0607	0.0169	–0.0019
2002—2005	0.0846	0.0186	0.0654	0.0003	0.0004
1980—2005	–1.0319	0.2352	–1.3853	0.1541	–0.0359

Note: in unit of "tons of carbon/10,000RMB".

The change of energy intensity had decisive impacts on that of CO_2 emission intensity, based on the data from the China Statistical Yearbook and China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.12. shown in Figure 4.12. During 1980—2002, CO_2 emission intensity of China's material production sectors demonstrated a dramatic decline, and energy intensity contributed over 80% to the decrease of CO_2 emission intensity. But during 2002—2005, CO_2 emission intensity was rising, with energy intensity contributing over 37% to the rebounce of CO_2 emission intensity. Over 70% of the impact of energy intensity on CO_2 emission intensity was caused by the change of the energy intensity of secondary industry, as shown in Figure 4.13. During 1980—2005, the change of energy intensity resulted in a decrease of 1.38 tons of carbon/10,000RMB in CO_2 emission intensity, among which the impacts of primary industry, secondary industry and tertiary industry were 0.04 tons of carbon/10,000RMB, 1.27 tons of carbon/10,000RMB and 0.08 tons of carbon/10,000RMB respectively. Therefore, the change of energy intensity of secondary industry played a decisive role in the changes of CO_2 emission intensity of China's material production sectors.

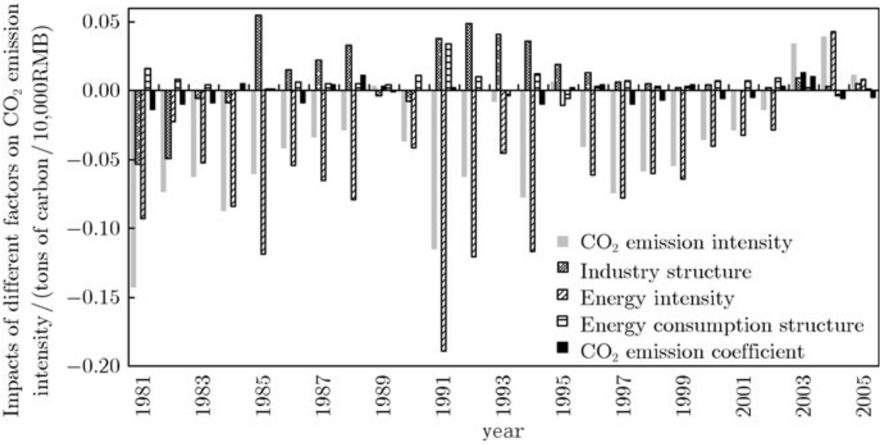


Figure 4.12 Impacts of factors on the CO_2 emissions of material production sectors during 1980—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

Changes of industry structure and the structure of final energy use are not good for the decline of CO_2 emission intensity by offsetting partial impacts of energy intensity, based on the data from the China Statistical Yearbook and China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.13. This is because secondary industry occupies a proportion that increases every year in the value added of material production sectors:

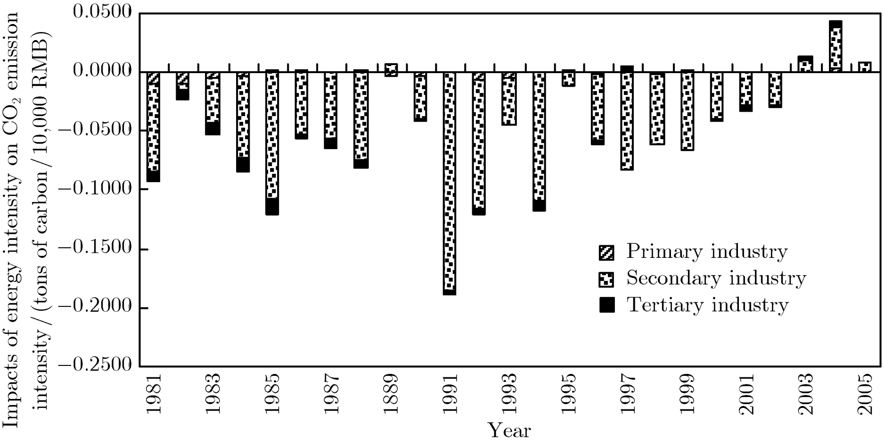


Figure 4.13 Impacts of energy intensity of material production sectors on the CO_2 emission intensity during 1980—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

32.04% in 1980, 47.54% and 15.50 percentage points up in 2005. Furthermore, the proportion of electricity in final energy use structure is increasing year by year. Since China's power mainly consists of thermal power, its CO_2 emission coefficient is far higher than that of coal. Thus, the structure of final energy use is developing towards carbon-intensive energy. The proportions of electricity in the final energy use in primary industry, secondary industry and tertiary industry were 12.58%, 8.81% and 1.68% respectively in 1980, and 18.54%, 21.08% and 7.88% respectively in 2005, increasing 5.96%, 12.27% and 6.20% respectively.

The impact of CO_2 emission coefficient is relatively small, as shown in Figure 4.13. The impact of CO_2 emission coefficient on CO_2 emission intensity is mainly embodied in that of CO_2 emission coefficient of electricity, causing the overall slowdown of the speeding-up of CO_2 emissions.

Therefore, the decline of CO_2 emission intensity is mainly a result of the drop of energy intensity in China. However, further decline of future CO_2 emission intensity should not be dependent on that of energy intensity only. The adjustment of the final energy use structure and industry structure, in particular that of product mix as well as the final energy use of secondary industry will greatly promote the decrease of CO_2 emission intensity.

4.2.3 CO_2 emissions in material production sector

On the basis of Formula (4.6) and by means of LMDI method, we made a computational analysis on the change of CO_2 emission intensity of the final energy use of China's material production sectors during 1980—2005.

According to Table 4.3 and Figure 4.14 (Based on the data from the China Statistical Yearbook and China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.14 and Table 4.3), energy intensity and value added are two determinative factors for the CO_2 emission increase of China's material production sectors. The value added brought about the increase of CO_2 emissions during 1980—2005 while energy intensity especially that of secondary industry led to the decrease of CO_2 emissions (as shown in Figure 4.15) during 1980—2002. Its impact was gradually growing during 1980—1995, but gradually shrinking during 1995—2002. However, CO_2 emissions increased during 2002—2005.

During 1980—2005, the increase of the added of value various industries caused an increase of 1.277 billion tons of CO_2 emissions. And the change of industry structure brought an increase of 181 million tons CO_2 emissions; the change of the structure of final energy use brought an increase of 89

Table 4.3 Changes of CO2 emissions in material production sectors in China during 1980—2005

Time/year	Emissions change	Impact of industry structure	Impact of energy intensity	Impact of energy consumption structure	Impact of CO2 emission coefficient
1980—1985	7682.50	–749.18	–9107.05	656.53	–414.74
1985—1990	10801.94	2107.24	–8845.32	1315.14	365.94
1990—1995	15776.99	10583.52	–26224.33	2337.76	–336.25
1995—2000	2148.99	2869.99	–28865.00	2414.25	–1334.52
2000—2002	6137.83	395.12	–7660.14	2149.41	–195.64
2002—2005	39774.05	2902.92	10331.20	37.96	–158.65

Unit: 10,000 tons of carbon.

Data Source: China Statistical Yearbook and China Energy Statistical Yearbook.

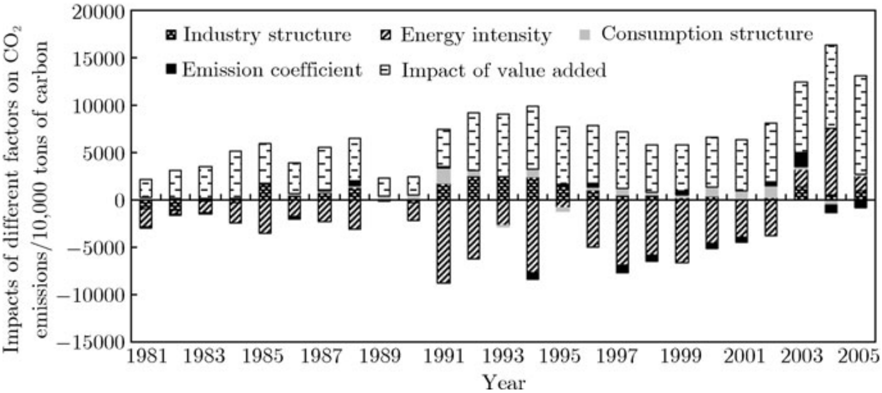


Figure 4.14 CO2 emissions of China's three industries in 1981—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

million tons of carbon. In total, an increase of 1.548 billion tons of carbon was achieved. However, the decrease of energy intensity resulted in 704 million tons of CO2 emission reduction. The dropping CO2 emission coefficient caused a decrease of 21 million tons of carbon. Therefore, the CO2 emissions of China's material production sectors had an increase of 823 million tons in total.

Furthermore, according to Table 4.3, the increase of CO2 emissions from the final energy use was mainly during 2002—2005, which accounted for 48.32% of the total increase during 1980—2005. The determinative factor was the increase of economic growth and energy intensity. During 2002—2005, the rise of the value added of material production sectors resulted in a CO2 emission increase of 267 million tons. Its impact on CO2 emissions was 20.87% of that of 1980—2005. The impact of energy intensity variation (mainly the increase of energy intensity of secondary industry, based on the data from the China Statistical Yearbook and China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.15) was that CO_2 emissions increased by 103 million tons of carbon.

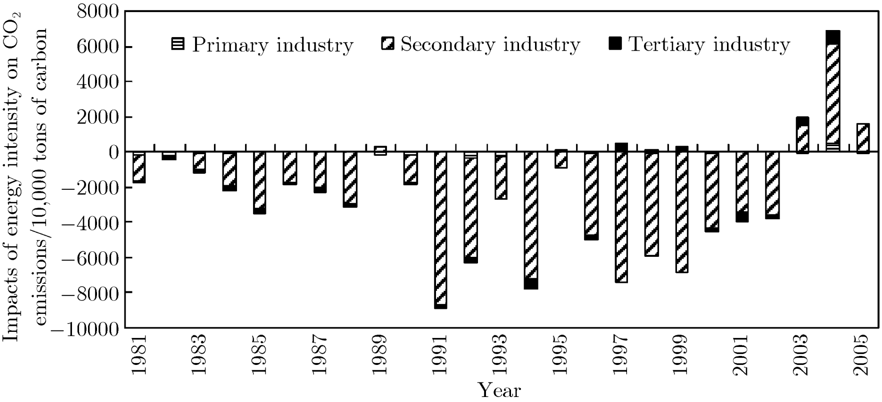


Figure 4.15 Impacts of energy intensity of material production sectors in China on the CO_2 emissions during 1980—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

The above analysis indicates that China's industry structure and energy consumption structure were developing towards carbon-intensive during 1980—2005, and that economic development will certainly result in the increase of CO_2 emissions. Though energy intensity can alleviate the increase of CO_2 emissions to some extent, its impacts are subject to the change of the energy intensity of secondary industry. Based on the above analysis, we come to the following conclusions:

(1) Energy intensity is the determinative factor for the change of CO_2 emission intensity of the final energy use in material production sectors. During 1980—2002, the CO_2 emission intensity of China's material production sectors showed a dramatic decline, and energy intensity contributed over 80% to the decrease of CO_2 emission intensity. But during 2002—2005, CO_2 emission intensity was rising, with energy intensity contributing over 37% to the rebounce of CO_2 emission intensity. However, there is a rising trend of CO_2 emissions from material production sectors because of economic development. Nevertheless, CO_2 emissions reduction should not be achieved by lowering the economic growth rate. We must slow down the emission increase by decreasing CO_2 emission intensity.

(2) Changes of industry structure and structure of final energy use are not for the decline of CO_2 emission intensity by offsetting partial impacts of energy intensity. It indicates that it is necessary to adjust the structure

of final energy use and industry structure of material production sectors, in particular secondary industry. Two major policies and measures have been provided for such adjustment:

① Adjustment of product mix: Some macro-control policies are adopted by the government to guide household consumption behaviors in their transition towards non-energy- intensive/carbon-intensive so as to lower the demand on energy-intensive/carbon- intensive products. On the other hand, the government may consider the export guidance on energy-intensive/carbon-intensive products, or the proper import increase of such products, or the transfer of partial production of such products.

② Provide support for the production and sale of energy-conserving products by improving manufacturing facilities, raising energy efficiency, lowering the energy consumption per unit product, carrying out preferential taxation and monetary policies, etc.

(3) The emissions from electricity has a great promotional role in the decline of CO_2 emission intensity of material production sectors. With the technological advances of power generation, the reduction of gross coal consumption for power generation, the shutdown of small sized thermal power plant as well as the development and utilization of hydropower and nuclear power, the emissions of electricity still has a great potential contribution to the decrease of CO_2 emission intensity in the future.

To sum up, though there has been a large decrease of CO_2 emission intensity in recent years in China, there is still a large room for China's CO_2 emission intensity to decline with its economic development. Through our analysis, it can be determined that future analysis on the decline of China's CO_2 emission intensity should be mainly concentrated on that of energy intensity, in particular the change characteristics of energy intensity of different sectors of secondary industry and their CO_2 emission intensity, so as to find out the way secondary industry has been developing towards carbon-intensive type in recent years. It will play an important role in further lowering future CO_2 emission intensity of China.

4.3 Study on characteristics of CO_2 emissions change from final energy use in industry sector

4.3.1 Current status of CO_2 emissions in industry sector

The industrial sector is an energy-intensive sector, energy consumption of which accounts for about 40% of global energy use (Price et al., 2000). China's industrial end energy consumption alone accounts for 5.60% of the total global industrial end energy use in 2004 (IEA, 2007a). Figure 4.16 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.16) shows that during 1980—2005, final energy use of China's industrial sector occupied over 60% of its total final energy use, over 50% of its total coal consumption and over 70% of its total power consumption. However, its value added only accounted for 36%—53% of China's GDP (constant 1990 RMB). Furthermore, thermal power generation occupies about 80% of China's power generation.

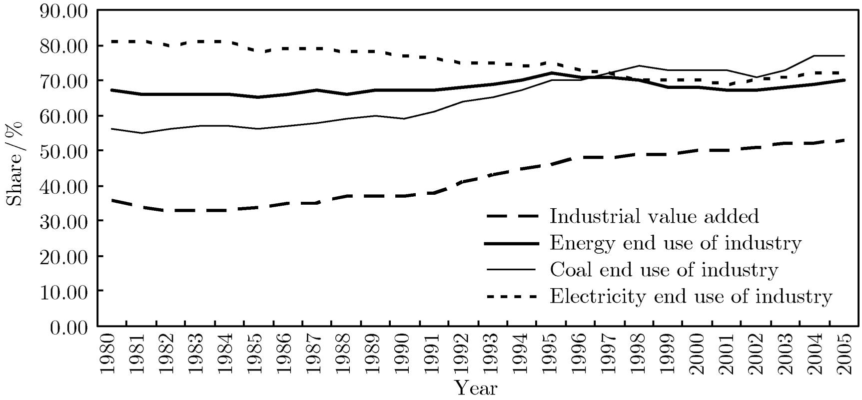


Figure 4.16 Change of the shares of secondary industry in the end use of energy, coal, power and GDP

[Data Source: China Energy Statistical Yearbook]

Figure 4.17 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.17) shows that during 1999—2005, final energy use and CO_2 emissions of China's industrial sector

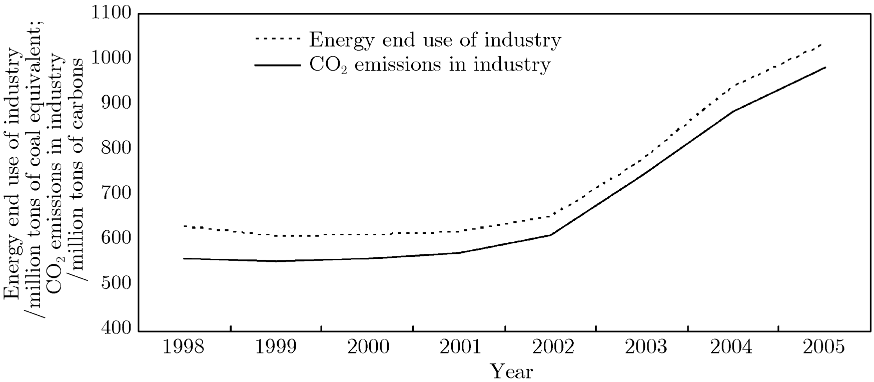


Figure 4.17 Final energy use and CO_2 emissions of the secondary industry during 1998—2005

[Data Source: China Energy Statistical Yearbook] increased rapidly, especially during 2002—2005 when the increase rate reached 52% and 60% respectively. But, which industrial sectors should be responsible for final energy use increase and what is the reason?

Therefore, the industrial sector is one of the major sectors of China's CO_2 emissions. We find it's necessary to make analysis on the change of its emissions, which is very important for the plan of future energy strategies and CO_2 emission reduction strategies.

This section analyzes impacts of different impact factors on the change of CO_2 emissions of China's industrial sector during 1998—2005. Its purpose is to find out those factors that have mainly boosted the change of CO_2 emissions from China's industry as well as impacts of the change of power consumption on industrial CO_2 emissions.

4.3.2 Method for analysis

(1) The factors that influence CO_2 emissions from the final energy use in the industrial sector are decomposed as in Formula (4.7).

$$C=\sum_{ij}C_{ij}=\sum_{ij}Q\frac{Q_i}{Q}\frac{E_i}{Q_i}\frac{E_{ij}}{E_i}\frac{C_{ij}}{E_{ij}}=\sum_{ij}QS_iI_ie_{ij}R_{ij} \tag{4.7}$$

Here, Q refers to value added of industrial sector; C refers to CO_2 emissions from final energy use of material production sectors; C_{ij} refers to CO_2 emissions of energy j in sector i; E_{ij} refers to the use of energy j in sector i; E_i refers to final energy use in sector i; Q_i refers to value added of sector i; I_i refers to energy intensity of sector i; e_{ij} refers to the proportion of energy j in final energy use of sector i; R_{ij} refers to CO_2 emission coefficient of the use of energy j in sector i; S_i refers to the proportion of value added of sector i.

(2) Data.

Since 1998, China has been using the statistics on wholly state-owned industrial enterprises and non-state-owned industrial enterprises with annual sales revenue of over 5 million RMB in respect of its industry statistics. Therefore, official statistics will help little in forming long time series data of industrial sector. So, we calculated value added of various industrial sectors on the basis of price indices of different industrial sectors and their value added during 1998—2005 with the presentation in constant 2001 price. This section makes analysis on 36 industrial sectors.

Therefore, the change of CO_2 emissions of China's industrial sector during 1998—2005 was analyzed. Data of final energy use, including raw coal, cleaned coal, other washed coal, coke, coke oven gas, other gases, other char products, crude oil, diesel oil, kerosene, gasoline, fuel oil, LPG, dry refinery gas, other petroleum products, natural gas, heat, power, etc., are sourced from "*China Energy Statistical Yearbook*" (the National Bureau of Statistics, 2001, 2006 and 2007).

Since the time span considered is limited to 1998—2005, we assume that different kinds of energy (coal, petroleum, natural gas, etc.) have constant CO_2 emission coefficients. As a matter of fact, all these CO_2 emission coefficients have changed, but limited to subtle change which is negligible during our analysis of macro-change. But the changes of CO_2 emission coefficient of power and heat are available. Due to the changes of fuel structures (coal, oil, natural gas, water power, nuclear energy, etc.) for power generation and heat supply as well as the technological progress from year to year, there have been significant changes in the CO_2 emission coefficients of power and heat.

4.3.3 Analysis of CO_2 emissions change in industry sector

Based on the LMDI method, we made analysis on the impact of different factors on the change of China's industrial CO_2 emissions during 1998—2005.

Table 4.4 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Table 4.4) shows that during 1998—2005, there was an increase of 420.15 million tons of CO_2 emissions from China's industry. The number was 249.20 million from its manufacturing of chemical raw materials and products, manufacturing of non-metallic mineral products, and smelting and pressing of ferrous metals. Contribution of these three sectors on the total increase of industrial CO_2 emissions was 59.31%. This is because that high investment stimulated the product demand of these sectors. During 2002—2005, investment contributed an average rate of 40%

Table 4.4 Impact of different factors on CO_2 emissions of industrial sectors in China

Time/year	Change of industrial CO_2 emissions	Impact of activity	Impact of industrial energy intensity	Impact of fuel mix	Impact of CO_2 emission coefficient	Impact of structure shift
1998—1999	–7.50	38.70	–61.24	8.16	3.92	2.96
1999—2000	5.94	40.77	–32.11	10.22	–4.93	–8.01
2000—2001	11.14	54.76	–48.20	8.74	–5.10	0.95
2001—2002	41.95	63.22	–25.50	8.41	2.45	–6.64
2002—2003	129.58	88.19	24.59	–1.87	12.62	6.05
2003—2004	143.16	135.29	44.21	0.65	–8.14	–28.85
2004—2005	95.89	63.14	10.64	8.73	–6.59	19.96
1998—2005	420.15	484.07	–87.61	43.05	–5.78	–13.58

Unit: million metric tons of carbon.

Data Source: China Energy Statistical Yearbook.

to China's economic growth, apparently higher than other countries. And over 60% of the investment came from that in the construction industry.

The industrial activity level was the major factor for carbon emissions increase of the sector. During 1998—2005, the rise of value added in the industrial sector led to an increase of 484.07 million tons of industrial CO_2 emissions. And its impacts keep increasing from 1998 to 2004. Meanwhile, the change of final energy use also contributed to the increase of industrial CO_2 emissions. During 1998—2005, 43.05 million tons of carbon were added.

Final energy use intensity of industry, structure share, CO_2 emission coefficient of heat and power reduced CO_2 emissions by 87.61 million and 13.58 million tons of carbon respectively during 1998—2005. However, during 1998—2002, there was a trend of industrial emissions decrease due to the decrease of final energy use intensity of industry, which caused the increase of CO_2 emissions during 2002—2005 on the contrary.

1) Impacts of energy intensity on industrial CO_2 emissions

Real energy intensity was the most important impact factor for the CO_2 emissions reduction in the industrial sector during 1998—2002. It is because that energy intensity of almost all the industrial sectors has dropped. During 2002—2005, industrial CO_2 emissions were increased by industrial final energy use intensity because of the rebounce of energy intensity of heavy industry sectors.

Figure 4.18 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.18) shows that among the 87.61 million tons of carbons reduced by industrial final energy intensity, 49.30% or 43.19 million were caused by the energy intensity change of the manufacturing of chemical raw materials and products, the manufacturing of non-metallic mineral products, and the smelting and pressing of ferrous metals. These three sectors are energy-intensive sectors since their final energy use accounted 50% of industrial final energy use while their value addedonly occupied 14%—17% of the industrial sector during 1998—2005. However, energy intensity of these sectors declined by 29%, 19% and 24% respectively during 1998—2004.

However, an increase of 33.93 million tons (among which 24.06 million tons were due to the change of energy intensity of coal mining and dressing and petroleum and natural gas extraction) of carbon was achieved by the energy intensity of the six industrial sectors: exaction of oil and natural gas, mining and processing of non-ferrous metals ores, mining and processing of non-metal mineral ores, manufacture of plastic products, tap water production and supply, petroleum processing and coking. This offset the CO_2 emission reduction of three energy-intensive sectors by 78.56%.

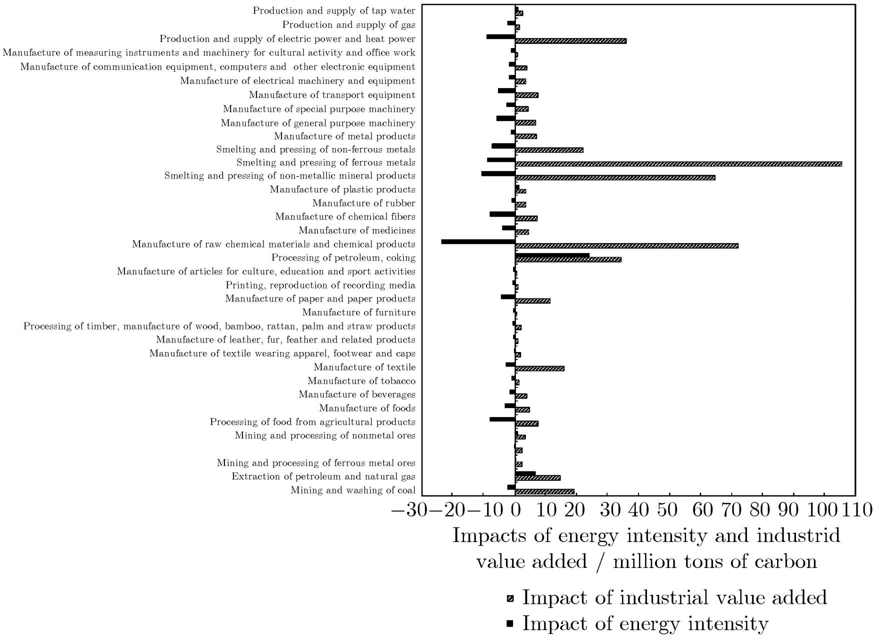


Figure 4.18 Impacts of the economic development of industry and energy intensity change on CO_2 emissions of industry during 1998—2005

Though there has been a dramatic decline of energy intensity in many industrial sectors, there is still a large room for its decline, especially in energy-intensive sectors. Compared with international advanced levels, China lags behind in the production process, technology and management level of these sectors. Energy-intensive sectors have been playing a major role in the infrastructure construction in China. Therefore, in order to further boost the decline of energy intensity, we need to update and improve production processes, enhance energy efficiency and replace fossil fuels with clean fuels in these sectors.

2) Impact of industrial activity on CO_2 emissions in industrial sector

The increase in industrial activity is the most important factor that boosts the rapid increase of industrial CO_2 emissions in China. Industrial economic growth caused the increase of industrial CO_2 emissions by 38.70, 40.77, 54.76, 63.22, 88.18, 135.29 and 63.15 million tons of carbon respectively during 1998—1999, 1999—2000, 2000—2001, 2001—2002, 2002—2003, 2003—2004, and 2004—2005. Figure 4.18 shows that the industrial CO_2 emissions increased by 318.03 million tons of carbon with the economic growth in sectors of production and supply of electricity, steam and hot water, smelting and pressing of ferrous metals, manufacture of non-metallic mineral products, smelting and pressing of non-ferrous, manufacture of raw chemical materials and chemical products, processing of petroleum, coking. It accounted for 65.70% of the CO_2 emissions increase with the economic development of all industrial sectors, indicating that we can slow down industrial CO_2 emissions by lowering the growth speed of economic development in some sectors, in particular by decreasing products export from those energy-intensive sectors, properly increasing and diversifying the import sources. However, we can hardly change the role of industrial economic growth in rising CO_2 emissions, since no country would be willing to reduce CO_2 emissions by sacrificing its economic development. Therefore, as the second largest country of CO_2 emissions, China is facing a challenge of how to coordinate the development relationship among all sectors within industry in its efforts to achieve the slow increase of CO_2 emissions and the sustainable development of its economy.

3) Impacts of CO_2 emission coefficient on industrial CO_2 emissions

Impacts of CO_2 emission coefficient on industrial CO_2 emissions refer to the influences of CO_2 emission coefficients of power and heat. Figure 4.19 shows that impacts of CO_2 emission coefficient on industrial CO_2 emissions were the least ones, mainly because of the little change of CO_2 emission coefficients of power and heat. China's power generation mainly consists of thermal power generation, while over 75% of power was generated by coal during 1998—2005.

Therefore, it is favorable to alleviate industrial CO_2 emissions by enhancing power generation technology, reducing gross coal consumption rate for power generation, raising the share of power generation with renewable energy such as hydro-power, nuclear power and biomass power, and cutting power waste.

4) Impact of industry structure shift on industrial CO_2 emissions

Table 4.4 shows that the change of industry structure helped reducing industrial CO_2 emissions during 1999—2000, 2001—2002 and 2003—2004, and increased CO_2 emissions during 1998—1999, 2000—2001, 2002—2003 and 2004—2004. It shows that impacts of industry structure on CO_2 emissions were changing without obvious rules during 1998—2005. Meanwhile, the impacts were relatively small, indicating that industry structure change had small impacts on the alleviation of industrial CO_2 emissions during 1998—2005. Figure 4.19 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.19) shows that structural change of industrial sectors towards non-heavy industry sectors reduced 75.93 million tons of carbon, accounting for 35.14% of CO_2 emissions reduction of the industrial sector. However, the change of some heavy industry sectors, e.g. the share rise of value added of ferrous metals smelting and pressing, non-ferrous smelting and pressing, etc in the industrial values added led to the increase of industrial CO_2 emissions by 56.21 million tons of carbon.

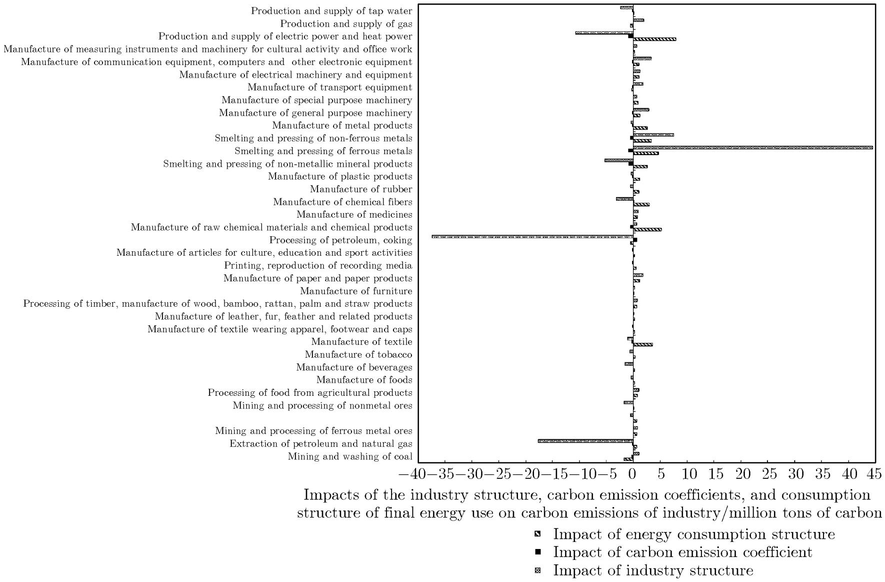


Figure 4.19 Impacts of the industry structure, CO_2 emission coefficient, and consumption structure of final energy use on CO_2 emissions of industry

[Data Source: China Energy Statistical Yearbook]

5) Impact of the final energy use mix on the change of industrial CO_2 emissions

Figure 4.20 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Figure 4.20) shows that CO_2 emissions per unit energy use of China's industrial sector were increasing during 1998—2003 and decreasing during 2003—2005, indicating that final energy use of industry was changing towards carbon-intensive during 1998—2003 but towards low-carbon during 2003—2005. This is because the increase of power demand was higher than that of other kinds of energy such as coal, petroleum products, etc. during 1998—2003, while the demand on coal was higher than that of power, petroleum products, etc. during 2004—2005. Furthermore, CO_2 emission coefficient of electricity is apparently higher than that of coal.

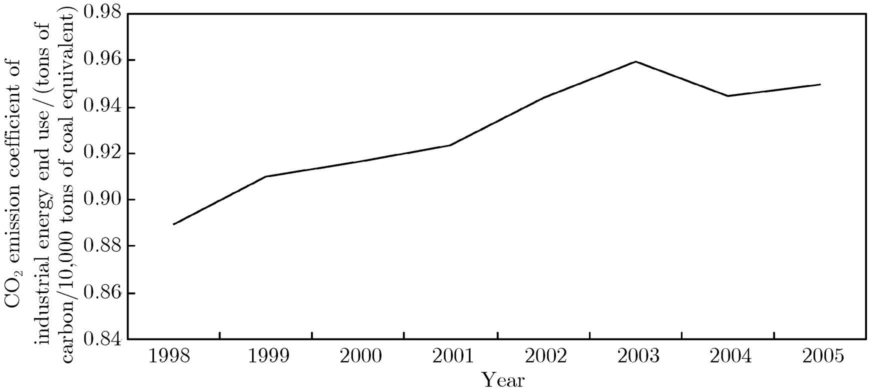


Figure 4.20 CO_2 emissions per unit of final energy use in industrial sectors over the period 1998—2005

[Data Source: China Energy Statistical Yearbook]

Table 4.4 shows that the final energy use structure of industry sector helped to increase the industrial CO_2 emissions. Since the coal share lowered while power share rose in the structure of final energy use in 32 industrial sectors, as shown in Figure 4.19. It can be seen from Table 4.5 (Based on the data from China Energy Statistical Yearbook, the results are calculated and shown in Table 4.5) that the change of coal and power shares had large impacts on industrial CO_2 emissions. Due to the decline of coal share, industrial carbon emissions were reduced. And CO_2 emissions increased with the change of power share as a result of higher CO_2 emission coefficient. However, whether the replacement of coal with power can reduce CO_2 emissions or not depends on whether higher power utilization efficiency can offset its higher CO_2 emission coefficient. Therefore, to lower the CO_2 emission coefficient of power is favorable to the alleviation of CO_2 emission growth.

Table 4.5 Impacts of final energy use structure shift of industry sector on CO_2 emissions

Time/year	Impact of coal share change	Impact of coke share change	Impact of petroleum products share change	Impact of natural gas share change	Impact of heat share change	Impact of electricity share change
1998—1999	–11.23	2.30	–0.16	0.96	3.02	13.27
1999—2000	–10.64	–0.19	1.18	0.42	2.31	17.13
2000—2001	–8.35	2.02	–1.22	0.68	1.65	13.95
2001—2002	–11.08	4.26	1.68	–0.14	–0.65	14.33
2002—2003	13.53	–6.38	–4.23	0.57	–4.07	–1.29
2003—2004	8.89	–1.30	–3.00	–0.43	–4.20	0.69
2004—2005	–12.75	10.47	–4.91	1.26	4.69	9.97

Data Source: China Energy Statistical Yearbook.

Through the above analysis, we come to the following conclusions:

(1) Industrial economic growth and industrial final energy use intensity are the most important factors on the change of industrial CO_2 emissions in China during 1998—2005. Industrial economic growth brought about an increase of 484.07 million tons of carbon during 1998—2005 and the impact was increasing year after year during 1998—2005. The change of industrial final energy use intensity reduced CO_2 emissions by 167.05 million tons during 1998—2002, but increased by 79.44 million during 2002—2005. As a result, CO_2 emissions of China's industrial sector were rapidly increasing during 2002—2005. The decline of energy intensity in heavy industry sectors is of great significance to the alleviation of industrial CO_2 emission increase.

(2) During 1998—2005, the change of industrial structure also contributed to the alleviation of industrial CO_2 emission increase in China during 1998—2005. And 35.14% of the industrial CO_2 emission reduction was caused by the change of industrial structure. However, the structural shift of smelting and pressing of ferrous metals and non-ferrous metals sectors, etc led to the rise of industrial CO_2 emissions by 56.21 million tons of carbon. Therefore, the CO_2 emission increase in these energy-intensive sectors should be firstly slowed down. The development of low-CO_2 emission sectors should be encouraged. And the share of value added of carbon-intensive sectors in industrial value added should be maintained or lowered by reducing their product exports and properly increasing imports.

4.4 Conclusion

This chapter makes a quantitative analysis on the change of CO_2 emissions and CO_2 emission intensity from power generation and consumption, final energy use on material production sectors and industrial sectors. From the analysis we found that:

(1) Power generation is a major sector of CO_2 emissions in China. There was a rapid increase of CO_2 emissions from power generation during 1980—2005 in China. CO_2 emissions from power generation accounted for 38.73% of the total CO_2 emissions from fossil fuels in 2005. Furthermore, the increase of CO_2 emissions from power generation has played a boosting role in the rise of total CO_2 emissions from fossil fuels in China. In 1980—2005, the increase of CO_2 emissions from China's power sector had an average contribution of 49.86% to the increase of total CO_2 emissions of fossil fuels. During 1998—1999 and 2000—2001, the contribution of CO_2 emissions from the power sector to the total CO_2 emissions increase from fossil fuels was

as high as 114.79% and 124.36% respectively. Therefore, it is an effective measure to slow down the increase of CO_2 emissions by reducing the growth rate of CO_2 emissions from power generation in China. China must reduce its coal consumption for power generation by enhancing its power generation technology, while further lowering the proportion of thermal power especially that of coal-fired power, in its efforts to bringing down the CO_2 emission coefficient of power generation and consumption. On the other hand, the huge demand on electricity in the future makes it necessary for China to alleviate the increase of CO_2 emissions from power generation and consumption by transforming its economic growthpattern and promoting the efficiency of electricity utilization.

(2) Energy intensity is the determinative factor for the change of CO_2 emission intensity from final energy use in material production sectors. During 1980—2002, CO_2 emission intensity of China's material production sectors demonstrated a dramatic decline, and energy intensity contributed over 80% to the decrease of CO_2 emission intensity. But during 2002—2005, CO_2 emission intensity was rising, with energy intensity contributing over 37% to the rebounce of CO_2 emission intensity. Despite all this, due to the economic growth, CO_2 emissions from material production sectors demonstrated an ascending trend. Since the economic growth rate should not be cut to reduce CO_2 emissions, CO_2 emission intensity should be further lowered to alleviate the increase of CO_2 emissions. Furthermore, the results of analysis on CO_2 emission intensity change and CO_2 from the final energy use in material production sectors show that: Changes of industrial structure and final energy use structure are not good for the decline of CO_2 emission intensity by offsetting partial impacts of energy intensity. This indicates that it is necessary to adjust industrial structure and final energy use structure of material production sectors, in particular secondary industry.

(3) Industrial growth and the final energy use intensity of industry were the most important impact factors for the change of China's industrial CO_2 emissions during 1998—2005. Industrial growth added 484.07 million tons of CO_2 emissions during 1998—2005, and its impacts kept increasing during 1998—2004. The change of final energy use intensity of industry reduced CO_2 emissions by 167.05 million tons during 1998—2002, but increased by 79.44 million tons during 2002—2005. As a result, CO_2 emissions from China's industrial sector were rapidly increasing during 2002—2005. The energy intensity decline of heavy industry sectors is of great significance to the alleviation of industrial CO_2 emission increase.

During 1998—2005, the change of industrial structure also contributed to the alleviation of industrial CO_2 emission increase in China during 1998—2005. And 35.14% of the CO_2 emission reduction in the industrial sector was caused by the change of industrial structure. However, the share rise of value added of smelting and pressing of ferrous metals and non-ferrous metals sectors, led to the rise of industrial CO_2 emissions by 56.21 million tons of carbon. Therefore, the CO_2 emission increase in these energy-intensive sectors should be firstly slowed down. The development of low-CO_2 emissions sectors should be encouraged. And the share of value added of these carbon intensive sectors in industrial value added should be maintained or lowered by reducing the product exports from high-CO_2 emissions sectors or properly increasing the imports.

China is a non-Annex I country. Though it has no obligation of quantitative emission reduction during 2008—2012, China is obliged to alleviate global climate change by reducing greenhouse emissions. And it is a matter of time for China to participate in the future international system of emission reduction since it is the second largest country of CO_2 emissions. Therefore, China must slow down the increase of CO_2 emissions, in particular by cutting the CO_2 emissions from the industrial sector. Based on the analysis above, CO_2 emission reduction strategy for industrial sector should focus on the following aspects:

① Energy-intensive sectors, e.g. manufacture of raw chemical materials and chemical products, manufacture of non-metallic mineral products, smelting and pressing of ferrous metals should give priority to the import of advanced technology, the updating and transformation of production process, further increase of energy efficiency and the promotion of these sectors' energy intensity to reach international advanced level. The squandering of these sectors' products should be decreased. The demand increase on these sectors' products should be slowed down. And the share of value added of these sectors in industrial value added should be maintained or lowered to some extent by reducing the product exports from high-CO_2 emissions sectors or properly increasing the imports. With preferential policy of finance and taxation, the end use of renewable energy should be promoted in these sectors and the structure of final energy use should develop in the direction favorable for CO_2 emission reduction.

② To lower the CO_2 emission rate of electricity by enhancing power generation technology, introducing clean power such as wind power, biomass electric power generation, landfill gas power generation, and reducing the loss of power during its transition and transportation.

③ To promote the development of the industrial structure of final energy use towards clean and low-carbon orientation, decrease the share of coal and improve the efficiency of power generation; to promote energy conservation, adopt the system of energy conservation verification, and set the goal of energy conservation for some industrial sectors to improve energy efficiency.

④ To plan rational and coordinate the development of industrial sectors, as well as energy use and environmental protection.

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Chapter 5

Impacts of Household Consumption and Export Trade on CO_2 Emissions

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Energy consumption and its CO_2 emissions are not only affected by technical efficiency but also greatly influenced by human behavior. Currently, China is undergoing a transition period. The transition of economy will bring about a series of profound changes on expanding of household consumption scale, upgrading of consumption structure, etc. The issue of sustainable consumption has attracted the common concern from the international community. People's consumption behavior has a deciding impact on the production of products or services of various sectors of the national economy to a great extent. It even has impacts on the output level of other economic sectors. With global economic integration and the reform of China's economy, China has become the third largest trading nation in the world. In 2005, China's foreign trade reached 11.69 trillion RMB, with its exports accounting for 53.6%. Final consumption mainly comprises of household consumption and export trade. Therefore, this chapter analyses the following questions: To what extent are Chinese households impacting CO_2 emissions?

- How are the variation of energy intensity, household consumption scales and consumption structures impacting CO_2 emissions?
- What behaviors are those of carbon-intensive emissions?
- To what extent are the exports of Chinese products impacting CO_2 emissions?

- Which sectors' product exports have brought about greater CO_2 emissions?
- How are the variation of energy intensity, export scales and export products mix impacting CO_2 emissions?

5.1 Impact of household consumption on CO_2 emissions

Since the World Summit on Sustainable Development held in June 1992 in Rio de Janeiro, the issue of sustainable consumption has attracted the common concern from the international community. People's consumption behavior has a deciding impact on the production of products or services of various sectors of the national economy to a great extent. It even has impacts on the output level of other economic sectors. Household consumption is a key component of final consumption. Therefore, the analysis of the impact of household energy consumption on the environment has become one of issues with broad concerns. Vringer and Block (1995) carried out an analysis on the "household energy consumption in the Netherlands in 1990". With the input-output model, Lenzen (1998) made an assessment on the impact of Australian consumers' behavior on energy consumption and greenhouse emissions. Weber and Perrels (2000) made a quantitative analysis of the "impact of life style on energy needs and emissions in 1990s and the first decade of the 21st century in the former West Germany, France and the Netherlands". Reinders among others (2003) predicted the direct and indirect demands on energy from the people of 11 EU countries. By means of Consumer Lifestyle Approach (CLA), Bin and Dowlatabadi (2005) analyzed the relationship between consumer behaviors and energy utilization as well as CO_2 emissions in the USA. With the input-output model, Park and Heo (2007) analyzed the direct and indirect energy consumption of Korean people during 1980—2000. Cohen among others (2005) analyzed the direct and indirect impacts of Brazilian citizens with different income levels on energy consumption. Pachauri and Speng (2002) studied household energy consumption in India. And Wei among others (2007) studied the impact of the change of urban and rural residents' consumption behaviors on the end use of energy and CO_2 emission during 1998—2002 in China.

Currently, China is witnessing a period of social transformation, which has brought about profound changes to housing, employment, life, consumption pattern, etc. Not only socio-economic problems but also resources and environmental problems are involved. First of all, it is the change of Chinese countryside in two aspects: ① urbanization, namely the converting of rural population to urban population. There is a big difference in the quality and quantity of demand on energy use by urban residents and rural residents. Urbanization brings a large rural population into the cities, which change their energy consumption behaviors and greatly increase energy consumption. ② Rural life style develops towards urban one, and energy consumption undergoes a gradational transition from non-commercial-energy-oriented towards commercial-energy-oriented style. The income increase of rural people may lead to the increase in commodity demand. A large part of the new income is used for greater household consumption expenditure, which stimulates to some extent rural household consumption of hard goods such as refrigerator, computer, etc, consequently increasing the demand of electricity. In a word, the overall development and modernization of the countryside have improved farmers' living standards and as a result a higher demand on energy will certainly be brought about. Besides, great changes have taken place in the household consumption structure of urban residents of China. Since 1980s till mid 1990s, Chinese urban residents witnessed the first consumption structure upgrading that was centered upon the popularization of household appliances. As a result, refrigerator, color television and washing machine have come into consumption concerns. In late 1990s, the level of consumption was upgraded again, thus turning housing consumption, car consumption, communication and electronic products consumption, cultural education consumption, holiday consumption and tourist consumption into consumption concerns. Important impacts on China's energy consumption and its CO_2 emissions have been engendered by this change of urban and rural structure and consumption structure.

China is a typical country with dualistic structure and it is necessary to analyze the impact of the change of urban and rural household consumption patterns on CO_2 emission. Its purpose is to find out: During the period of China's transformation of society, to what extent is household consumption impacting CO_2 emissions? Which consumptions are CO_2 emission-intensive? What difference exists in the impacts of urban and rural households, and of households with different income levels on CO_2 emissions? How are the changes of urban and rural household consumption expenditure, consumption patterns and energy intensity impacting CO_2 emissions?

5.1.1 Current household consumption in urban and rural areas

Since 1991, there has been a rising trend of income per capita for households in both urban and rural areas of China. However, the income per capita of urban households has been increasing apparently higher than that of rural ones. In 2005, the income per capita of urban households was 2.86 times of that in 1991 and the number was 1.97 for rural households, based on the data from China Statistical Yearbook, the results are calculated and shown in Figure 5.1.

The increase in household income largely goes as the increase of consumption expenditure and the change of household consumption patterns. Figure 5.2 (Based on the data from China Statistical Yearbook, the results are calculated and shown in Figure 5.2) shows that during 1985—2005, there was a rapid growth of consumption expenditure among urban and rural households, in particular the consumption expenditure of urban households.

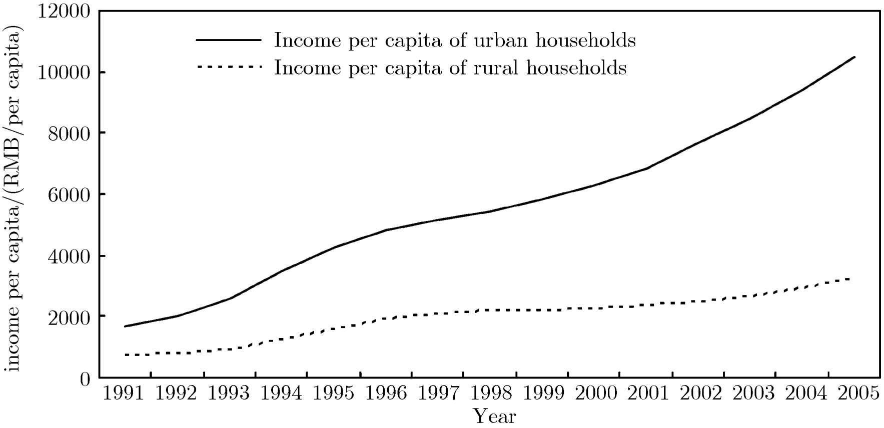

Figure 5.1 Change of urban and rural income per capita during 1985—2005

[Data Source: China Statistical Yearbook]

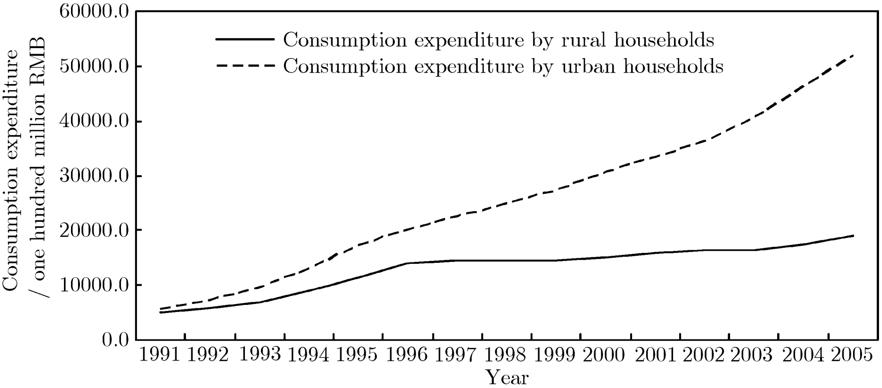

Figure 5.2 Change of urban and rural consumption expenditure during 1985—2005

[Data Source: China Statistical Yearbook]

Meanwhile, China has witnessed a change of consumption patterns among urban households during 1992—2005, based on the data from China Statistical Yearbook, the results are calculated and shown in Figure 5.3. There was a dramatic decline of food and clothing consumption expenditure, whereas an obvious rising proportions of medical care, housing, transportation, communication, in consumption. Figure 5.4 (Based on the data from China Statistical Yearbook, the results are calculated and shown in Figure 5.4) shows that during 1993—2005, China was also undergoing a change of consumption patterns among rural households. There was a dramatic decline of food consumption expenditure, whereas obvious rising proportions of medical care, transportation, communication, in consumption. During 1991—2005, Engel coefficients for urban and rural households demonstrated a trend of decline. In 1991,

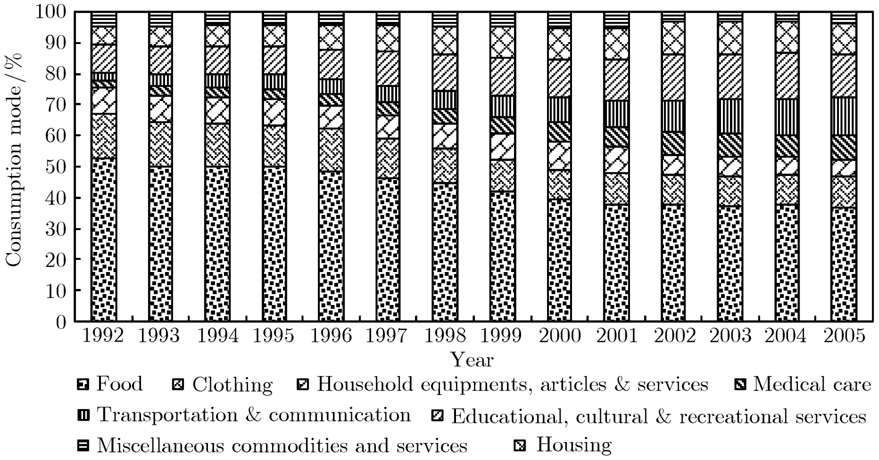

Figure 5.3 Change of urban consumption mode in China during 1992—2005

[Data Source: China Statistical Yearbook]

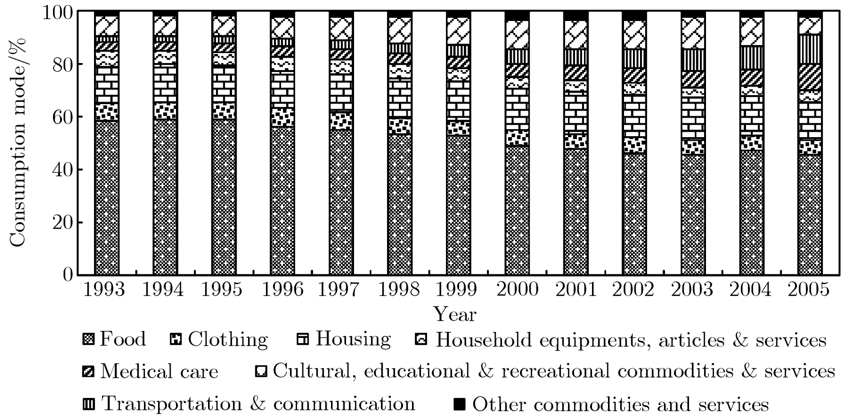

Figure 5.4 Change of rural consumption mode in China during 1993—2005

[Data Source: China Statistical Yearbook]

the Engel coefficients were 53.8% and 57.6% for urban and rural households respectively, and they were reduced to 36.7% and 45.5% respectively in 2005.

Because of the gap between urban and rural structures and income levels, there is also a big difference in the consumption expenditure per capita for urban households and rural households with different income levels in China, based on the data from China Statistical Yearbook the results are calculated and shown in Figures 5.5 and 5.6. The consumption expenditure per capita

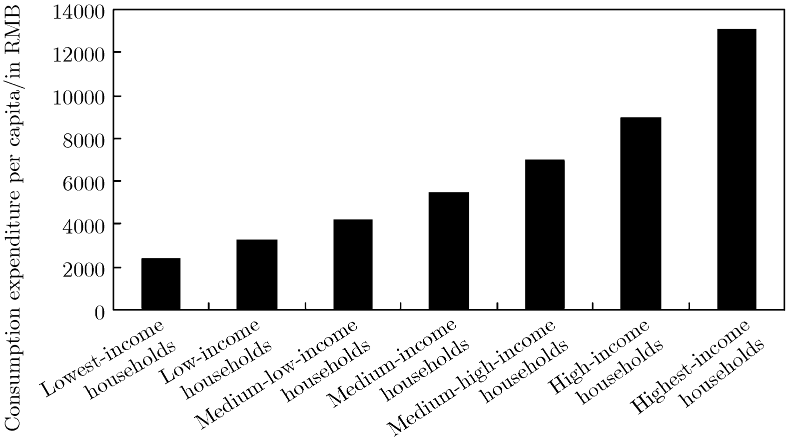

Figure 5.5 Chinese urban consumption expenditure per capita of different income level in 2002

[Data Source: China Statistical Yearbook]

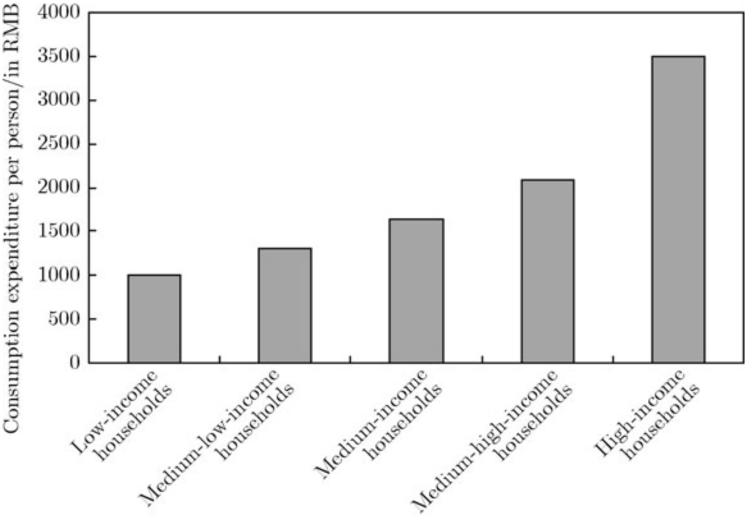

Figure 5.6 Chinese rural consumption expenditure per capita of different income levels in 2002

[Data Source: China Statistical Yearbook]

of urban households with the highest income is six times that of urban households with the lowest income in China, while the consumption expenditure per capita of rural households with high incomes is three times that of those with low incomes.

Thus it can be seen that since 1980s, great changes have taken place in resident population, household income, urban and rural households, and the consumption patterns of urban and rural households with different incomes in China. Then, to what extent are these changes influencing CO_2 emissions?

5.1.2 Methodology: Input-Output Model

There are basically three methods for the analysis on the energy consumption of and CO_2 emissions from households: the basic list of input-output, input-output consumption expenditure method, and input-output procedure analysis (Kok et al., 2006). The method of input-output procedure analysis requires detailed data on consumption items and is suitable for the analysis on CO_2 emissions of different household consumption patterns. The basic list of input-output and the input-output consumption expenditure method can be used for the explanation of the energy use and CO_2 emissions of household consumption from a macro level. For reasons of data availability and study objectives, there are comparatively greater chances to adopt the basic list of input-output and the input-output consumption expenditure method.

The input-output analysis method is an analytical framework developed by Professor Wassily Leontief in late 1930s (Miller and Blair, 1985). It is fundamentally aimed at evaluating the interdependence relationship among various industries in the economy.

The input-output method mainly covers the preparation of quincuncial input-output production table and establishes relevant linear algebraic equation system to construct an economic mathematical model that simulates the actual national economic structure and social products reproduction process. Thus, we can make a comprehensive analysis and identify the proportional relation between the complicated relationship among various sectors of national economy and reproduction. This characteristic of the input-output method is conducive to comprehensive research view.

The input-output production table shows the interdependence between various sectors. Rows of the table present the output distribution of each sector in the whole economy, while columns of the table describe the input combination of the sectors (Miller and Blair, 1985). Relevant linear algebraic equation system depicts the output distribution of each sector in the whole economy in mathematical versions, namely the output sold to production sectors in the way of intermediate input or acting as final utilization.

The analysis on the energy-related environmental problems of the input-output model can be traced back to late 1960s, some experts have broadened the input-output analysis and applied it in solving energy and energy-related environmental problems. In 1970s and 1980s, some energy problem analysts advanced this technology further (Miller and Blair, 1985). There have been a lot of achievements in this regard. Some of them were focused on the sensitivity analysis of certain or several socio-economic factors (Burtraw et al., 1998; Kainuma et al., 2000; Kim, 2002; Lee and Lin, 2001; Yabe, 2004). Some other analysis attached importance to the impact of one certain activity or event like international trade, policies on environmental protection and finance, etc on energy consumption and relevant CO_2 emissions (Bach et al., 2002; Christodoulakis et al., 2000; Sánchez-Chóliz and Duarte, 2004).

The radical Formula (5.1) for the input-output model:

$$X = (I - A)^{-1}CY \tag{5.1}$$

Here, X and Ystand for gross output matrix and final utilization matrix respectively (Yrefers to the final consumption of rural households and urban households separately, and export as well); A stands for technical coefficient matrix; C stands for energy intensity matrix.

In this section, therefore, on the basis of the basic lists of input-output and energy prices in 1992, 1997 and 2002, an analysis was carried out on CO_2 emissions by Chinese urban and rural households with the input-output model. And on the basis of consumption expenditure data of urban and rural households with different incomes, the CO_2 emissions of urban and rural households with different incomes and CO_2 emissions embodied in the export trade of China were calculated.

The analysis in this section does not include hydropower, nuclear power and renewable energy, instead primary energy sources limited to raw coal, crude oil and natural gas. The consumption of oil products, power and heat belongs to indirect consumption, resulting in less direct CO_2 emissions than actual consumption. Data on the final consumption of urban and rural households are directly sourced from the input-output tables in 1992, 1997 and 2002. The division of urban and rural households with different incomes and the consumption expenditures based on different incomes are derived from "*China Statistical Yearbook 2003*". Coal and petroligenic natural gas outputs of the coal mining sector and the petroligenic natural gas exploitation sector in 1992, 1997 and 2002 come from energy balance sheets in 1992, 1997 and 2002 respectively.

5.1.3 CO_2 emissions of household consumption

5.1.3.1 Impacts of Chinese household consumption on CO_2 emissions during 1992—2002

Based on the input-output model and by means of the input-output tables in 1992, 1997 and 2002, we calculated and acquired the direct CO_2 emissions and indirect CO_2 emissions of Chinese urban and rural households, data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.1.

Table 5.1 Direct and indirect impacts of urban and rural household on CO_2 emissions during 1992—2002

Impacts of urban and rural household on CO_2 emissions	In 1992	In 1997	In 2002
Total households	2.736	3.997	3.921
Total urban households (hundred million tons of carbon)	1.172	2.038	2.818
#Direct impact (hundred million tons of carbon)	0.096	0.051	0.288
#Indirect impact (hundred million tons of carbon)	1.076	1.987	2.530
Total rural households (hundred million tons of carbon)	1.564	1.959	1.103
#Direct impact (hundred million tons of carbon)	0.486	0.18	0.132
#Indirect impact (hundred million tons of carbon)	1.078	1.779	0.971
Total households	2.736	3.997	3.921
CO_2 emissions of household consumption accounted for 36.52% of the CO_2 emissions of primary energies in 1992. CO_2 emissions of household consumption accounted for 43.90% of the CO_2 emissions of primary energies in 1997. CO_2 emissions of household consumption accounted for 42.31% of the CO_2 emissions of primary energies in 2002.			

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

In 1992, the 274 million tons of direct and indirect CO_2 emissions from Chinese household consumption accounted for 36.52% CO_2 emissions from primary energy consumption. Among them, 117 million tons of direct and indirect CO_2 emissions were from urban household consumption, and 156 million tons from rural household consumption. There are basically equal CO_2 emissions from household consumption of urban households and of rural households, as shown in Table 5.1. In 1997, the 400 million tons of direct and indirect CO_2 emissions from Chinese household consumption accounted for 43.90% of CO_2 emissions from primary energy consumption. Among them, 204 million tons of direct and indirect CO_2 emissions were from urban household consumption, while 196 million tons from rural household consumption. The indirect CO_2 emissions of urban households were 11.69% greater than those of rural households.

In 2002, the 392 million tons of direct and indirect CO_2 emissions from Chinese household consumption accounted for 42.31% of primary CO_2 emissions. Among them, 282 million tons of direct and indirect CO_2 emissions were from urban household consumption, while 110 million tons from rural household consumption. The indirect CO_2 emissions of urban households were 2.61 times of those of rural households.

In spite of the fact that there are more rural households than urban households in China, indirect CO_2 emissions from its urban households were apparently higher than its rural households during 1997—2002. In 1992—2002, the indirect CO_2 emissions of urban households gained an increase of 135.13%, while those of rural households were reduced by 9.93%.

5.1.3.2 Indirect CO_2 emissions from household consumption during 1992—2002

For the convenience of problems analyzing, household consumption can be divided into seven categories: food; clothing, household equipments and services; medical insurance; educational, cultural and recreational services; housing; transportation and communication; and others. Table 5.2 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.2) shows that primary CO_2 emissions from the food consumption expenditure of Chinese rural households occupied over 40%, which was the largest part. During 1992—1997, CO_2 emissions from the food consumption expenditure of Chinese urban households occupied over 30%. While in 2002, indirect CO_2 emissions from housing consumption expenditure occupied 26.09%, which was the largest share. Indirect CO_2 emissions from clothing, household equipments & services also reached over 20%. However, as for indirect CO_2 emissions from per unit money consumption expenditure, housing belonged to energy-intensive behavior during 1992—2002, data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.3.

Indirect CO_2 emission is related not only to household consumption scale, but also to population, consumption structure, energy intensity, energy consumption structure, and energy CO_2 emission coefficient. These factors co-determine the change of indirect CO_2 emission. Tables 5.4 and 5.5 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.4 and 5.5) reflect the energy intensity change of different kinds of consumption and different sectors in urban and rural areas during 1997—2002, as shown in the following aspects:

Table 5.2 Indirect CO_2 emissions of households with different consumption expenditure in China

Different consumption expenditure	In 1992		In 1997		In 2002	
	Rural households	Urban households	Rural households	Urban households	Rural households	Urban households
Food	0.46	0.40	0.90	0.64	0.41	0.63
Clothing, household equipments & services	0.22	0.24	0.32	0.43	0.15	0.55
Medical insurance	0.04	0.05	0.05	0.10	0.04	0.11
Education & culture	0.04	0.04	0.07	0.07	0.05	0.19
Transportation & communication	0.06	0.04	0.08	0.09	0.05	0.18
Housing	0.18	0.20	0.24	0.47	0.19	0.66
Miscellaneous	0.08	0.10	0.12	0.18	0.07	0.21

Unit: hundred million tons of carbon.

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

Table 5.3 Indirect CO_2 emissions of household per unit money consumption expenditure in China

Different consumption expenditure	In 1992		In 1997		In 2002	
	Rural households	Urban households	Rural households	Urban households	Rural households	Urban households
Food	0.12	0.14	0.16	0.16	0.09	0.09
Clothing, household equipments & services	0.19	0.18	0.17	0.18	0.11	0.12
Medical insurance	0.18	0.15	0.16	0.17	0.09	0.08
Education & culture	0.15	0.15	0.15	0.13	0.06	0.06
Transportation & communication	0.25	0.23	0.17	0.16	0.09	0.09
Housing	0.52	0.84	0.42	0.91	0.14	0.44
Miscellaneous	0.15	0.16	0.14	0.15	0.08	0.09

Unit: kg carbon/RMB.

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

Table 5.4 Consumption and energy intensity of different sectors of urban and rural household in 1997

Urban area	Proportion /%	Energy intensity /(kce /RMB)	Rural area	Proportion /%	Energy intensity /(kce /RMB)
Animal husbandry	9.84	0.08	Crop production	20.35	0.13
Apparel & other fiber products manufacturing	6.51	0.10	Animal husbandry	12.69	0.08
Merchandise	6.20	0.11	Other food processing & manufacturing industries	6.77	0.15
Other food processing & manufacturing industries	6.04	0.15	Merchandise	4.85	0.11
Crop production	5.83	0.13	Real estate business	3.74	0.08
Grain, oil and feedstuff processing	5.20	0.12	Alcohol & potable spirit manufacturing	3.40	0.16
Health service	4.11	0.15	Fishery	3.24	0.09
Fishery	3.12	0.09	Grain, oil and feedstuff processing	3.13	0.12
Catering	3.11	0.10	Apparel & other fiber products manufacturing	3.03	0.10
Finance industry	2.99	0.06	Tobacco processing	2.62	0.07
Tobacco processing	2.91	0.07	Catering	2.39	0.10
Leather, fur & down and their products industry	2.74	0.10	Household electrical appliances manufacturing	2.27	0.19
Household electrical appliances manufacturing	2.70	0.19	Butchery and meat & egg processing	2.13	0.08
Alcohol & potable spirit manufacturing	2.46	0.16	Finance industry	1.90	0.06
Real estate business	2.28	0.08	Educational business	1.73	0.20
Butchery and meat & egg processing	2.09	0.08	Pharmaceutical industry	1.64	0.15
Household electronic apparatus manufacturing	1.72	0.18	Other beverage manufacturing industries	1.63	0.14

Continued

Urban area	Proportion /%	Energy intensity /(kce /RMB)	Rural area	Proportion /%	Energy intensity /(kce /RMB)
Aquatic products processing	1.57	0.09	Neighborhood service	1.56	0.17
Neighborhood service	1.43	0.17	Other agricultural sectors	1.43	0.10
Other beverage manufacturing industries	1.42	0.14	Other transport and communication facilities manufacturing industries	1.38	0.16
20 sectors	74.28	0.11	20 sectors	81.87	0.12
Other kinds of consumption	25.72	0.27	Other kinds of consumption	18.13	0.23
Average energy intensity of all sectors		0.15	Average energy intensity of all sectors		0.14

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

Table 5.5 Consumption and energy intensity on different sectors of urban and rural household in 2002

Urban area	Proportion /%	Energy intensity /(kce/RMB)	Rural area	Proportion /%	Energy intensity /(kce/RMB)
Animal husbandry	7.29	0.05	Agriculture	17.24	0.08
Catering	7.04	0.06	Real estate business	12.55	0.04
Real estate business	6.43	0.04	Animal husbandry	9.83	0.05
Educational business	6.06	0.09	Wholesale & retail trade	5.09	0.06
Wholesale & retail trade	6.01	0.06	Other food processing& manufacturing sectors	4.59	0.10
Agriculture	5.46	0.08	Educational business	3.65	0.09
Other food processing & manufacturing sectors	4.93	0.10	Catering	3.52	0.06
Neighborhood service & other service sectors	4.84	0.10	Neighborhood service & other service sectors	3.32	0.10
Health service	4.41	0.07	Fishery	3.13	0.07

Continued

Urban area	Proportion /%	Energy intensity /(kce/RMB)	Rural area	Proportion /%	Energy intensity /(kce/RMB)
Textile, apparel & footwear manufacturing	3.78	0.10	Finance industry	2.90	0.03
Fishery	2.43	0.07	Grain grounding industry	2.21	0.08
Power & heat production and supply sector	2.36	0.50	Health service	2.14	0.07
Finance industry	2.35	0.03	Tobacco industry	2.09	0.02
Information transfer service sector	2.20	0.05	Pharmaceutical industry	1.81	0.09
Household utensils manufacturing	1.83	0.12	Butchery & meat processing	1.62	0.06
Leather, fur, feather (down) & their products sector	1.73	0.08	Textile, apparel & footwear manufacturing	1.60	0.10
Tobacco industry	1.63	0.02	Vegetable oil manufacturing	1.55	0.08
Pharmaceutical industry	1.32	0.09	Alcohol & potable spirit manufacturing	1.41	0.08
Butchery & meat processing	1.24	0.06	Road transportation sector	1.34	0.13
Travel industry	1.18	0.05	Power & heat production and supply sector	1.27	0.50
20 sectors	74.53	0.08	20 sectors	82.87	0.07
Other kinds of consumption	25.47	0.14	Other kinds of consumption	17.13	0.13
Average energy intensity of all sectors		0.10	Average energy intensity of all sectors		0.08

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

(1) The energy intensities of various sectors in 2002 was apparently lower than that in 1997. In 2002, the average energy intensity of indirect CO_2 emissions of urban households was 0.10kg coal equivalent per RMB. The average energy intensity of indirect CO_2 emissions of rural households was 0.08kg coal equivalent per RMB. While in 1997, the average energy intensity of indirect CO_2 emissions of urban households was 0.15kg coal equivalent per RMB. The average energy intensity of indirect energy consumption of rural households was 0.14kg coal equivalent per RMB. The energy intensity

decrease has slowed down the rate of increase of indirect energy consumption.

(2) There is a big difference in the consumption scales and consumption patterns between urban households and rural households in China. In 2002, the 20 largest sectors occupied 82.87% of rural household consumption, among which, the consumption on agricultural sector occupied 17.24%. And the 20 largest sectors occupied 74.53% of urban household consumption, among which, the consumption on agricultural sector occupied 5.46%, ranking in the sixth place. Regarding to the absolute quantity, the consumption on agricultural sector by rural households was also larger than that of urban households. Table 5.6 reflects the change of final consumption by Chinese urban and rural households during 1992—2002. In 1992, the final consumption of urban households was less than that of the rural households, while in 1997 the contrary thing happened. In 2002, the final consumption of urban households was more than two times that of the rural households, 516.50% more than that in 1992. In spite of the fact that rural population is apparently higher than urban population, the change of consumption scale and consumption pattern of urban and rural households led to a higher indirect energy consumption by urban households than by rural households in 1997 and 2002.

(3) According to Table 5.6, the final consumption on various sectors by Chinese rural households increased by 170.82% during 1992—1997, but 8.58% lower during 1997—2002 (mainly attributed to consumption decrease in agricultural consumption). Furthermore, the energy intensity on various sectors in 2002 was somewhat lower than that of 1997 (as shown in Tables 5.4 and 5.5), resulting in a lower indirect energy consumption in 2002 than in 1997.

Table 5.6 Final consumption of urban and rural household during 1992—2002

Consumption of urban and rural household	1992	1997	2002	1992—1997	1997—2002	1992—2002
Consumption of urban households (hundred million RMB)	5888	17980.7	36299.6	205.38%	101.88%	516.50%
Consumption of rural households (hundred million RMB)	6572	17798.3	16271.7	170.82%	–8.58%	147.59%

5.1.4 Impact factors of household CO_2 emissions

In order to further analyze the reasons for the change of impacts of household consumption on CO_2 emission, we will study the impact factors for the change of household CO_2 emission during 1992—2002. Household CO_2 emission is decomposed into population, per capita consumption expenditure, consumption expenditure structure, energy intensity and CO_2 emission coefficient of primary energy consumption:

$$C = \sum C_{ij} = \sum_{ij} P_i \frac{Q_i}{P_i} \frac{Q_{ij}}{Q_i} \frac{E_{ij}}{Q_{ij}} \frac{C_{ij}}{E_{ij}} \tag{5.2}$$

Here, C refers to household CO_2 emission, including direct and indirect CO_2 emissions; i refers to for two categories of households, namely urban and rural households, $i = 1, 2$; j refers to for consumption expenditure category; E refers to household energy consumption, including direct and indirect energy consumption; Q_i refers to final consumption of category i households; Q_{ij} refers to category j consumption of category i households; $\frac{E_{ij}}{Q_{ij}}$ refers to CO_2 emissions from per unit of category j consumption, reflecting the change of energy intensity; $\frac{Q_i}{P_i}$ refers to per capita consumption of category i households; $\frac{Q_{ij}}{Q_i}$ refers to consumption expenditure structure of category i households. $\frac{C_{ij}}{E_{ij}}$ refers to the CO_2 emissions per unit of household energy consumption, reflecting the change of energy consumption structure and the increase of energy utilization efficiency.

China's population growth, the increase of per capita consumption and the change of consumption structure all enhanced the increase of household CO_2 emissions. Among them, the increase of per capita consumption plays the greatest boosting role, data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Figure 5.7. During 1992—1997, the three changes increased 126 million tons of carbon in total and decreases 0.08 million tons of carbon during 1997—2002, with per capita consumption contributing 64.68% and 65.84% respectively; Population growth contributed 15.97% and 21.16% respectively; and consumption structure contributed 8.71% and 13.00% respectively. The decline of energy consumption caused by per unit money consumption or the decline of energy intensity has slowed down the growth rate of household CO_2 emissions, which was 0.63 million tons of carbon fewer in 1997 than in 1992 and 2.20 million tons of carbon fewer in 2002 than in 1997. During 1992—1997, the change of CO_2 emission coefficient from household energy use increased CO_2 emissions by 0.20 million tons of carbon, but during 1997—2002 it was

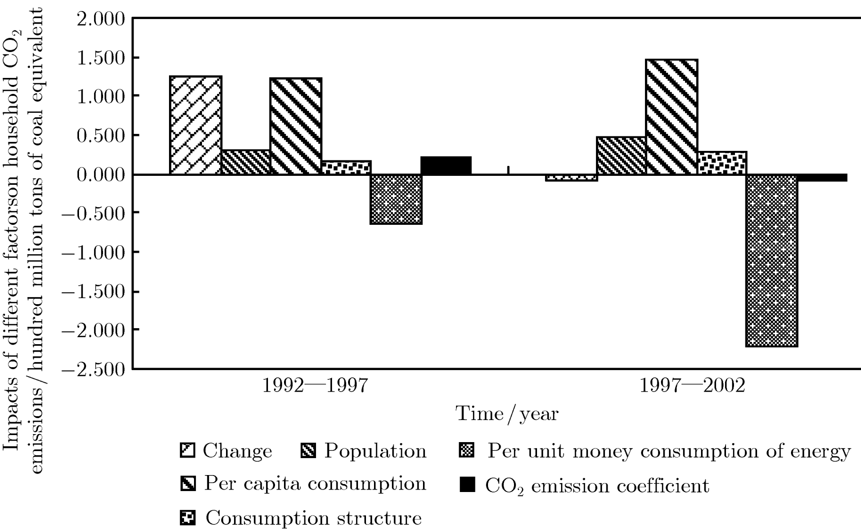

Figure 5.7 Impacts of different factors on household CO2 emissions

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

reduced by 0.09 million tons of carbon. Thus it can be seen that it is favorable for mitigating the increasing rate of household CO_2 emissions by means of population control, lowering of energy intensity of production sectors, and the guidance of household consumption structure to a low carbon direction.

5.1.5 Urban and rural household CO_2 emissions under different income levels

Figures 5.8 and 5.9 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Figures 5.8 and 5.9) indicate that there is a big difference in per capita indirect CO_2 emissions under different income levels. In regard to urban households, per capita indirect CO_2 emissions reached 1,684.70kg carbon for households with highest income, 1,120.92kg carbon for households with high income, 852.24kg for medium-high-income households, 690.82kg for medium-income households, 528.27kg for medium-low-income households, 418.30kg for low-income households and 313.73kg for lowest-income households. As for rural households, the number was 352.39kg carbon for high-income households, 208.52kg for medium-high-income households, 163.92kg for medium-income households, 129.63kg for medium-low-income households and 98.65kg for low-income households.

Table 5.7 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.7) shows

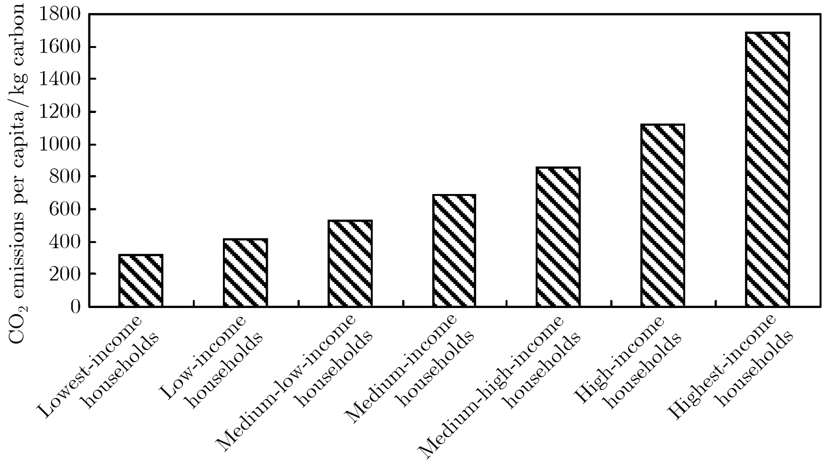

Figure 5.8 Indirect CO_2 emissions per capita of urban households with different income levels in China 2002

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

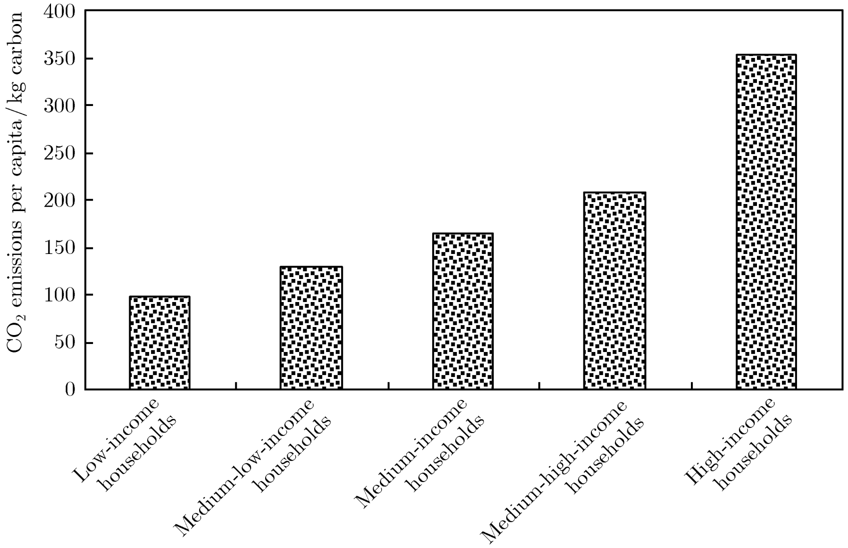

Figure 5.9 Indirect CO_2 emissions per capita of rural households with different income levels in China 2002

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

that both per capita consumption expenditure and per capita indirect CO_2 emissions of urban households with the highest income equals to 1.5 times those of urban high-income households, 1.9 times of consumption expenditure and 2.0 times of indirect CO_2 emissions of urban medium-high-income households; 2.4 times of either consumption expenditure or indirect CO_2 emissions of urban medium-income households; 3.1 times of consumption expenditure and 3.2 times of indirect CO_2 emissions of urban medium-low-income households; 4.0 times of either consumption expenditure or indirect CO_2 emissions of urban low-income households; and 5.5 times of consumption expenditure and 5.4 times of indirect CO_2 emissions of urban lowest-income households.

Table 5.7 Comparison of per capita expenditure and indirect CO_2 emissions between urban highest income households and other level income households

Index	Urban high-income households	Urban medium-high-income households	Urban medium-income households	Urban medium-low-income households	Urban low-income households	Urban lowest-income households	Rural high-income households	Rural medium-high-income households	Rural medium-income households	Rural medium-low-income households	Rural low-income households
Per capita consumption expenditure	1.46	1.88	2.39	3.10	4.00	5.46	3.73	6.25	7.93	9.95	12.96
Per capita indirect CO_2 emissions	1.50	1.98	2.44	3.19	4.03	5.37	4.78	8.08	10.28	13.00	17.08

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

Per capita consumption expenditure and per capita indirect CO_2 emissions of urban highest-income households equals to 3.7 and 4.8 times respectively of those of rural high-income households, 6.3 times of consumption expenditure and 8.1 times of indirect CO_2 emissions of rural medium-high-income households; 7.9 times of consumption expenditure and 10.3 times of indirect CO_2 emissions of rural medium-income households; 10 times of consumption expenditure and 13 times of indirect CO_2 emissions of rural medium-low-income households; 13 times of consumption expenditure and 17 times of indirect CO_2 emissions of rural low-income households. This shows that households with higher incomes tend to consume energy-intensive products.

Therefore, with the increase in the income of urban and rural households as well as the speeding-up of urbanization, the household indirect CO_2 emissions will keep growing in China.

Through the above analysis, we come to following conclusions:

(1) The input-output table reveals that the direct and indirect impacts of urban and rural households on CO_2 emissions accounted for about 40% of total CO_2 emissions from primary energy utilization during 1992—2002 in China. Therefore, the guidance of household consumption behaviors is of great significance to the mitigation of CO_2 emissions.

(2) In spite of the fact that during 1992—2002 urban population was less than rural population, urban household indirect CO_2 emissions was higher than that of rural households. Indirect CO_2 emissions from food, clothing, household equipments and services accounted for over 50% of indirect CO_2 emissions. And housing is the greatest carbon-intensive behavior.

(3) Due to the variation existents in Chinese households' income, the indirect CO_2 emissions also make great difference. Per capita indirect CO_2 emissions of urban highest-income households is 5.37-plus and 17 times of that of urban lowest-income households and rural low-income households. Per capita annual income of urban highest-income households is 13 times that of rural low-income households, which means that with the increase in the income of urban and rural households as well as the speeding-up of urbanization, the household indirect CO_2 emissions will keep growing in China.

(4) The consumption scaling-up of urban and rural households, the urban population growth, and the upgrading household consumption structure are the main reasons for the increase of household energy consumption. However, the decline of energy intensity has slowed down the growth rate of energy consumption. On one hand, it is necessary to guide the household consumption to transit toward the non-carbon-intensive mode of consumption; on the other hand, the energy intensity of products is to be further lowered so as to conduce to the slowdown of the growth rate of household CO_2 emissions.

5.2 Impact of export trade on CO_2 emissions

Energy is one of the basic input elements of economic development. Any production or consumption activity can not be separated from the utilization of energy. In the era of economic globalization, international trade has already become an important part of economic development. Therefore, broad concerns have been caused on the impact of international trade on energy consumption and environment, and numerous studies have been carried out by researchers at home and abroad (Battjes et al., 1998; Fieleke, 1975; Machado et al., 2001; Mäenpää and Siikavirta, 2007; Peters and Hertwich, 2006; Rhee and Chung, 2006; Sánchez-Chóliz and Duarte, 2004; Wyckoff and Roop, 1994). They analyzed the way foreign trade brought impacts to energy consumption and environmental change, and predicted the energy consumption and pollutant emission of some countries during their foreign trade. The analysts hold that the more open the economy was the greater impact foreign trade would bring, that foreign trade structure and the technical efficiency during production process had greater impacts on energy and pollutant emissions from foreign trade, and that the impact of import and export trade on energy consumption and pollutant emission should not be neglected.

5.2.1 Current export trade status of China

Since December 2001 after China was formally entered into the WTO (World Trade Organization), it has increasingly deepened its relation with and influence in the world economy and sped up the progress of global economic integration. China's foreign trade maintains a trend of growth. In 2005, its foreign trade amounted to 11.69 trillion RMB, which ranked the third in the world, with exports accounting for 53.6% of the total.

China's foreign trade has been maintaining its good growth trend. The amount totaled 11.69 trillion RMB in 2005, ranking the third in the world, in which export accounted 53.6% of the total.

Figure 5.10 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and Shown in Figure 5.10) shows the total amount and proportion of commodity exports of China during 1990—2005. It can be seen that China's gross exports increased rapidly

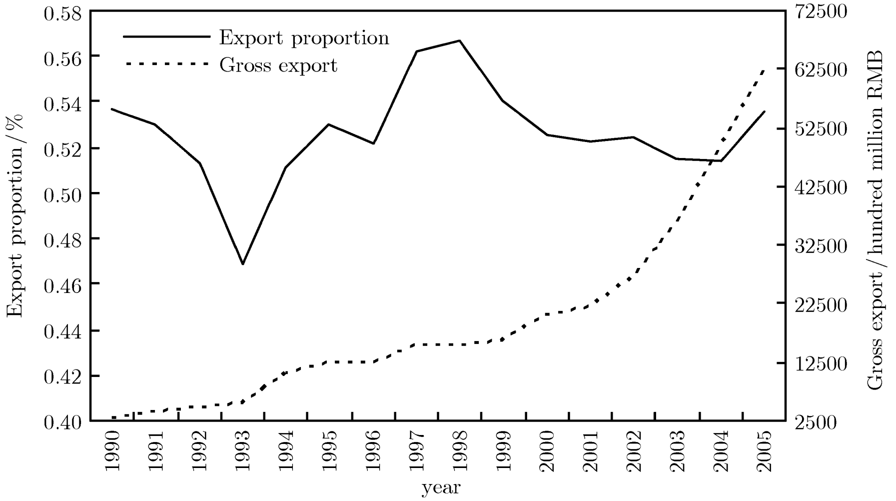

Figure 5.10 Changes of commodity export in China during 1990—2005

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)] during 1990—2005 to reach RMB 6264.81 billion in 2005, an increase of over 19 times over 1990. Furthermore, its exports were greater in amount than imports. The proportion of exports in its foreign trade was averaged at 52.61%.

During 1990—2005, China's export structure took great changes as well, data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and Shown in Figure 5.11. Primary export grew slowly, with its proportion descending year after year, from 25.59% in 1990 to 6.44% in 2005, downward by 19.15%. The export growth of machinery and transportation equipments was rather fast, from 9.00% in 1990 to 46.23% in 2005, and occupied the position of the largest export category during 2001—2005. This indicates that China has already become one of the most important manufacturing bases of the world.

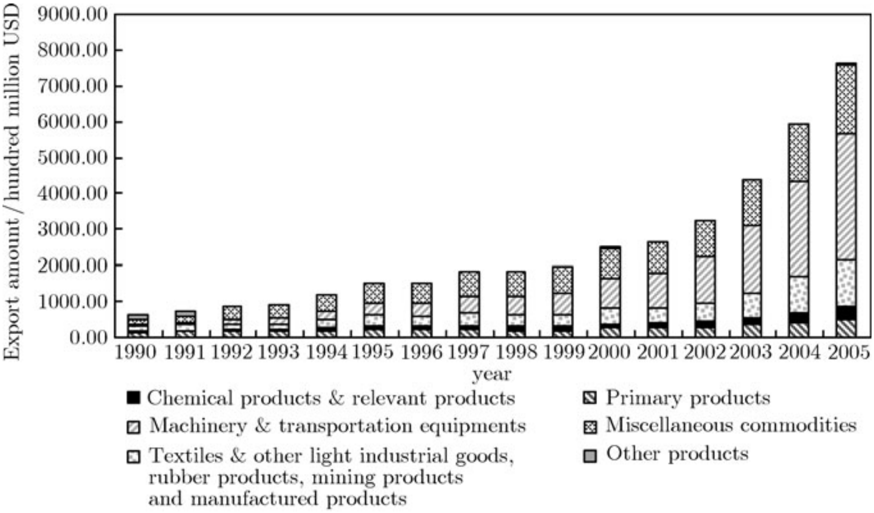

Figure 5.11 Classification of commodity export in China during 1990—2005

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

Undoubtedly, commodity exports increased energy consumption and pollutant emissions. Then, to what extent are the exports of Chinese products impacting CO_2 emissions? How are the variations of export scale, export structure and energy intensity impacting CO_2 emissions? On the basis of the input-output model in Section 5.1, this section carries out an analysis on the impact of China's export trade on CO_2 emissions.

5.2.2 CO_2 emissions embodied in exports

Since there is no breakdown into import and export in the input-output table of 1992, this section carried out an analysis on the impact of the commodity export on CO_2 emissions in 1997 and 2002.

There was a decrease of 19.15% in CO_2 emissions from energy products' direct export of China in 2002 compared with 1992. But the indirect CO_2 emissions from its commodity export increased by 16.38% during the same period. Direct and indirect CO_2 emissions from commodity export were 282 million tons and 313 million tons of carbon in 1997 and 2002 respectively, accounting for over 30% of CO_2 emissions from primary energy utilization Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Table 5.8. This means that about 1/3 of China's CO_2 emissions from its primary energy utilization was a result of meeting the production and living needs of other countries.

Table 5.8 Impacts of products export on CO_2 emissions in China 1997 and 2002

Export on CO_2 emissions	In 1997	In 2002
Direct impact	0.449	0.363
Indirect impact	2.375	2.764
Total	2.824	3.127
In 1997, CO_2 emissions from China's commodity export accounted for 31.02% of those from prime energy utilization		
In 2002, CO_2 emissions from China's commodity export accounted for 33.74% of those from prime energy utilization		

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

Figure 5.12 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Figure 5.12) shows the commodity export of China's 17 sectors in 1997 and 2002, from which we can see that: the machinery industry sectors had the lion's share in China's export, 29.01% and 38.12% of its gross export in 1997 and 2002 respectively. Textile industry came next, its proportions were 23.38% and 17.76% respectively; service industry also exported a lot, with proportions of 13.45% and 16.65% respectively. However, we can see from Table 5.9 that there were greater CO_2 emissions from the commodity exports of mechanical industry, energy resources mining industry, textile industry, chemical industry and service industry sectors, accounting for 73.40% and 77.32% of CO_2 emissions from total commodity exports.

Tables 5.9 and 5.10 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Tables 5.9 and 5.10) indicate that: in 1997, there were greatest CO_2 emissions from commodity exports of energy resources mining industry, petroleum processing

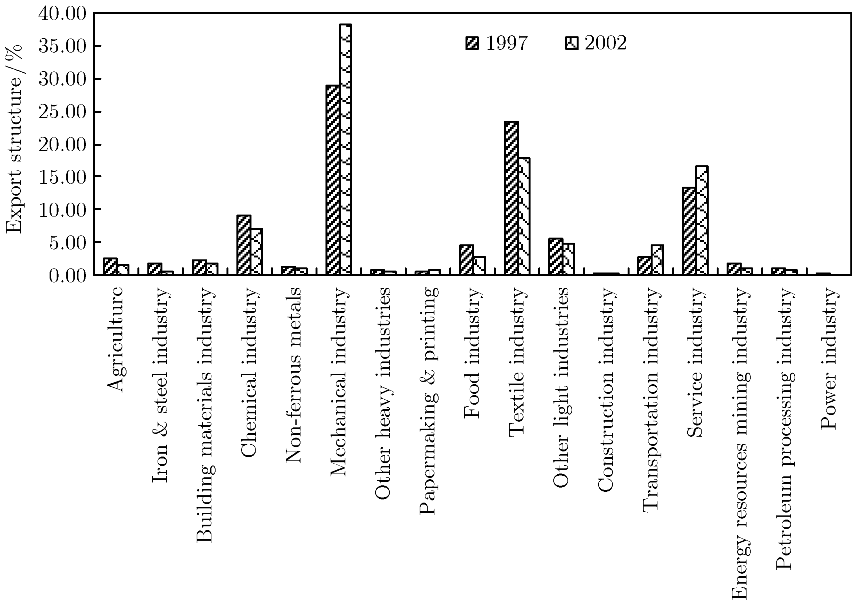

Figure 5.12 Commodity export of different sectors in 1997 and 2005

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

Table 5.9 CO_2 emissions embodied in products exports of different sectors in 1997 and 2002

Sector	In 1997	In 2002
Agriculture	0.03	0.03
Iron & steel industry	0.12	0.03
Building materials industry	0.09	0.08
Chemical industry	0.33	0.31
Non-ferrous metals	0.04	0.04
Mechanical industry	0.72	1.06
Other heavy industries	0.02	0.05
Papermaking & printing	0.01	0.02
Food industry	0.06	0.05
Textile industry	0.34	0.40
Other light industries	0.11	0.12
Construction industry	0.00	0.01
Transportation industry	0.07	0.16
Service industry	0.19	0.26
Energy resources mining industry	0.49	0.39
Petroleum processing industry	0.16	0.14
Power industry	0.03	0.00

Unit: hundred million tons of carbon.

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

industry, power industry and iron and steel industry sectors; while in 2002, commodity exports of energy resources mining industry, petroleum processing industry, power industry and other heavy industries brought the greatest CO_2 emissions. Therefore, in terms of the alleviation of CO_2 emissions growth and energy security, it is inadvisable to increase the commodity exports of these sectors in future and more policy restrictions should be imposed upon the commodity exports of these sectors. This is because direct and indirect CO_2 emissions from commodity exports of various sectors are co-determined by export scale, energy intensity and energy consumption structure.

Table 5.10 CO_2 emissions embodied in unit monetary products export of different sectors

Sector	In 1997	In 2002
Agriculture	0.08	0.05
Iron & steel industry	0.39	0.15
Building materials industry	0.25	0.12
Chemical industry	0.22	0.12
Non-ferrous metals	0.22	0.12
Mechanical industry	0.15	0.08
Other heavy industries	0.18	0.23
Papermaking & printing	0.15	0.07
Food industry	0.08	0.05
Textile industry	0.09	0.06
Other light industries	0.12	0.08
Construction industry	0.19	0.09
Transportation industry	0.14	0.10
Service industry	0.08	0.05
Energy resources mining industry	1.60	1.83
Petroleum processing industry	0.90	0.72
Power industry	0.75	0.42

Unit: kg carbon/RMB.

Data Source: China Input-Output Table and China Statistical Yearbook (2003).

5.2.3 Impact factors of CO_2 emissions embodied in export trade

In order to make an analysis on the factors impacting the change of CO_2 emissions from commodity exports during 1997—2002, we break CO_2 emissions from commodity exports into CO_2 emission coefficients of export scale, export structure, energy intensity and primary energy consumption:

$$C = \sum C_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{C_i}{E_i} \tag{5.3}$$

Here, C refers to CO_2 emissions of export trade, including direct and indirect CO_2 emissions; i refers to commodity exports category; E refers to energy consumption from commodity exports, including both direct and indirect energy consumption; Q refers to export scale; Q_i refers to export scale of category i commodity; $\frac{E_i}{Q_i}$ refers to CO_2 emissions of per unit category i

commodity, reflecting the change of energy intensity; $\frac{Q_i}{Q}$ refers to commodity export structure; $\frac{C_{ij}}{E_{ij}}$ refers to the CO_2 emissions per unit of energy consumption, reflecting the change of energy consumption structure and the increase of energy utilization efficiency.

It can be seen from Figure 5.13 (Data are prepared and calculated from China Input-Output Table and China Statistical Yearbook (2003) and shown in Figure 5.13) that China's CO_2 emissions from commodity exports increased by 30 million tons of carbon in 2002 compared with 1997. The greatest impact on the increase of CO_2 emissions was from the scale-up of commodity exports, resulting in an increase of 219 million tons of carbon in direct and indirect CO_2 emissions from commodity exports. The change of commodity export structure led to a decrease of 59 million tons of CO_2 emissions; the lowered energy intensity of commodity export sectors reduced CO_2 emissions by 121 million tons of carbon; and the decrease of CO_2 emission coefficient resulted in a decrease of 9 million tons of CO_2 emissions.

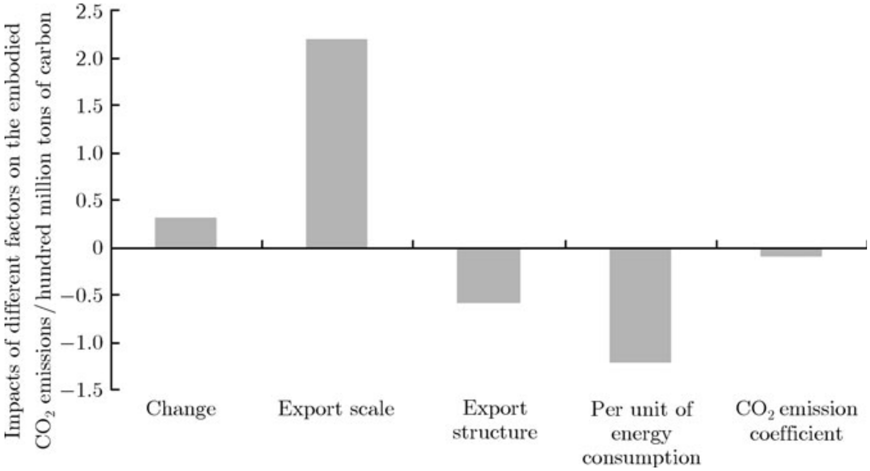

Figure 5.13 Impacts of different factors on the embodied CO_2 emissions in commodity export in China during 1997—2005

[Data Source: China Input-Output Table and China Statistical Yearbook (2003)]

Through the above analysis, we have come to the following conclusions:

(1) Direct and indirect CO_2 emissions from commodity export were 282 million tons and 313 million tons of carbon in 1997 and 2002 respectively, accounting over 30% of CO_2 emissions from primary energy utilization. This means that about 1/3 of China's CO_2 emissions from its primary energy

utilization was a result of meeting the production and living needs of other countries.

(2) There were greater CO_2 emissions from the commodity exports of mechanical industry, energy resources mining industry, textile industry, chemical industry and service industry sectors. The gross emissions of these sectors accounted for 73.40% and 77.32% of CO_2 emissions from total commodity exports in 1997 and 2002 respectively.

(3) In terms of the mitigation of CO_2 emissions growth and energy security, it is inadvisable to increase the commodity exports from the sectors of energy resources mining industry, petroleum processing industry, power industry, iron and steel industry and other heavy industries in future and more policy restrictions should be imposed upon the commodity exports from these sectors.

(4) China's CO_2 emissions from commodity exports increased by 30 million tons of carbon in 2002 compared with 1997. The greatest impact on the increase of CO_2 emissions was from the scale-up of commodity exports, resulting in an increase of 219 million tons of carbon in direct and indirect CO_2 emissions from commodity exports. The change of commodity export structure towards low-carbon-emitting commodities led to a decrease of 59 million tons of CO_2 emissions; the lowered energy intensity of commodity export sectors reduced CO_2 emissions by 121 million tons; and the decrease of CO_2 emission coefficient resulted in a decrease of 9 million tons of CO_2 emissions.

5.3 Conclusion

Using the input-output tables of 1992, 1997 and 2002, this chapter carried out an analysis on the direct and indirect impacts of rural and urban household consumption and export trade on CO_2 emissions. Our research findings are as follows:

(1) The direct and indirect impacts of urban and rural households on CO_2 emission accounted for about 40% of total CO_2 emissions from primary energy utilization during 1992—2002 in China.

(2) Indirect CO_2 emissions from food, clothing, household equipments and services accounted for over 50% of total indirect CO_2 emissions during 1992—2002. And housing is the greatest carbon-intensive behavior.

(3) The consumption scaling-up of urban and rural households, the urban population growth, and the upgrading household consumption structure are the main reasons for the increase of household CO_2 emissions. However, the

decline of energy intensity has slowed down the growth rate of CO_2 emissions.

(4) CO_2 emissions from commodity export accounted over 30% of CO_2 emissions from primary energy utilization in 1997 and 2002. This means that about 1/3 of China's CO_2 emissions from its primary energy utilization was a result of meeting the production and living needs of other countries.

(5) There were greater CO_2 emissions from the commodity exports of mechanical industry, energy resources mining industry, textile industry, chemical industry and service industry sectors. The gross emissions of these sectors accounted for 73.40% and 77.32% of CO_2 emissions from total commodity exports in 1997 and 2002 respectively.

The above analysis was made from the macro level on the impacts of households and export trade on CO_2 emissions. Next, we will make an analysis from the micro point of view on the impacts of household consumption patterns and import trade on China's CO_2 emissions.

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Chapter 6

Study on Regional CO_2 Emissions Change in China

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China's CO_2 emissions relies on not only the growth of total emissions but also the changes of regional emissions. The resource distribution and economic development vary from region to region, and the study on the characteristics of CO_2 emission evolution in carbon-intensive sectors has indicated that economic development, industrial structure and energy intensity have the greatest impacts on CO_2 emissions. Therefore, the LMDI method has been adopted in this chapter to analyze the variation of China's regional CO_2 emissions, so as to provide information about slowing the emission growth speed in provincial level in China. The key subjects of study include:

- What are the characteristics of regional total CO_2 emissions?
- What are the characteristics of regional per capita CO_2 emissions?
- What are the different features of CO_2 emissions from regional power generation?
- What are the differences in regional CO_2 emission intensity?
- Which factors will affect CO_2 emissions? And what are their shares?

6.1 Comparison analysis of regional CO_2 emissions

6.1.1 Comparison analysis of regional total CO_2 emissions

According to the figures of 1997 and 2005, the spatial distribution of China's CO_2 emissions from final energy use has changed a lot. Data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.1. In 1997, the CO_2 emissions from final energy use of Liaoning, Hebei, Shandong, Jiangsu, Guangdong, Henan, Sichuan, Hubei and Shanxi accounted for 50.71% of total 30 provinces, municipalities and autonomous regions (exclusive of Taiwan and Tibet as a result of data avaliability), while in 2005, that of Shandong, Hebei, Guangdong, Jiangsu, Henan, Liaoning and Zhejiang Province accounted for 49.99%. It can be observed that the variation of CO_2 emission distribution is closely related to the changes of economic growth, energy intensity, energy consumption structure etc.

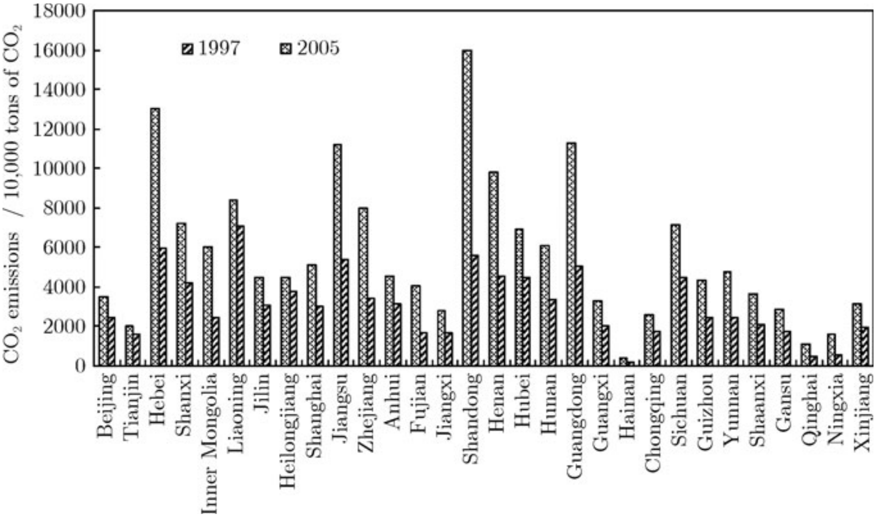

Figure 6.1 Changes of CO_2 emissions in 30 provinces of China in 1997 and 2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

Furthermore, the gross CO_2 emissions from the final energy use of China's 30 provinces, municipalities and autonomous regions increased by 83.77% in 2005 compared with that of 1997. Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong were characterized by the greatest increase of emissions from final energy use, which were 9.11%, 7.51%, 5.91%, 13.39%, 6.75% and 8.01% respectively. It shows that a majority of CO_2 emissions from China's final energy use are from major industrial provinces such as Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong Provinces, which should be paid special attention to during the mitigation of CO_2 emissions.

6.1.2 Comparison analysis of regional per capita CO_2 emissions

The CO_2 emissions per capita in 30 provinces have increased from 0.76 ton in 1997 to 1.33 tons in 2005 by 0.57 ton. Compared with those in 1997, the regional CO_2 emissions per capita have increased more or less, with the greatest increase in Ningxia Hui Autonomous Region: from 1.00 ton in 1997 to 2.71 tons in 2005 Data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.2.

In 2005, the CO_2 emissions per capita of Beijing, Shanxi, Inner Mongolia, Shanghai, Qinghai and Ningxia Province reached above 2.0 tons, while those of Anhui, Jiangxi, Guangxi and Hainan were only below 0.8 ton. Such a difference is related to many reasons, such as resource reserves, economic structure, economic development level, people's living standard and climatic conditions.

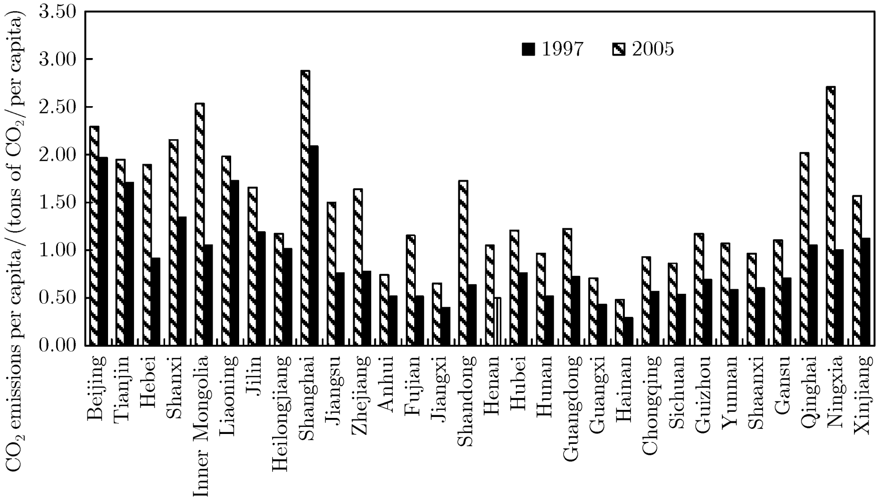

Figure 6.2 CO_2 emissions per capita of different provinces in 1997 and 2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

6.1.3 Comparison analysis of regional CO_2 emission intensity

Compared with the year of 1997, the CO_2 emission intensity has declined in a majority of provinces in 2005, except for Qinghai, Shandong, Yunnan and Fujian Provinces, while significant decreases took place in Beijing, Tianjin, Liaoning, Jilin and Heilongjiang (all above 30%), among which Tianjin showed the greatest drop of 51.40%, data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.3.

The CO_2 emission intensity is high in Shanxi, Inner Mongolia, Guizhou, Gansu, Qinghai and Ningxia, reaching more than 1.50 tons of CO_2/RMB 10,000 in 2005. The emission intensity of Ningxia reached 2.67 tons of CO_2/RMB 10,000 (the highest one) in 2005, representing an increase of 40.67% over 1997, which was mainly caused by the growth of final energy use resulting from the industrial development. The emission intensity was low in Beijing, Shanghai, Guangdong and Hainan in 2005, reaching only 0.50 ton of CO_2/RMB 10,000. The emission intensity of Hainan was only 0.44 (the lowest one) ton of CO_2/RMB 10,000. Such great differences are closely related to regional economic structure, economic development, industrial structure and energy intensity.

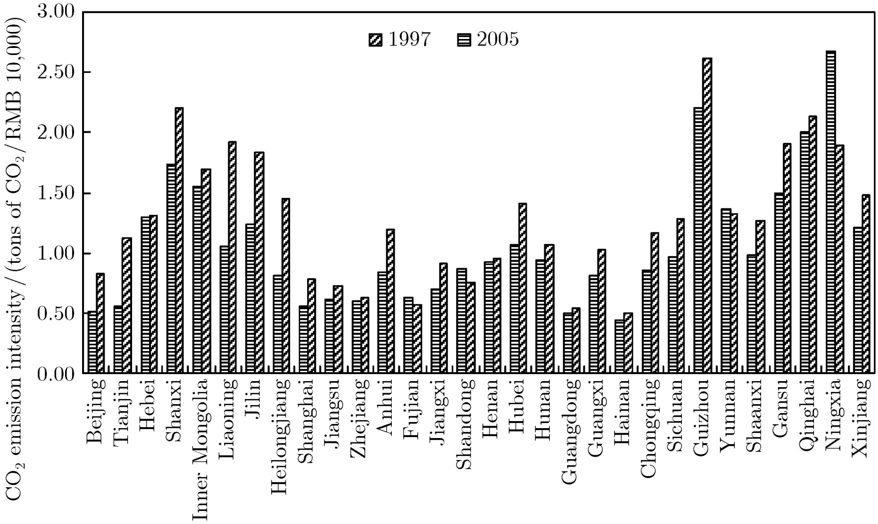

Figure 6.3 CO_2 emission intensity of different provinces in 1997 and 2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

6.1.4 Regional electrical CO_2 emission coefficient analysis

Compared with the year of 1997, the national average electrical CO_2 emissions coefficient dropped in 2005, data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.4, except for Liaoning, Jilin, Shandong, Henan, Sichuan, Qinghai and Ningxia Province. In 2005, the CO_2 emissions coefficient of Henan and Shandong increased by 37.18g carbon/kWh and 16.34g carbon/kWh respectively. All other provinces have managed to decrease their CO_2 emission coefficients, and that of Guangxi has declined by 19.79%. Therefore, priorities should be given to decrease the emission coefficients of major thermal power generation provinces.

The CO_2 emission coefficient of power generation industry in 1997 was above 300g carbon/kWh in Yunnan, Sichuan, Guangxi, Jilin, Xinjiang, Inner Mongolia, Heilongjiang, Jiangxi, Qinghai, Hubei, Guizhou and Hunan. The highest 454.95g carbon/kWh was found in Yunnan, followed by Sichuan (399.55g carbon/kWh). Hebei, Shanxi, Inner Mongolia, Jiangsu, Zhejiang,

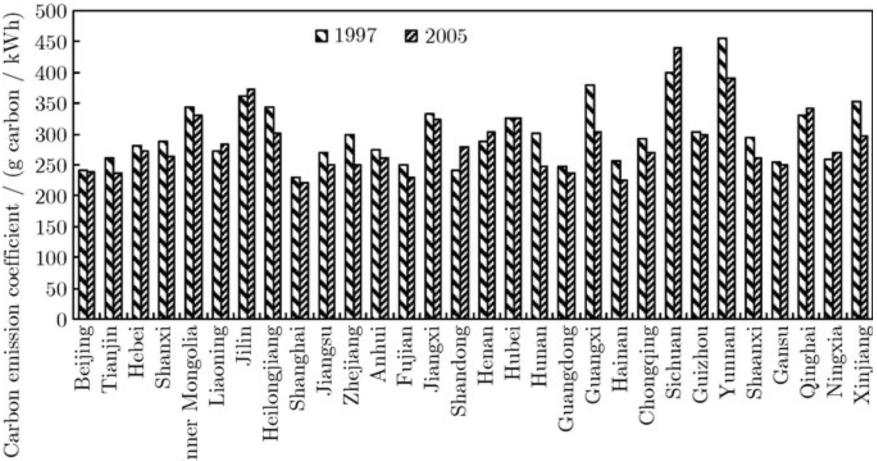

Figure 6.4 Changes of CO_2 emission coefficient of power generation in different provinces in 1997 and 2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

Shandong, Henan and Guangdong are several provinces which have high thermal power generation share in China. As shown in Figure 6.4, the CO_2 emission coefficient of power generation was high in these provinces. In particular, the emission coefficient of Inner Mongolia reached 345g carbon/kWh and 330g carbon/kWh in 1997 and 2005 respectively, while that of Guangdong, Shandong, Beijing and Shanghai was comparatively lower (below 250g carbon/kWh).

According to the above analysis, there are two ways to minimize the CO_2 emission coefficient of major thermal-powered provinces: ① to improve the thermal power generation technology in Hebei, Shandong, Jiangsu and Henan in order to reduce coal consumptionof power generation; ② to decrease the share of thermal power in these provinces. Since these provinces are major grain producers, we can take full advantage of CDM to increase the share of biomass power in the power generation structure so as to reduce the emission coefficient.

We have analyzed the regional distribution and variation of China's CO_2 emissions. Which factors have influenced the related regional variation? What is the extent of the influence? An empirical research has been conducted in this section.

6.2 Method for analysis of regional CO_2 emissions variation

1) Decomposition of China's regional CO_2 emissions

In order to analyze changes of China's regional CO_2 emissions, we have adopted LMDI method to decompose CO_2 emissions into economic growth, industrial structure, energy intensity and CO_2 emission coefficient, as indicated in Formula (6.1).

$$C=\sum_{ij}C_{ij}=\sum_{ij}Q_i\frac{Q_{ij}}{Q_i}\frac{E_{ij}}{Q_{ij}}\frac{C_{ij}}{E_{ij}}=\sum_{ij}QS_{ij}I_iR_{ij} \tag{6.1}$$

Here, C refers to CO_2 emissions from final energy use of material production sectors in 28 provinces; C_{ij} refers to CO_2 emissions from final energy use of the jth industry in the ith province; Q_i refers to value added in the ith province; Q refers to sum of values added in 28 provinces; E_{ij} refers to final energy use of the jth industry in the ith province; R_{ij} refers to CO_2 emission coefficient of final energy use of j industry in the ith province; S_{ij} refers to share of the jth industry in the ith province; I_i refers to energy intensity of the ith province.

2) Data

This chapter has discussed the changes of CO_2 emissions from the final energy use of 28 provinces during 1997—2005. The corresponding GDP data is derived from the "*1998 China Statistical Yearbook", "1999 China Statistical Yearbook", "2000 China Statistical Yearbook", "2001 China Statistical Yearbook", "2002 China Statistical Yearbook", "2003 China Statistical Yearbook", "2004 China Statistical Yearbook", "2005 China Statistical Yearbook" and "2006 China Statistical Yearbook*", all expressed at constant prices of 2005.

The final energy use of material production sectors in these provinces includes: raw coal, cleaned coal, briquette, other washed coals, coke, coke-oven gas, other coal gases, crude oil, gasoline, kerosene, diesel oil, fuel oil, LPG, refinery dry gas, other petroleum products, natural gas, electric and heat. Energy resources for thermal power generation include: rough coal, cleaned coal, briquette, other washed coals, coke, coke-oven gas, other coal gases, crude oil, gasoline, kerosene, diesel oil, fuel oil, LPG, refinery dry gas, other petroleum products, and natural gas. All these data are derived from "*1997—1999 China Energy Statistical Yearbook", "2000—2002 China Energy Statistical Yearbook", "2004 China Energy Statistical Yearbook", "2005 China Energy Statistical Yearbook" and "2007 China Energy Statistical Yearbook*".

Since the time period of the research was limited to 1997—2005, we assumed that the CO_2 emission coefficients of different energies (coal, petroleum and natural gas) remained unchanged. As a matter of fact, they have all changed slightly, and such slight changes can be neglected from the perspective of macro-level study. However, the variation of CO_2 emission coefficient of power generation and heat industry can be obtained. As a result of the variance in fuel structure (coal, petroleum, natural gas, hydropower and nuclear energy) of the power generation industry from year to year and the technological advancements in this industry, the CO_2 emission coefficient of power generation industry has changed significantly. Therefore, during the decomposition of CO_2 emission intensity, the impact of emission coefficient only refers to the influence from the emission coefficient of power and heat generation industry. The emission coefficients of power generation and heat in respective provinces were calculated in line with the power outputs (hydropower, thermal power , nuclear power and heat production) and the CO_2 emissions from the power generation industry of relating provinces, and were different from the national average emission coefficients of power generation industry.

Since "*China Energy Statistical Yearbook*" doesn't contain the energy consumption data of Taiwan, Tibet, Ningxia and Hainan, this section has therefore only analyzed the changes of CO_2 emissions from the final energy use of 28 provinces.

6.3 Analysis of regional CO_2 emissions during 1997—2005

By using the method mentioned above, we can have the empirical result of different CO_2 emission amounts of 28 provinces during 1997—2005 attributed to various regional economic growth, industrial structure, final energy use intensity and CO_2 emission coefficient.

It can be observed from Table 6.1 (Data are prepared and calculated

Table 6.1 Factors influencing China's CO_2 emissions during 1997—2005

Time/year	Change of CO_2 emissions	Impact from economic growth	Impact from industrial structure	Impact from energy intensity	Impact from CO_2 emission coefficient
1997—1998	−491.33	6427.75	832.73	−7148.50	−603.30
1998—1999	−59.06	5748.93	660.61	−6194.71	−273.89
1999—2000	3980.82	6405.97	1005.15	3237.51	−6667.80
2000—2001	2253.45	6746.20	713.04	−14666.58	9460.79
2001—2002	8286.80	8328.22	1058.88	−1585.41	485.12
2002—2003	21428.68	11999.73	1100.11	6886.63	1442.21
2003—2004	4591.54	14370.35	1659.21	−15179.75	3741.73
2004—2005	22041.56	15586.62	1913.57	9182.68	−4641.31
1997—2005	62032.46	75613.77	8943.30	−25468.13	2943.55

Note: The unit of CO_2 emissions is 10,000 tons of CO_2.

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Table 6.1) that the growth of China's CO_2 emissions varied during 1997—2005. CO_2 emissions indicated the fastest growth during 2002—2003 and 2004—2005 and accounted for 70.08% of the total growth of CO_2 emissions during 1997—2005. Generally, changes in economic growth, energy intensity, industrial structure and CO_2 emission coefficient have all resulted in the increase of CO_2 emissions.

The growth of CO_2 emissions during 1997—2005 was mainly driven by the economic development of material production sector and changes of industrial structure in 27 provinces. As a result of economic development, CO_2 emissions in 28 provinces increased by 756.14 million metric tons carbon during 1997—2005. Meanwhile, the increase in the ratio of secondary industry in the industrial structure has also resulted in the growth of CO_2 emissions by 86.43 million metric tons carbon. The increase in the share of electric power in final energy use consumption structure and the change of CO_2 emission coefficient have helped increase CO_2 emissions by 29.44 million tons. However, the drop of final energy use intensity has also resulted in the decrease of CO_2 emissions by 254.68 million metric tons carbon. Therefore, China's total CO_2 emissions from the final energy use consumption of the material production sector in 28 provinces increased by 620.32 million metric tons carbon in 2005 over 1997.

During 1997—2005, CO_2 emissions increased by 620.32 million metric tons carbon, and 55.68% of these emissions were from Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong. As indicated in Figure 6.5, CO_2

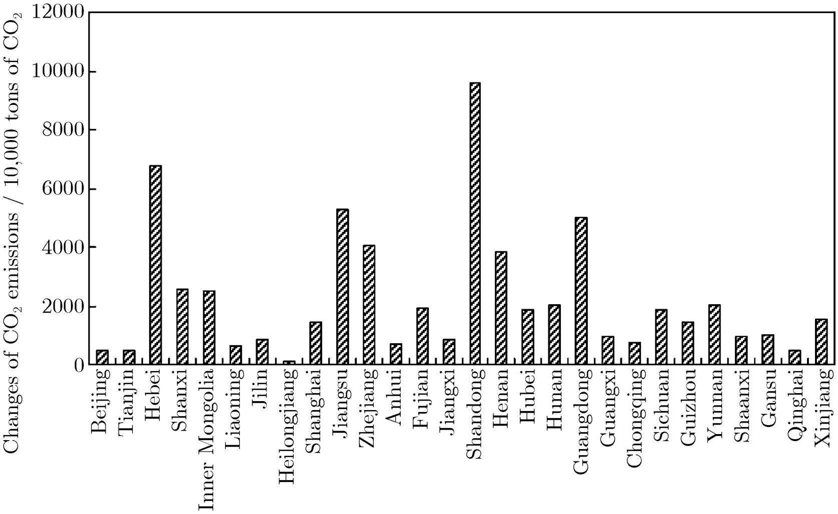

Figure 6.5 Changes of CO_2 emissions of 28 provinces during 1997—2005

emissions of these provinces have increased by 67.80, 52.74, 40.60, 96.20, 38.17 and 49.89 million tons carbon respectively. All of them are major industrial provinces with huge demands for final energy. Furthermore, the swift growth of value added of industry in these provinces during 1997—2005 has resulted in the quick increase of final energy use, bringing about the rapid increase of CO_2 emissions. Therefore, in order to mitigate the growth of emissions, emphasis should be put upon Shandong, Hebei, Guangdong, Jiangsu, Zhejiang and Henan provinces.

6.3.1 Impact from economic growth on regional CO_2 emissions

The fast growth of material production sectors in these provinces was the major cause for the increase of CO_2 emissions, with impacts increasing year after year (as indicated in Table 6.1). Figure 6.6 indicates the impacts of economic development on CO_2 emissions of different provinces.

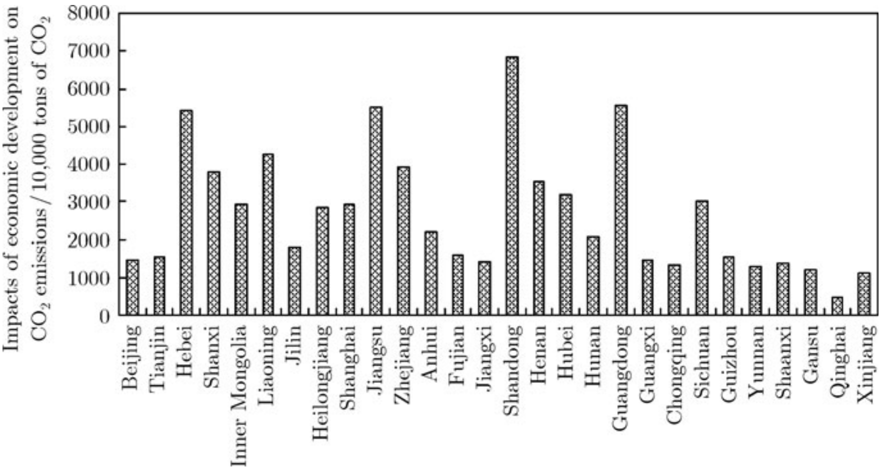

Figure 6.6 Impacts from economic development on CO_2 emissions of different provinces during 1997—2005

It can be observed from Figure 6.6 that the economic growth in Hebei, Shanxi, Liaoning, Jiangsu, Zhejiang, Shandong, Henan and Guangdong has helped increase CO_2 emissions by 54.18, 38.04, 42.63, 55.13, 39.13, 68.49, 35.44 and 55.63 million tons carbon respectively (totally 388.68 million metric tons carbon, representing 51.40% of the overall impact of economic growth on CO_2 emissions). These provinces are not only major energy consumption provinces but also major provinces with high economic development level, with contribution rate to GDP growth accounting for 47.77% as their gross

GDP constituted 50.10% and 52.68% of national GDP in 1997 and 2005 respectively. Therefore, the policy makers of these provinces are confronted with the challenge of how to coordinate between economic growth and reduction of CO_2 emissions.

6.3.2 Impact from industrial structure on regional CO_2 emissions

The change in industrial structure during 1997—2005 has increased CO_2 emissions, with impacts increasing year by year (as indicated in Table 6.1). Figure 6.7 indicates the impacts of industrial structure change on CO_2 emissions of 28 provinces.

Only the industrial structure change in Beijing, Heilongjiang and Shanghai Province has mitigated CO_2 emissions, data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.7, while in all other provinces it has all increased the emissions. In Hebei, Inner Mongolia, Shandong, Hubei, Sichuan, Guangdong, Henan and Jiangsu provinces, 56.95% of the total increment of CO_2 emissions was caused by industrial structure change, which was mainly represented by the increase in the proportion of secondary industry. Therefore, non-energy-intensive industries should be encouraged and the development of energy-intensive industries should be controlled in these provinces. Meanwhile, the technological transformation of energy-intensive industries should also be strengthened to improve the efficiency of energy utilization and slow down the growth speed of energy consumption and CO_2 emissions.

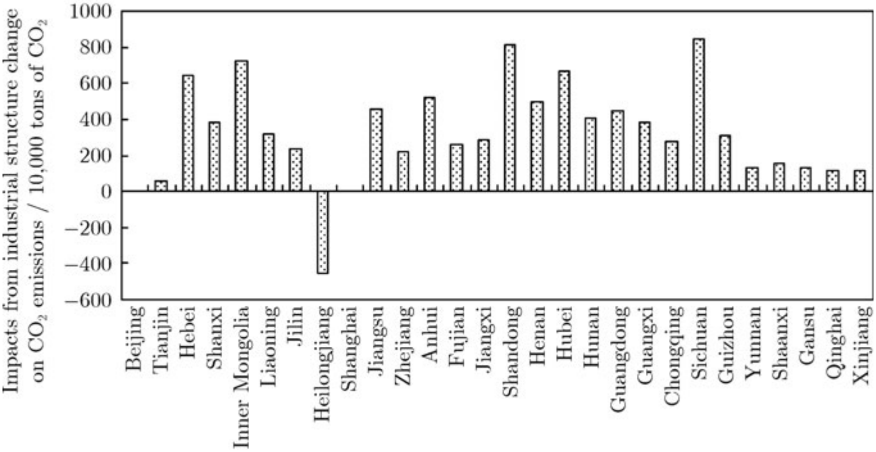

Figure 6.7 Impacts from industrial structure change on CO_2 emissions of different provinces during 1997—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

6.3.3 Impact from energy intensity on regional CO_2 emissions

Energy intensity is key to the reduction of CO_2 emissions (as shown in Table 6.1). However, instead of decreasing emissions, the impact from energy intensity has resulted in the increase of CO_2 emissions by 68.87 and 91.83 million metric tons carbon respectively during 2002—2003 and 2004—2005. Such an increase resulted from the rebound of energy intensity in such major industrial provinces as Shandong, Hebei, Jiangsu, Henan and Guangdong.

Figure 6.8 (Data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.8) shows the impact from energy intensity change on CO_2 emissions during 1997—2005. The energy intensity change in Hebei, Shandong, Fujian, Yunnan and Xinjiang province has resulted in the increase of CO_2 emissions by totally 45.29 million metric tons carbon, with the greatest increase originating from Shandong. The energy intensity change in other provinces has all reduced CO_2 emissions, with the greatest decrease originating from Liaoning, Sichuan, Hubei, Anhui and Heilongjiang (totally 140.91 million metric tons carbon). Such difference is due to the difference of changes in energy intensity Data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.9. Meanwhile, the drop of energy intensity is mainly resulted from the decrease of energy intensity in the secondary industry, with the greatest drops originating from Liaoning, Hubei and Sichuan. Owing to the energy intensity

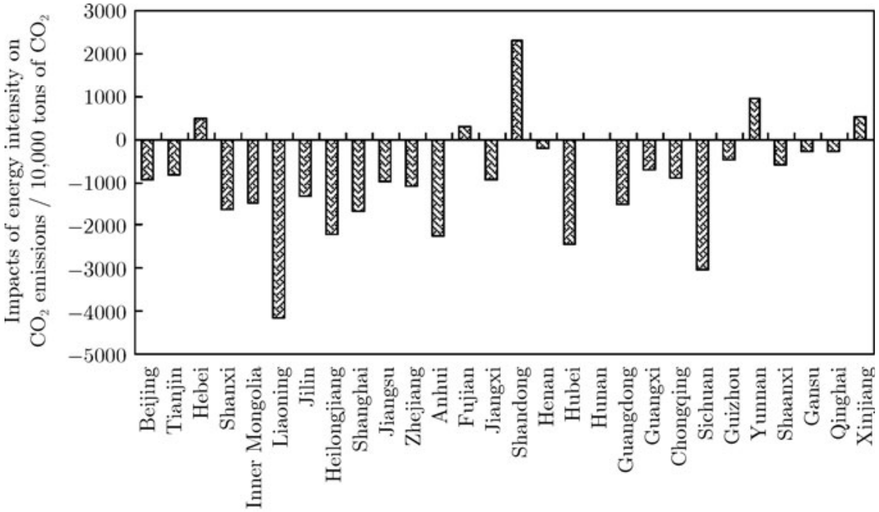

Figure 6.8 Impacts from energy intensity change on CO_2 emissions of 28 provinces during 1997—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

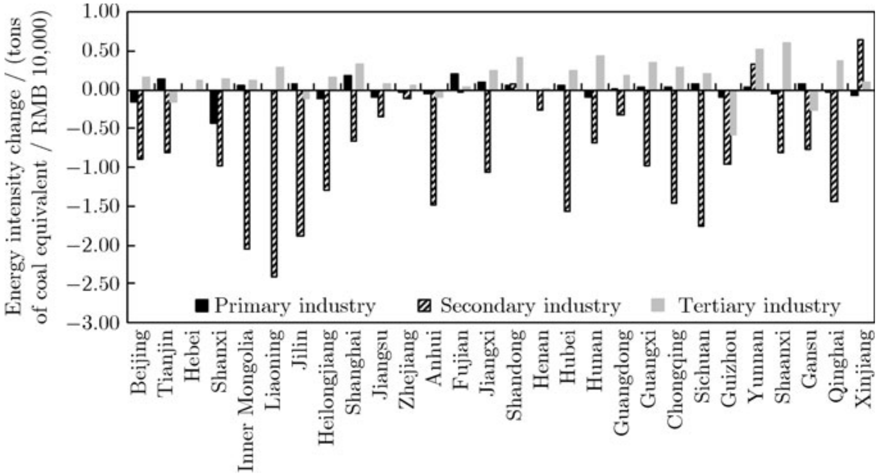

Figure 6.9 Energy intensity changes of three industries of different provinces during 1997—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

rebound during 2003—2005, major industrial provinces such as Hebei, Shandong, Henan, Jiangsu, Zhejiang and Guangdong are confronted with greater challenges in the reduction of energy intensity to mitigate CO_2 emissions.

6.3.4 Impact from CO_2 emission coefficient on regional CO_2 emission

The CO_2 emission coefficient can not only reflect the influence of CO_2 emission coefficient variation of electricity and heat, but also reflect the impacts of energy consumption structure changes on CO_2 emissions.

It can be observed from Table 6.1 that the impact of CO_2 emission coefficient on CO_2 emissions is smaller than that of other factors. Changes of CO_2 emission coefficient have contributed to the mitigation of CO_2 emissions during 1997—2000 and 2004—2005, but increased CO_2 emissions during 2000—2004. The reason for the increase is that the share of electricity in final energy use grows. Compared with 1997, the proportion of electricity in final energy use in Zhejiang and Sichuan increased by 6.98% and 6.14% respectively in 2005. Therefore, the change of CO_2 emission coefficient in both provinces has contributed most to the increase of CO_2 emissions by 10.14 and 10.29 million metric tons carbon respectively, data are prepared and calculated from China Statistical Yearbook and China Energy Statistical Yearbook, and shown in Figure 6.10, accounting for 69.40% of the overall impact. Hence, the emission coefficient of power generation should be reduced and the efficiency of electricity utilization be enhanced to reduce electricity waste.

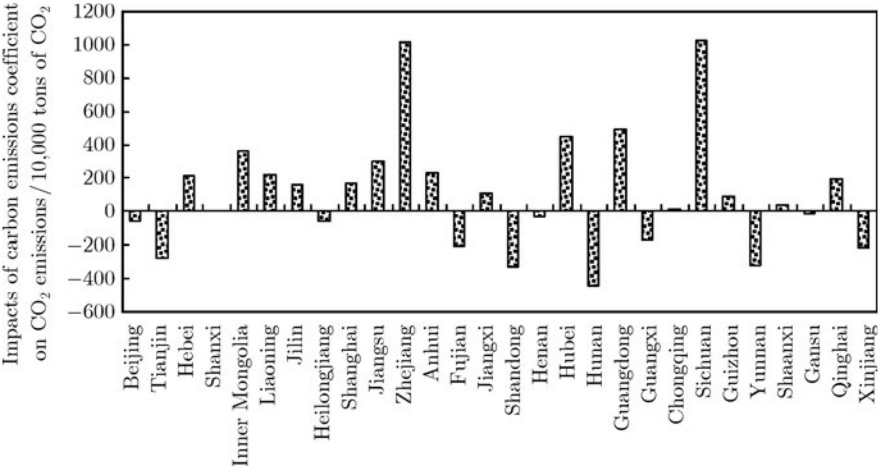

Figure 6.10 Impacts of CO_2 emission coefficient on CO_2 emissions of 28 provinces during 1997—2005

[Data Source: China Statistical Yearbook and China Energy Statistical Yearbook]

6.4 Conclusion

According to the analysis and empirical research conducted in this chapter, the status was discovered that China's CO_2 emissions vary from region to region.

(1) China's CO_2 emissions from final energy use are mainly originated from major industrial provinces such as Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong, and efforts should be focused on these provinces during the mitigation of CO_2 emissions. Compared with those of 1997, Hebei, Jiangsu, Zhejiang, Shandong, Henan and Guangdong Province were characterized by the greatest increase of CO_2 emissions from final energy use in 2005, accounting for 50.68% of overall emissions increase from final energy use in 30 provinces, municipalities and autonomous regions.

(2) Differences in regional economic structure, economic development and industrial structure will result in the difference in regional CO_2 emission intensity, which is high in Shanxi, Inner Mongolia, Guizhou, Gansu, Qinghai and Ningxia (more than 1.50 tons CO_2/RMB 10,000) and low in Beijing, Shanghai, Guangdong and Hainan (less than 0.50 tons CO_2/RMB 10,000).

(3) The economic growth and energy intensity decrease will have the greatest impact on CO_2 emissions from final energy use, while economic development is key to the increase of emissions, and the change of energy intensity can more or less decrease emissions. Despite the slight decrease of CO_2

emission intensity in 2005 over 1997, the economic growth has contributed to the continual growth of CO_2 emissions in all provinces.

(4) The energy intensity is closely related to the economic structure, energy efficiency and energy resources distribution. Owing to the rebound of energy intensity during 2003—2005, the energy intensity growth in Hebei, Shandong, Fujian, Yunnan and Xinjiang has resulted in the increase of CO_2 emissions. Therefore, the energy intensity should be further reduced to mitigate CO_2 emissions.

On basis of the research findings given in this chapter, we believe that in such developed provinces as Hebei, Inner Mongolia, Shandong, Hubei, Sichuan, Guangdong, Henan and Jiangsu,the non-energy-intensive industries should be given priority to during the economic development, and energy-intensive industries should be constrained. Meanwhile, the technological upgrading of energy-intensive industries should also be strengthened in order to improve the efficiency of energy use and slow down the growth of energy consumption and CO_2 emissions.

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Chapter 7

CO_2 Emission Abatement Technology and Impact Analysis

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The reduction of global CO_2 emissions and mitigation of global climate change has become the consensus shared by the international community. How to effectively reduce CO_2 emission is not only a scientific problem, but also a technical problem. With the upsurge in the calls for reducing CO_2 emissions, a variety of emerging CO_2 emissions technologies have become important options for reducing CO_2 emissions. What are the technical economy characteristics, emission reduction potentials and development prospects for different CO_2 emissions technologies? In regard to these questions, this chapter introduces the most important CO_2 emissions technologies at the present time, and analyzes the following questions in line with the result of technical simulation:

- Currently, what are the major CO_2 emission reduction technologies?
- How is the status of major CO_2 emission reduction technologies?
- How about the abatement potential of different CO_2 emission reduction technologies?
- What challenges and opportunities will be faced by different CO_2 emission reduction technologies? How is the future development perspective?

- During the process of CO_2 emission reduction, what contributions has the renewable energy power generation technology made to socio-economic development?

7.1 Major CO_2 emission abatement technologies

Since 1970s, many studies have proved that technical advancement is one of important ways to solve environmental problems. IPCC has emphasized in "*The Special Report on Emission Scenario*" and "*The Third Assessment Report*" that: Technical advancement should be the most important decisive factor for addressing future greenhouse gas emissions and climate change, ranking above all other driving factors (IPCC, 2000; 2001). Technical advancement will play an irreplaceable role in the improvement of energy consumption, enhancement of energy efficiency, relief of environmental pressure, reduction of greenhouse gas emissions, and mitigation of global climate change. The progress of energy technologies will play a critical role in the co-ordinated development of energy, economy, environment and climate systems under the sustainable development framework, and will exert revolutionary influence. In "*Energy Technology Perspective 2006*", through scenario analysis, IEA has pointed out that: by 2050, under the influence of key energy technologies, the global CO_2 emissions will come back to the current level, and the oil demands will drop by half. It will be a fundamental need to reduce the CO_2 emissions of power plants through renewable energy technology, CO_2 capture and storage technology and nuclear energy technology (in acceptable countries) (IEA, 2006b). Therefore, efforts shall be made to promote the progress of energy technologies, especially the development of CO_2 emissions reduction technology.

According to the evaluation of World Energy Council, fossil fuel accounted for 77% of world primary energy supply in 1990. If existing policy framework is maintained, this proportion will drop to 64% in 2050. Even if there are policies to constrain CO_2 emissions, this proportion will not be lower than 57% (WEC, 2005). Accordingly, the overall CO_2 emissions from fossil fuel consumption will increase substantially. According to the statistics of International Energy Agency, during the past 30 years, coal should be the responsible for 40% of world CO_2 emissions, while the share of petroleum and natural gas accounted for 31% and 29% respectively (IEA, 2004). According to World Energy Council (WEC, 2005), even if the energy intensity drops in the future, the CO_2 emissions from energy consumption will increase by 62% during 2002—2030 under the existing policy system (including "*Tokyo Pro-*

tocol "), and will still increase by 37% even under more rigid policy system. Therefore, the development of clean energy technologies, low-CO_2 emission technologies, renewable energy and new energy has become the major concerns for the international community.

Currently, there exists three major CO_2 emissions reduction technologies: ① to enhance energy efficiency, energy conversion ratio and save energy, i.e., advanced power generation technologies such as IGCC and NGCC; ② to adopt alternative fuels and develop low-carbon fossil fuels, nuclear energy, renewable energy and new energy; ③ to separate, capture and store CO_2 during fossil fuel consumption (Chen Xiaojin, 2006). The energy conservation and high-efficiency energy use technologies, new energy technologies and CO_2 capture and storage technologies driven by these three category have drawn the broad attention of academic circles and policy makers, especially the CO_2 capture and storage technologies. In 2005, IPCC released the "*Special Report on Carbon Dioxide Capture and Storage*" and regarded this technology as one of major options for mitigating climate change, in the hope of arousing worldwide attention to this technology (IPCC, 2005).

7.1.1 Renewable energy technology

Renewable energy include water, wind, biomass , solar power, geothermal and ocean energy, all of which are characterized by great potential and low environmental pollution. With far lower greenhouse gas emissions than that of fossil fuel (even near to zero emission) and allowing sustainable use, these energy can help reduce CO_2 emissions, mitigate global climate changes and accomplish the sustainable utilization of energy. Since 1970s, the development and utilization of renewable energy had already been a major concern of the world, and renewable energy have witnessed the quickest development. We will hereby introduce the renewable energy development status of China and the long term potential of CO_2 emission reduction enabled by these technologies.

7.1.1.1 With good potential for CO_2 emission reduction, the hydropower shall be well developed

Hydropower is currently the most mature renewable energy utilization technology with huge potential for emission reduction. The development of hydropower will help reduce CO_2 emissions. China is rich in hydropower resources, with the theoretical reserve of water power resource hitting 6.08 trillion kWh/year and average power reaching 694 million kWh, accounting for 1/6 of that of world. The exploitation rate of such resources in developed countries have reached 60%, while China remains to be a beginner of water power development (only 22%). Therefore, China has good potential for water power development.

According to the study on the relationship between the water quality of reservoir and greenhouse gas emissions, the greenhouse gas emissions of hydropower is lower than that of thermal power by 1—2 order of magnitude, and the greenhouse gas emissions of reservoir is closely related to water quality. According to the evaluation and empirical research on the greenhouse gas emissions of water reservoir as conducted by Environment Committee of International Hydropower Association, the net GHG emissions caused by the water reservoir is zero. Although some people believe that the corruption of plants submerged by the reservoir will result in the emissions of substantial greenhouse gas, more researchers consider that the GHG emissions of reservoir can be classified into renewable CO_2 emissions, i.e., normal carbon cycling (Zhang Boting, 2007). Therefore, hydropower development will bring huge potential for CO_2 emission reduction, while small hydropower is also one of preferential options of CDM program.

According to the national renewable energy development planning (National Development and Reform Commission, 2007), by 2010, China's installed capacity of hydropower will hit 190 million kW, including 140 million kW from large- and medium-sized hydropower stations and 50 million kW from small hydropower stations. By 2020, China's installed capacity of hydropower will hit 300 million kW, and the exploitation rate of hydropower development will reach 46%—47%, including 225 million kW from large- and medium-sized hydropower stations and 75 million kW from small hydropower stations. According to the estimate of related organizations (Special Committee of Renewable Energy of China Association of Resources Comprehensive Utilization, 2004), by 2010 and 2020, the CO_2 emission reduction caused by small hydropower stations will reach 40 million tons and 60 million tons respectively. It can be seen that the development of hydropower is of great significance for the mitigation of CO_2 emissions.

7.1.1.2 Well-developed Wind power technology should be encouraged with great potential for emission reduction

The wind power technology has witnessed long-term development, and mainly includes the small-sized off-grid wind turbine and large-sized on-grid wind turbine, while the latter has experienced the quickest development during the past years (Chinese Wind Energy Association, 2007). China enjoys abundant wind resources, and wind power develops quickly in China. After decades of development, China's on-grid wind power generation has entered into the phase of scaled-up development.

1) Booming development of wind power and continual drop of costs

China's wind power sector develops quickly, with on-grid wind power initiating from 1980s. By the end of 2005, the installed capacity of wind power has ranked top 7 in the world (Li Junfeng et al, 2006). So far, there are 61 wind farms and 124 under-construction wind farms throughout the country, with total installed capacity reaching 1.264 million kW in which 600kW and 750kW wind turbines accounting for 95% and 64% respectively. Furthermore, there are also 250,000 small-sized independent wind turbines installed in remote areas, with gross capacity reaching 60,000kW. During recent years, the wind farm development is migrating from land to the ocean. Along with the technical advancements and the broadening of application scale, the cost of wind power keeps decreasing, with cost effectiveness getting closer to that of conventional energy resources. Owing to the differences in technology and region, the technical-economical index varies from wind farm to wind farm.

2) Given great potential for CO_2 emission reduction, the development of wind power technology shall be encouraged

Wind power enjoys a broad potential for CO_2 emission reduction. Wind turbine with unit capacity of 1MW can decrease CO_2 emissions by 2,000 tons per year (Xinhua News Agency, 2007). Wind power is almost a commercialized renewable energy utilization technology. Despite the notable investments and high power generation costs, the wind power is suitable for serving as a CDM project. According to the national renewable energy development planning, by 2010 and 2020, the installed capacity of wind power will reach 5 million kW and 30 million kW respectively (National Development and Reform Commission, 2007). It can be predicted that: after 2020, wind power will enter into the phase of complete commercialization, and by 2030, the installed capacity is expected to reach 150—200 million kW, making wind power the top three major power sources (Special Committee of Renewable Energies of China Association of Resources Comprehensive Utilization, 2004). Wind power holds great potential for emission reduction, and will help decreaseing CO_2 emissions by 11 million tons by year 2020.

7.1.1.3 Despite the abundant biomass resources, the related technology is undeveloped and efforts shall be made to promote technological R & D

Biomass power generation includes agriculture and forestry biomass power generation, garbage power generation and biogas generation. Biomass energy is currently the most widely used renewable energy source in the world (Chinese Wind Energy Association, 2007), but such energy is mainly consumed for cooking in the low-efficient furnace of rural people in developing countries, and only a small proportion of them are used for central or distributed power generation, heat supply, gas supply and liquid fuel extraction in developed countries and few developing countries. The latter application represents the future development trend of biomass energy and shows tremendous development potential. The development trend of modern biomass energy is high-efficient and clean utilization, namely, to transform biomass energy into high-grade energies, including electric power, fuel gas and liquid fuel etc.

1) Despite the abundant biomass energy resources, the technology is underdeveloped and the power-generation costs is high

By the end of 2005, the installed capacity of China's biomass power was about 2 million kW, including 1.7 million kW from bagasse power generation and 0.2 million kW from garbage power generation. However, in respect of the biomass power generation technology, there is a large gap between China and the world advanced level. Furthermore, being another form of biomass energy utilization, the biogas and related technologies have been well developed in China. By the end of 2005, the total number of biogas digester pit users has reached 18 million households throughout the country, with annual output reaching about 7 billion cubic meters. China has also begun to produce biomass liquid fuel. Currently, China's yearly output of fuel ethanol (produced from grain) is 10.2 million tons, and the yearly output of biodiesel produced from oil crop reaches 50,000 tons.

Currently, China's biomass generator sets are mainly imported. With the commercialization of biomass power generation and the localization of generator sets, the unit investment cost will drop substantially. Meanwhile, China's biomass electric power generation technologies are still at the stage of demonstration, and their commercialization and localization largely rely on the biomass energy development policy of China. Based on the feasibility study reports of existing biomass power generation pilot projects and those which have entered into the phase of feasibility study, the economic parameters of biomass electric power generation are given in Table 7.1 (Based on the data from Sun Liyuan (2004), the results are calculated and shown in Table 7.1).

2) Biomass energy holds great potential for CO_2 emission reduction and shall be strengthened

According to the national renewable energy development planning, by

Table 7.1 Economic parameters of power generation of different biomass energies

Type	Garbage power generation		Culm power generation			Biogas power generation		
	Bagasse direct-fired	Chaff Gasification	Fixed bed gasification	Direct-fired	Fluidized bed gasification	Small-sized cultivation farm	Large-sized cultivation farm	Industrial wastewater
Scale /kW	12000	200	4000	24000	4000	200	1000	2000
Unit fixed assets /(RMB/kW)	4611	6400	8286	13330	9188	34379	20987	18150
Fuel price /(RMB/ton)	50	0	300	280	280	0	0	0
Operating time/h	3240	3000	6500	6500	6500	7000	7000	7000
Power-generation cost /(RMB/kWh)	0.3266	0.5477	0.5392	0.5082	0.5183	0.9174	0.6123	0.5348
Price /(RMB/kWh)	0.5195	0.6963	0.7059	0.7758	0.7148	1.018	0.5775	0.4863

Data Source: Sun Liyuan, 2004.

year 2010, the total installed capacity of China's agriculture and forestry biomass power (including bagasse power generation) will reach 4 million kW, and that of garbage power and methane power will reach 0.5 million kW and 1 million kW respectively. By year 2020, the gross installed capacity of biomass power (including bagasse power generation) will reach 24 million kW, and that of garbage power and methane power will reach 3 million kW and 3 million kW respectively. The methane utilization in the countryside will reach 15 billion cubic meters and 20 billion cubic meters respectively in 2010 and 2020 (National Development and Reform Commission, 2007). Both biomass power generation and biogas utilization can help reducing CO_2 emissions. By 2010 when the annual biomass power outputs reach 20 billion kWh, the CO_2 emissions will be reduced by 14 million tons, and the biogas utilization can reduce methane emissions by 7.5 billion cubic meters, which is about 45 million tons of CO_2. By 2020 when the annual biomass power outputs reach 80 billion kWh, the CO_2 emissions will be reduced by 75 million tons, and the biogas utilization can reduce methane emissions corresponding to 60 million tons of CO_2.

7.1.2 Advanced power generation technologies

Thermal power sector is the major CO_2 emissions sector. The improvement of power generation technologies and adoption of advanced power generation technologies will effectively reduce the CO_2 emissions caused by the power sector. Currently, the IGCC (Integrated Gasification Combined Cycle) and NGCC (Natural Gas Combined Cycle) have drawn broad attention.

IGCC purifies the low-heat synthesis gas generated from the gasification of such carbides as coal, refinery coke, residual oil and biomass fuel and then sends the gas into gas-steam combined cycle generation or chemical production system (Tang Yunlin, 2004). IGCC integrates the combined-cycle power generation technology with coal gasification and gas purification technologies in an organic way, and is considered a sustainable clean-coal power generation technology complying with the development trend of power generation technologies in the 21st century. It has become a highly concerned clean energy utilization technology in 21st century.

NGCC utilizes the high temperature flue gas generated from gas flaring to generate power in the gas turbine. The waste gas exhausted can produce steam in the heat recovery boiler, and the steam drives the steam turbine to generate power. Such a combination of gas and steam is called combined cycle generation.

We will hereby analyze these two advanced power generation technologies in the perspective of current development status and future development.

Both IGCC and NGCC have entered into the phase of commercial demonstration, while there are still obstacles to large-scale application. China has been tracking the development of IGCC since 1980s, and will also construct IGCC demonstration power stations in Yantai (Zhang Chunxia, 2004). In the "11th Five-year Plan" released in February 2006, Yantai has taken this 300MW IGCC power station as a key demonstration project. Similar projects include Shanghai 400MW IGCC project, Hebei Chaohua 120MW IGCC Power Plant and Liaoning Fuxin heat, power and coal gas combined supply project based on IGCC (Xu Lianbing, 2005).

After entering into the 21st Century, the role of NGCC has changed significantly. Instead of being used for emergency power supply and peak modulation, it has now become an important part of the power grid. In industrialized countries, the newly added capacity of NGCC has even exceeded that of thermal power. Along with the adjustment of energy structure policies, NGCC has been developed to some extent in China. Currently, natural gas power generation units in Hangzhou Banshan Power Plant, Zhangjiagang Huaxing Power Plant and Shanghai Chemical Industry Park Thermal Power Plant have been put into production, while those of Beijing Jingfeng and other power plants have completed construction and are currently at the phase of commissioning test (Zhang Huanyun, 2005). With the acceleration of China's natural gas resource exploration process, the implementation of West-East natural gas transmission project and the strengthening in the cooperation with overseas partners, the technology of natural gas power generation and especially the application scale of NGCC will develop and broaden gradually. However, since China is scarce in natural gas resource and high in gas price, the primary energy structure dominated by coal will remain unchanged in a long period, making the development of NGCC not as fast as other countries. Nonetheless, with more and more severe environmental protection situation, the continual development and introduction of natural gas resources and the maturation of related technologies, the share of NGCC in China's electric power system will increase substantially.

Currently, China's IGCC and NGCC power generation technologies are also confronted with certain risks and barriers in development, including:

(1) The initial construction cost of IGCC power plant can be rather high and the construction period can be very long. From Table 7.2 (Based on the data from Sun Liyuan (2004), the results are calculated and shown in Table 7.2), we can find out that the unit cost of IGCC demonstration power plant is

about twice of the unit cost of coal-fired power plant. Therefore, the on-grid power price and heat price will not have market competitiveness.

Table 7.2 Comparison between a domestic coal power plant and IGCC demonstration plant

Items compared	Coal-fired thermal power plant (300MW)	IGCC power plant (300MW)
Unit static investment/(RMB/kW)	4298	8110
Estimated power price/(RMB/kW)	313.62	429.98
Estimated heat price/(RMB/MJ)	24.21	58.01J
Construction period/months	20	36

Data Source: Xu Lianbing, 2005.

(2) China doesn't own mature core technologies of IGCC. The equipments and key technologies related to IGCC power system, gasification system and high temperature purification system need to be imported from developed countries.

(3) The operational reliability of IGCC power plant needs to be improved.

(4) The overall availability ratio of IGCC power plant fails to reach the expected value. The availability ratios of four IGCC power plants using coal as the raw material only reach 60%—80%, which need to be further improved.

Different from IGCC, the overall cost of NGCC mainly depends on the price of natural gas. Therefore, given the fluctuation of oil-gas price, the overall cost, emission reduction cost and operating cost are all subject to many uncertainties.

(1) The uncertainties in power generation costs. The fuel cost of NGCC accounts for 60%—85% of the overall power generation costs. In contrast, the fuel costs of renewable energy, nuclear energy and coal-based power plants account for 40% or below (IEA, 2006a), as indicated in Figure 7.1 (Based on the data from National Science Library, Chinese Academy of Sciences (2007), the results are calculated and shown in Figure 7.1). Therefore, the rise of fuel price will have greater economic impact on NGCC power station than other technologies. Since it is hard to predict the future price of natural gas, the greatest challenge faced by NGCC will be the uncertainty of generation cost. The rise of gas price will result in the transformation from natural gas power generation to coal-fired power generation, which has been proved by the development histories of United States and Europe during recent years.

In addition, the rapid increase in the scale of NGCC power generation will also result in the rise of gas price. For China, the current gas market is still at the primary stage, and is featured by unbalanced resource distribution, high transportation cost and limited reserves. All these factors will result in higher operating costs and greater operating risks of the natural gas power plant.

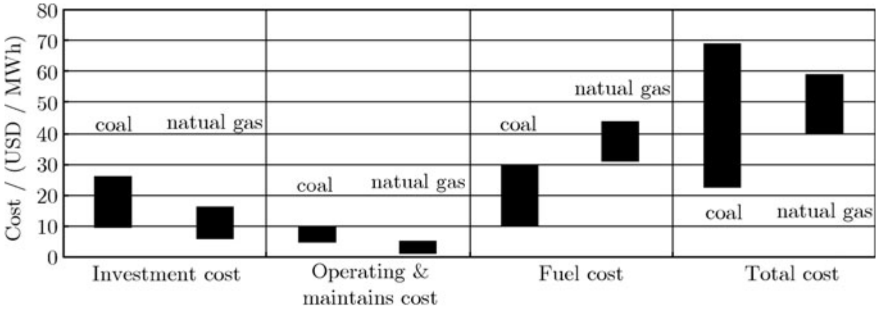

Figure 7.1 Cost comparison between coal and gas power plants

[Data Source: National Science Library, Chinese Academy of Sciences (2007)]

(2) NGCC equipments are expensive and domestic technologies are not mature. China doesn't have the capability to produce NGCC generators, which need to be imported. Therefore, the prices of spare parts are also high.

(3) The domestic electricity price of NGCC is not competitive. The high gas price has resulted in high operating cost of such power plants. If the on-grid electricity price is too low, it will be very hard for these power plants to survive.

(4) From the perspective of resource supply, the natural gas resources are not abundant in China, which will go against the development of natural gas power generation in China.

7.1.3 Carbon capture and storage technology

The development of any technology has a driver behind. The factor driving the development of carbon capture and storage (CCS) is: to reduce CO_2 emissions from fossil fuel consumption while meeting the energy demand of economic development, so as to mitigate climate change. The technology of carbon capture and storage is aimed to separate CO_2 from the emission sources of industry or related energy and then transport CO_2 to a storage site for permanent isolation. In the near future, such fossil fuel as petroleum, coal and natural gas will still be our major energy sources. According to "*International Energy Outlook 2007*" released by EIA in 2007, the average growth rate of coal consumption in the next few decades will reach 2.2%, and the share of coal in the world primary energy consumption structure will increase from 25.6% in 2004 to 28.4% in 2030. It is predicted that in the future energy structure the share of natural gas in world primary energy consumption structure will be further increased from 23.1% in 2004 to 24.3% in 2030. The annual average growth rate of petroleum will reach 1.4%, and the share of petroleum in world primary energy consumption structure will drop from 37.7% in 2004 to 34.1% in 2030. Such huge fossil fuel consumption will cause enormous CO_2 emissions. This report also points out that: the CO_2 emissions will reach 43 billion tons in 2030, representing a growth of 65% over 2004.

Therefore, positive efforts have been made by different countries to study and develop CO_2 emission reduction technologies, while CCS is one of emerging CO_2 emission reduction technologies with the broadest application prospect. CCS is expected to achieve zero emission from fossil energy use, and is therefore attached importance to by developed countries.

7.1.3.1 Despite the late start, CCS technology develops rapidly, with great potential for scaled-up development and commercialization

IPCC has indicated in the "*Special Report on Carbon Dioxide Capture and Storage*" that: CCS has good potential for decreasing the overall climate change mitigation costs and increasing the flexibility in GHG emission reduction. CCS is considered as one of the options for reducing atmospheric emissions of CO_2 from human activities (IPCC, 2005).

CSS technology is mainly applicable to major CO_2 emission sources such as thermal power plants, iron and steel plants and oil refineries. Its top superiority is to realize zero CO_2 emissions from fossil fuel combustion. CCS can be divided into three parts: ① separate and capture CO_2 from industrial and related energy emission sources; ② CO_2 transportation and the geologic storage or oceanic storage of CO_2.

(1) Capture. The major objectives of CO_2 capture include: fossil fuel fired power plants, iron and steel plants, cement plants, oil refineries and other centralized CO_2 emission sources. Currently, there are about 8,000 point sources in the world with annual CO_2 emissions exceeding 100,000 tons, with total CO_2 emissions reaching 13.466 billion tons per year.

The process of capture is to separate CO_2 from other gases. The CO_2 separation system can be mainly classified as post-combustion system, pre-combustion system and oxygen-enriched combustion system. The development stage and application status of these three capture systems vary from each other. Currently, the pre-combustion capture system is the most developed system with extensive application in the fertilizer and hydrogen production industry. The post-combustion system can only be economically feasible under certain circumstances. The oxygen-enriched combustion system will result in the increase of costs, and is therefore at the stage of demonstration. To enable convenient transportation and storage, the CO_2 will be sufficiently compressed by the capture equipment before transportation.

(2) Transport. The captured CO_2 will be transported to the storage site far from the emission source. Major ways of CO_2 transport include pipeline transport, ship transport, railway transport and road transport. However, restricted by cost and technological level, the most economic way of CO_2 transport is pipeline transport. Since the shipping cost is related to shipment distance, the ship transport of CO_2 is only considered economically feasible under certain circumstances. For instance, for the transport of CO_2 less than a few million tons or overseas shipment, the ship transport is then more economically feasible. According to the current development status, owing to the few transport needs, the scale of CO_2 ship transport is still on the small side. Although the railway transport and road transport of liquefied CO_2 are more developed in technology, they are small in transport scale and poor in economic feasibility when compared with pipeline transport and ship transport. Therefore, they are unlikely to become the choices for large-scale CO_2 transport.

(3) Storage. The captured CO_2 will be injected into the subsurface geologic structure/deep ocean or be frozen in the inorganic carbonate via industrial process. CO_2 can be stored in abandoned oil fields/gas fields, coal bed (ECBM), saline aquifer and deep ocean layer as well as used to Enhanced Oil Recovery(EOR). In respect of carbon storage method and technological development level, some technologies are ready for commercialization and partial commercialization, such as EOR, ECBM and EGR. Since these technologies can enhance the recovery rate of related products, the CO_2 injection cost can be partially or fully offset. Therefore, these technologies are more or less developed throughout the world. Owing to the uncertainties in ecological impact, the ocean storage technology is still at the research stage. Among these storage methods, the CO_2 storage capacity differs from each other. As indicated in Table 7.3 (Based on the data from DNV (2003), the results are calculate and shown in Table 7.3), saline aquifer boasts the greatest storage capacity, while EOR and ECBM have the smaller storage capacity.

After decades' development, there are now over 100 CCS projects being implemented or to be implemented throughout the world (Qu Jiansheng, Zeng Jingjing, 2007). However, a majority of them are used for EOR. The

Table 7.3 Storage capacity of different storage pools

Storage base	Capacity (100 million tons of CO_2)
Oil/gas field	9000—13000
Abandoned oil field	1260—4000
Abandoned gas filed	About 8000
Enhanced oil recovery	610—1230
Coal bed	600—1500
Saline aquifer	60000—100000
Total	70000—115000

Data Source: DNV (2003).

earliest CO_2 storage project is the Permian Basin oil field project in United States. Since 1972, the total CO_2 stored by this project has exceeded 50,000 tons. The first CO_2 storage project aimed for GHG emission reduction is the Sleipner project of Norway, which has been separating CO_2 from natural gas since 1996 and injecting the CO_2 into 800m deep seabed saline fen for storage, with daily storage capacity reaching 2700 tons and accumulated volume hitting 20 million tons. Meanwhile, a number of large-scale CCS projects are also being implemented. As indicated in Table 7.4 (Based on the data from IEAGHG (2006), the results are calculated and shown in Table 7.4), CCS research projects are mainly located in North America and Europe, and are fewer in Asia and Australia.

Table 7.4 Statistics of *carbon dioxide capture and storage* projects

Project	Asia	Australia	Europe	North America	Others	Total
Demonstration projects of CO_2 capture	4	1	4	6	1	16
Research projects of CO_2 capture	1	1	15	23	—	40
Demonstration projects of CO_2 geologic storage	1	2	4	4	2	13
Research projects of CO_2 geologic storage	5	2	16	31	—	54
Research projects of CO_2 deep ocean storage	1	—	2	5	—	8
Total	12	6	41	69	3	131

Data Source: IEAGHG (2006).

Although China has just started the research and demonstration projects of CCS, China is a early user of CO_2 EOR technology in the oil field, such as Daqing Oil Field (1990—1995), Subei Oil Field (1996), Liaohe Oil Field (from 1990), Shengli Oil Field and Zhongyuan Oil Field etc. In addition, China has, through international cooperation, implemented a number of CCS projects, including Jilin oil field recovery utilization project and China-Canada Bianqin coal-bed gas CO_2 storage technology development project (Sun Maoyuan, 2003). Generally speaking, compared with developed countries, China still needs to further strengthen the researches on CCS technologies and project practice. Besides taking an active part in international cooperation and promoting capacity building, China shall also strengthen independent research & development, properly advance demonstration projects and implement practical application projects.

7.1.3.2 CCS technologies are currently higher in costs and more competitive than other emission reduction technologies

According to IEA (2006a), the current costs of CCS power plants are between USD 30—90/tons of CO_2 or even higher, which mainly include capture cost (USD 20—80/tons of CO_2), transport cost (USD 1—10/100 kilometers), and storage & monitoring cost (USD 2—5/tons of CO_2). Furthermore, the application of CCS will increase the power generation costs of power plants. IEA (2006a) has indicated in the report that: the power generation cost of power plants applied with CCS technology will increase by USD 20—30/MW; by 2030, owing to the technological advancements, the cost of CCS will drop to USD 25/tons of CO_2, and the corresponding power generation cost will only increase by USD 10—20/MW. However, if it is used for EOR, the cost of CCS will be offset. The research findings of IPCC show that EOR will reduce the extra cost caused by CCS application by USD 10—20/MW. However, the economic benefit of EOR mainly depends on the oil price (IPCC, 2005).

Despite the high cost of CCS application, CCS is compatible with many energy infrastructures and has good cost competitiveness. Therefore, compared with other emission reduction technologies, CCS is still competitive to a certain extent. Based on the data from World Coal Institute (2005), the results are calculated and shown in Table 7.5. Generally speaking, the cost of CCS technology and the integration of CCS technology with other advanced power generation technologies are far lower than the abatement cost of renewable energy. Moreover, the cost increase of CCS will be comparatively small when integrating advanced power generation technologies with CCS technology (i.e., NGCC and IGCC) (as indicated in Table 7.5).

The cost of CCS application can be different if different technologies are selected. Furthermore, owing to the differences in the type of fuel and technology adopted by the power plant, the cost data of CCS cannot be treated

Table 7.5 Comparison of cost between carbon mitigation with fossil fuel, renewable energy and nuclear energy technology

Technology	Abatement cost related to coal (USD per ton of CO_2)	Abatement cost related to natural gas (USD per ton of CO_2)
Offshore wind power	−63—125	−61—291
Onshore wind power	11—287	265—592
Biological fuel	108—200	240—447
Nuclear energy	44—80	89—164
Tidal energy	277—597	572—1168
IGCC+CCS	24—45	101—188
New IGCC+CCS	54—101	151—282
Coal-fired power plant +CCS	66—122	195—362
New coal-fired power plant + CCS	92—221	243—566

Data Source: World Coal Institute (2005).

in same manner. We can summarize the cost range and influencing factors of CCS technology according to historical data: under most circumstances, the cost of CO_2 capture and separation (including compression) accounts for the greatest proportion in the overall cost structure; the cost of CO_2 transport mainly depends on the quantity, distance, population density, land type and other influencing factors. In contrast, the cost of CO_2 injection and storage is comparatively lower.

7.1.3.3 The scaled-up development of CCS technology mainly relies on technological improvement and cost reduction

Although CCS technology has great potential for emission reduction and is one of technological options for CO_2 emission reduction, the extensive application of CCS mainly relies on the technology maturity level, cost, overall emission reduction capacity, technical popularity/transfer in developing countries, capacity of technological application, policies and rules, possible environmental problems and public response etc.

Potential risks and hazards of CCS on social environment: the CO_2 may leak into the atmosphere and endanger human health and safety; the CO_2 may leak and the saline water may replace ground water; the impact on terrestrial eco-system and marine eco-system; induced earthquake, land subsidence or other hazards. Furthermore, the promotion and scaled-up application of CCS technology are still confronted with a number of obstacles such as technology, cost, market, policy and mechanism etc.

1) Currently, CCS technology is high in cost and weak in market competitiveness

Currently, the major obstacle inhibiting the technical application of CCS is the high costs. The implementation of CCS system will result in the increase of a number of costs. The CCS technology can only be extensively applied after the overall cost is reduced to USD 25—30/ton of CO_2 (IPCC, 2005). Along with the advancements of CCS technologies and the expansion of scale economy, the cost will be reduced in the future. Furthermore, the investment and financing of CCS projects are confronted with a number of problems. Therefore, we should develop a standardized framework to strengthen the inputs of CCS from the government and private sector, the research and development of and the acceptability to CCS, so as to resolve the uncertainties in technology and market and promote the technological development of CCS.

2) There is no international convention related to CO_2 storage

From the aspect of legal protection, some countries have begun to cover the coastal geologic storage of CO_2 in their policies. For instance, the conventional way adopted in some countries is that the government takes the long-term responsibility for the CO_2 storage, like underground mining operation and etc. In addition, there are also some international conventions (i.e., *United Nations Convention of the Sea*, *London Convention* and *Convention for the Protection of the Marine Environment of the North-east Atlantic*) referring to the environmental change caused by the injection of CO_2 into the ocean. However, none of these conventions has given consideration to CO_2 storage (IPCC, 2005).

3) As a CDM project, CCS needs to be further studied on methodology and assessment approach, and the incentive mechanism is absent

According to the mechanism of CDM, any energy efficiency improvement technology, advanced new and renewable energy technology, advanced waste energy recovery technology and GHG recovery technology can be the technological options of CDM project cooperation. However, the current CDM methodology is mainly involved with the CO_2 capture and storage in natural ecosystem, and the CCS methodology and accounting system shall be further studied. Some researchers believe that: there is a great doubt that whether CCS can be treated as a CDM project in terms of methodology, technical reliability and project additionality (Research Center for Sustainable Development, Chinese Academy of Social Sciences, 2006). Furthermore, CCS may be faced with the following challenges: how to embody the goal of promoting sustainable development of CDM? Whether it can be coordinated with the preferential development fields of host country? How about its competition with other CDM projects and its financing? In order to address these problems, a mechanism which is more suitable than CDM shall be established internationally. With the launch of "*Kyoto Protocol*", the international community shall pay more attention to the real effect of this protocol. Considering the existing technologies and economic feasibility, the effect of CCS on the mitigation of global climate change is still limited in the near future. Some developed countries have launched a number of pilot projects, while the development of CSS remains weak in developing countries.

Generally speaking, CCS is an important technology enabling CO_2 emission reduction and low-carbon economy. The current technologies are feasible but high in costs. CCS should be further developed in order to reduce costs and be applied extensively, so as to play an important role in the mitigation of global CO_2 emissions and global climate change.

7.1.4 Energy conservation technologies

There are many ways to reduce CO_2 emissions, and the most direct one is to reduce energy consumption, especially the consumption of fossil fuels. For a long time, China has been upholding the policy of "simultaneously to conserve and explore energy, giving first priority to the former" to enhance the efficiency of energy utilization and reduce energy consumption of per unit output. Now China has managed to decrease energy consumption by hundreds of million tce.

According to the "*Intermediate- and Long-term Planning for Energy Conservation*", by 2010, China's energy consumption per RMB 10,000 of GDP (constant prices of 1990, the same below) will drop from 2.68 tons coal equivalent in 2002 to 2.25 tons of coal equivalent. The capacity of energy conservation will hit 400 million tce, representing a decrease of CO_2 emissions by 1 billion tons. By 2020, the energy consumption of per RMB 10,000 GDP will drop to 1.54 tce. The capacity of energy conservation will hit 1.4 billion tce, which are equivalent to 111% of the newly added energy outputs (1.26 billion tce) planned for the corresponding period and represent a decrease of CO_2 emissions by 3.5 billion tons. If this goal can be accomplished, China's CO_2 emissions will be decreased substantially, and the international emission reduction pressure imposed on China will be well eased. In order to accomplish the aforementioned goal of energy conservation, China has proposed three key areas of energy conservation: energy conservation of major industries, energy conservation of transportation and communication, and energy conservation of building, commercial and households use. Meanwhile, this plan has also identified 10 major projects and developed the specific implementation plans. Through the implementation of the aforesaid 10 major projects, 240 million tce (including the increment) can be saved during the "11th Five-year Period". CO_2 emissions from power generation, industrial production, transportation/electricity/residential building and commercial energy consumption account for 34%, 25%, 23% and 18% respectively of gross CO_2 emissions anthropogenic. We will analyze the corresponding energy-saving technologies, methods and energy conservation & emission reduction potentials for power industry, iron and steel industry, building materials industry, transportation energy conservation, building energy conservation and government/resident energy conservation.

7.1.4.1 The key to the energy conservation of power industry is to reduce coal consumption and line loss during power distribution

The coal consumption and transmission loss during power supply is an important indicator to measure the energy efficiency and economical operation level of the power sector. During recent years, the coal consumption and transmission loss rate of China's power supply sector have decreased substantially. From 1980 to 2006, the net coal consumption rate dropped from 448g/kWh to 366g/kWh, while the transmission loss rate dropped from 8.9% to 7.08%. Although the energy conservation initiatives of China's power industry have been proved to be effective, there is still a big gap between China and major industrial countries. These differences include (Wang Zhixuan et al, 2003): ① China's coal consumption of power supply is 60g/kWh higher than the advanced international standard, and is equivalent to that of developed countries in 1970s; ② China's transmission loss rate is 2%—2.5% higher than that of advanced international power companies; ③ the power generation structure is not appropriate enough, the proportion of new and renewable energy needs to be increased, and the share of large generating units is too small. According to the estimate, if the existing small generating units of China are completely replaced by large ones, 90 million tce can be saved and 220 million tons of CO_2 emissions can be mitigated per year (Chen Deming, 2007). Therefore, China boasts great potential for the energy conservation and emission reduction of the power industry.

From such aspects as energy conservation technologies, policies and measures related to the power industry, according to "*Intermediate- and Long-term Planning for Energy Conservation* " and "*Policy Outline of China's Energy Conservation* ", the average coal consumption of power distribution per kWh will be reduced to 360g standard coal by 2010 and 320g standard coal by 2020 in China's thermal power plants. The integrative station service power consumption rate will reach 5.5% by 2010 and 5.1% by 2020. The transmission loss rate will drop to 7.2% by 2010 and 6.8% by 2020. The accomplishment of such goals will greatly decrease the energy consumption and CO_2 emissions of the power industry.

7.1.4.2 Iron and steel industry boasts the greatest potential for energy conservation and emission reduction

The iron and steel industry is characterized by high energy consumption and high CO_2 emissions, and is considered as one of industries with the greatest potential for energy conservation and emission reduction. Currently, China's iron and steel industry has consumed about 480 million tce, accounting for 17% of the gross energy consumption of China (next to the power industry), while the total energy consumption of key iron and steel enterprises hits 198 million tce.

China's iron and steel industry has played an important role in energy conservation. During 1990—2005, the comprehensive energy consumption per ton of steel was reduced from 1.61 tce to 0.741 ton of standard coal. The comparable energy consumption per ton of steel of major iron and steel enterprises was reduced from 0.997 ton of standard coal to 0.714 ton of standard coal (Wang Taichang et al, 2007). However, compared to developed countries, China still lags behind in respect of some economic-technical indicators of the iron and steel industry. There is a long way to go for the iron and steel industry to accomplish energy conservation and emission reduction.

According to the "*Policy for Developing the Iron and Steel Industry*", the comprehensive energy consumption per ton of steel will drop to 0.73 ton of standard coal by 2010 and to 0.7 ton by 2020, while the comparable energy consumption per ton of steel will drop to 0.685 ton of standard coal by 2010 and 0.64 ton by 2020.

7.1.4.3 Cement industry plays a critical role in the energy conservation of the building materials industry

Cement industry is the energy hog of the building materials industry, with energy consumption accounting for 50% of the total energy consumption of the building materials industry. The cement industry is the key to the energy conservation of building materials industry. The comprehensive energy consumption of cement industry has dropped to 142g coal equivalent/ton in 2006. However, there is still a major gap between China and developed countries. Currently, the comprehensive energy consumption of China's cement industry is about 26% higher than international standard.

The elimination of backward cement production technique and the adoption of advanced cement production process can substantially decrease energy consumption and CO_2 emissions from cement production. If 50 million tons of backward cement production capacity can be eliminated, 4.5 billion kWh of electricity will be saved, 40 million tons of CO_2 emissions will be decreased, and 7 million tons of coal will be conserved. Therefore, the cement industry can provide distinct effect of energy conservation and emission reduction. According to "*Policy Outline of Energy Conservation*" (2005), the energy consumption level of China's cement industry will reach or approximate to the world average by 2020. During 2000—2020, it is estimated that comprehensive energy consumption of cement products will drop from 162g standard coal to 129g standard coal. Should this goal be accomplished, the cement industry will play a critical part in energy conservation and emission reduction.

Furthermore, the transportation, building, government and residence sectors also have great potentials for energy conservation and emission reduction. According to the research findings of "Study on the Technologies for Detecting and Analyzing Human Factors in Global Environment Change" (11th Five-year National Sci-tech Support Program) (Ministry of Science and Technology, PRC, 2007), if all residents can actively take part in *National Energy Conservation & Emission Reduction*, 77 million tce will be saved and 200 million tons of CO_2 emissions will be decreased per year, offering significant economic, social and environmental benefits.

7.2 Analysis of CO_2 emission abatement capability of technologies

CO_2 emission reduction technologies such as renewable energy, advanced power generation technologies and CCS are all characterized by considerable potential for emission reduction, and will play a critical role in developing low-carbon economy in the future. We will hereby introduce the emission reduction capability and potential of these emission reduction technologies.

7.2.1 Renewable energy could mitigate CO_2 emissions effectively with long term abatement potential

According to the resource status and technological development level of renewable energy, hydropower, biomass, wind and solar energy will witness the quickest development in the future. The wind power generation technology has been matured basically. With economical efficiency approximating to that of conventional energy, the wind energy will maintain quick growth in the future years, while the trend of solar energy development will be photovoltaic power generation and heat utilization. Generally speaking, during the past 20 years, a majority of renewable energy has experienced quick development, with industry scale, economical efficiency and commercialization level being enhanced year after year. It is expected that: during 2010—2020, a majority of renewable energy technologies will become competitive in the market and experience quicker development after 2020. Advancements in renewable energy technologies will have great contribution to CO_2 emission reduction. Table 7.6 (Based on the data from National Development and Reform Commission (2007), the results are calculated and shown in Table 7.6) indicates the CO_2 emission reduction potential of renewable energy in 2010 and 2020. If the development of China's renewable energy meets the goal for year 2010, 600 million tons of CO_2 emissions will be decreased per year. If the goal for 2020 is met, 1.2 billion tons of CO_2 emissions will be reduced per year (National Development and Reform Commission, 2007).

Table 7.6 CO_2 mitigation potential of major renewable energy in 2010 and 2020

Renewable energies	Emission reduction potential/10,000 tons of CO_2	
	2010	2020
Hydropower	4000	6000
Wind Power	200	1100
Biomass energy	5900	135000

7.2.2 IGCC and NGCC now are in commercial demonstration and may accomplish the overall optimization of energy conservation and emission reduction

Compared with other power generation technologies, IGCC and NGCC provide less CO_2 emissions. In particular, the CO_2 emissions of NGCC are only 50% of that of traditional coal-fired power generation. Based on the data from National Science Library, Chinese Academy of Sciences (2007), the results are calculated and shown in Figure 7.2. The fuel used in NGCC is natural gas, which is featured by low CO_2 intensity. Meanwhile, NGCC boasts high generating efficiency, which can effectively reduce CO_2 emissions. Currently, the heat efficiency of NGCC under LHV (low heat value) can reach 60%. In contrast, the world average efficiency of gas fired power plants was only 42% in 2003 (IEA, 2006a). Therefore, the CO_2 emissions per unit of power output of NGCC power plants are only 50% of that of ordinary coal-fired power plants. According to "Energy Technology Perspective 2006" (IEA), by 2050, under the circumstance of technical advancements (ACT Scenario), NGCC's contribution to the reduction of world CO_2 emissions will reach 5%—7% (IEA, 2006b).

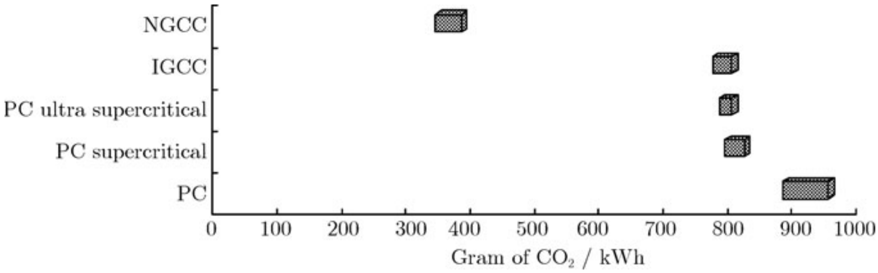

Figure 7.2 CO_2 emissions of different fossil fuel power plants

[Data Source: National Science Library, Chinese Academy of Sciences (2007)]

NGCC/IGCC and CCS are considered as technologies with the greatest potential for accomplishing CO_2 emission reduction. The combination of both NGCC/IGCC and CCS can well improve coal efficiency and even achieve zero emission of CO_2. Compared with the CCS technology applied in the traditional coal-fired power generation industry, NGCC and IGCC consume less energy and lower cost during CO_2 capture. Based on the data from IPCC (2005), the results are calculated and shown in Table 7.7.

Table 7.7 Comparison of mitigation potential and costs between different generation technologies with and without CCS

Power plant performance and cost parameters	PC Power Plant	NGCC	IGCC
Reference power plant without CCS:			
Power utilization cost /(USD/kWh)	0.043—0.052	0.031—0.050	0.041—0.061
Power plant with CO_2 capture:			
Demand for fuel increase/%	24—40	11—22	14—25
CO_2 capture/(kg/kWh)	0.82—0.97	0.36—0.41	0.67—0.94
Net CO_2/(kg/kWh)	0.62—0.7	0.3—0.32	0.59—0.73
Reduce rata of net CO_2/%	81—88	83—88	81—91
Power plant with CCS:			
Power plant performance and cost parameters	PC Power Plant	NGCC	IGCC
Power utilization cost /(USD/kWh)	0.063—0.099	0.0430—0.077	0.055—0.091
CCS cost/(USD/kWh)	0.019—0.047	0.012—0.029	0.01—0.032
Increase in power utilization cost/%	43—91	37—85	21—78
Mitigation cost/(USD/ton of CO_2)	30—71	38—91	14—53
Mitigation cost/(USD/ton of carbon)	110—260	140—330	51—200

Continued

Power plant performance and cost parameters	PC Power Plant	NGCC	IGCC
Power plant with CCS and EOR:			
Power utilization cost /(USD/kWh)	0.049—0.081	0.037—0.07	0.04—0.075
CCS cost/(USD/kWh)	0.005—0.029	0.006—0.022	(−0.005)—0.019
Increase in power utilization cost/%	12—57	19—63	(−10)—46
Mitigation cost/(USD/ton of CO_2)	9—44	19—68	(−7)—31
Mitigation cost/(USD/ton of carbon)	31—160	71—250	(−25)—120

Data Source: IPCC (2005).

The CO_2 emission reduction capability of NGCC can be very different in cases with and without CCS. When CCS is not applied, the CO_2 emissions of NGCC will be 0.344—0.379kg/kWh. In contract, the CO_2 emissions of traditional coal-fired power plants are 0.736—0.811kg/kWh, which are quite higher (IPCC, 2005). After the CCS technology has been applied, the CO_2 emissions of NGCC drop substantially, with the representative value of CO_2 emissions reaching 0.052kg/kWh, which is only 14% of that without CCS. Therefore, NGCC has great potential for emission reduction.

7.2.3 CCS may reach near zero emission

According to the report of World Energy Council, in the reference scenario, the world CO_2 emissions will reach 38 million tons by 2030 and 55 million tons by 2050. If CCS is applied, the CO_2 emissions will decrease by 6 million tons (16%) by 2030 and 18 million tons (33%) by 2050. Based on the data from WEC (2005), the results are calculated and shown in Figure 7.3. IPCC has pointed out in the report that: under the circumstance when the GHG concentration in the aerosphere is maintained between 450—750 ppmv① , in the combination of CO_2 emission mitigation schemes with the lowest cost, the accumulated emission reduction potential of CCS② can reach 22—220 billion tons (6—60 billion tons of CO_2), which means: CCS would have contributed to 15%—55% of total world emission reduction before 2100 in a series of reference scenarios.

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① ppmv is a unit of gas concentration, namly: parts per million by volume.

② Economic potential is the GHG emission reduction capacity of a certain scheme, namely, the cost benefits (such as the market value of CO_2 emission reduction and the cost of other schemes) of this scheme under the given general circumstance.

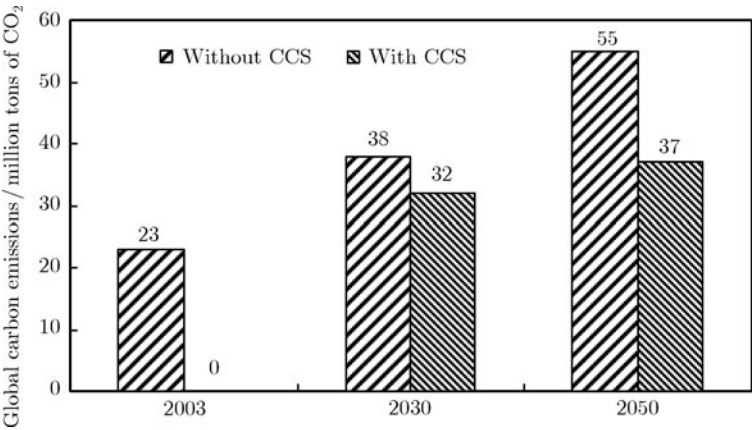

Figure 7.3 Global CO_2 emissions in the case of with and without CCS [Data Source: WEC (2005)]

IEA has also utilized the Energy Technology Perspective model to analyze the potential of CCS for future world CO_2 emission reduction (IEA, 2004). Under the circumstance when the carbon tax rate reaches USD 50/ton of CO_2, CCS will be widely applied in 2015. By 2020, 2030 and 2050, about 2.3 million tons, 8.5 million tons and 18.1 million tons of CO_2 will be captured and stored, and the CO_2 captured by power plants will account for 53%, 70% and 80% of all captured CO_2 respectively. The rest will come from fuel processing industry and manufacturing industry. According to the "Energy Technology Perspective 2006" released by IEA, by 2050, the CCS applied in thermal power plants, industry and synthetic fuel production sector will contribute to 20%—28% of world CO_2 emission reduction, and become the second largest emission reduction technology after energy efficiency improvement (IEA, 2006a).

IPCC pointed out that the major contribution of CCS system to the mitigation of climate change comes from its application in the power sector. However, to reduce CO_2 emissions with CCS will be accompanied by certain penalties (IPCC, 2005). From Table 7.8 (Based on the data from IPCC (2005), the results are calculated and shown in Table 7.8), it can be observed that the application of CCS in the power plant will increase energy consumption, power generation costs and capital costs, and hence decrease the power generation efficiency of the power plant. From Table 7.8, it can be observed that under the circumstance of accomplishing the same CO_2 emission reduction rate, the greatest increase in energy demand and highest rise of power generation costs take place in PC power plants after CCS is applied. Although the energy demand of IGCC power plants is slightly higher than that of NGCC power plants, the capital cost increment rate and power generation cost growth rate are far lower than that of NGCC power plants and PC power plants. Although the energy demand growth rate of NGCC power plants after applying CCS is the lowest one (about 16%), the capital cost increment rate of NGCC power plants is the highest one (76%). Therefore, in general, the application of CCS by different types of power plants will result in different technological-economic indicator variations.

Table 7.8 Variation of technological and economic indicators of carbon capture techniques of new plants based on present technology

Index	New NGCC power plants	New PC① power plants	New IGCC power plants
CO_2 emission reduction rate with CCS adopted/%	86	85	86
Energy demand growth rate with CCS adopted/%	16	31	19
Capital cost increment rate with CCS adopted/%	76	63	37
Power generation cost growth rate with CCS adopted/%	46	57	33

Data Source: IPCC (2005).

7.3 Socio-economic impact analysis of renewable electricity

Despite the booming technological development of the renewable electricity at the present time, the power generation costs are apparently higher than that of traditional thermal power generation technology. Under the current level of technological development, should scaled-up development of renewable electricity be launched in China, how the impact on economic development, power sector and end users will be. Therefore, this section has utilized the computable general equilibrium model of CEEPA to analyze the impacts of replacing conventional power generation technologies with renewable electricity.

7.3.1 China Energy and Environmental Policy Analysis Model (CEEPA)

This section has adopted the CEEPA model developed by Center for Energy and Environmental Policy Research (CEEP). In order to analyze problems conveniently, we have considered 20 sectors (agriculture, forestry, live-

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① PC refers to pulverized coal.

stock husbandry, other agriculture, iron and steel industry, building materials industry, chemical industry, non-ferrous metals industry, other heavy industry, papermaking/printing industry, other light industry, construction industry, traffic transport industry, service industry, coal mining and dressing industry, oil production industry, natural gas exploitation industry, petroleum processing industry, power generation and distribution industry, and heat production and distribution industry), 2 kinds of residents (urban residents and rural residents) and the economic behaviors of the government (including 6 basic modules: production module, income module, expense module, investment module, foreign trade module and environment module).

1) Decomposition of power sector

The power sector is further subdivided in accordance with the mode of power generation (as indicated in Figure 7.4. McFarland (2004) and Wing (2008) have studied the modelization of power generation technologies and their impacts in the general equilibrium model. By referring to the research findings of Wing (2008) and in accordance with the bottom-up data of China's power industry (including the installed generation capacity, overnight cost, operating cost, heat consumption rate and capacity factor of various power generation technologies), a nonlinear programming model is used to divide the production behavior of power sector into three basic activities: operation management, power transmission & distribution and power generation. In this model, seven power generation modes are considered: coal-fired power generation, oil-fired power generation, gas-fired power generation, hydropower, nuclear power, wind power, and biomass power (as indicated in Figure 7.4).

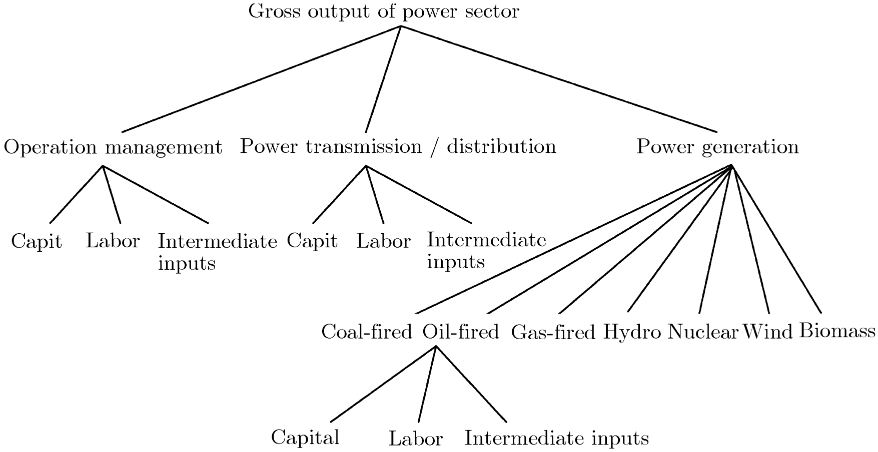

Figure 7.4 Decomposition of electric power sector

2) Handling of the capital market

Considering that power generation projects are always accompanied with long construction period and poor capital mobility, the capital supply in market is divided into fully liquid capital and non-liquid capital used for specific power generation technologies (Liang Qiaomei, 2007). In order to avoid the circumstance that the complete restriction on capital flows will result in zero capital return, we assume that non-liquid capital is partially reversible, and a CET function is used to describe the adjustment between fully liquid capital and the capital used for specific power generation technologies. Under the clearance of capital market, there will be a balance of distribution and demand between the fully liquid capital and the capital used for specific power generation technologies.

According to the "*Middle- and Long-term Planning of Renewable Energy Development*", we set up the power generation model of renewable energy, and assume that renewable electricity can replace 2%—5% of thermal power.

In order to simulate the substitution of thermal power by hydropower, wind power and biomass power, the exogenous variables include the power outputs of hydropower, wind power and biomass power, while the endogenous variables include the power outputs of coal-fired power, oil-fired power, natural gas power and nuclear power.

7.3.2 Analysis of socio-economic impact of renewable electricity

From the aforementioned model, this section has obtained the following major findings:

7.3.2.1 Impacts on macro economy

The impacts on macro economy include the impacts on real GDP, consumption and investment. The GDP as mentioned herein is the real GDP described in expenditure approach and composed of aggregate consumption, gross investment and net export. Since the model adopts the closure law set by the exogenous variable of offshore savings in international trade balancing, the value of net export remains unchanged. Hence, the GDP is mainly affected by aggregate consumption and gross investment. According to Table 7.9, the impacts of gross investment and aggregate consumption under both substitution goals are negative, and thus the impact on real GDP shall be negative.

According to the savings-investment closure law of this model, the gross investment is completely transformed from the endogenous variable of gross savings. The key components of gross savings include enterprise savings,

Table 7.9 Impacts of different renewable electricity schemes

Index	Substitute 2%/%	Substitute 5%/%
GDP	−0.031	−0.121
Gross investment	−0.016	−0.024
Gross consumption	−0.019	−0.089
Average ROIC	−0.002	−0.006
Demand for labor	−0.001	−0.003
Disposable income of rural population	−0.004	−0.008
Disposable income of urban population	−0.001	−0.006
Consumer price index of rural population	0.003	0.007
Consumer price index of urban population	0.013	0.023
Energy intensity	−0.006	−0.012
CO_2 emission coefficient of primary energies	−0.01	−0.1
CO_2 emissions	−1.213	−3.832

personal savings and government savings. Since renewable electricity is considered as a capital intensive technology, the average ROIC and demand for labor will drop when compared with the reference scenario, resulting in the drop of enterprise's gross profit when compared with the reference scenario and then the decrease of enterprise savings.

In respect of aggregate consumption, since this model adopts the closure law of the exogenous government consumption, the aggregate consumption is mainly influenced by the resident consumption, which plays a dominant role in the aggregate consumption. Since the resident consumption is mainly determined by the disposable income of residents and the price level, it is propotional to the disposable income of residents and inversely propotional to the price level. According to Table 7.9, the labor demand and enterprise profit decrease, and the disposable incomes of urban/rural residents drop dramatically when compared with the reference scenario. According to the fluctuation of consumer price index, the rise in the consumer price index of urban/rural residents will result in the drop of disposable income, the decrease in the consumption of urban/rural residents and hence the drop in aggregate consumption.

7.3.2.2 Impacts on different sectors

Figure 7.5 indicates the impacts of two substitution of power generation with renewable energy on the outputs of energy intensive sectors.

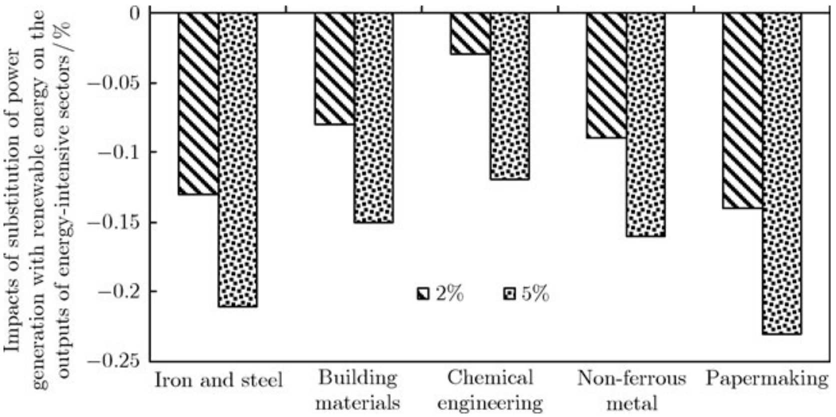

Figure 7.5 Impacts of different substitution of power generation with renewable energy on the outputs of five energy-intensive sectors

1) Impacts on the outputs of energy intensive sectors

According to Figure 7.5, we can find that different renewable electricity schemes have all resulted in the decrease in the outputs of energy intensive sectors such as iron and steel, construction materials, chemical engineering, non-ferrous metal, papermaking and etc, with iron and steel and papermaking sectors being subject to the greatest influence. These sectors are not only energy intensive sectors, but also electricity intensive sectors. The rise of power price will also result in the drop in output. Therefore, besides increasing the proportion of renewable electricity, we shall also consider the subsidy offered to power generation enterprises and electricity intensive sectors.

2) Impacts on the product prices of energy intensive sectors

According to Figure 7.6, we can find out that different renewable electricity schemes have all resulted in the rise in the product prices of such energy intensive sectors as iron and steel, construction materials, chemical engineering, non-ferrous metal, papermaking and etc, while the price rise under the 5% substitution scenario is apparently greater than the 2% substitution scenario. The impacts are different, with papermaking sector being subject to the greatest rise in product price, followed by iron and steel, non-ferrous metal, construction material and chemical engineering sectors.

3) Impacts on energy consumption and CO_2 emissions

Both substitution schemes can apparently decrease energy intensity, primary energy CO_2 emission coefficient and CO_2 emissions (as indicated in Table 7.10). It shows that the increase in the share of renewable energy consumption will contribute to energy conservation and CO_2 emission reduction.

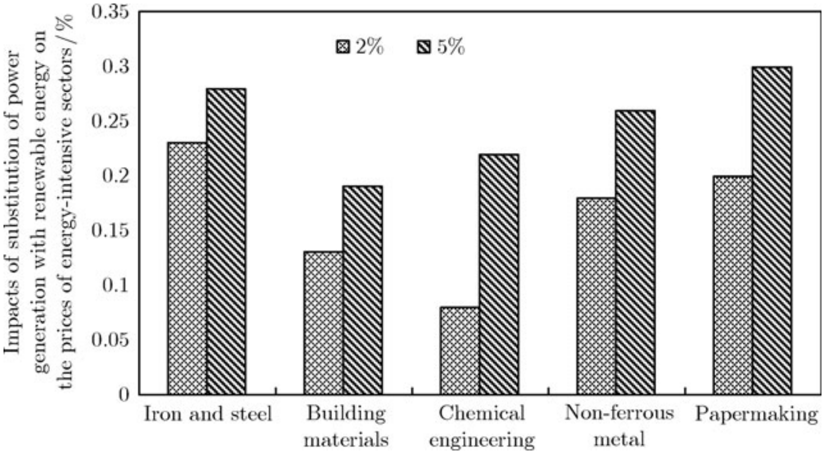

Figure 7.6 Impacts of different substitution of power generation with renewable energy on the prices of five energy-intensive sectors

Table 7.10 Impacts of different alternative schemes on energy consumption and CO_2 emissions of energy intensive sectors

Sector	Substitute 2%/%			Substitute 5%/%		
	Energy intensity	CO_2 emission coefficient	CO_2 emissions	Energy intensity	CO_2 emission coefficient	CO_2 emissions
Iron and steel	−0.021	0.003	0.001	−0.089	−0.001	−0.006
Construction materials	−0.013	0.002	0.001	−0.065	−0.001	−0.006
Chemical engineering	−0.018	−0.009	−0.004	−0.078	−0.01	−0.008
Non-ferrous metal	−0.011	−0.006	−0.002	−0.065	−0.02	−0.02
Papermaking	−0.013	−0.04	−0.03	−0.070	−0.07	−0.06

Table 7.10 indicates the impacts of different substitution schemes on the energy intensity, energy CO_2 emission coefficient and CO_2 emissions of five energy intensive sectors. We can see that the energy intensity of five sectors has dropped slightly. The impacts on CO_2 emission coefficient and CO_2 emissions are different. Under the 2% substitution scenario, the CO_2 emission coefficients of iron and steel sector and construction materials sector increase when compared with the reference scenario, while that of chemical engineering sector, non-ferrous metal sector and papermaking sector has dropped. Under the 5% substitution scenario, the CO_2 emission coefficient and CO_2 emission drop in all sectors.

According to the impact analysis of two different renewable electricity schemes, it has occurred to us that both the 2% and 5% substitution scenario will result in the decrease of real GDP: 0.031% for the 2% substitution scenario and 0.12% for the substitution scenario. Furthermore, according to the impact analysis of sectors, the outputs and product prices of such energy intensive sectors as iron and steel, construction materials, chemical engineering, non-ferrous metal and papermaking will be severely affected. The extent of these potential adverse impacts will substantially affect the feasibility of related policies. However, in respect of the impacts on energy consumption and CO_2 emissions of respective sectors, the CO_2 emission coefficient and CO_2 emissions of iron and steel and construction materials sectors have increased by 0.003%/0.002% and 0.001%/0.001% respectively when compared with reference scenario. Such a fact is not favorable for the implementation of renewable electricity policies, and fails to achieve CO_2 emission reduction. Therefore, the renewable electricity policies shall not merely take the power generation sector into consideration.

7.4 Conclusion

This chapter mainly introduces the renewable energy technology, CCS technology, energy-saving technology and low-carbon power generation technologies of IGCC and NGCC, and simulates the impact of renewable electricity on the mitigation of GHG emissions.

(1) CCS has a great potential for emission reduction, but the related costs need to be reduced and the technology needs to be further developed.

IPCC considers that CCS is "one of options for mitigating climate change" in the special report of 2005. The key feature of CCS is the *carbon dioxide capture and storage* of large CO_2 emission sources. It can effectively control and reduce the CO_2 emissions of thermal power plants. Boasting great potential for emission reduction, CCS can help reduce more than 1/3 of world CO_2 emissions by 2050. CCS is on the way toward commercialization. Despite the high costs of CCS, such approaches as EOR/EGR can help reduce costs. Currently, the application of CCS will also result in the increase of energy consumption. Therefore, scaled-up application of CCS will be needed, and the future development will be oriented by the reduction of investment costs and energy consumption during operation.

(2) The emerging low-carbon power generation technologies of IGCC and NGCC will be the key to reduce CO_2 emissions in power plants.

The thermal power plants are the major CO_2 emission sources in the world. The emerging power generation technologies of IGCC and NGCC can well improve power generation efficiency and substantially decrease CO_2

emissions. The combination of IGCC/NGCC and CCS can even achieve zero CO_2 emission of thermal power plants. Owing to its energy reserve situations, China's coal-based energy structure will remain unchanged in a long time. Being applicable to the situation of China, IGCC has great potential for development. However, the construction costs of IGCC power stations are currently on the high side. With technical advancements and increase in efficiency, IGCC will be widely applied in China.

The power generation efficiency and emission reduction potential of NGCC power stations are even higher than that of IGCC power stations. Furthermore, there are also other incomparable superiorities. However, the power generation costs of NGCC rely excessively on the price of natural gas. Therefore, there are many uncertainties in the power generation costs of NGCC. In particular, since the natural gas resources are not abundant in China, the NGCC technology shall be developed moderately.

(3) Boasting good potential for scaled-up development, renewable energies can reduce CO_2 emissions but will also result in GDP losses.

The renewable energy utilization is one of technologies boasting good potential for scaled-up development and capable of reducing CO_2 emissions effectively, including hydropower, wind power and biomass power. The renewable energy is developing swiftly in China, while some technologies have reached or approximated to the level of commercialized development. Seeing from the perspectives of resource reserve, technology or industry, the renewable energy has great potential for scaled-up development. Renewable energy plays an important role in the process of low-CO_2 emission development of China's energy structure. However, the power generation costs shall be further reduced, so as to decrease the adverse impact on energy intensive sectors and even GDP.

China's energy development policy is: "simultaneously conserve and explore energy, giving first priority to the former". The most direct ways to reduce CO_2 emissions are to adopt energy-saving technologies, improve the efficiency of energy utilization and decrease energy consumption. Compared with developed countries, China is low in the efficiency of energy utilization and therefore has great potential for energy conservation and emission reduction.

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Chapter 8

Simulations of CO_2 Mitigation Policies

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Energy and environmental policies should be one of the most important measures for CO_2 emission abatement. Through properly introducing related policies, the exterior environmental costs can be internalized, the market behaviors can be regulated and controlled in a macro way, the behaviors of producers and consumers can be changed, and thus the development of economy could be guided toward a low-carbon direction.

The effective formulation and implementation of policies are complicated processes. In order to promote efficient and proper proceeding of the policy-making process, it is very necessary to simulate the corresponding policies in a scientific way. This chapter summarizes the existing major mitigation policies and especially focuses on the two major mitigation tools, i.e. carbon taxation and carbon trading. The analysis of this chapter focuses on:

- What are the impacts of different carbon tax schemes on key socio-economic indices of China such as economic growth, household income, consumption and investment?
- How would different carbon tax schemes affect the production and international competitiveness of China's energy- and trade-intensive sectors?
- Which carbon tax scheme boasts better effect in protecting economic development and ensuring the international competitiveness of national industries?
- Can China enact some unilateral market policies to influence the trade

price of CO_2 market and help China make greater profits through carbon trading?

- Which countries are more sensitive to the policy of CO_2 emission trading market in China? Which countries are favorable buyers to China?

8.1 Major mitigation policies

Like noise and the automobile off-gas, the harm associated with excessive CO_2 emissions represents also an external cost. Therefore, no matter CO_2 emissions are going to be reduced by changing the behaviors of producers and consumers, or by promoting technical advancements, related policy restraints or incentive measures should always be introduced in order to achieve the expectant mitigation effect.

The existing policies/measures for dealing with climate change include: controlling measures, fiscal policies and emission trading.

Controlling measures directly control CO_2 emissions or energy consumption through methods such as emission allowance, energy use/emission standard and power supply quota. For example, EU ETS has implemented the policy of CO_2 emission allowance for industries such as energy, iron and steel, cement, paper and brick-making, and imposes a fine on enterprises with excessive emissions. Japan has requested organizations with excessive energy consumption to make rectifications within certain time limit, and those who still fail to come up to the standards after the rectification will be imposed a fine and exposed to the public. The Renewable Portfolio Standard (RPS) is being implemented in countries/regions such as US and EU, requiring that renewable electricity shall constitute certain shares in power supply structure. Energy efficiency/emission standards have also been released in respective countries for specific equipments, vehicles or buildings. Fiscal policies include various energy/environmental related taxes or subsidies.

According to the principles of Pigouvian Tax, various kinds of taxes aiming at reducing GHG emissions allow different producers to select their controlled amount according to their own mitigation cost. Compared with other control devices, such as discharge standard or penalty, the cost of such taxes would be lower under the same total control amount. Carbon tax has been imposed in Denmark, Finland, Netherlands, Sweden and Germany since 1990. Ecological tax has been imposed in French since 1999. The "climate change tax" has been introduced by United Kingdom since 2001, with the tax base as the consumption of coal, natural gas and electricity. Japan has also begun to collect the environmental tax on the carbon content of fossil fuels such as petroleum, coal and natural gas since January 2007. These taxation measures can not only help guide production and consumption pattern toward low energy consumption and low emission through price leverage, but also increase government revenue and hence raise funds for other energy conservation and emission mitigation activities.

Another form of promoting energy conservation and emission mitigation through fiscal means, with energy environment tax revenues and other financial revenues, is that the government encourages and promotes the R&D of advanced technologies via tax abatement, subsidies and special funds. For instance, EU has implemented such policies as tax abatement or subsidy to encourage wind power, hydropower, biological energy and other renewable energies. French has increased the related fiscal subsidies to a great extent to encourage the development of biological energies. The energy/environmental tax revenues can also be used to reduce or exempt other existing distortion taxes, so as to improve the overall socio-economic welfare and help enhance the feasibility of policies. For example, among the 1.1—1.2 billion pounds collected from climate change tax per year, 100 million pounds are used to subsidize energy-saving investment, 66 million pounds are allocated to the carbon fund for helping commercial and public sectors to reduce CO_2 emissions and look for the commercial opportunities of low-carbon technologies, and 876 million pounds are used to ease the social security tax of enterprises.

Emission trading is a mitigation measure combining direct control with economic stimulation based on emission allowance, which is also referred to as cap-and-trade system. The allowance defines the maximum allowable emission capacity of each enterprise. When without emission trading, the enterprise has to independently bear such costs as equipment upgrading and the fine for excessive emissions. By allowing enterprises with excessive emissions to buy the emission allowance from enterprises with emissions lower than its allowance, emission trading can reduce the abatement cost of the entire society. Currently, the CO_2 emission trading market has been established in countries/regions such as European Union, United States and Japan.

Compared with the pure controlling measures, fiscal policies and the trading system taking advantage of the price leverage can help reduce abatement costs. They are thus more popular and have become the focus of studies. This chapter will discuss the potential impacts of related policies if introduced by China, exemplified with carbon tax and bilateral trade respectively.

8.2 Study on carbon taxation policy

The current disregard to environmental factors of the manufacturing system is one of major causes of the current severe environment situation in China. At the 6th National Environment Protection Conference, the Ministry of Finance claimed that during the "11th Five-year Plan" period the basic principle of "total amount control of pollutant discharge" will be further clarified, and reforms on the use right system will be promoted (Xinhua News agency, 2006). At the 1st International Symposium on Environmental and Natural Resources Economics in East Asian Countries, an environmental tax reserve scheme for China has taken shape (China Taxation Planning Research Center, 2006). In this scheme, carbon tax is identified for scrutiny in design of the future environmental tax/fee system. However, the foundation and implementation of a carbon tax policy would be a complicated process. When designing the tax scheme, it is important to consider how to reduce as far as possible its negative impact on the economy, and to increase its political feasibility, etc. In order to provide decision support for the future environmental tax reform of China, in this section our CEEPA model was applied to analyze the potential impacts of introducing a carbon tax policy into China.

8.2.1 Setting of carbon tax schemes

Carbon tax was first introduced by Finland in 1990, and then levied in Sweden, Norway, the Netherlands and Denmark. Cansier and Krumm (1997) gave a reviewing introduction on the carbon tax schemes of these countries. As for the manner of levy, Finland and the Netherlands have no tax relief policy for the production sectors, whilst Sweden, Norway and Denmark apply tax relief for production sectors (especially for energy-intensive sectors). For example, Norway implements only half the tax rate on their pulp and paper industry, as well as their fish meal industry, and completely exempts the important segments of the air and sea transport from the tax. In Sweden, the tax rate for the industrial sector is only a quarter of that for households; in Denmark, energy-intensive sectors could enjoy a substantially lower tax rate than that for the other sectors and that for households so long as they commit themselves to qualified energy saving measures defined by the administration. As for the manner of revenue recycling, Sweden, Norway, Finland and Netherlands assign all the tax revenue to the general public budget, while Denmark uses the carbon taxes paid by a certain sector to subsidize its labor inputs or energy saving investments.

Based on these existing tax schemes, four carbon tax schemes are set out in this study, as shown in Table 8.1. It is noted that this study does not intend to accurately simulate the complicated tax scheme in each country, but aims at comparing the impacts of different manners of levy and revenue recycling on China's economy and on the development of energy- and trade-intensive sectors.

Scheme S1 follows the pattern of Finland and Netherlands. A uniform tax rate is assumed for all the sectors as well as for households. All the tax revenue is assigned to government income.

Scheme S2 follows the tax scheme of Sweden. All the production sectors enjoy a uniform tax rate which equals only a quarter of that for households. All the tax revenue is assigned to government income.

Table 8.1 Description of carbon tax schemes

Schemes	Manner of levy			Manner of revenue recycling	
	Tax relief for production sectors	Uniform tax rate for all the production sectors	Exempt energy- and trade-intensive sectors from carbon tax	Assign to the government's general budget	Subsidizing indirect tax
S1	N	Y	N	Y	N
S2	Y	Y	N	Y	N
S3	Y	N	Y	Y	N
S4	Y	N	Y	N	Y

Scheme S3 is a simplification of the tax relief pattern in Norway, supposing that energy- and trade-intensive sectors are completely exempted from carbon tax. Based on the realities of China, in this model the exempted sectors include iron and steel industry, building materials industry, chemical industry, non-ferrous metals industry, and paper industry. All the tax revenue is assigned to government income.

Scheme S4 is similar to the pattern of Denmark, assuming that energy- and trade-intensive sectors are completely exempted from carbon tax, and the tax paid by one sector is completely reimbursed to that sector to reduce its indirect tax.

8.2.2 Analysis the effects of carbon tax policy

A baseline scenario encompassing up to the year 2020 was run where no emission restriction and no carbon tax existed. A carbon tax was then levied from year 2012, the target of which is to obtain a specific reduction of CO_2 emissions in 2020 from the corresponding baseline level. In this instance we set the reduction target as 5% and 10%, respectively; and then rerun the model to simulate the four carbon tax schemes. The following illustrates the major results expressed in variations from the corresponding baseline values. (Liang et al., 2007; Liang Qiaomei, 2007).

8.2.2.1 Macroeconomic impacts of different carbon tax schemes

Table 8.2 shows the main macroeconomic impacts of different carbon tax schemes in the 5% and 10% reduction case, respectively.

Table 8.2 Macroeconomic impacts of different carbon tax schemes

Index	Five percent reduction				Ten percent reduction			
	S1	S2	S3	S4	S1	S2	S3	S4
GDP/%	−0.290	−0.089	−0.320	0.817	−0.736	−0.394	−0.845	1.192
Total investment/%	0.120	0.413	0.080	1.381	0.023	0.522	−0.127	2.168
Total consumption/%	−0.544	−0.398	−0.569	0.487	−1.212	−0.960	−1.299	0.617
Average return on equity/%	−0.597	−0.513	−0.557	0.915	−1.251	−1.105	−1.184	1.673
Labor demand/%	−0.379	−0.177	−0.409	1.040	−0.913	−0.569	−1.022	1.654
Rural household/% disposable income/%	−0.784	−0.559	−0.774	0.414	−1.716	−1.335	−1.743	0.384
Urban household/% disposable income/%	−0.754	−0.531	−0.742	0.569	−1.658	−1.279	−1.680	0.693
Rural consumer price index/%	−0.045	0.129	−0.001	0.026	−0.084	0.288	0.005	0.062
Urban consumer price index/%	−0.007	0.160	0.048	0.059	−0.006	0.352	0.105	0.135
Energy intensity/%	−4.753	−4.970	−4.763	−5.720	−9.397	−9.752	−9.373	−10.978
CO_2 /TPES/%	−0.936	−1.528	−0.857	−2.347	−1.857	−2.853	−1.691	−4.639

1) Impacts on GDP

For GDP, in both reduction cases, the three schemes (S1,S2,S3), where all the carbon tax revenues are assigned to the government's general budget, will incur GDP loss in 2020 compared to the baseline scenario. Moreover, the corresponding loss severity will increase with a reduction target. Scheme S3, where energy- and trade-intensive sectors are exempted from carbon tax, but no tax revenue is reimbursed to any sector, showed the largest loss of GDP. The decreasing rate of GDP under scheme S3 in the 5% and 10% reduction case will be 0.03% and 0.11% point higher, respectively, than that under scheme S1, and will be 0.23% and 0.45% point higher, respectively, than that under scheme S2. When exempting energy- and trade-intensive sectors, if at the same time completely reimbursing the tax paid by one sector to reduce the indirect tax in that sector, the negative impact of carbon tax on GDP could be entirely removed, as shown by the results of scheme S4. In the 5%

and 10% reduction case, scheme S4 will increase GDP from the baseline value by 0.82% and 1.19%, respectively, implying a “double dividend”.

The GDP index discussed herein is the real GDP calculated with an expenditure approach, consisting of total expenditure on final consumption, total capital formation and net export of goods and services. Since in the foreign trade balance of this model, foreign saving is considered exogenous, in all the cases the net export of goods and services will be fixed at the corresponding base-year value. Therefore, all the carbon tax schemes will influence GDP through their impacts on total consumption and total investment. The ratio of net export to GDP is quite small, which is only about 1.07% in 2020 in the baseline scenario. Thus, such an assumption of fixing foreign saving will rarely affect the impacting force or direction of different carbon tax schemes on GDP.

It can be seen from Table 8.2 that: in both reduction cases, the impact of scheme S4 on total investment and total consumption will be positive, further leading to the increase of GDP. In the 5% reduction case, the impacts of schemes S1—S3 on total investment are all positive, while their impacts on total consumption are all negative. Since the share of total consumption over GDP is much larger than that of total investment (e.g. in the baseline scenario in year 2020 the share of total investment over GDP will be 37.65%, while that for total consumption will be 61.28%). The impacts of different carbon tax schemes on GDP will be, to a greater extent, decided by their effect on total consumption. Therefore, in these three schemes, GDP will all become losses. When the reduction target rises to 10%, the positive driving force of scheme S1 on total investment will reduce, while that of scheme S3 will become negative. At the same time, the negative impact of these two schemes on total consumption will all increase; thereby the loss severity rate of GDP in both schemes will increase. The positive driving forces of scheme S2 on total investment will increase with the increase of reduction target, but the corresponding increase of its negative impact on total consumption will be larger than the former; thereby the loss severity rate of GDP in this scheme will also increase.

The impact of different carbon tax schemes on total investment and total consumption will be discussed in detail in the following two sections.

2) Impacts on total investment

It can bee seen from Table 8.2 that, given the same reduction target, the rise of total investment driven by scheme S4 will be much larger than those driven by the other three schemes. In the 5 percent reduction case, the increasing rate of total investment driven by scheme S4 will be 1.26%, 0.97% and 1.30% higher than that driven by schemes S1, S2 and S3, respectively. In the 10% reduction case, the increasing rate of total investment driven by scheme S4 will be 2.14% and 1.65% higher than that driven by schemes S1 and S2, respectively. According to the closure principle of invest-saving balance in this model, total investment is transformed endogenously from total saving. The major components of total saving are enterprise saving, household saving and government saving. In the baseline scenario the ratios of these savings to total saving are 40% for enterprise saving, 32% for household saving and 28% for government saving. The impacts of different carbon tax schemes on these savings in the two reduction cases are presented in Table 8.3. It can be seen that, the advantage of scheme S4 in stimulating total investment mainly comes from its promoting effect on enterprise and household saving. Through subsidizing the pre-existing indirect tax with carbon tax revenue, scheme S4 lowers the tax burden on labor and capital. As shown in Table 8.2, this, on the one hand, could increase the average return on equity, and thereby could increase total profit and further bring on the increase of enterprise saving. On the other hand, the relative lower labor cost will stimulate the demand for labor, and hence will drive-up total labor income—given the assumption of a rigid wage rate. Simultaneously, the increase of total profit will raise the profit distribution from enterprise to household. As two of the most important components of household income, the increase of total labor income and total enterprise profit distribution will drive up total household disposable income, and thereby increase total household saving under given marginal saving rate. As for schemes S1—S3, both average returns on equity and labor demands under these three schemes will decline. Consequently both enterprise and household saving under these schemes will decrease. Whereas the decreasing rates under scheme S2 are both smaller than those under S1 and S3. All the carbon tax revenues under schemes S1—S3 are assigned to government income, which will lead to the increase of government saving. The increase of government saving in these three schemes is large enough to completely counteract the reductions in enterprise and household saving; and hence could drive up the total investment. The increasing rate of government saving under scheme S4 is much smaller than that under the other three

Table 8.3 Impacts of different carbon tax schemes on various savings

Deposit	Five percent reduction				Ten percent reduction			
	S1	S2	S3	S4	S1	S2	S3	S4
Enterprise savings/%	−0.620	−0.394	−0.592	1.408	−1.405	−1.019	−1.396	2.356
Household savings/%	−0.762	−0.538	−0.750	0.529	−1.673	−1.293	−1.696	0.613
Government savings/%	2.185	2.618	1.964	1.975	4.041	4.776	3.467	3.040

schemes. However, since the share of government saving over total saving is the smallest among the three savings, the increasing rate of total investment under scheme S4 will still be larger than that of the other three schemes.

3) Impacts on total consumption

For total consumption, since the closure principle anticipates a government balanced budget, the government consumption is considered exogenous, and different carbon tax schemes will influence total consumption through their impacts on household consumption. Household consumption dominates total consumption in the 2020 baseline scenario with a ratio of 82.98%. Household consumption is determined mainly by household disposable income and the level of consumer price. Moreover, it is positively correlated with the former, while negatively correlated with the latter.

The model result shows that compared with the baseline scenario, both rural and urban household disposable income will decrease under schemes S1—S3 because of the reductions in labor demand and enterprise profits. As for the variation of consumer price index (CPI), both rural and urban CPI will decrease under scheme S1. But such a slight decrease is not able to counteract the negative impacts of the reductions in disposable income. Therefore both rural and urban household consumption under this scheme will decline and further incur the reduction of total consumption. The reduction of total consumption under scheme S2 in the 5% reduction case could be explained with the same reason. Both rural and urban CPI under scheme S3 will increase, combining the decrease in corresponding household disposable income. It is anticipated that both rural and urban household consumptions under this scheme will decline and further cause the reduction in total consumption. The reduction of total consumption under scheme S2 in the 10% reduction case could be explained with the same reason. Both rural and urban CPI under scheme S4 will slightly increase. But the corresponding household income will also increase because of the increase in labor demand and enterprise profit. The forward driving force of the increase in household disposable income is large enough to surpass the backward driving force of the increase in CPI. Consequently this will lead to the increase in both rural and urban household consumption and, furthermore, in total consumption.

4) Impacts on energy intensity and CO_2/TPES

All the four carbon tax schemes are evidently able to reduce energy intensity and CO_2/TPES. Given the same reduction target, the largest decrease of both indices corresponds to scheme S4, followed by that of scheme S2. Scheme S4 shows obvious advantage in its effect of reducing CO_2/TPES compared to the other three schemes. In the 5% reduction case, the decreasing rate of CO_2/TPES under this scheme will be 2.51, 1.54 and 2.74 times those under schemes S1, S2 and S3, respectively. While in the 10% reduction case, the decreasing rate under this scheme will be 2.50, 1.63 and 2.74 times those under schemes S1, S2 and S3, respectively. The CO_2/TPES reflects the variation of energy structure. The smaller this index, the more environmentally friendly the energy structure is. Hence it can be seen that the effect of scheme S4 on improving energy structure is the better amongst all schemes.

8.2.2.2 Impacts of different carbon tax schemes on energy- and trade- intensive sectors

The impacts of different carbon tax schemes on energy and trade-intensive sectors in the 10% reduction case are illustrated as follows.

1) Impacts on sectoral output

Figure 8.1 shows the impacts of different carbon tax schemes on sectoral output of the energy- and trade-intensive sectors in the 10% reduction case.

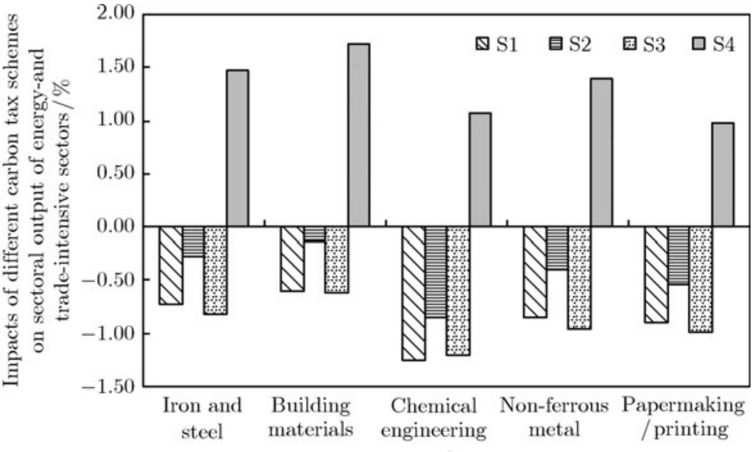

Figure 8.1 Impacts of different carbon tax schemes on sectoral output of energy- and trade-intensive sectors in the 10% reduction case

It can be seen from the result that the implementation of schemes S1—S3 will all result in the reduction of sectoral output in all the five energy- and trade-intensive sectors. The ascending ranking of the decreasing amplitudes of the sectoral outputs are the same in these three schemes, i.e. chemical industry, paper industry, non-ferrous metals industry, iron and steel industry and Building materials industry. The negative impacts of scheme S2 on these sectors is clearly smaller than those of schemes S1 and S3. The sectoral output loss of chemical industry, paper industry, non-ferrous metals industry, iron and steel industry and building materials industry under scheme S2 are 0.41%, 0.34%, 0.45%, 0.46% and 0.47% smaller than those under scheme S1, respectively; and are 0.36%, 0.44%, 0.56%, 0.55% and 0.49% smaller than those under scheme S3, respectively. The largest negative impact on the output of chemical industry corresponds to scheme S1. While the largest negative impact on the output of iron and steel industry, building materials industry, non-ferrous metals industry and paper industry all correspond to scheme S3. On the basis of scheme S3, through reimbursing the carbon tax revenue to production sectors, scheme S4 could completely eliminate the negative impact on the output of all the energy and trade-intensive sectors. Under this scheme, the output of paper industry, chemical industry, non-ferrous metals industry, iron and steel industry and building materials industry will rise by 0.98%, 1.07%, 1.40%, 1.48% and 1.71%, respectively, from the baseline level.

2) Impacts on sectoral output price

As shown in Figure 8.2, all four schemes will lead to the rise of sectoral output price in iron and steel industry, chemical industry and non-ferrous metals industry. Whereas the largest increased rates of the sectoral output price all correspond to scheme S1, followed by scheme S2. The rise of sectoral output price in these three sectors could be alleviated through completely exempting energy- and trade-intensive sectors from carbon tax. In the 10% reduction case, the increasing amplitudes of sectoral output price in iron and steel industry, chemical industry, and non-ferrous metals industry under

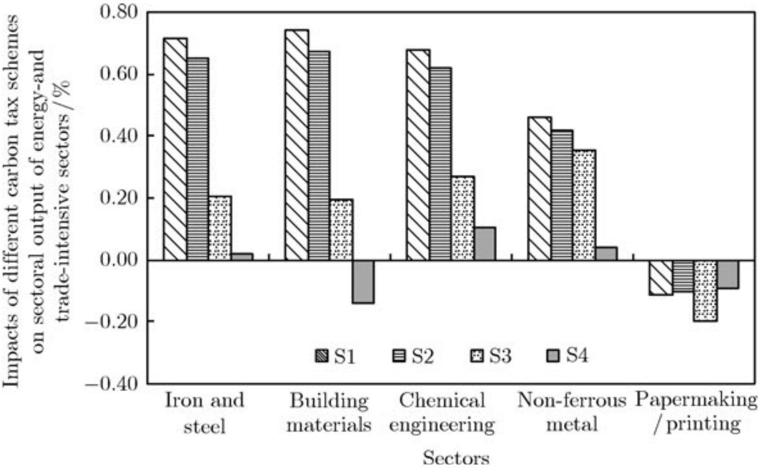

Figure 8.2 Impacts of different carbon tax schemes on sectoral output price of energy- and trade-intensive sectors in the 10% reduction case

scheme S3 are smaller than those under scheme S1 by 0.51%, 0.41% and 0.10%, respectively. While the corresponding increasing amplitudes under scheme S4 are 0.70%, 0.57% and 0.42% smaller, respectively, than those under scheme S1. As for the output price of building materials industry, the impacts of schemes S1—S3 would be positive. Whereas the increasing rate under scheme S3 is smaller than that under schemes S1 and S2 by 0.55% and 0.48%, respectively. Scheme S4 will not induce a rise in the output price in building materials industry. The impact of all the schemes on the output price of paper industry will be negative.

3) Impacts on sectoral export

It can be seen from Figure 8.3 that, schemes S1—S3 will each bring on sectoral export loss in all the five energy- and trade-intensive sectors. The largest decreasing amplitudes of iron and steel industry, building materials industry and chemical industry all correspond to scheme S1, while schemes S2 and S3 could reduce their negative impact on the exports of these three sectors through tax relief. In the 10% reduction case, the decreasing amplitudes of the export in iron and steel industry, building materials industry and chemical industry under scheme S2 will be 0.51%, 0.53% and 0.46% smaller, respectively, than those under scheme S1. While the corresponding decreasing amplitudes under scheme S3 will be 0.36%, 0.47% and 0.41%, respectively, smaller than those under scheme S1. However, the negative impact on the exports of non-ferrous metals industry and Paper industry by scheme S3 will be the largest among the three schemes, closely followed by that of scheme

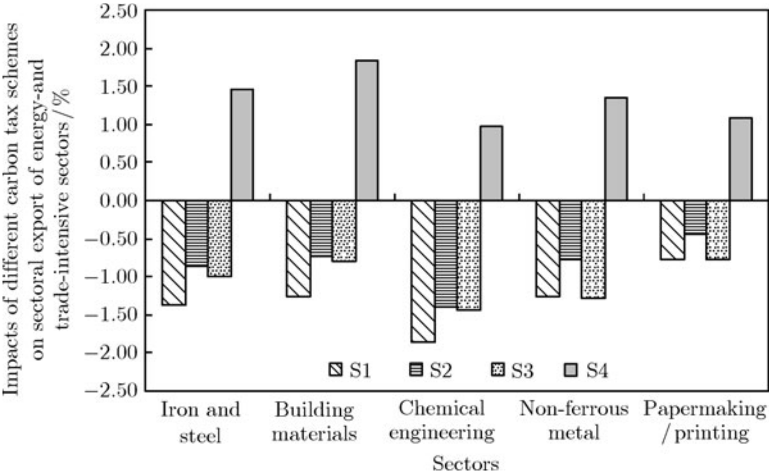

Figure 8.3 Impacts of different carbon tax schemes on sectoral export of energy- and trade-intensive sectors in the 10% reduction case

S1. The manner of tax relieving under scheme S2 could still alleviate the negative impact of carbon taxing on the exports of these two sectors. The decreasing amplitudes of export in non-ferrous metals industry and Paper industry under scheme S2 are 0.50% and 0.34% smaller, respectively, than those under scheme S3.

Scheme S4 could completely eliminate the negative impact on the exports of all the energy- and trade-intensive sectors by utilizing carbon tax revenue to reduce indirect tax. The exports of these sectors under this scheme will all increase, compared to the baseline scenario. In the 10% reduction case, the increasing amplitudes of exports in these sectors will all be close to, or surpass, 1%. Especially the increasing amplitude of export in building materials industry will result in about 1.84%.

4) Impacts on sectoral profit

As illustrated in Figure 8.4 that, scheme S3 will incur loss of sectoral profit in all the energy- and trade-intensive sectors. The corresponding decreasing amplitudes under this scheme are much larger than those under the other three schemes. In the 10% reduction case, this scheme will reduce the profit of iron and steel industry and building materials industry by 1.47% and 1.14%, respectively. The impact on profit of the three other schemes for these two sectors will be positive or slightly negative (scheme S1 on the profit of iron and steel industry). The loss amplitude of profit in chemical industry, non-ferrous metals industry and paper industry caused by scheme S3 is higher than the corresponding minimum loss amplitudes in the other three schemes

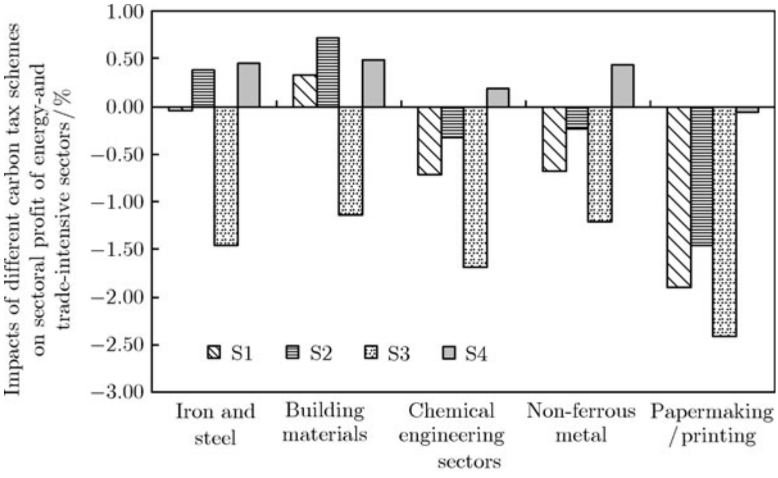

Figure 8.4 Impacts of different carbon tax schemes on sectoral profit of energy- and trade-intensive sectors in the 10% reduction case

by 1.37%, 0.99% and 2.35%, respectively. Thus it can be seen that if simply exempting energy- and trade-intensive sectors from carbon tax whilst assigning all the tax revenue to government income, the negative strikes on the profit of energy- and trade-intensive sectors will not only be larger than those under the schemes where all the production sectors are relieved (S2) or subsidized (S4), but also be larger than those under the scheme where no production sector is relieved or subsidized (S1). Scheme S4 will not have negative impacts on the profit of Iron and Steel industry, building materials industry, chemical industry and non-ferrous metals industry. In the 10% reduction case, the profit loss of paper industry under this scheme is only some 0.06%, which is smaller than the corresponding amplitude under scheme S1, S2 and S3 by 1.84%, 1.40% and 2.35%, respectively.

5) Impacts on sectoral CO_2 emissions

As presented in Figure 8.5, that under the three schemes, where all or part of the production sectors are relieved from carbon tax (S2—S4), the decreasing amplitudes of CO_2 emissions in the five energy- and trade-intensive sectors will all reduce in comparison to those under scheme S1. Under the two schemes where energy- and trade-intensive sectors are completely exempted, the CO_2 mitigation effects of all the exempted sectors are weakened. In the 10% reduction case, the decreasing rates of CO_2 emissions in iron and steel industry, building materials industry, chemical industry, non-ferrous metals industry and paper industry under scheme S3 will decrease by 9.01%, 9.64%,

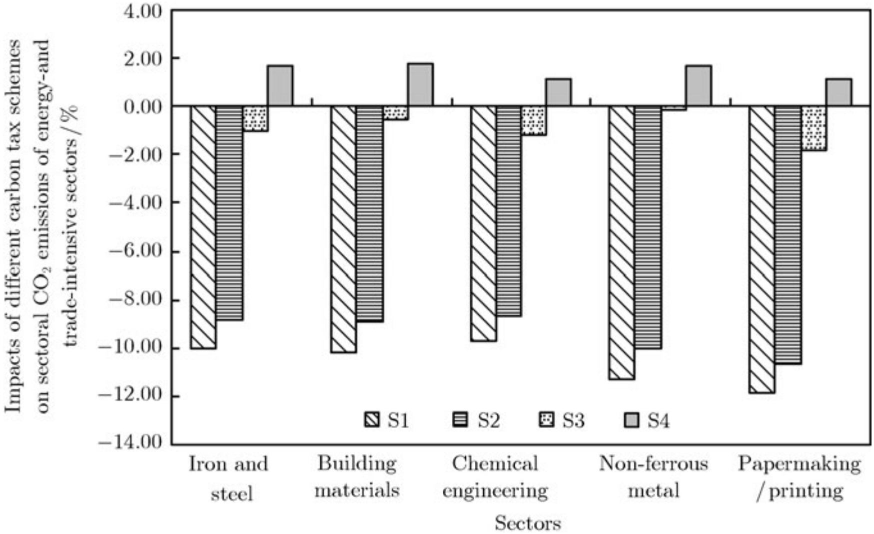

Figure 8.5 Impacts of different carbon tax schemes on sectoral CO_2 emissions of energy- and trade-intensive sectors in the 10% reduction case

8.52%, 11.12% and 9.99%, respectively, in comparison to those under scheme S1. The corresponding ratio of sectoral mitigation amount to total mitigation amount will decrease from the 7.01%, 6.03%, 10.21%, 1.12% and 0.82% under scheme S1 to 0.70%, 0.31%, 1.28%, 0.02% and 0.13%, respectively. Under scheme S4, CO_2 emission in all the five exempted sectors will increase compared to the baseline scenario. Thus it can be seen that when completely exempting energy- and trade-intensive sectors from carbon tax, if there are no other policy restriction, the mitigation burden of the exempted sectors will in a great extent shift to other sectors. In order to exert as much as possible the mitigation effects of the energy- and trade-intensive sectors, when protecting these sectors by complete exemption, the Denmark pattern could be referred to. This would require the exempted sectors to commit themselves to qualified energy saving or emission mitigating measures (Cansier and Krumm, 1997).

8.2.2.3 Net-tax payment

Referring to the study of Felder and Schleiniger (2002), here net-tax payment is used to compare the political feasibility of different carbon tax schemes.

The net-tax payment of a sector equals its total carbon tax payments, minus its total indirect tax subsidy. A negative net tax payment implies that the sector benefits from the policy, and vice versa. Summing up all the positive net-tax payments, we obtain a total net-tax payment, which reflects the scale of intersectoral transfers. Table 8.4 shows the sectoral net-tax payment in each sector in the 10% reduction case.

The result shows that without any reimbursement of carbon tax revenue to production sectors, under schemes S1 and S2, all the sectors will be net payers. While under scheme S3 all the sectors, except the five exempted ones, will be net payers. Under these three schemes, the net payments of Petroleum Refining industry and Electricity Production and Supply industry are larger than those of the other sectors. Under schemes S1, S2 and S3 the ratio of the sectoral net-tax payment to total net-tax payment will be 31.86%, 31.73% and 34.72%, respectively, for Petroleum Refining industry; while 27.07%, 27.15% and 37.23%, respectively, for Electricity Production and Supply industry. The ratios of sectoral net-tax payment to sectoral output in these two sectors are also larger than those in the other sectors. This implies that these three schemes are likely to be opposed by Petroleum Refining industry and Electricity Production and Supply industry, which are two relatively powerful sectors in China. Thus the political feasibility of these three schemes would be seriously affected. Scheme S4 could entirely eliminate the intersectoral transfers and hence make the net-tax payment zero in all the sectors. Therefore, compared with the other schemes, scheme S4 has a relatively higher advantage with regard to policy feasibility.

Table 8.4 Sectoral net-tax payment in the 10% reduction case

Sector	Sectoral net-tax payment /(RMB 100 million, at 2002 constant prices)				Ratio of sectoral net-tax payment to sectoral output/%			
	S1	S2	S3	S4	S1	S2	S3	S4
Agriculture	38.97	35.91	50.40	0.00	0.04	0.04	0.05	0.00
Iron and Steel	173.83	159.85	0.00	0.00	0.41	0.37	0.00	0.00
Building Materials	146.81	135.05	0.00	0.00	0.52	0.48	0.00	0.00
Chemical industry	261.17	239.90	0.00	0.00	0.34	0.31	0.00	0.00
Non-ferrous metal	24.16	22.24	0.00	0.00	0.15	0.14	0.00	0.00
Papermaking/printing	16.84	15.50	0.00	0.00	0.09	0.08	0.00	0.00
Other heavy industries	204.00	187.81	281.37	0.00	0.11	0.10	0.15	0.00
Other light industries	69.00	63.50	97.26	0.00	0.05	0.05	0.07	0.00
Construction	12.09	11.16	15.61	0.00	0.01	0.01	0.01	0.00
Transportation	25.72	23.68	31.70	0.00	0.05	0.05	0.07	0.00
Service	131.10	120.72	174.88	0.00	0.05	0.04	0.06	0.00
Coal mining and dressing	53.44	48.81	70.81	0.00	0.43	0.39	0.57	0.00
Crude oil exploitation	14.84	13.70	17.94	0.00	0.15	0.14	0.18	0.00
Natural gas exploitation	7.47	6.67	22.49	0.00	1.14	1.04	3.43	0.00
Petroleum Refining	914.95	836.77	944.02	0.00	5.04	4.60	5.22	0.00
Electricity Production and Supply	777.35	716.06	1012.26	0.00	2.85	2.62	3.71	0.00
Total	2871.72	2637.32	2718.72	0.00	0.26	0.24	0.25	0.00

8.2.3 Discussion of carbon tax policy

Summarizing the above results of the model, the following recommendations are proposed for China's future carbon tax scheme design.

(1) To alleviate the negative impact of carbon tax on the economy, when designing the tax scheme it would be better to relieve or subsidize the production sectors.

GDP is an important index to evaluate the social and economic cost of a mitigation policy. As a developing country, in order to meet the increasing material and cultural needs of the people, it is especially important for China to maintain a relatively speedy and high growth. Model results show that the variation of GDP is sensitive to the setting of tax schemes. If there is no tax relief or subsidy for any sector (scheme S1), the GDP loss caused by carbon taxing will be very obvious. For example, in the 10% reduction case, the GDP loss caused by scheme S1 will reach 0.74 percentage points, which will seriously compromise China's overall goal of economic construction.

As for the impacts on sectoral level, scheme S1 shows obviously negative strike on the energy- and trade-intensive sectors. For example, in the 10% reduction case, the sectoral output loss of the five energy- and trade-intensive sectors caused by scheme S1 will be 0.60%—1.26%, sectoral export loss will be 0.77%—1.86%, and sectoral profit loss will be 0.04%—1.90%. Energy- and trade-intensive sectors are the major cost undertakers of carbon tax. The scale of the potential negative impacts of carbon tax on these sectors will to a great extend influence the feasibility of the policy. Due to its obvious negative impacts on the production activity and international competitiveness of the energy- and trade-intensive sectors, scheme S1 is of high possibility to be strongly opposed by these sectors and hence its feasibility of implementation will be weaken.

Under the same reduction target, the negative impact of carbon tax on economic growth could be effectively reduced through proper tax relieving or subsidizing the production sectors. If all the sectors could enjoy a reduced tax rate which equals a quarter of that for households (scheme S2), the GDP loss caused by carbon tax in the 10% reduction case will decrease by 0.34 percentage points in comparison to those under scheme S1. If totally exempting energy- and trade-intensive sectors from carbon tax, and reimbursing all the tax revenue paid by one sector to reduce the indirect tax of that sector (scheme S4), the negative impact of carbon tax on GDP could be completely removed; and the development of GDP could even be promoted. At the sectoral level, scheme S2 and S4 also could obviously moderate the negative strike on energy- and trade-intensive sectors compared to scheme S1.

Thus, in order to secure economy growth and improve political feasibility, introducing tax relief or subsidy for the production sectors should be set as one of the basic principles in the future carbon tax designing.

However, it should also be noted that if simply exempting part of the sectors while not subsidizing the other un-exempted sectors (scheme S3), the negative impact on GDP will be even larger than that under scheme S1 where no tax relief or subsidy measure is adopted. Therefore, when designing the carbon tax scheme one should be cautious to select a proper manner of tax relieving of subsidizing.

(2) If all the carbon tax revenue is going to be assigned to the government income, it is better to implement a uniform tax relieving rate for all the production sectors.

Tax is an important measure of the state to raise funds, especially for developing countries. In such a circumstance, if all carbon tax revenues are included into the government revenue instead of stipulating a special purpose for tax proceeds use, then the protection of production sectors in respect of taxation model shall be considered.

Tax revenue is an important tool for the nation's fund collection. In this case, if all the carbon tax revenue is going to be assigned to the government income instead of being assigned to a particular purpose, protections for production sectors should be carried out in the course of tax levying.

In this study, the two schemes, where all the revenues are assigned to the government's general budget while protecting production sectors with the manner of levy, are schemes S2 and S3. Scheme S2 relieves all the production sectors with a uniform tax rate, while scheme S3 totally exempts energy- and trade-intensive sectors from carbon tax; which implies a different tax rate between the exempted and un-exempted sectors. Model result shows that: compared with scheme S1 where there is no any tax relief or subsidy policy, the negative strikes of scheme S2 on GDP, employment, as well as on the output, export and profit of energy- and trade-intensive sectors will be much smaller, while scheme S3 will deteriorate the negative impact on these indices and cause larger distortion. Comparing the effects of raising total tax revenue, scheme S2 performs much better than scheme S3. For example, in the 10% reduction case, scheme S2 and S3 will increase total tax revenue by 2.06% and 1.45%, respectively.

Therefore, if the emphasis leads more to fund collection and the carbon tax revenue is going to be totally assigned to the government income, it would be better to refer to the Swedish pattern and relieve all the sectors with a uniform rate.

(3) The Denmark pattern, which completely exempts energy- and trade-intensive sectors and subsidizes all the un-exempted sectors, is a relatively ideal scheme.

Model result shows that the effect of scheme S4 which simulates the Denmark tax scheme, would be better, not only in alleviating the negative impact of carbon tax on the macro economy but also in protecting energy- and trade-intensive sectors. By utilizing the carbon tax revenue to reduce indirect tax, scheme S4 can completely eliminate the negative impact of carbon tax on GDP, employment and total consumption. Compared with the other schemes, this scheme has obvious advantages in stimulating total investment and improving energy structure. As for the effect on protecting energy- and trade-intensive sectors, this scheme could entirely remove the negative impact of carbon tax on the total output and export of these sectors, and could increase the profit of iron and steel industry, Building materials industry, chemical industry and non-ferrous metals industry. In the 10% reduction case, the profit loss of paper industry caused by scheme S4 is only some 0.06%, which is smaller than the 1.46%–2.41% caused by the other three schemes. Scheme S4 can completely eliminate the intersectoral transfers, and thus has obvious advantage in policy feasibility compared to the other schemes.

However, one of the major weak points of this scheme is that it would strongly weaken the mitigation effects of exempted sectors. The result of sectoral CO_2 emissions shows that, emissions by the exempted sectors under this scheme will rise instead of reduction in comparison to the baseline level. Therefore, during practical application, the Denmark approach should be further referred to, and the exempted sectors shall commit themselves to qualified energy saving or emission mitigating measures defined by the government.

Summing up the above analysis, if the emphasis is not put on fund collection, in general this quasi-Denmark pattern scheme could be a relatively ideal tool to alleviate the negative impact of carbon tax on the macro economy of China and to protect energy- and trade-intensive sectors. That is, carbon tax should be completely exempted for iron and steel, building materials, chemical, non-ferrous metals and paper industries. At the same time, related regulations or rules should be put forward for these exempted sectors to make sure they carry out quantified energy saving or emission mitigating measures. For example, the China Medium and Long-Term Energy Conservation Plan issued by the National Development and Reform Commission (National Development and Reform Commission, 2004) has specified detailed and quantified targets of the unit energy cost for major products in year 2010 and 2020. Similar restricts corresponding to the five exempted sectors should be specified. For the other sectors, carbon tax should be collected under a uniform rate according to the reduction target, e.g. Table 8.5 shows the rates of specific duty in the reduction case of 1%–10%. All the taxes paid by one sector should be completely reimbursed to that sector through adjusting its indirect tax. For example, in the 10% reduction case, the indirect tax rate for agriculture in 2020 should be reduced by 6% compared to that in year 2002.

Table 8.5 Carbon tax rate in different reduction case under scheme S4

Reduction target /%	1	2	3	4	5	6	7	8	9	10
Carbon tax rate (RMB/ton of carbon, at 2002 constant prices)	31	63	95	129	163	198	234	271	309	348

8.3 Study on carbon pricing mechanism based on bilateral trading model

The CO_2 abatement costs of developed countries/regions are different from that of developing countries/regions. Designing an emission trading mechanism will help reducing the overall CO_2 abatement cost of a country/region, so as to mitigate global warming at a lower cost, and benefit in win-win situation or multilaterally. During the trading process, each participant will manage to reduce its abatement cost or obtain more incomes and technology transfer from emission trading, so as to better share the benefits of emission reduction. The process of emission trading is like a game between participants. The design of gaming rule or trading mechanism, as well as the objective conditions (such as the marginal abatement cost) of respective participants, will influence the distribution of emission reduction benefits. Up to date, the emission trading markets have been established by many countries or International organizations, such as European Union, United Kingdom, Norway, United States, Japan and Australia. How to design a specific rule of emission trading? How does each participant make a specific decision under the given trading rule? These are the focal questions being studied by the domestic and overseas academic community.

Haites and Mullins (2001) have discussed the initiatives of United Kingdom and Denmark to record and control the CO_2 emissions trading activities. Bahn et al. (2001) have also used the MARKAL-MACRO model to simulate the ERUs markets of many countries for emission trading and to evaluate the feasibility of building ERUs trading market in many countries, so as to decrease the differences in the marginal abatement cost of respective countries through cooperative emission reduction. Bosello and Roson (2002) have studied the impacts of emission trading system on the social welfare of two countries. It is believed that the key to policies and scientific researches related to climate change relies on justice and efficiency. The justice mainly focuses on the distribution of emission rights and emission reduction target among countries, while efficiency puts emphasis on the potential profits which can be obtained by trading countries through the application of a flexible mechanism. Meanwhile, they believed that the current emission trading still has many problems, including the uncertainty of some market rules. Burtraw et al. (1998) have studied the bilateral market trading of sulfuric dioxide and discussed how to reduce the transaction cost through modeling simulation.

The game theory is becoming an important tool for studying carbon trading. By using the game theory to study the bilateral trading issues among developed countries, Rehdanz and Tol (2005) have studied the impacts of market rule design on trading situations and environmental benefits. Kemfert (2004) and Bernard (2007) have also used the game theory and the general equilibrium model to conduct a simulation analysis on the emission trading market, and it is believed that the main suppliers of the emission trading market will be China and Russia.

World Bank (2004) believed that China's CERs would account for 50% of global CERs in 2010. This figure was considered to be 60% according to Zhang (2006). Currently, China has become the most important host country of CDM project. Up to October 1, 2007, China has taken up 44.9% shares in the CERs trading market. Based on the data from UNFCCC (2007), the results are calculated and shown in Table 8.6.

Table 8.6 Issued CDM projects and CERs

Host regionsor countries of CDM projects	Item number	Registered projects Certified Emission Reductions/kCERs	Ratio/%
Latin America	290	33624.74	20.03
Asia Pacific	476	124438.89	74.14
China	118	75420.96	44.93
India	282	27802.59	16.56
Europe and Central Asia	8	371.00	0.22
Saharan Africa	13	3823.46	2.28
North Africa & Middle East	16	5589.57	3.33
Total	803	167847.64	100

Data Source: UNFCCC (2007); up to October 1, 2007.

Compared with the price in the carbon trading markets of developed countries in the corresponding period, the trade price of CERs is on the low side. It was believed by Liu Lancui and Wu Gang (2007) that the CDM is only at the initial phase of development, while the sellers' market is suffering from fierce price competition.

China is the biggest supplier in the CERs market. Whether the price of CERs in China can be increased? Whether the price of CERs can be limited? Will the increase or limitation of price affect the transactions? This section will build a model to preliminary study these questions.

8.3.1 Bilateral trading model

The difference between developed countries and developing countries in the abatement cost is one of fundamental conditions for the existence of Clean Development Mechanism. Therefore, this section has built a nonlinear programming model of bilateral trading on the basis of the abatement cost function of different countries. The abatement cost function is derived from the global marginal abatement cost model of 12 countries/regions as built by Ellerman and Decaux (1998) and Zhang (2000, 2001 and 2002); the models are indicated in Formulas (8.1) and (8.2).

Marginal abatement cost function of Region i:

$$MC_i = a_i Q_i^2 + b_i Q_i \tag{8.1}$$

Total abatement cost of Region i:

$$TCD_i = \frac{1}{3} a_i Q_i^3 + \frac{1}{2} b_i Q_i^2 \tag{8.2}$$

Here, Q_i refers to the domestic emission reductions of Region i; a_i and b_i are the parameters in the marginal abatement cost function. Developed countries are represented by United States, EU and Japan, while developing countries are represented by China.

8.3.1.1 Bilateral trading model without price bounding

This section assumes such a bilateral emission trading market: developed country A (Annex I country) and a representative developing country B (non-Annex I country). The former one needs to commit to an emission reduction goal, while the latter one is not subject to any specific emission reduction obligation. During this study, China will be the developing country, and the CO_2 emission quota sold represents the certified emission reductions (CERs) of CDM project. Developed countries will respectively select United States, European Union and Japan. The commitment maker (developed country) expects to accomplish the emission reduction goal at the lowest cost, while the emission quota seller (developing country) expects to obtain the greatest profit from the transaction, including more financial support and technology transfer.

On basis of the abatement cost function of Ellerman and Decaux (1998), we have built a bilateral trading model. C_{A} refers to the abatement cost of country A; G_{B} refers to the proceeds received by country B from country A during the transaction; Q_{A} and Q_{B} respectively refer to the domestic emission reductions of country A and country B; T_{A} refers to the emission reductions target of country A; q_{A} and q_{B} refer to the quantity of CO_2 emission quota purchased by country A and the quantity sold by country B; p_{A} and p_{B} refers to the emission quota purchase price of country A and the selling price of country B; a_{A} and b_{A} refers to the parameters in the marginal abatement cost function. The bilateral emission trading model is shown below.

$$\begin{aligned} & \min C_{\mathrm{A}} = \frac{1}{3}a_{\mathrm{A}}Q_{\mathrm{A}}^3 + \frac{1}{2}b_{\mathrm{A}}Q_{\mathrm{A}}^2 + p_{\mathrm{A}}q_{\mathrm{A}} \qquad (8.3)\\ \text{s.t.} \quad & Q_{\mathrm{A}} + q_{\mathrm{A}} \geqslant T_{\mathrm{A}} \\ & \max G_{\mathrm{B}} = p_{\mathrm{B}}q_{\mathrm{B}} - \left(\frac{1}{3}a_{\mathrm{B}}Q_{\mathrm{B}}^3 + \frac{1}{2}b_{\mathrm{B}}Q_{\mathrm{B}}^2\right) \qquad (8.4)\\ \text{s.t.} \quad & Q_{\mathrm{B}} \geqslant q_{\mathrm{B}} \end{aligned}$$

The abatement cost of developed countries is generally divided into domestic abatement cost and off shore purchase cost. Therefore, the quantity of domestic emission reductions plus offshore purchased quantity must be more than the emission reduction target stipulated in "*Kyoto Protocol*". Developing countries are sellers of the emission permits. Therefore, the objective function shall be set to maximize the profits, and the yield of emission quota (domestic emission reductions) must be more than the quantity sold.

Under the equilibrated circumstance, the purchase price is equal to the selling price($p_{\mathrm{A}} = p_{\mathrm{B}} = p*$), and the purchased quantity equals to the sold quantity($q_{\mathrm{A}} = q_{\mathrm{B}} = q*$); the quantity of domestic emission reductions of country A shall be $Q_{\mathrm{A}}* = T_{\mathrm{A}} - q*$, while the quantity of domestic emission reductions of country B shall be $Q_{\mathrm{B}}* = q*$. The abatement cost of developed countries and the profit of developing countries are fully optimized in the model. When the transaction price is lower than the domestic marginal abatement cost, the overall abatement cost of developed countries can be reduced through trading; when the selling price of emission permits is higher than the domestic marginal abatement cost in the developing countries, and the developing countries can gain profits by selling the emission permits. The trade quantity and trade price will increase along with the increase in the emission reduction target. When the marginal abatement cost of developing countries is equal to that of developed countries, the emission trading will be ended.

Currently in China, CDM is only at the preliminary phase of development, and there is a great difference between the price of CERs in the primary market and that in the secondary market. The market price of CERs in CDM is lower than the market price of $\mathrm{CO_2}$ in European Union. In order to avoid the cut-throat competition among suppliers and to obtain more funds and technologies to support activities related to the mitigation of climate change, National Development and Reform Commission of PRC has stipulated the guiding price to regulate the selling price of CERs. We will hereunder set the price floor in the bilateral trading model and discuss its impact on trading situation.

8.3.1.2 Bilateral trading model with price floor

First, we shall set the price floor of model according to the guiding price stipulated by National Development and Reform Commission of PRC, and analyze whether the price floor policy will increase China's profits obtained from CO_2 emission trading.

If the government of developing country offers a bottom price of v, then the transaction will only take place when the trade price is $p* \geqslant v$; from the view of developed country, only when the marginal abatement cost of MC_{A} is greater than the limited price of v can develop country purchases the emission quota from developing country to accomplish the emission reduction target. When MC_{A} is lower than v, the develop country will not purchase emission permits from other countries. Instead, it will accomplish the emission reduction target via domestic emission reduction initiatives. When MC_{A}, the marginal abatement cost of developed countries, equals to v, then the corresponding quantity of domestic emission reductions (Q_{A}) shall be the critical point of developed countries whether to purchase the CO_2 emission permit or not (as indicated in Formula 8.5).

$$MC_{\mathrm{A}} = a_{\mathrm{A}}Q_{\mathrm{A}}^2 + b_{\mathrm{A}}Q_{\mathrm{A}} = v \tag{8.5}$$

When $MC_{\mathrm{A}} \leqslant v$, the developed country will be able to accomplish the emission reduction target through domestic emission reduction initiatives at cheaper cost than offshore purchase. Therefore, the developed country will not choose to trade but to launch emission reduction initiatives within the country. By this time, the trade quantity will be $q^{(1)} = 0$, and the trade price of $p^{(1)}$ will not exist any more. The developing country will not able to obtain any profit.

When $MC_{\mathrm{A}} > v$, the developed country will choose to purchase emission permits from other countries, and the transaction can be divided into three circumstances:

(1) When $MC_{\mathrm{A}} > v \geqslant MC_{\mathrm{B}}$, the limit price will be higher than the marginal abatement cost of the developing country. The trade price will be $p^{(2)} = v$, and the trade quantity of $q^{(2)}$ can be obtained via $\begin{cases} p^{(2)} = a_{\mathrm{A}}Q_{\mathrm{A}}^2 + b_{\mathrm{A}}Q_{\mathrm{A}} \\ q^{(2)} = T_{\mathrm{A}} - Q_{\mathrm{A}} \end{cases}$.

(2) When $MC_{\mathrm{A}} > MC_{\mathrm{B}} > v$, the price floor policy will have no impact on the emission trading. The actual trade price of $p^{(3)}$ will equal to the marginal abatement cost of the developing country: $p^{(3)} = a_{\mathrm{B}}Q_{\mathrm{B}}^2 + b_{\mathrm{B}}Q_{\mathrm{B}}$, with trade quantity $q^{(3)} = Q_{\mathrm{B}}$.

(3) When $MC_{\mathrm{B}} \geqslant MC_{\mathrm{A}}$, the marginal abatement cost of developing country will be higher than that of developed country. The transaction will

not take place between both countries. Otherwise, CDM will not be needed.

In conclusion, whether the government of developing country would set the price floor of emission trading and the difference in price floor will all influence the emission trading. If the price floor can be properly determined, then the developing country will be table to obtain more profits. Therefore, we will conduct related simulation studies.

8.3.2 Trading scenarios

According to the country classification indicated in Annex B of "*Kyoto Protocol*", Ellerman and Decaux (1998) have calculated the CO_2 emissions data of United States, European Union and Japan in 1990 (as indicated in Table 8.7).

Table 8.7 Carbon mitigation indicators of US, EU and Japan

Countries and regions	Emission data of 1990 /Mtc	Emission reduction rate committed/%	Emission reduction target
United States	1362	7	571
European Union	822	8	308
Japan	298	6	144

Data Source: Ellerman and Decaux (1998).

In order to stabilize the market, National Development and Reform Commission of PRC has stipulated the guiding price (bottom price) for the emission trading of CDM project. Along with the fluctuation of market, this price will also be adjusted accordingly. Therefore, this section assumes that the guiding price for emission trading is USD 8/ton CO_2.

Owing to the direct connection between the quantity and abatement cost, three scenarios have been established for the quantity of emission permits purchased by developed countries (as indicated in Table 8.8).

Table 8.8 Scenarios

price scenario	Without price bounding			With price bounding		
Upper limit for the proportion of purchase	Unlimited (100%)	20% of emission reduction target	50% of emission reduction target	Unlimited (100%)	20% of emission reduction target	50% of emission reduction target

Note: The upper limit for the proportion of purchase refers to the upper limit for the proportion of emission permits purchased by developed countries from developing countries to the emission reductions target.

8.3.3 Comparison and analysis of carbon pricing mechanism

According to the aforementioned model and scenarios and by conducting the numerical simulation of trade price and trade quantity of the developed country and the developing country, as well as the profit of developing country, our research findings are given below.

8.3.3.1 Scenario without price bounding

Compared with the circumstance without emission trading, the existence of emission trading is more beneficial to the developed country for accomplishing the emission reduction target. From Table 8.9, we can find out that: if the quantity purchased by developed country from developing country is not limited, then the developed country can substantially reduce the cost of emission reduction by purchasing emission permits from other countries. For example, without emission trading, Japan has to pay a high price (USD 34.256 billion) in order to achieve a smaller emission reduction target (144Mtc). Under the scenario of free trading without price bounding, the overall abatement cost will drop to USD 682 million (as indicated in Table 8.9).

Table 8.9 Emission mitigation targets of developed countries and mitigation costs under different scenarios

Countries and regions	Emission reduction target (Mtc)	Without emission trading		Overall abatement cost under free trade/USD 100 million
		Marginal abatement cost /(USD/ton of carbon)	Overall abatement cost /USD 100 million	
United States	571	186	375	97
European Union	308	274	305	31
Japan	144	583	343	7

Given the aforementioned data and model design, the emission trading will be the most favorable choice for Japan. Without emission trading, the unit abatement cost of Japan will be higher than that of United States and European Union (USD 583/ton of carbon). As for Japan, the trade price will be USD 4.78/ton of carbon under the scenario of free trade without price bounding, USD 2.08/ton of carbon under the scenario of 50% purchase limit, and USD 0.75/ton of carbon under the scenario of 20% purchase limit. Therefore, the drop in the proportion of emission permit purchased by developed countries from the CDM market could also be one cause for the low trade price in the CDM market.

Table 8.10 Bilateral trade prices in without price bounding

Countries and regions	q(unlimited)	$q \leqslant 50\%T_A$	$q' \leqslant 20\%T_A$
United States	20.94	12.53	3.64
European Union	11.20	5.34	1.74
Japan	4.78	2.08	0.75

When limiting the proportion of emission permits purchased by developed countries from developing countries, the stricter the limit is, the lower the trade price will be (Table 8.10), and the lesser the profit that will be received by developing countries (Table 8.11).

Table 8.11 Benefits of China without price bounding

Countries and regions	q(unlimited)	$q \leqslant 50\%T_{\mathrm{A}}$	$q \leqslant 20\%T_{\mathrm{A}}$
United States	49.73	20.60	2.25
European Union	16.94	4.53	0.56
Japan	3.71	0.79	0.11

Under the three scenarios of this model, owing to the high emission reduction target (571Mtc), China can receive the greatest proceeds from the emission trading with United States. However, with the restriction in the proportion of purchasable quantity, the profit has dropped from USD 4.973 billion (unlimited proportion) to USD 225 million under the scenario with 20% purchase limit.

It has occurred to us that the restriction in the purchasable proportion will inhibit the need of developed countries to purchase emission permits from developing countries and result in the drop of trade price, hence decreasing the profit received by developing countries during the emission trading.

8.3.3.2 Scenario with price bounding

According to the scenario design with price bounding and the model indicated in Section 8.3.1.2, we assume that the bottom price is USD 8/ton of carbon, i.e., v=8, and simulate the consequences of three scenarios. The different trade prices at which developed countries can purchase different proportion of emission permits from developing countries are given in Table 8.12.

Table 8.12 Trade price under price floor policy

Countries and regions	q(unlimited)	$q \leqslant 50\%T_{\mathrm{A}}$	$q \leqslant 20\%T_{\mathrm{A}}$
United States	20.94	12.53	8.00
European Union	11.20	8.00	8.00
Japan	8.00	8.00	8.00

Note: The trade prices are the constant USD in 1985.

Under the policy that stipulates a bottom price of USD 8/ton of carbon, compared with the trade prices given in Table 8.10, some transactions concluded at lower prices are now limited in the trade price (for example, under the scenario with unlimited purchasable quantity, the trade price of Japan is USD 4.78/ton of carbon, which is changed to USD 8/ton of carbon after price limitation), while those with trade price higher than the bottom price will remain unaffected (for example, under the scenario with unlimited purchasable quantity, the trade price of United States is USD 20.94/ton of carbon. Since $MC_{\mathrm{B}} > v$, the trade price will remain to be USD 20.94/ton of carbon after price limitation). In this model, Japan has suffered from the greatest impact caused by v=8. The trade price will all change into USD 8/ton of carbon under three scenarios of Japan (as indicated in Table 8.12).

When comparing between the scenario with price bounding (USD 8) and the scenario without price bounding, if the purchasable proportion of developed countries is not limited, the profit received by China will increase by 121% during its trade with Japan; if the purchasable proportion is limited to $50\%T_{\mathrm{A}}$, the profit received by China will increase by 90% and 537% respectively during its trade with EU and Japan; if the purchasable proportion is limited to $20\%T_{\mathrm{A}}$, the profit received by China will increase by 221%, 686% and 1894% respectively during its trade with US, EU and Japan. It has occurred to us that the establishment of guiding price is beneficial to China. On the one hand, it can control the trade price and avoid cut-throat competition in the market; on the other hand, it can help increase the profit. When the price is limited to v=USD 8/ton of carbon, China's profit is given in Table 8.13.

Table 8.13 Benefits of China under price floor policy

Countries and regions	q(unlimited)	$q \leqslant 50\%T_{\mathrm{A}}$	$q \leqslant 20\%T_{\mathrm{A}}$
United States	49.72	20.60	7.23
European Union	16.94	8.63	4.42
Japan	8.20	5.05	2.19

By comparing the results indicated in Table 8.13 and Table 8.11, we can conclude that: the profit of developing countries will remain unchanged when the trade price is not affected and will increase when the bottom price policy is implemented. The price floor can raise the trade price and increase the profit of developing countries. It will play an important role in the market stabilization of developing countries and protection of native enterprises.

The above discussion indicates that the price floor will not necessarily increase the profit of developing countries. When the bottom price is lower than the marginal abatement cost of developing countries, the price floor will not affect the trade. Only a proper guiding price can give full play to the positive role of price floor policy.

8.3.3.3 A reasonable range for price rise

Through above analysis, we think that a premise for the price floor policy to take effect is a rational guiding price. And what price could be a rational price floor? If we could find a rational range for price floor according to the developed countries' purchase quantity of emission permits in developing countries, developing countries could adjust the price floor within this range to gain further benefit, which shall help them have more funds and technology to support the activities related to climate change and hence alleviate the resource and environment pressure in developing countries. Through simulation, we obtained a chart showing the profiting variation with price fixing by developing countries as shown in Figure 8.6.

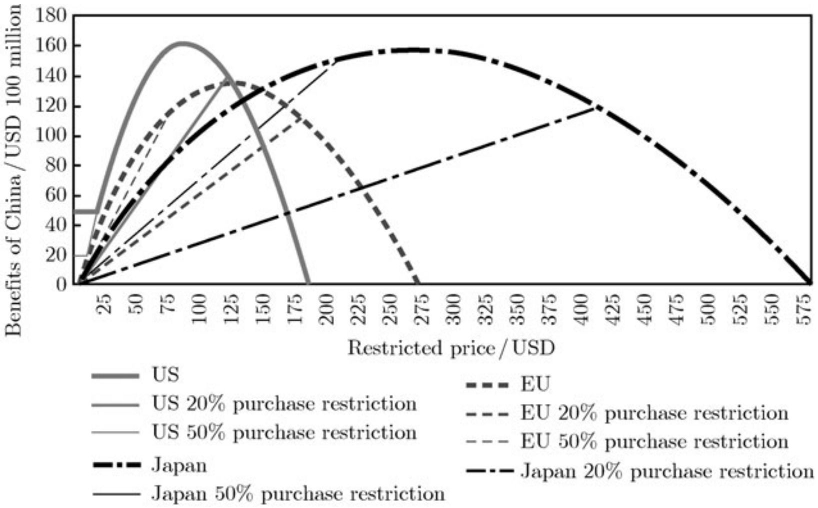

Figure 8.6 Benefits of China from trade with different developed countries under price floor policy

1) The scenario without limiting proportion of purchase

When the price floor varies between (0, 21), trade between China and the U S is not affected and the benefits from the trade stays at USD 4.973 billion [(0, 12) for EU; (0, 5) for Japan]. This is because that when the price floor v is less than the marginal abatement cost of USD 20.94 in developing countries, developing countries will not adopt price floor policy in trade. Under such circumstances, trade is market-oriented and developing countries' benefits won't increase either.

When developing countries lift the price floor to $v \geqslant$USD21/ton of carbon (EU: $v \geqslant 12$; Japan: $v \geqslant 5$), the price floor is larger than the marginal abatement cost in developing countries. Under such circumstances, developing countries shall adopt price floor policy in trade and their benefits shall increase as they raise the floor price.

China gains largest benefits from trade with the U S (USD 16.08 billion) when v=USD 87/ton of carbon, with EU (USD 13.448 billion) when v=USD 124/ton of carbon, and with Japan (USD 15.668 billion) when $v=$ USD 265/ton of carbon.

If the price floor is kept raised even when the largest benefit is achieved for developing countries, benefit shall decrease till the price reaches the value of marginal abatement cost in developed countries. Under such circumstances, developed countries won't purchase any emission quota from developing countries and developing countries shall gain zero profit as shown in Figure 8.6.

2) The emission reductions quota that developed countries can purchase from developing countries should not be larger than 50% of emission reduction targets

Developing countries' profit increases as the price floor is raised. At certain point when the fixed price rises result in decrease in the volume of transaction to below 50% of emission reduction targets, trade shall not be affected by the limit of purchase quota and developing countries' benefit is the same as when there is no limit of purchase quota.

3) The emission reductions quota that developed countries can purchase from developing countries should not be larger than 20% of emission reduction targets

As 20% of the emission reduction targets (US: 114.2Mtc; EU: 61.6Mtc; Japan: 28.8Mtc) is less than the optimal transaction without price bounding (US: 191.77Mtc; EU: 109.86Mtc; Japan: 59.30Mtc); developing countries can only achieve maximum benefit within allowed volume of transaction when there is limit on purchase, then the increase rate is rather slow. This is because the quantity of purchase is too small compared with the other two situations and raised price floor has a small influence over benefit.

Through the above-mentioned model of bilateral carbon dioxide emission trade between developed countries and developing countries, simulation is conducted to show the influence of different ratio ceilings of emission trade in developed countries and price floor policy in developing countries over emission trade and conclusions or inspiration are drawn as follows:

(1) According to the model specification and simulation results in this section, it does not exist that the unit abatement cost in Japan is USD 583, larger than those both in the US (USD 186) and EU (USD 274), which shows that emission trading is best favorable to Japan; in addition, compared with no price bounding circumstance and the situation of floor price at USD 8/ton of carbon, China's benefit from trade with Japan increases 121% without limiting proportion of purchase for developed countries; China's benefit from

trade with EU and Japan increases 90% and 537% respectively under the circumstance of purchase proportion no larger than $50\%T_{\mathrm{A}}$; and the increase rate of China's trade benefit with the US, EU and Japan reaches 221%, 686% and 1894% respectively under the circumstance of purchase proportion no larger than $20\%T_{\mathrm{A}}$. Therefore, a rational guiding price is favorable to China; it can control trade price on the one hand and bring about more benefits on the other.

(2) Under the circumstance of no price bounding, as the restriction over the purchase proportion of emission permits for developed countries become more and more strict, price of emission permits becomes lower. Therefore, if the ratio of emission quota purchase in CDM market for developed countries decreases, it might cause lowered price in CDM market transaction.

(3) In our model under the circumstance of USD 8/ton of carbon , China's trade benefit with the US increases only when the limit proportion of purchase is set to be 20%; with EU, China's benefit both increases when the limit proportion of purchase is set to be 50% and 20%; with Japan, China's benefit increases under all the three situations. It is observed that price fixing does not necessarily increase the benefits of developing countries; only rational price floor policy can increase the benefits of developing countries; whereas bilateral trade with different countries, there exists different reasonable floor price range or best price fixing point.

The establishment of CDM aims at helping developing countries with their sustainable development through capital assistance and technical transfer, whereas developed countries may utilize the mechanism to decrease cost of achieving emission reduction targets. It is a win-win mechanism. This section is a preliminary study of bilateral transaction in emission trading market. Further research on gaming mechanism designing and abatement cost function is necessary, so as to better fit practical situation and provide specific decision-making plan for China's participation in emission trading.

8.4 Conclusion

This chapter is a simulated investigation of CO_2 emission tax and emission trading policy.

(1) In the aspect of carbon taxes, the established dynamic and computable general equilibrium model CEEPA is used to simulate the introduction of carbon tax policy into China and to compare the macroeconomic influences exerted by different carbon tax plan on China's GDP, consumption and investment as well as the influences on the production, export and emission in the energy intensive trading sectors. Analytical results show that proper tax

reduction/exemption or allowance for production sectors will alleviate the negative influence cause by carbon taxes on the overall economic growth as well as the production operation and international competition capability of energy intensive trading sectors. Among these, the "Danish Model", which exempts carbon taxes for energy intensive trading sectors while returning tax revenue to the non-exemption sectors, is relatively optimized.

(2) In the aspect of emission trading, through establishing the model of bilateral carbon dioxide emission trade between developed countries and developing countries, simulation is conducted in this chapter to show the influence of different ratio ceiling of emission reduction trade in developed countries and price floor policy in developing countries on emission trade. Suggestions based on analytical result are finally given as: the proportion of emission reductions purchasable by developed countries from developing countries to the emission reduction target ceiling has influence on both the transaction price on international CDM market and the volume of transaction. Developing countries could stabilize the market to gain more benefits from emission trading through appropriate price floor policy. Guiding price should be within a rational range; within this range, the higher the fixed price the more the benefits will be, and there exists a best price fixing point. However, bilateral trade with different countries claims different rational fixed price range or best price fixing point.

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Chapter 9

International Carbon Market and Its Impacts on CO_2 Emission Abatement

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The entry into force of the *"Kyoto Protocol"* means not only the start of legal binding of greenhouse gas emission reduction goals and duties on industrialized countries, but also the beginning of greenhouse gas emission reductions via market mechanism. Global carbon markets have been primarily established so far and can be divided into quota based markets and project based markets. Quota based carbon markets are represented by the CO_2 emission trading scheme of EU, while project based carbon markets are mainly the CDM project markets and JI project markets. Carbon market plays an important role in CO_2 emission reductions, decrease of emission reduction cost, publicity of emission reduction policy, carbon financing and promotion of low carbon development.

With carbon market as focus, this chapter will analyze in detail the basic characteristics and influencing factors of international carbon market as well as its current status, so as to evaluate both the effects of international carbon market on alleviating global warming and promoting CO_2 emission reductions, and the uncertainty and weaknesses of carbon market. Analysis will concentrate on the following questions:

- What are the characteristics and mechanism of international carbon markets?
- Whether international carbon market is an effective way to promote CO_2 emission reductions?
- Whether has energy market become an obvious factor of influencing the macro fluctuation of international carbon market?
- What characteristics are demonstrated in the micro liquidity of international carbon market?
- How is the dynamics of current international carbon market development and what challenges are there?
- How is China's socio-economic development influenced by CDM projects related to renewable energy power?

9.1 International carbon market

On the 16th February 2005, *"Kyoto Protocol"* entered into force, which means that the greenhouse gases emission reduction goal and duty for industrialized countries has legal binding; hence industrialized countries are faced with present and/or prospective emission reduction pressure internationally, nationally or regionally. In order to effectively have the emission reduction duty fulfilled, *"Kyoto Protocol"* provides three types of flexible mechanism, i.e. clean development mechanism (CDM), joint implementation (JI) and international emission trade (IET/ET). It is these mechanisms that establish a practically working basis for the global emission reductions campaign and lay a foundation for the development of carbon market.

With the bound of *"Kyoto Protocol"*, CO_2 emission credit for each nation becomes a kind of scarce resource, and the emission credit of discharging additional carbon beyond basic need displays attributes of a commodity. As the environmental impact of CO_2 is going global and in the long term CO_2 will show the same warming effect, the emission place and emission reduction place become substitutable. Meanwhile, since CO_2 emission reductions claim cost and it is different in countries, CO_2 emission credit possesses value and a commercial market of carbon dioxide emission generated in the field of alleviating climatic change.

Figure 9.1 gives the trading rules for carbon market stipulated in *"Kyoto Protocol"*. Within the stated period, any country and/or region that could not achieve the emission reduction goal can buy emission quota from carbon market, while countries that already fulfill the goal and possess marginal quota may sell their quota on the market.

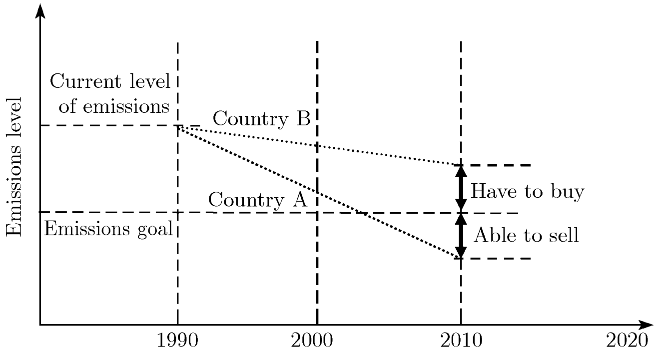

Figure 9.1 The carbon Market under the *"Kyoto Protocol"* Rules

As a matter of fact, marginal reduction cost and emission quota price together decided whether a country and/or an enterprise will participate in carbon market trade or not. When a country or enterprise is under market system with emission restriction, it will weigh the relationship between the emission quota price and its marginal reduction cost. If the allowed emission quota for the country or enterprise is insufficient to meet its greenhouse gases emission requirement, it will consider the relationship among emission reduction cost, emission quota price and penalties. If the marginal reduction cost is higher for the country or enterprise, they would be willing to pay higher price for additional emission quota. On the other hand, a country or an enterprise that has additional emission quota would be willing to sell the quota and gain benefits. If this market could progress with standardized development, a final equilibrium price would be formed. Under this equilibrium price, marginal reduction cost for all enterprises are the same, which ensures the fulfillment of emission reduction goals in the carbon market with minimum costs. Therefore, within the context of carbon market, a country or an enterprise has two options: achieving emission reduction goals by itself, or purchasing emission quota from the carbon market.

Therefore, establishing of international carbon market helps reduce carbon dioxide emission, lower the average CO_2 emission reduction cost globally, widen the adoption of emission reduction policy, realize carbon financing and promote low carbon development.

International carbon market could be categorized into two types according to transaction mode: quota-based (or emission permit) market (such as IET) and project-based market (such as CDM and JI). Carbon market under *"Kyoto Protocol"* is the main part on international carbon market.

Transactions on international carbon market experienced two phases: from 1996 to 2000, and from 2001 till now. During the first phase, carbon trade mainly happened in non-Kyoto market, i.e. voluntary market or retail market. Volume of transaction then shows no obvious law, with irregular fluctuation. The maximum yearly transaction volume of 40 million tons CO_2 occurred in 1996, while the minimum yearly transaction volume of 14 million tons CO_2 appeared in 2000. During the second phase, the carbon market gradually moved from non-Kyoto market towards Kyoto market. This is because a common understanding of international liability for alleviating climatic change has been reached and Kyoto rules attracted more and more attention.

Since the entry into force of *"Kyoto Protocol"* and launching of European Union emission trading scheme (EU ETS), both the project-based emission reduction trading market and the quota-based CO_2 emission quota trading market responded to such occurrences with rapid growth. Table 9.1 (Based on the data from World Bank (2007a), the results are calculated and shown in Table 9.1) gives an outline of the international carbon trading market during 2005—2006.

Table 9.1 Carbon market: volumes and values in 2005—2006

Market type	Market	2005		2006	
		Volume /million tons of CO_2	Value /USD 100 million	Volume /million tons of CO_2	Value /USD 100 million
Allowances	EU ETS	321	79.08	1101	243.57
	New South Wales, Australia	6	0.59	20	2.25
	Chicago Climate	1	0.03	10	0.38
	UK-ETS	0.30	0.0131	N. a.	N. a.
	Sub total	328	79.71	1131	246.20
Project-based transactions	Primary CDM	341	24.17	450	48.13
	Secondary CDM	10	2.21	25	4.44
	JI	11	0.68	16	1.41
	Others	20	1.87	17	0.79
	Sub total	382	28.94	508	54.77
Total		710	108.64	1639	300.98

Note: Primary CDM markets refer to the CDM projects that are purchased between the original owner of the carbon resource and the buyer; secondary CDM markets refer to the CDM projects in which the seller is not the original owner. N/A in the table indicates unavailable data. Source: World Bank (2007a).

Data in Table 9.1 show that in 2006 global carbon market value reached USD 30 billion (23 billion Euros), three times of that in 2005, and transaction volume was 16.39 million tons of CO_2 equivalent, strongly doubled the value in 2005. Statistical results from Point Carbon indicate that the global carbon market value in 2007 increased 80% compared with 2006, climbing up to 40 billion Euros (Point Carbon, 2008). From these it is clear that international carbon market is developing rapidly and various parties are actively participating, and most of the countries hold optimistic attitude towards international carbon trading market (World Bank, 2007a). In addition, the EU ETS has predominated carbon trading market and the transaction volume of CO_2 occupies 67% of global total volume.

In the carbon market and other related markets, projects concerning cleaning technology attracted most attention among investors in the capital market. Up to March 2007, there were 58 carbon funds on the market that had raised over USD 11.8 billion (9 billion Euros) of capital while in May 2006, there were 40 carbon funds on the market that had raised USD 4.6 billion (3.7 billion Euros) of capital, among which about 50% came from UK. In 2006, investment in cleaning technology and related fields created a record of USD 70.9 billion (New Energy Finance, 2006). Most of the companies on carbon market are growing rapidly with good profit.

9.1.1 Overview of quota based market

Quota based market mainly deals with international emission trade. According to the IET mechanism, buyers purchase the emission reduction quota established and allocated (or auctioned) by administrators under the cap and trade system, such as the assigned amount units (AAU) under *"Kyoto Protocol"*, or the EU ETS under European Union emission Allowances(EUAs). Among the countries and regions who committed to emission reductions by *"Kyoto Protocol"*, EU took the lead by establishing the biggest European Union Emission Trading Scheme (EU ETS). And some national emission trading mechanisms were founded, such as UK Emission Trading Scheme (UK ETS), the Norway Emission Trading Scheme (N ETS) and Japan's Voluntary Emission Trading Scheme (J VETS).

In addition, due to the sense of responsibility for protecting global environment and confidence on carbon market, some countries and regions voluntarily established participatory GHG emissions trading market without commitment to the emission reduction duty stated in *"Kyoto Protocol"*, such as US Chicago Climate Exchange (CCX) and Australia N.S.W. Greenhouse Emission Reductions Scheme (NSW/ACT) (Currently Australia already signed the *"Kyoto Protocol"*, but it didn't take any emission reductions duty when establishing the scheme.).

Actually these emission reduction schemes are obviously different from each other. Major differences lie in the types of restricted GHG, emission source, whether it is compulsory, duration of emission reductions and punishment for violation, etc., which are shown in Table 9.2. (Based on the data from Ellis, Tirpak (2007), the results are calculated and shown in Table 9.2).

Table 9.2 Key characteristics of different emissions trading schemes

Market	Eligible gases	Emission source	Mandatory or Voluntary	Participants	Target: indexed or fixed	Time scale	Noncompliance penalty
EU ETS, Phase I	CO_2	Combustion plants, oil refineries, coke ovens, I&S, cement, glass, lime, brick, ceramics, pulp and paper	Mandatory	Emitters	Fixed	2005—2007	EUR 40 (+ shortfall to be made up in following year)
EU ETS, Phase II	CO_2 +opt-in (e.g. N_2O)	As above, + possible "opt-in" for some gases/ sectors(e.g. industrial N_2O in the Netherlands)	Mandatory	Emitters	Fixed	2008—2012	EUR 100(+ shortfall to be made up
NSW/ ACT, Australia	6 type of greenhouse gases	Production and use of electricity	Mandatory	Electricity retailers, large elec. users	Indexed	2003—2020	AUS 11.5/t shortfall if over-emission not made up in subsequent year
UK ETS	6 type of greenhouse gases	Various industrial sectors and energy use	Voluntary	Emitters and users	Fixed	2002—2006	GBP30 + make up credits in next year + nonpayment of subsidy
Chicago Climate Exchange	6 types of greenhouse gases	Electricity generation, manufacturing industry	Voluntary	Emitters (and offset providers)	Fixed	2003—6, 2007—10	No defined penalty, but reward and/or punishment for some carbon offsets providers

Note: Carbon offset refers to the form of trading in compensation of CO_2 emissions by enterprises or individuals who, due to production or daily life, inevitably keep emitting CO_2 but have no way of repair the consequences by themselves. Data source: Ellis, Tirpak (2007).

Regarding market influence, EU ETS is currently world's largest carbon market in terms of market value or transaction volume; its market value is far higher than other exchanges and obviously exceeds other project based markets including CDM (Capoor, Ambrosi, 2006). The trends of EUAs transactions in EU exchanges (including ECX, Nordpool, EEX, Powernext, EXAA) and OTC market from January 2005 to December 2007 are shown in Figure 9.2 (Based on the data from exchanges of ECX, Nordpool, EEX, Powernext and EXAA and Pointcarbon, the results are calculated and shown in Figure 9.2), and from the figure it is observed that the transaction volume of CO_2 emission reductions in EU CO_2 emission trading market increases with years. In 2007, the global transaction volume of CO_2 equivalent is 2.7 billion tons, and 1.6 billion tons, i.e. 2/3 of the volume, is transacted via EU ETS; among the global transaction value of 40 billion Euros, 28 billion Euros comes from EU ETS (Point Carbon, 2008). Regarding market function, EU ETS Phase I (2005—2007) achieved larger success. It not only promoted interior emission reductions in EU, but also had positive influence on CO_2 emission reductions worldwide.

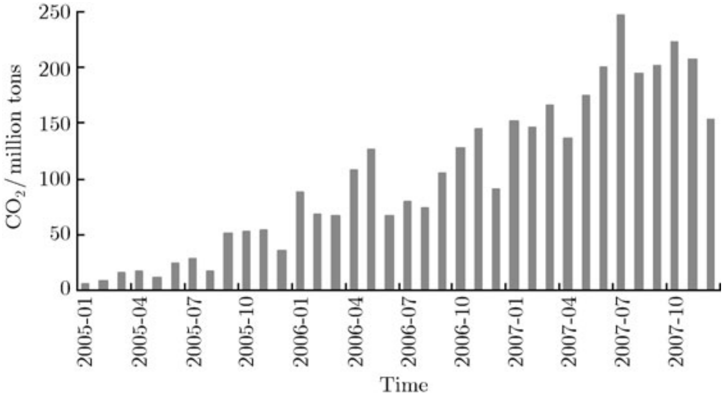

Figure 9.2 The Transaction Volumes of EU EUAs

(Data Source: exchanges of ECX, Nordpool, EEX, Powernext and EXAA and Point Carbon; transaction volume of futures include all contracts due before 2012)

9.1.2 Overview of project based market

Project based market is primarily markets based on CDM and JI. It grew rapidly. According to market transaction, contraction volume of CDM and JI increased greatly in 2006, reaching about USD 5 billion (about 3.8 billion Euros). The same growth happened to voluntary carbon trading among enterprises and individuals, and transaction value climbed up to USD 100 million (about 80 million Euros).

Compared with drastic price fluctuation in EU market, project based carbon market price is relatively stable. In 2006, developing countries sold approximately 4.5 million tons of primary CDM credits, equivalent to about USD 5 billion (380 million Euros). The average price of approved CERs is USD 10.9 (8.4 Euro) (World Bank, 2007a). In the secondary markets ①, the prices of approved emission reductions are much higher than in primary markets, normally ranging between USD 14.30—19.50 (11—15 Euros).

At present in the project-based market, as trading of CDM projects are very active and the CDM market has direct relation with China, this section shall focus on the introduction of CDM markets. Continuous and healthy development of CDM markets are confronted with series of challenges, mostly reflected in project type distribution, geographical distribution, scale, direct benefit of sustainable development of the project, influence on promoting technical transfer, etc.

9.1.2.1 CDM exporting countries are mainly large developing country

So far, CDM projects are mainly concentrated in the several large developing countries who have relatively strong economic power and political influence, whereas other relatively poor developing countries have less CDM projects and hence it is hard for them to get advanced technology and/or equipment through CDM projects. The CERs quantity in India, China, Korea and Brazil occupies 92% of the total quantity assigned by UN. Africa, as a continent with lowest GDP per capita, is the major region with many developing countries, but CDM projects developed slowly there. The CERs registered by Egypt only takes 13% of the total CERs (UNFCCC, 2007; World Bank, 2007a).

It can be seen from the distribution of the number of CDM project that India is the largest CDM exporter and China ranks the second. According to Figure 9.3, there are 948 CDM projects in 49 countries of the world registered in EB up to February 27, 2008. India is the country claiming most CDM projects; the 316 projects take 33.3% of the total CDM projects worldwide. Following India is China, having 161 projects and taking 17%, a slight rise compared with 14.8% in September of 2007. Brazil and Mexico rank the third and the forth, having 125 projects and 101 projects respectively.

China is the second largest emitter, but the number of CDM projects in China is less than that in India. Two reasons caused this: ① the Chinese government always encourages technical transfer and resists CDM projects

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① It means that the sellers are not the original project owners or the country where the project is originally located.

with additional condition, and ② in order to promote sustainable development, the Chinese government prefers to inter-governmental cooperation of CDM projects (LIU Lancui, WU Gang, 2007).

From the registered CERs number, China and India are the first and second largest exporter respectively. Up to February 27, 2008, about 60% of the CERs in the CDM market were provided by China and India, and following them were Korea, 18% and Brazil, 14.9%. Based on the data from UNFCCC (2007), the results are calculated and shown in Figure 9.4. The proportion taken by Asia was over 80% and the remaining less than 20% were shared by other countries and regions.

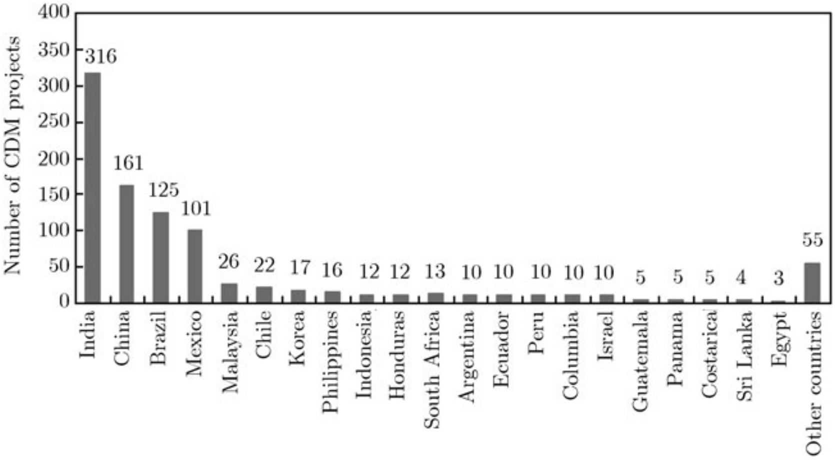

Figure 9.3 Number of registered CDM projects

[Data Source: UNFCCC (2007), data by February 27, 2008]

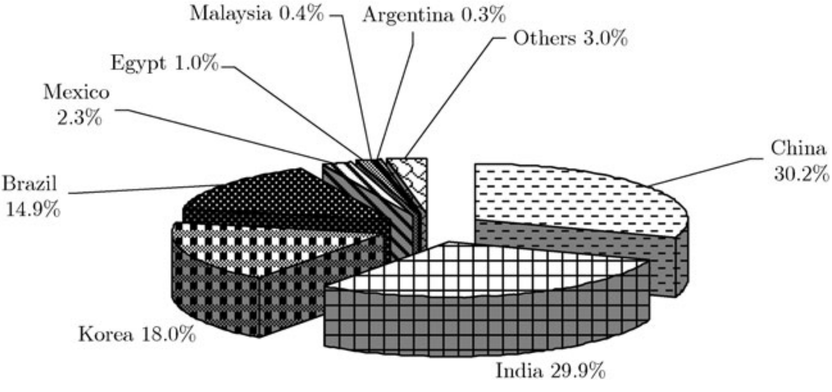

Figure 9.4 Registered CERs projects by region

[Data Source: UNFCCC (2007), data by February 27, 2008]

To sum up, the major CDM project cooperation parties for developed countries are the larger developing countries like China, India, Brazil and Mexico, while other relatively smaller poor developing countries are not participating; hence CDM projects only benefit a few relatively advanced developing countries while having little impact on foreign direct investment, technical transfer, government revenue increase and promotion of sustainable development.

9.1.2.2 CDM projects are mainly energy-related projects and emission reductions focus on non-CO_2

It can be seen from the CDM projects number that, energy-related projects take up about 55% of registered CDM projects, waste disposal projects, 21%, agricultural projects, 7%, and HFCs/sulphur hexafluoride/other chemical projects, only 1.3%, which are all shown in Table 9.3 (Based on the data from UNFCCC (2007), the results are calculated and shown in Table 9.3). Energy industry (including renewable energy) is the sector where most CDM projects are implemented, since it is basically a high energy-consuming industry.

Table 9.3 Registered CDM projects by sector

Sector	Number of registered projects
Energy industries (renewable - / non-renewable sources)	653
Energy distribution	0
Energy demand	16
Manufacturing industries	69
Chemical industry	23
Construction	0
Transport	2
Mining/Mineral production	7
Metal production	1
Fugitive emissions from fuels (solid, oil and gas)	98
Fugitive emissions from production and consumption of halocarbons and sulphur hexafluoride	16
Solvents use	0
Waste handling and disposal	256
Afforestation and reforestation	1
Agriculture	83

Note: One project may belong to several sectors. Data in the table is up to February 25, 2008. Source: UNFCCC (2007).

From the perspective of emission reductions, however, the situation is totally reversed. Up to February 27, 2008, the emission reductions in the project-centered energy industry occupied only 25% of total emission reductions, and the fugitive emission reductions related to fuel (solid, oil and gas) and/or halocarbon, sulphur hexafluoride production and consumption occupied only 37% of registered projects, based on the data from UNFCCC (2007), the results are calculated and shown in Figure 9.5.

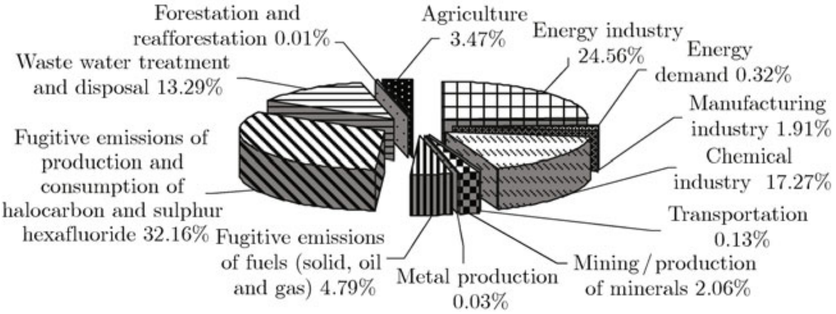

Figure 9.5 Registered CERs by sector

[Data Source: UNFCCC (2007), data by February 27, 2008]

9.1.2.3 CDM investors are mainly UK, Holland and Japan

Up to November 8, 2007, the investment projects of UK occupied 41% of the total projects, and the number of project in the whole Europe took 83%. No matter in terms of the passion in CDM investment or considering the operation of EU ETS, the European continent always took the lead in global warming control. The European governments as well as individuals' attention and active involvement in emission reductions campaign deserves respect and learning by other countries, especially those who are far from fulfilling their duties in emission reductions.

From transaction value, European buyers took about 86% of the CDM market share in 2006 (World Bank, 2007a). Japan took up to 40% of the market share in 2005, almost the same as the proportion taken by Europe. Japanese buyers are more sensitive to price and more serious about the details in negotiation, which is why the market share taken by Japan obviously decreased when CDM price rose in 2006.

In the project based market, EU becomes the largest buyer. Figure 9.6 (Based on the data from UNFCCC (2007), the results are calculated and shown in Figure 9.6) shows the distribution of CDM projects by purchase country up to February 27, 2008. It can be observed that UK purchased most CDM projects, taking 40% of the total number, following it is Netherlands taking 5%, Japan taking 12%, Switzerland taking 6%, and Sweden and Germany taking 5% respectively. In summary, EU is the major buyer of CDM projects and purchased 82% of total projects.

9.1.2.4 Project based carbon market price rises, with JI price lower than CDM price

There has been obvious price rise in project based market. Figure 9.7 (Based on the data from World Bank (2007a), the results are calculated and shown in Table 9.7) shows the price distribution in project based market in 2005 and 2006. For CDM projects, the average price of CERs is about USD 10.90(8.40 Euros)/ton of CO_2, with an increase of 52% compared to the price in 2005 (This average price considered different types of contract.). In 2006, the lowest CER price was USD 6.8(5.20 Euros)/ton of CO_2, an increase of 173% compared with the lowest price of USD 2.50(1.90 Euros)/ton of CO_2 in 2006. Similarly, JI prices in 2006 showed drastic rise from 2005 prices too. The average price of ERUs was USD 8.70(6.70 Euros)/ton of CO_2 in 2006, an increase of 45% from 2005 price.

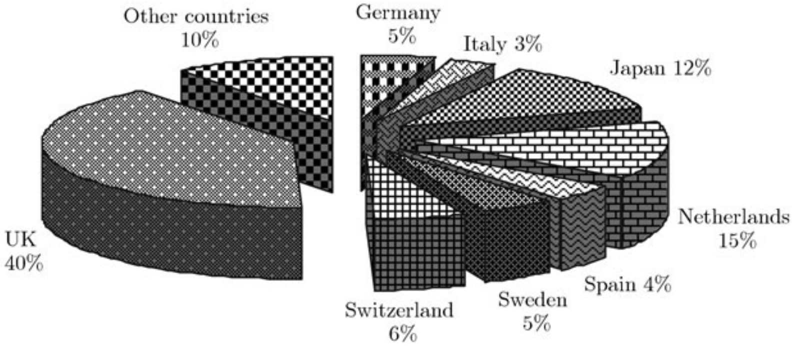

Figure 9.6 Registered Projects by Investor Parties
[Data Source: UNFCCC (2007), data is sorted according to number of projects up to February 27, 2008]

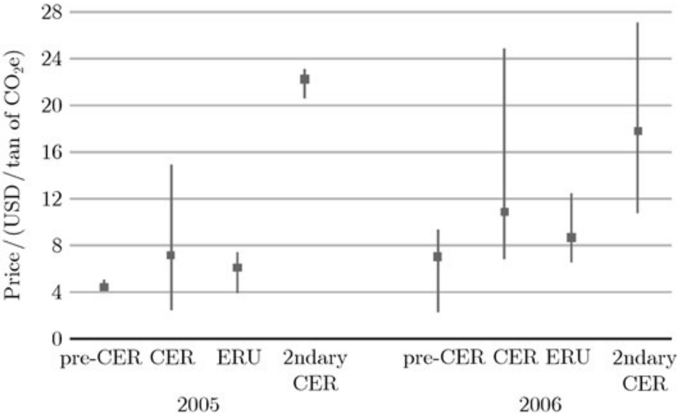

Figure 9.7 Observed prices for project-based transactions in 2005 and 2006
[Data Source: World Bank (2007a)]

With comparison of the CDM and JI project price, ERUs price is still lower than CERs price. In 2006, the trading price of JI projects was USD 6.60—12.40/ton of CO_2, lower than both the primary CERs price (USD 6.80—24.75/ton of CO_2) and secondary CERs price (USD 10.75-27/ton of CO_2). In addition, Russia is the major exporter of JI projects. But, its current legal and institutional establishment still needs improvement, which partially caused instability to the ERUs price. In actual trading, if prepayment is high enough (over 50%), ERUs price often gives rebate.

For the buyers and sellers in international market, the following factors usually decides the base price in negotiation: particularity of the project, price of relevant Chinese projects, rebate rate of primary CERs, price of similar emission reductions projects, etc. The price of CERs in secondary markets is also a reference in negotiation. Although EU ETS is currently the largest carbon market and demanding party, other trading markets still show high potential of development. Moreover, due to the instability of EU ETS price, Japan and other countries do not consider this factor much in negotiation.

9.1.2.5 CDM projects show smaller impact on sustainable development

To promote the sustainable development of developing countries is one of the two objectives of CDM. *"The Marrakesh Agreement"* after *"Kyoto Protocol"* restated the right of host country to decide whether the CDM project promotes sustainable development of the country. It stipulated that CDM projects promoting the sustainable development of non-Annex I countries shall comply with the following principles:

① in compliance with the development strategy and priority fields of developing countries; ② promoting advanced, efficient and environment friendly technical transfer, especially energy technology transfer, for developing countries; ③ assisting the socio-economic development of developing countries; ④ assisting to build the capacity of developing countries in alleviating and being adapted to climatic change; and ⑤ assisting the improvement of regional environment of developing countries.

The PDD documents of many projects indicate the project's direct positive impact on sustainable development in many aspects, such as environment (within the scope of project, local environment or larger scale), economy, technical transfer (including knowledge transfer), health, social benefit (referring to local community, excluding employment), employment, education of clean technology, acquisition of ideas and information, and improvement of energy utilization. Therefore, Table 9.4 (Based on the data from UPDD and Ellis et al. (2007), the results are calculated and shown in Table 9.4) comprehensively evaluates the significance of different types of registered CDM projects in promoting sustainable development according to Marrakesh Agreement and the PDD of CDM projects. As host country makes the decision of whether the CDM project promotes the sustainable development of developing country, instead of monitoring by assigned operation unit or Executive Board (EB), the impact of CDM project on host country's sustainable development stated in PDD is rather macroscopic.

Table 9.4 Direct and indirect effects on sustainable development caused by CDM projects

Project	Description	Direct and indirect effects on sustainable development							
		Environment	Economy	Introduction of advanced equipments	Health	Social development	Employment	Exemplary effect	Energy supply
Renewable energy utilization	Mainly power generation using wind, water, terrestrial heat and biomass energy as well as solar energy utilization	√	√	H	√	√	√		√
HFC 23	HCFC22 production avoiding emission of HFC23	△		L		*			
N_2O	Decompounding N_2O generated in fatty acid production			L		*	√		
Fuel conversion	Substitution of coal or petroleum products for gas	√		H		√	√		
Efficiency improvement	Improvement of energy utilization efficiency by energy supplier or demander	√		H	√	√	√	√	

Continued

Project	Description	Direct and indirect effects on sustainable development							
		Environment	Economy	Introduction of advanced equipments	Health	Social development	Employment	Exemplary effect	Energy supply
CH_4 reclamation	Reclamation of industrial CH_4	√		L					
CH_4 avoidance	Avoiding generation of CH_4 in utilization of solid wastes	√		L					√
Industrial waste gases	Utilizing high-temperature gases generated in steel plant or concrete factories to generate electricity for local use	√		M-H			√		√
Landfill gases	Collecting landfill gases for burning or electricity generation	√	√	M-L	√	√	√	√	√
Concrete	Reducing refinery dross in concrete production	√		M					√

Continued

Project	Description	Direct and indirect effects on sustainable development							
		Environment	Economy	Introduction of advanced equipments	Health	Social development	Employment	Exemplary effect	Energy supply
Bagasse	Utilization of bagasse in electricity generation	√		H	√	√	√	√	√
Animal waste	Reformation of animal waste management system in farms	√		L	√	√	√	√	√
Afforestation	Absorbing greenhouse gases by afforestation and reforestation	√		L		√			

Note: Summary of the impact of registered CDM projects on sustainable development is drawn from PDD and Ellis et al. (2007). √ indicates direct impact; △ indicates only reducing global greenhouse gases emission; ∗ indicates CERs benefits; H indicates causing high-degree technical transfer; M indicates moderate technical transfer; L indicates basic technical transfer.

Almost the PDD of all CDM projects mentioned their impacts on environment and employment, namely reducing the emission of substances polluting the air, water and soil, reducing generation of wastes, and increasing employment for local population. The significance of different types of CDM projects are differently stated in PDD. CDM projects' impact of, among others, introducing advanced and friendly energy technology is very important for sustainable development, which is explained in many PDD.

A glance at the types of current CDM projects:

(1) Energy and waste disposal projects can effectively improve regional

environment, increase income of local population and employment, and promote local economic development, showing obvious benefit for sustainable development.

(2) Renewable energy and energy efficiency improvement projects can really bring about, to some degree, technical transfer for host country, or promote application of advanced technology, hence assisting sustainable development by reducing pollutant emission, increasing energy supply, and improving the living standard for local population.

(3) HFCs/sulphur hexafluoride/other chemical projects are different, whose contents are mainly collection and decomposition of chemical waste gases that are usually not regional pollutant and have small influence on local environment. Besides, the technology needed to complete the tasks does not require high technical content or deserve wide utilization. Therefore, these projects contribute less for direct sustainable development in host country.

As host country makes the decision of whether the CDM project promotes its sustainable development, instead of monitoring by assigned operation unit or EB, supervision of CDM project as whether it promoted host countries' sustainable development is far from enough considering the superfluity and boundary of the project.

From the macroscopic angle, CDM projects' are necessary impact on host countries' sustainable development is still small and measures to promote the sustainability of CDM projects.

9.1.2.6 Market characteristics of CDM projects in China

As stated above, China has been a key host country of CDM projects and playing an important role in international carbon market. China's CERs and number of CDM projects rank the first and second worldwide respectively. India is another key CDM project exporter, and the distribution of CDM projects by sector in China and India are shown in Figures 9.8 and 9.9 (Based on the data from UNF (2007), the results are calculated and shown in Figure 9.8 and 9.9).

To sum up, the distribution characteristics of CDM project types can be shown as follows in comparison with other large exporters of CDM projects (such as India, Brazil, etc.):

(1) At present, CERs in China come mainly from non-CO_2/non-CH_4 emission reduction projects, taking 57% of total project emission reductions and largely higher than the 34% in India; whereas CERs from projects related to energy efficiency improvement, new energy and renewable energy

development, and recovery utilization of CH_4 and/or coal-bed methane, are extremely small. Implementation of non-CO_2/non-CH_4 emission reduction projects can only bring about benefits in emission reductions and hardly introduces advanced technology, which has unclear effects for the sustainable economic, social and environmental development in China. In addition, the great benefits from CERs of non-CO_2/non-CH_4 emission reduction projects seriously obstructed the development of energy efficiency and renewable energy projects that are capital intensive and require less emission reductions.

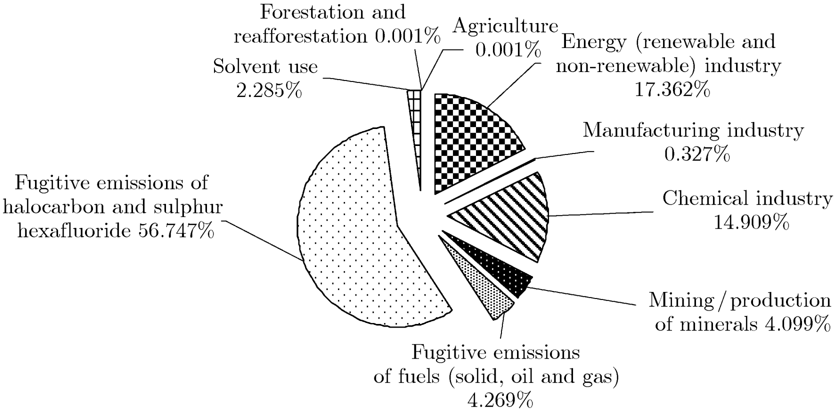

Figure 9.8 Registered CERs in China by sector

[Data Source: UNFCCC (2007), up to February 27, 2008]

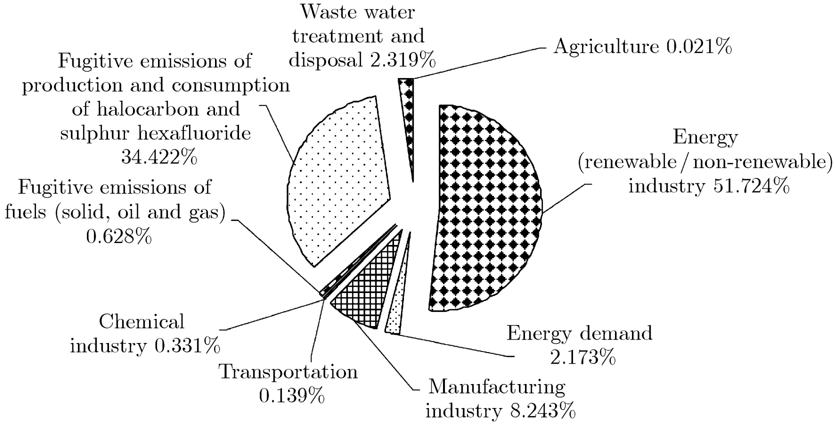

Figure 9.9 Registered CERs in India by sector

[Data Source: UNFCCC (2007), up to February 27, 2008]

(2) CDM projects in China cover narrower field, mainly wind power, hydro electricity and HFC23, and the introduction of advanced energy technology

in these projects are left behind India and Brazil. India and Brazil developed a series of projects related to hydro electricity, wind power, biomass electric power generation, solar energy utilization, bagasse electricity, energy efficiency improvement and fuel switch, making use of CDM projects. These projects saved substantive fossil energy for the countries, promoting diversification of energy consumption structure and ensuring energy security to some degree.

(3) The direct effect of CDM projects in China on promoting local sustainable development is not as good as in India. The Indian government and/or enterprises valued the contribution made by CDM projects and made full use of local resources to attract the projects that can promote sustainable environmental, social and economic development of the nation, which is a good reference of Chinese government and enterprises. This fact means a lot to China's energy security, environmental safety or even economic security.

Based on the above analysis of CDM projects in China and especially the challenges, we suggest:

(1) The future CDM project cooperation in the prior fields of China should emphasize macro control and policy guidance of government. By taking advantage of Chinese CDM funds, government should develop and encourage application of CDM projects that has significance to national economy, environment and society, such as projects related to biomass electric power generation, energy efficiency improvement, animal waste reclamation and landfill gas, and also provide prophase development cost or low-interest loan for these projects. Government entities should guide and supervise international cooperation of CDM projects through series of financial, legal and other policies so that the projects could be beneficial to China's sustainable development.

(2) To actively develop methodology for energy efficiency improvement projects, so as to promote equipment replacement and technological reform in our high energy consuming industries (steelworks, cement production plant, power plant, etc.), improve energy utilization efficiency, and decrease fossil energy consumption, which helps to realize the goal set in the 17th Communist Party of China National Congress Report, i.e. building a moderately prosperous society in all respects by 2020.

(3) To establish unified seller's market for Chinese CDM projects trading that is supervised by government, stabilize CERs price, avoid cut-throat competition and build the international competition capability of Chinese CDM projects.

9.2 Relationship between EU carbon market and energy price

Global climate change and *"Kyoto Protocol"* have become one of the focal points that observed by the whole universe. To fulfill the commitment in *"Kyoto Protocol"* with low cost, EU established EU ETS. Currently EU ETS is the largest carbon market worldwide and also the wind vane of international carbon market trading. Its development reflects the trend of world carbon market and its market quotation directly influences global CO_2 trading price.

Researches on EU carbon market already attracted much attention from scholars, but it is still on initial progress. Through empirical research, Christiansen and Wettestad (2003) gave very good comments on the pioneering work done by EU in greenhouse gases emission reductions, and discussed major factors influencing successful future emission trading from three different angles. Jepma (2003) discussed the defects of greenhouse gases emission trading order within EU, and warned that such order did not conceivably linked with the *"Kyoto Protocol"* mechanisms (such as CDM and JI); he further concluded that not only the order itself was risky, but also it might be avoided by member parties in the future who possibly would design local climate policy. Against the emerging doing of signing negotiation agreements covering emission trading among many member countries, Boemare et al. (2003) pointed out that the co-existence of such "top-down" and "bottom-up" trading schemes might cause complication of related policy and, taking France and UK for example, explained existing common problems caused by inter-playing of member country policy and EU policy.

Yet after proposal of EU ETS, many scholars conducted deep studies on EU ETS. Based on EPPA model, Reilly and Paltsev (2005) established EPPA-EURO model to analyze EU ETS carbon market, especially the trends of carbon price, and found that carbon price during 2005—2007 should have been 0.6—0.9 Euros/ton of CO_2, which was tremendously different from actual 20—25 Euros/ton of CO_2; they then analyzed causes of such difference. Ruchner et al. (2006), starting from the emission reductions data released by European committeeman, discussed the problem of whether credits were excessively allocated or discounted, and provided method of measuring excessive allocation or discount. Buchner et al. (2006) also reviewed the problem of EU ETS emission credits allocation, including experience gained during the process of allocating and general principles, and analyzed the influence of EU ETS on global climate change. Soleille (2006) compared the effects as well as similarities and differences of command control mode and EU ETS as two policy tools for reducing pollution and pointed out that it is hard to say which is more effective, as the effectiveness does not lie in the policy tool itself but depends on the strength of goal set; as a result the national assignment plan setting emission reductions quota is very important. Georgopoulou et al. (2006) argued that, based on analysis of EU ETS Phase I allocation plan, due to synthetic action of non-transferability of credits crossing the phases, increase in number of CDM project and requirements of continuing emission reduction, credits allocation in Phase II would be extremely strict and deserve special attention from relevant enterprises and government. Laurikka (2006) introduced a simulation model to discuss impact of IGCC investments on emission trading (especially EU ETS). Haar and Haar (2006) qualitatively analyzed the policy-making uncertainty in EU ETS, including potential influence on economic development, effects on reduction of greenhouse gases emission and benefits/cost issues, and pointed out that governmental and academic research of EU ETS is insufficient. Böhringer et al. (2006) took Germany for example and quantitatively analyzed excessive cost of CERs with numerical simulation; results showed that effective national allocation plan is not sensitive to international carbon price but more easily influenced by efforts of talking emission intensive industrial sector round.

Chinese researchers' attention to international carbon market just took a few steps and no study of quantitative investigation on international carbon market has been published. ZHANG Shengdong et al. (2005) gave qualitative division of the basic structure of international carbon markets and emphatically introduced project based carbon markets from the respects of trading entity, transaction quantity, trading price and trading type.

9.2.1 Relationship between carbon prices and energy prices

Current researches on EU ETS largely emphasize design of the scheme and emission reduction policies, which bear reaching significance for getting to know EU ETS and even the global CO_2 emission trade. Carbon prices are the information carrier and focal embodiment of carbon market development; the trend of carbon prices are formed by synthetic action of several factors, like energy prices, weather condition, emission reductions policy of related government and/or authoritative institution, anticipation of carbon market traders, and even market condition of CDM and JI projects (Christiansen and Wettestad, 2003; Springer, 2003b). Among these factors, energy prices are one of the important player and one of the most direct indicator of whether the carbon market is mature. Therefore, analysis of energy prices and research on whether there is an interacting relationship between energy price and carbon price are very important and offer good guidance for the discovery of internal mechanism of carbon market and the analysis/prediction of carbon price trend. However, there has been few studies on this so far and we found that the only publication is about the impact of energy price and weather factor on CO_2 price by Mansanet-Bataller et al. (2007), who concluded that abnormal temperature and energy price (petroleum and natural gas) have obvious influence on CO_2 price. But, they used the OTC forward price in 2005 when market then was far from mature with inactive trading; the authors regarded OTC forward price practically the same as futures price, yet as carbon futures market trading became frequent, the trends of forward price and futures price showed differences while futures price itself demonstrated divergence against different phases. Moreover, the energy prices quoted by the authors did not include electric power, whose price trend (especially the price in Germany) has obvious influence on the fluctuation of carbon market. This could be observed from the trade review of ECX (European Climate Exchange, 2007). Therefore, in order to making futures price functionally reflect traders' anticipation and guide market trend, and to consider the new characteristics of carbon market development, we adopted data of carbon market futures price in 2006 and further quantitatively analyzed the inter-acting relationship between carton futures price and energy futures price.

As known to all, CO_2 emissions mainly come from use of fossil energy, especially electric power, petroleum, natural gas and coal; hence carbon prices are always closely related to the prices of these energy. Generally, when market is mature enough, increase of petroleum and natural gas prices will cause use of coal with lower price; this is particularly true with the large energy-consuming electricity generating industry. This means that coal price will rise and CO_2 emissions will increase, so that carbon price will rise with the increasing demand in carbon market.

Based on such mechanism of supply and demand on carbon market and energy market, energy price and carbon price should be positively proportional to each other and there should be clear interactive relationship between them. However, whether there really exist such relationship between EU carbon market and energy market? Are they clearly interactive? To answer these questions, we shall apply econometrics instruments, like co-integration theory, vector error correct model (VECM) and Granger causality test, to empirically investigate the relationship and influencing mechanism between the carbon price and energy price in EU.

9.2.2 Model of cointegrating relationship test between carbon prices and energy prices

9.2.2.1 Data sources

The ECX in Netherlands is the exchange with largest carbon transaction volume; its daily transaction volume usually occupies 80% of the total volume of key exchanges in Europe. Therefore, the transaction in ECX reflects the market status of EU ETS to greater degree.

Based on the two phases of EU ETS (2005—2007 as Phase I, 2008—2012 as Phase II), this section selects several key carbon futures contract (expire in December of 2005, 2006, 2007, 2008 and 2009 respectively) of ECX as subjects of investigation. The trend of prices are shown in Figure 9.10 (Based on the data from ECX (2006), the results are calculated and shown in Figure 9.10).

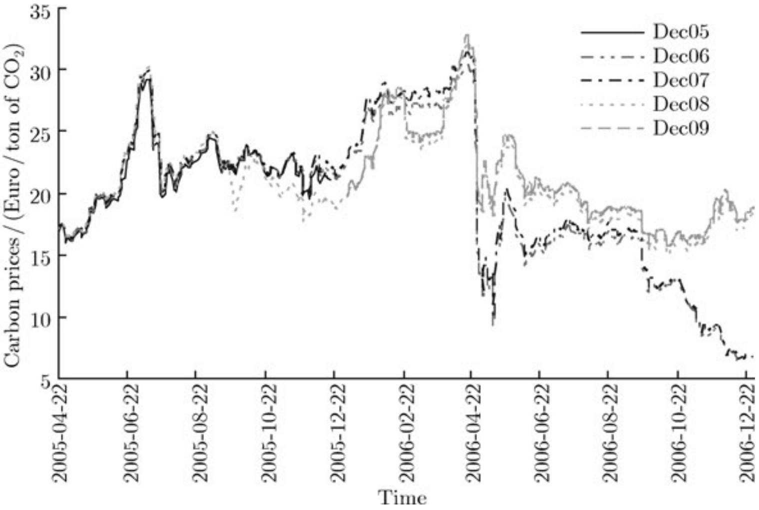

Figure 9.10 The carbon prices of ECX (April 22, 2005—December 29, 2006) [Data Source: ECX (2006)]

As before May 2006 all countries were not active in participating in carbon trading, the entire EU carbon market trading was rather weak; on the other hand, various non-market factors greatly influenced carbon price trend, especially during the period from the end of April 2006 to the beginning of May when the factories and power plants of Estonia, Belgium, Czech, Netherlands, France and Sweden released certified data in advance, plus many speculating funds taking the chance, carbon prices slumped violently and the markets' weakness continued. Till 15 May when European Commission formally issued the certified credits data, contraction prices began to rise to normal level. For a precise study and investigate of the interactive relationship between carbon prices and energy prices, we should use data of a normally operating market. Therefore, the sampling period is set as from May 15, 2006 to December 29, 2006.

Considering the big difference in contract prices in the two EU ETS phases while contracts during the same phase show consistency in high degree, we presume that contract prices of Dec 07 and Dec 08 represent contract prices of Phase I and Phase II respectively. Energy prices that influenced Europe carbon prices mainly include power prices, oil prices, coal prices and gas prices. Here we adopt representative energy prices.

As Germany ranks the first in both the installed capacity and plant output in Europe, owning the largest electricity market in EU, we use electricity futures prices on Germany in representation of European electricity price measured at Euro/MWh. Oil prices are the latest Brent futures prices provided by Platts at cent/barrel, which is converted into dollar/barrel in this section. As the European coal futures market was recently established, we use the coal futures prices of the three ports (Amsterdam, Rotterdam and Antwerp) in EEX of Germany at dollar/ton. Furthermore, as UK is the largest gas consumer in Europe and the gas prices in UK can basically reflect the gas market transactions in Europe, we adopt the UK gas futures index prices of ICE at penny/caloric unit. All energy prices are daily data. After calculating the natural logarithm, the price trend is obtained as shown in Figure 9.11 (Based on the data from ECX (2006), the results are calculated and shown in Figure 9.11).

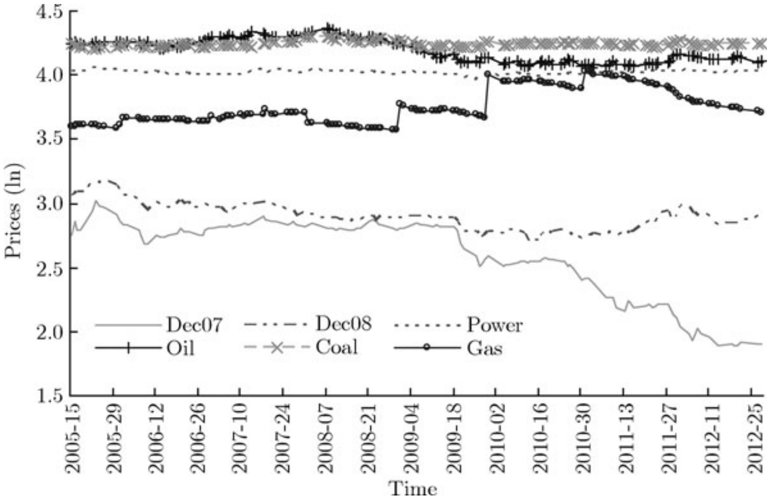

Figure 9.11 The logarithm prices of energy-carbon contracts in 2006

[Data Source: ECX (2006)]

From the trends of carbon prices and energy prices, it can be discovered that various energy prices are generally concordant with Phase II carbon prices and also the Phase I carbon prices before October, and that after October in Phase I as market expectation of carbon contract was pessimistic and trading was weak with decreasing prices while energy prices, except that gas prices showed relatively bigger fluctuation, were rather stable, Phase I carbon prices demonstrated certain differences, or even reversed trend, from energy prices during this period.

9.2.2.2 Methodology and variables

Our goal is to investigate empirically whether there is an interactive relationship between EU carbon futures prices and energy futures prices. Methods like cointegration theory, vector error correct model and Granger causality test can be very useful in achieving this goal.

We use EG two-step system to identify the conintegrating relationship between the two series. If the cointegrating relationship exists between the two series, it means that, even they are not stable, the regression between them is meaningful and that there is a long-term and balanced interactive relationship between them.

Cointegrating relationship also indicates the causal relation between two variables, but not showing the direction of this causal relation, i.e. which is the cause and which is the effect, or interactive as both cause and effect. Actually, the Granger cause-and-effect relationship can be obtained via VECM (Glasure and Lee, 1997; Granger, 1988).

To be specific, when conintegrating relationship exists between series Y_t and X_t, VECM can be established for the first order difference series and its corresponding *vecm*, as shown in Formulas (9.1) and (9.2):

$$\Delta Y_t = \alpha_1 + \sum_{i=1}^{p} \beta_{1,i} \Delta X_{t-i} + \sum_{i=1}^{p} \gamma_{1,i} \Delta Y_{t-i} + \delta_1 vecm_{1,t-1} + \mu_{1,t} \tag{9.1}$$

$$\Delta X_t = \alpha_2 + \sum_{i=1}^{q} \beta_{2,i} \Delta Y_{t-i} + \sum_{i=1}^{q} \gamma_{2,i} \Delta X_{t-i} + \delta_2 vecm_{2,t-1} + \mu_{2,t} \tag{9.2}$$

Here, p and q are the optimized lagging numbers that can be obtained by setting the minimum AIC value for the model. If coefficient δ before *vecm* is obvious, a long-term Granger causal relationship exists, and it can make up the defects of normal linear Granger causality test. Another advantage of this method is that it can detect the strength of long-term balanced conintegrating relationship in adjusting the short-term fluctuation of dependent variables.

As each first order difference series is steady, regular method of finding Granger causal relationship can be introduced, i.e. to test the short-term causal relationship between carbon prices and energy prices with ordinary linear causality test.

In addition, when there are more than two variables, multiple cointegrating relationships between the variables may exist and EG two-step system is unable to find all the cointegrating vectors. Therefore, when investigating the overall influencing relationship between carbon prices at two phases and all energy prices, we adopt Johansen cointegration test to judge the cointegrating relationship.

The variables and their definitions used in this section are listed in Table 9.5.

Table 9.5 Variable selection and definition

Variable	Definition	Variable	Definition
ln_Dec07	Dec07 carbon contract logarithm price	Δln_Dec07	First order difference of Dec07 carbon contract logarithm price
ln_Dec08	Dec08 carbon contract logarithm price	Δln_Dec08	First order difference of Dec08 carbon contract logarithm price
ln_Elec	Electricity futures contract logarithm price in Germany	Δln_Elec	First order difference of electricity futures contract logarithm price in Germany
ln_Oil	UK Brent oil futures index logarithm price	Δln_Oil	First order difference of UK Brent oil futures index logarithm price
ln_Coal	Coal futures contract logarithm price in Germany	Δln_Coal	First order difference of coal futures contract logarithm price in Germany
ln_Ng	UK gas futures index logarithm price	Δ ln_Ng	First order difference of UK gas futures index logarithm price

9.2.3 Analysis of interactions between carbon prices and energy prices

9.2.3.1 Correlation between carbon prices and energy prices

Before starting the study of cointegrating relationship, we first investigate the correlation between carbon prices at two phases and energy prices during the sampling period. The obtained Pearson correlation coefficients are shown in Table 9.6.

Table 9.6 Pearson correlation coefficients between carbon price and energy price

Variable	ln_Dec07	ln_Dec08
ln_Elec	−0.2314	0.4307
ln_Oil	0.6930	0.6494
ln_Ng	−0.5929	−0.6880
ln_Coal	0.0665	−0.2153

We discovered that carbon prices are not positively related, or show variation in the same direction as intuitively predicted, to all the energy prices. In particular, the carbon prices at two phases are obviously in negative correlation to gas prices. Specifically:

(1) Electricity prices are positively correlated to Phase II carbon prices

This is in consistency with the intuitive logic between electricity prices and carbon prices. In the European electricity market, German electricity takes a predominating position and its electricity is mainly coal generated. Therefore, rise of electricity price will cause increase use of coal and more emissions of CO_2 and finally cause rise of carbon prices. But, electricity prices and Phase I carbon prices are negatively correlated. Such negative correlation appeared because winter is a principal electricity-consuming season and electricity price kept rising steadily after October even though market trading was still weak, while during Phase I market expectation was rather low with little uncertainty and carbon contract prices kept falling.

Of course, such status reflects insufficient interaction between carbon market and electricity market and imperfection of the interaction mechanism.

(2) Oil prices are positively correlated to carbon prices at both phases and correlation degrees are similar

This is in consistency with previous intuitive inference. When oil prices rise people often turn to use coal at lower cost and increase CO_2 emissions, which requires more CO_2 emission credits and further push carbon prices to rise. When oil prices fall, as oil is cleaner than coal with smaller emission coefficient, people often use less coal and decrease emissions of CO_2 and as a result carbon prices fall.

(3) Carbon prices at both phases are negatively correlated to gas prices

The reason for the inconsistency with intuitive inference is that during the period from September to November the weather is convenient with enough precipitation, consequently more electricity is generated by gas, which is much cleaner and with lowest emission, rather than coal. As a result, carbon prices gradually fall back while gas prices rise, and both show reversed trends.

Another reason for the negative correlation between gas prices and carbon prices at Phase II is that gas is mainly used to generate electricity or as heating source. Affected by warm winter in 2006, people used less gas after November and the gas prices kept falling. But, soon Germany and Spain declared strict control of Phase II national allocation plan and EU committee released Phase II national allocation plan, many public sectors and financial institutions actively purchased Phase II CO_2 emissions credits. In addition, coal is cheaper than gas while gas' elasticity of substitution for coal is rather small in other industries. Therefore other industries still use large quantity of coal despite of warm winter, and require more CO_2 emissions. As a result, carbon prices in Phase II rise obviously and demonstrate reversed fluctuation trend against gas prices.

(4) Coal prices are positively correlated to Phase I carbon prices and negatively correlated to Phase II carbon prices

This is very different with the case of other energy resources. The negative correlation is mainly caused by the inconsistency of the trends of coal prices and carbon prices during two periods. One period is from the end of May to the beginning of June, when gas prices fell drastically and electricity industry raised the use of cleaner and less-emission gas; as a result carbon prices fell while coal futures price trend is steady with little external influence. The other period is July and August, when the continental climate of Europe is hot and dry and there was a sudden increase of electricity demand. But hydro electricity is scarce and electricity generating facilities are limited. In order to meet the demand, coal was used in large quantity to generate electricity and consequently coal prices kept all the way rising. Meanwhile, traders of carbon market universally anticipates that the emission quota allocated by government would surely exceed actual emissions and carbon prices would fall, plus the uncertainty in people's prediction on Phase II emission quota; hence carbon prices in both phases show trends of overall falling. It can be observed that, to some degree, such negative correlation explains the obstacle existing in the interactions between carbon market and coal market, and that sometimes markets' expectation on government polity exerts larger influence on carbon prices trend than energy prices do.

Generally speaking, although energy prices and carbon prices demonstrate certain positive influential relationship, which is in consistency with theoretical mechanism, sometimes carbon price trend does not go side by side with energy price trend, due to abnormal weather condition or uncertainty of government polity, or even go in entirely reversed trend. This also verifies the viewpoint of Mansanet-Bataller et al. (2007) that abnormal weather in Germany influenced carbon price. Therefore, we may make the judgment here that energy prices do not become the dominant factor that controls carbon prices yet and that the relationship between energy prices and carbon prices does not entirely follow the theoretically predicted influential and interactive relationship. Further empirical research is necessary to find the detailed mechanism and the degree of influences between them.

9.2.3.2 Interactions between carbon prices and energy prices

In order to make the judgment as whether there is a long-term balanced cointegrating relationship between carbon prices and energy prices, we first adopt ADF method to test the steadiness of each series and results are shown in Table 9.7. It is not difficult to find that at 1% of significance level all original series are first order integrating.

Table 9.7 ADF unit root test results of time series

Original sequence	Statistical ADF value	Value of P	First order difference sequence	Statistical ADF value	Value of P
ln_Dec07	−1.6323	0.7751	Δln_Dec07	−9.5678	0.0000
ln_Dec08	−1.6745	0.7573	Δln_Dec08	−11.8212	0.0000
ln_Elec	−2.2407	0.4630	Δln_Elec	−11.2200	0.0000
ln_Oil	−1.8444	0.6784	Δln_Oil	−9.2431	0.0000
ln_Coal	−3.1561	0.0972	Δln_Coal	−10.0041	0.0000
ln_Ng	−1.8095	0.6955	Δln_Ng	−13.5832	0.0000

1) Interactions between carbon prices and electricity prices

The contract prices of Dec07 and Dec08 in ECX represent the carbon prices in Phase I and Phase II respectively, and German electricity prices represent European electricity price. Results of ADF test in Table 9.7 show that ln_Dec07, ln_Dec08 and ln_Elec are all first order integrating series. By establishing cointegration regression equation and test the residual series steadiness of the equation, we obtained results as shown in Table 9.8.

Table 9.8 Cointegration test between carbon prices and electricity prices

Parameters	ln_Dec07	ln_Dec08
C	23.8155(0.0026)	−6.9379(0.0002)
ln_Elec	−5.2986 (0.0069)	2.441669 (0.0000)
Statistical ADF value in residual steadiness test	−2.5472(0.3053)	−2.3129(0.0205)

Note: In the brackets are corresponding significance possibilities.

According to the residual steadiness test results, at significance level of 5% (or even 10%), there is no conintegrating relationship between ln_Dec07 and ln_Elec, but there is between ln_Dec08 and ln_Elec. And, the influence of electricity on carbon prices in Phase II is positively proportional.

As there is a long-term balanced conintegrating relationship between ln_Dec08 and ln_Elec, we applied VECM to test the Granger causal relationship between them and results are shown in Table 9.9. We found that from the long term, there exists mutual Granger cause-and-effect relationship between Phase II carbon prices and electricity prices.

Table 9.9 Granger causality test between carbon prices and electricity prices

Long-term	Original hypothesis	Error correct coefficient	*P*
	ln_Elec is not the Granger cause of ln_Dec08	−0.0476	0.0677
	ln_Dec08 is not the Granger cause of ln_Elec	−0.1438	0.0035
Short-term	Original hypothesis	Statistical value of F	*P*
	Δln_Elec is not the Granger cause of Δln_Dec07	0.6631	0.5763
	Δln_Dec07 is not the Granger cause of Δln_Elec	0.8495	0.4694
	Δln_Elec is not the Granger cause of Δln_Dec08	3.0783	0.0495
	Δln_Dec08 is not the Granger cause of Δln_Elec	0.3719	0.6902

Actually, the influence of carbon prices on electricity prices depends to greater degree on the quota for power plants. If the quota is excessive, influence might be small; but if the quota is insufficient, the influence must not be overlooked. Take July 2006 for example. It was hot and dry in Europe, which caused increasing demand on electricity, but hydro electricity is scarce and a nuclear power resource was in shortage due to frequent repair caused by high temperature. To satisfy market demand on electricity, coal was used in large quantity to generate electricity and CO_2 emissions increased; as a result the demand of power companies on emission reductions quota increased and finally electricity price rose.

In addition, as the life cycle of power plant is relatively long and costs of technological innovation is higher, more emission credits will be purchased, which pushes carbon prices to rise. In turn, to transfer part of the additional cost of buying quota, power plant will raise electricity prices.

Another reason for the obvious cointegrating relationship between electricity prices and forward carbon prices in Phase II is that both the construction and life cycle of power plant are relatively long.

Meanwhile, according to the coefficient of vector error correct the long-term balanced relationship between ln_Dec08 and ln_Elec has obvious adjustment effect on the short-term fluctuation of both electricity prices and carbon prices, with larger strength of adjustment for the former, about 3 times the latter.

As differential logarithmic series are all stationary series, we adopt standardized linear Granger causality test to study the short-term Granger causal relationship between carbon prices and electricity prices. Results are shown in Table 9.9. Test results show that is the short run, there is no Granger causal relationship between the changes of electricity prices and carbon prices and that there is irreversible causal relationship between electricity price change and Phase II carbon contract prices change. To be specific, electricity price change will cause carbon prices change, but carbon prices change won't cause electricity price change.

Such results indicate: ① the long-term and short-term influences of electricity prices on carbon prices are different, but they share one thing in common that electricity price change obviously causes fluctuation of Phase II carbon prices; and ② from the short term, interactions between electricity prices and carbon prices are not clear, which explains that the short-term electricity price change is not an influential power of controlling carbon prices trend.

2) Interactions between carbon prices and oil prices

We first investigate the interactions between the two carbon contract price (Dec07 and Dec08) and Brent oil futures price. According to the ADF integration test results in Table 9.7, ln_Dec07, ln_Dec08 and ln_Oil series are all first order integrating sequences. Therefore, we first adopt EG two-step system to check if there is long-term balanced cointegrating relationship between ln_Dec07 and ln_Oil or between ln_Dec08 and ln_Oil and then we check the long-term and short-term *Granger causal relationship* between them.

The cointegration test results are shown in Table 9.10. According to the corresponding residual steadiness test results, there isn't cointegrating relationship between ln_Dec07 and ln_Oil at significance level of 2% (or even 10%), but there is between ln_Dec08 and ln_Oil. It is discovered from the cointegrating coefficient that oil price has obvious positively proportional influence on Phase II carbon contract prices.

Table 9.10 Cointegration test between carbon prices and crude oil prices

Parameters	ln_Dec07	ln_Dec08
C	−7.8551(0.0000)	−0.3570(0.2363)
ln_Oil	2.4884(0.0000)	0.7756(0.0000)
Statistical ADF value in residual steadiness test	−0.9121(0.3631)	−2.5417(0.0120)

Note: In the brackets are corresponding significance possibilities.

Based on the cointegrating relationship, VECM is further applied to test the long-term Granger causal relationship between ln_Dec08 and ln_Oil and the results (as shown in Table 9.11) show that there is irreversible long-term Granger causal relationship between Phase II carbon prices and oil prices at significance level of 1%. To be specific, oil price change will Granger-cause carbon prices change, but not vice versa. Yet according to the error correct coefficient, the long-term balanced relationship between Phase II carbon prices and oil prices has certain corrective effect on the short-term fluctuation of carbon prices, but with relatively weak strength. The elastic coefficient is only −0.07.

Table 9.11 Granger causality test between carbon prices and crude oil prices

	Original hypothesis	Error correct coefficient	P
Long-term	ln_Oil is not the Granger cause of ln_Dec08	−0.0731	0.0042
	ln_Dec08 is not the Granger cause of ln_Oil	−0.0290	0.1144
Short-term	Original hypothesis	Statistical value of F	P
	Δln_Oil is not the Granger cause of Δln_Dec07	1.2849	0.2796
	Δln_Dec07 is not the Granger cause of Δln_Oil	1.5163	0.2228
	Δln_Oil is not the Granger cause of Δln_Dec08	0.5893	0.4438
	Δln_Dec08 is not the Granger cause of Δln_Oil	2.2522	0.1354

Because ln_Dec07, ln_Dec08 and ln_Oil are all first order integrating series, and their first order differential series are all stable, showing conformity with the premise of ordinary linear Granger causality test. Therefore, we adopt this method to test the short-term Granger causal relationship between carbon prices and oil prices and results (as in Table 9.11) show that there isn't obvious Granger causal relationship between carbon prices in both phases and oil prices at significance level of 10%.

This explains that in the long term, fluctuation of oil price has already influenced the trend of carbon prices and the long-term balanced relationship between oil prices and carbon prices has corrective effect on the short-term fluctuation of carbon prices. But, in the short term, the fluctuation of oil prices, especially the fluctuates on high level in 2006, didn't spread to carbon market immediately; and the short-term fluctuation of carbon prices was not influenced by oil prices. On the other hand, carbon prices trend is still not a key factor controlling oil prices no matter from the long term or from the short term. There is still much room for extended influence from carbon market and the interactions between carbon prices and oil prices need to be further bridged.

3) Interactions between carbon prices and gas prices

The interactions between European Phase I Dec_07 contract prices and European gas (represented by UK gas) prices and between the Phase II Dec_08 contract prices and gas prices are investigated respectively.

As ln_Dec07, ln_Dec08 and ln_Ng are all first order integrating, further study shows (as in Table 9.12) that there isn't obvious cointegrating relationship between ln_Dec07 and ln_Ng but there long-term balanced cointegrating relationship between ln_Dec08 and ln_Ng.

Table 9.12 Cointegration test between carbon prices and natural gas prices

Parameters	ln_Dec07	ln_Dec08
C	7.6120(0.0000)	4.9731(0.0000)
ln_Ng	−1.3361(0.0000)	−0.5530(0.0000)
ADF value in residual steadiness test	−0.0340(0.6699)	−2.6392(0.0085)

Note: In the brackets are corresponding significance possibilities.

Based on the cointegrating relationship between ln_Dec08 and ln_Ng, we adopt VECM to test the long-term Granger causal relationship between carbon prices and gas prices and results show (as in Table 9.13) that there is irreversible Granger causal relationship between gas prices and Phase II carbon prices. To be specific, in the long term at significance level of 1% (or even 10%), Phase II carbon prices are the Granger cause of gas prices, but not vice versa. Such results verify the lack of interaction between European gas market and carbon market.

Table 9.13 Granger causality test between carbon prices and gas prices

	Original hypothesis	Error correct coefficient	P
Long-term	ln_Ng is not the Granger cause of ln_Dec08	−0.0356	0.1626
	ln_Dec08 is not the Granger cause of ln_Ng	−0.0889	0.0034
Short-term	Original hypothesis	Statistical value of F	P
	Δln_Ng is not the Granger cause of Δln_Dec07	2.8694	0.0600
	Δln_Dec07 is not the Granger cause of	0.0473	0.9538
	Δln_Ng is not the Granger cause of Δln_Dec08	0.2610	0.6102
	Δln_Dec08 is not the Granger cause of Δln_Ng	1.1583	0.2836

By testing the Granger causal relationship of stable Δln_Dec07, Δln_Dec08 and Δln_Ng with ordinary linear Granger causality test we found (as in Table 9.13) that in the short term, gas price change will lead to Phase I carbon prices change and that there isn't obvious interaction between gas prices and carbon prices. This explains that the short-term indirect interaction between gas prices and carbon prices are not clear, or, even though the long-term Phase II carbon prices change will Granger-cause gas price change the short-term interactions are not obvious. In other words, instant fluctuation in carbon prices won't be transferred or reflected in gas price change.

4) Relationship between carbon prices and coal prices

Similar with in the case of other energy sources, we investigate the interactions between two carbon contract prices Dec_07 and Dec_08 and European coal futures prices (represented by coal futures price in the three ports).

ADF integration test shows that ln_Dec07, ln_Dec08 and ln_Coal are all first order integrating series (as in Table 9.7). Further we investigate whether there is cointegrating relationship between ln_Dec07, ln_Dec08 and ln_Coal respectively. Corresponding residual sequential steadiness test results show (as in Table 9.14) that there isn't obvious cointegrating relationship between Phase I carbon prices and coal prices at significance level of 5% (or even 10%) and that there is long-term balanced cointegrating relationship between Phase II carbon prices and coal price.

Table 9.14 Cointegration test between carbon prices and coal prices

Parameters	ln_Dec07	ln_Dec08
C	−1.8306(0.7289)	7.6659(0.0000)
ln_Coal	1.0406(0.4037)	−1.1242(0.0063)
ADF value in residual steadiness test	−1.7039(0.7451)	−2.0569(0.0384)

Note: In the brackets are corresponding significance possibilities.

Based on the above cointegrating relationship, we further test the long-term Granger causal relationship between Phase II carbon prices and coal prices. VECM test results reveal (as in Table 9.15) that in the long term, there is reversible Granger causal relationship between coal prices and Phase II carbon prices at significance level of 5%. According to the VECM coefficient and significance possibility, the long-term balanced relationship between them demonstrates stronger and more obvious corrective effect on short-term coal price change, i.e., about 2.6 times that on the short-term carbon prices change.

Through ordinary Granger causality test on differential stationary sequence Δln_Dec07, Δln_Dec08 and Δln_Coal, there is only irreversible causal relationship from carbon prices change to coal price change from short term.

Table 9.15 Cointegration test between carbon prices and coal prices

	Original hypothesis	Error correct coefficient	P
Long-term	ln_Coal is not the Granger cause of ln_Dec08	−0.0377	0.0374
	ln_Dec08 is not the Granger cause of ln_Coal	−0.0969	0.0012
	Original hypothesis	Statistical value of F	P
Short-term	Δln_Coal is not the Granger cause of Δln_Dec07	0.3371	0.7986
	Δln_Dec07 is not the Granger cause of Δln_Coal	2.8484	0.0394
	Δln_Coal is not the Granger cause of Δln_Dec08	0.8594	0.5264
	Δln_Dec08 is not the Granger cause of Δln_Coal	2.3424	0.0344

This explains that: ① although there isn't obvious cointegrating relationship between Phase I carbon prices and coal prices, in the short term, Phase I carbon prices change will still Granger-cause coal price change and the influence of carbon market on coal market already presents itself to some degree; ② although there is long-term reversible Granger causal relationship between Phase II carbon prices and coal prices, in the short term, coal price change will not obviously cause carbon price change. Therefore, European carbon market has obviously influenced the coal futures market in general. Of course, German coal futures market was recently established; it isn't a mature market, which is expressed not only in its inactive market trading, but also in its small contraction volume. Moreover, the position and actual consumption are distinctly inconsistent. As a result, coal price trend does not completely reflect the supply and demand of coal in Europe and thus unobvious interactions between the coal market and carbon market.

5) Overall influence between carbon prices and energy prices

As there is certain relativity between various energy prices, despite of the investigation of interactions between carbon prices and different energy prices, it is necessary to examine whether there is general cointegrating relationship between carbon prices and energy prices. Since the carbon prices in both phases and various energy prices series are all first order integrating, which is in conformity with the premise of Johansen cointegration test, we introduce the maximum eigenvalue method to judge whether there is long-term balanced interaction.

The conintegrating relationship between ln_Dec07 and ln_Dec08, both as dependent variable, and energy prices respectively are tested and results are shown in Table 9.16.

According to the significance testing, we found that there isn't obvious cointegration between ln_Dec07 and energy prices and that there is one and only one cointegration between ln_Dec08 and energy prices. Standardized cointegration coefficients are shown in Table 9.17, from which we obtain regression Formula (9.3) and vector error correct *vecm* Formula (9.4).

$$\begin{aligned}\mathrm{ln\_Dec08} = {} & 3.8689\ \mathrm{ln\_Elec} + 0.6049\ \mathrm{ln\_Oil} - 0.1973\ \mathrm{ln\_Ng} \\ & - 3.5719\ \mathrm{ln\_Coal} + 0.7123\end{aligned} \tag{9.3}$$

$$\begin{aligned}vecm = {} & \mathrm{ln\_Dec08} - 3.8689\ \mathrm{ln\_Elec} - 0.6049\ \mathrm{ln\_Oil} + 0.1973\ \mathrm{ln\_Ng} \\ & + 3.5719\ \mathrm{ln\_Coal} - 0.7123\end{aligned} \tag{9.4}$$

Table 9.16 Johansen cointegration test

Dependent variable: ln_Dec07				
Eigenvalue	Likelihood ratio	5%Critical value	1%Critical value	Cointegration number
0.101843	45.89087	68.52	76.07	None
0.085159	30.42378	47.21	54.46	At most 1
0.075473	17.60705	29.68	35.65	At most 2
0.042829	6.306926	15.41	20.04	At most 3
2.51E-05	0.003619	3.76	6.65	At most 4
Dependent variable: ln_Dec08				
Eigenvalue	Likelihood ratio	5%Critical value	1%Critical value	Cointegration number
0.229979	68.80740	68.52	76.07	None*
0.087147	31.17474	47.21	54.46	At most 1
0.069741	18.04480	29.68	35.65	At most 2
0.042156	7.634743	15.41	20.04	At most 3
0.009900	1.432657	3.76	6.65	At most 4

Note: "∗" indicates that the original hypothesis is refused at significance level of 5%.

Table 9.17 Standardized cointegration coefficients

Index	ln_Dec08	ln_Elec	ln_Oil	ln_Ng	ln_Coal	*C*
Coefficient	1.0000	−3.8689	−0.6049	0.1973	3.5719	−0.7123
Standard deviation		0.4884	0.1606	0.0963	0.4169	
Statistical T		−7.8991	−3.6771	1.9982	9.0221	

$$\begin{aligned}\Delta\mathrm{ln\_Dec08}_t = {} & -0.0004\ \Delta\mathrm{ln\_Dec08}_{t-1} + 0.3150\ \Delta\mathrm{ln\_Elec}_{t-1} \\ & + 0.0204\ \Delta\mathrm{ln\_Oil}_{t-1} - 0.0052\ \Delta\mathrm{ln\_Ng}_{t-1} \\ & - 0.1201\ \Delta\mathrm{ln\_Coal}_{t-1} - 0.0012 - 0.0727 vecm_{t-1}\end{aligned} \tag{9.5}$$

It is observed from Formula (9.3) that as previously argued the influence of electricity prices and oil prices on Phase II carbon prices is positive while the influence of gas prices and coal prices is negative. According to the absolute value of regression coefficients, it is also proved that electricity price exerts the largest influence and gas prices have the smallest. Because among the various energy resources, electricity possess highest emission coefficient, following it are coal and oil, and gas is the cleanest energy, showing lowest emission coefficient.

In addition, the square value of R in cointegration regression equation is 0.83, which indicates that the general change of various fossil fuel prices can explain 83% of the information of Phase II carbon price change. The important influence of energy price change on carbon prices trend is verified again and the study of interactions between energy prices and carbon prices is of great significance.

Based on the above cointegrating relationship, we establish a Vector Error Correct Model with $\Delta\text{ln\_Dec08t}$ as dependent variable, and the regression equation is expressed in Formula (9-5). From the regression coefficients of respective variables we found that the long-term balanced relationship between Phase II carbon prices and all energy prices has obvious negative corrective effects on its short-term fluctuations, but with weak long-term elasticity coefficient of about -0.07. In addition, according to the short-term elasticity coefficient, the short-term fluctuation of previous electricity price and oil price has a positive pulling effect on the Phase II carbon prices, while the short-term fluctuation of previous carbon prices, gas prices and coal prices has a negative holding effect on the Phase II carbon prices. According to the absolute degree of effect, electricity price has the largest short-term effect and previous carbon prices have the smallest short-term effect.

In summary, starting from futures prices, we found through research that the long-term and/or short-term interactions between energy prices and carbon prices are not fully demonstrated① , plus the influence of abnormal weather or governmental emission reduction polity on carbon market traders' anticipation, therefore there might appear negative correlation in conflict with intuitive logical inference. It explains that futures trade in carbon market is still not brought into full play of its market function to discover price, that energy prices are not the key factor influencing carbon price trend, and that establishment related to market system and trading environment need to be strengthened.

(1) According to the correlation between energy prices and carbon prices, only oil price positively correlates with carbon prices in both phases, gas

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① It agrees with the argument of carbon Finance (2007).

price negatively correlates with carbon prices in both phases, and the correlations between electricity price and Phase I carbon prices/coal price/Phase II carbon prices are all negative respectively. Such correlation test results show that there is obstacles of interactions between carbon market and energy market and that supply and demand in the market are not fully reflected in prices.

(2) According to the long-term balanced cointegration, no obvious cointegration exists between various energy prices and Phase I carbon prices, but there is long-term balanced cointegration with Phase II carbon prices. Major reason for such findings is that during the sampled period the European climate policy in Phase I is already very clear with relatively flexible requirements for each party in carbon market and mild punishment. Therefore, traders carry less burden and show relatively stable anticipation of carbon prices trend, which makes the influence of energy prices on carbon prices not so obvious. But, owing to the high uncertainty in climate policy in Phase II especially in national allocation plan, all market participants have very different anticipation of Phase II carbon price trend, which leads to an active carbon market and makes the long-term interactions between carbon prices and energy prices clearer.

(3) According to Granger causality test results, there is obvious reversible or irreversible Granger causal relationship between various energy prices and Phase II carbon price in the long term, provided that the cointegration conditions are met. Among them, electricity prices and coal prices both have reversible causal relationship with Phase II carbon prices, oil prices will Granger-cause Phase II carbon prices change, while gas price is somewhat influenced by carbon prices, instead of causing Phase II carbon prices change.

In the short term in general, interactions between energy prices and carbon prices are not so obvious and cases are few then there is obvious Granger causal relationship. Besides, the degree and direction of causal relationship between energy prices and carbon prices are greatly varied. Generally speaking, electricity price change causes Phase II carbon prices change, gas price change causes Phase I carbon prices change, carbon prices change in both phases causes coal price change and other causal relationships are not obvious. Such situation is mainly resulted from immaturity of relevant markets and the sensitivity to influences of emission reductions policy.

(4) According to the overall influence of all fossil fuel prices on carbon prices, there isn't obvious cointegration relationship between Phase I carbon prices and energy prices while there is only one cointegration between Phase II

carbon prices and energy prices. In addition, results from vector error correct model show that the long-term balanced relationship between Phase II carbon prices and all energy prices has obvious corrective effect on the short-term fluctuation of carbon prices, but the long-term elasticity coefficient is about -0.07, indicating moderate strength.

Through empirical research we found that although EU carbon market has already attracted, and will continue to, wide attention from the public it is not mature with imperfection; and that very often policy influence replaces energy prices as key factor leading carbon prices to continuous rise or fall. In the long term or short term, there aren't well-established interactions between carbon market and energy market.

Such phenomenon is primarily due to the lack in flexibility of market trade and information disclosure as well as redundancy of government intervention, in addition to influences of small number of traders and inactive market trading. Another important reason for unobvious interactions between carbon market and energy market is that mechanism of energy market is to be standardized yet. For example, the coal futures trade in Germany started on May 2, 2006 and related policy and regulations as well as trading operations are still to be improved; therefore, the coal price trend might not be able fully reflect the supply and demand of coal in the whole Europe.

Just the same as oil market in Europe, price fluctuation of carbon market is primarily event driven. Based on a comprehensive view of EU carbon market development, we believe that the future (especially the period from 2008 to 2012) price trend of EU carbon market will be greatly influenced by several events: Phase II, appearing during 2006—2007; CDM projects outcomes, appearing during 2006—2008; presidential election of the U S in 2008; the post-Kyoto framework in response to climate change, appearing during 2008—2009; policy of carbon buying government, mainly during 2007—2013; strategy of Russia, Ukraine and China in response to climate change, especially during 2010—1013, etc.

In summary, we argue that in the long term the European electricity sector is and will continue to be the key factor influencing the price trend of carbon futures in Europe; and that from the short term factors, in addition to energy prices, like governmental intervention and weather, cannot be overlooked and sometimes the latter shows more evident influence. In the future, despite of similarities as current status to large degree, carbon market will be more complicated, and, as a emerging new market, it has a long way to go before the transaction system is improved, non-market interference is furthest decreased and fluctuation of carbon prices can really reflect carbon supply and demand in the market.

9.3 Liquidity analysis of EU carbon market

Market liquidity is one of the important attribute of market transaction, an important indicator of market efficiency and functional performance, an indispensible part of the micro-structure of a market, and also one of the essential factors influencing the behavior of market price. The better market liquidity is, the higher the resource-allocating efficiency will be; therefore, in the futures market, liquidity is one of the goals of transaction system arrangement and contract design.

So far there hasn't been a commonly agreed definition to market liquidity. In the securities market, market liquidity is generally referred to as the security's ability to be easily converted, i.e. traders are able to complete large-volume transactions with lower cost yet without causing large fluctuation of market price. Similarly, in the futures market, we may regard market liquidity as "futures traders can complete large-volume futures contract quickly without causing obvious fluctuation of contract price". The essential part is the volume and value of the contracts under the circumstance of no price change or small fluctuation; if the volume or value is large enough, we say the futures market possesses nice liquidity.

Researches on market liquidity have already attracted wide attention from scholars and the industry, especially in the stock market where detailed discussion in many publication are conducted about the characteristics of stock market liquidity, measuring of liquidity, the relationship between liquidity and stock returns, major factors influencing liquidity, etc. (Aitken and Comerton, 2003; Bacidore et al., 2005; Brockman and Chung, 2006; Comerton-Forde et al., 2005; Ginglinger and Hamon, 2007; Marshall and Young, 2003; Wan Shuping, 2006). These studies are very important in our understanding of liquidity. Generally speaking, however, we found that most of the studies on market liquidity concentrate on the stock market with few attention to the futures market (Liu Xiaoxue, 2006; Han Xiaolong and Cao Qi, 2006), and as for the carbon futures market, there has been not any publication of research about market liquidity.

At present, EU ETS is the largest carbon market, whose development and status basically reflect the trend and status of world carbon market. Therefore, an in-depth analysis of EU carbon market liquidity and the influencing factors is significantly meaningful in understanding the global carbon market mechanism and system from the microscopic perspective.

9.3.1 Models for market liquidity study

In studies of market liquidity, in addition to the influencing factors, how to measure market liquidity is also an important part. Many publications discussed the measuring of market liquidity from different perspectives, which can be summarized in four aspects:

① Magnitude: reflecting the transaction cost of market participants, with major indicators including bid-asked spread, variance ratio, etc.

② Depth: reflecting the possible transaction volume under the circumstance of no price change, with major indicators including contraction depth, quotation depth, transaction volume open interest, etc.

③ Elasticity: reflecting the speed at which the price fluctuation caused by transaction from asymmetric information driver regresses equilibrium price; the larger elasticity is the better liquidity will be and the better market efficiency will be.

④ Timeliness: reflecting the time for waiting before a transaction got handled and the frequency of contraction.

In practical researches, generally one or more aspects will be considered. Given the data status of EU ETS, this section adopts Martin liquidity ratio with quantity-price incorporation characteristic to measure the liquidity of EU carbon market and meanwhile be able to measure the magnitude and depth of the market.

For a specific carbon contract, if relatively small transaction volume brings about large scale price fluctuations, the liquidity of this contract is lower; in contrast, if large volume only causes small fluctuations, the liquidity of the contract is higher. A carbon market with higher liquidity won't show large-scale price fluctuation due to small-volume transaction. The measurement index of liquidity ratio is the embodiment of the concept of incorporating volume and price, which reflects the interactions between carbon transactions and price changes. The frequently used liquidity ratios include Amivest liquidity ratio, Hui-Heubel liquidity ratios and Martin liquidity ratios, etc. Each of the liquidity ratios possesses its own strong points. In view of the availability of sample data, we adopt Martin liquidity ratio here.

The Martin liquidity ratio index refers to the price change caused by unit transaction volume, which can provide comprehensive measurement both in magnitude and in depth. As international carbon market emerged recently, in some cases there isn't any transaction volume in many trading days concerning some contracts, especially when the initial stage of a newly established market. For the convenience of measurement and explanation, we switch the numerator and denominator of traditional Martin liquidity ratio index to obtain a modified Martin liquidity ratio index as measurement of carbon market liquidity. For a specific carbon futures contract, the Martin liquidity ratio index can be defined as:

$$L = \frac{V_t}{(P_t - P_{t-1})^2} \tag{9.6}$$

Here, P_t is the settlement price of the contract on day t; $P_{t-1}$is the settlement price of the contract on day $t-1$; V_t is the contraction volume on day t, which, as its numerical value is very large, is modified as its natural logarithm. The larger index L is the better the contract liquidity in the market appears, and vice versa. Please note that when denominator is 0, i.e. when price remains unchanged, we set denominator as minimum price change unit, i.e. 0.01 Euro.

The weekday effect of liquidity is a common phenomenon in financial market and futures market. To test the day-of-the-week effect and compare the difference of various market liquidities, we adopt a nonparametric test method independent of specific distribution, i.e. Kruskal-Wallis test (K-W Test for short). This test is widely used for equivalent test of several independent samples. Its null hypothesis is that k series follow distributions with the same mean; and its alternative hypothesis is that k series do not have the same mean; thus the statistic KW complies with the χ^2 distribution with a degree of freedom as $k - 1$.

$$\mathrm{KW} = \frac{12}{N\,(N+1)} \sum_{j=1}^{k} \frac{S_j^2}{m_j} - 3(N+1) \tag{9.7}$$

Here, N is the sample size; k is number of series to be tested; S_j^2 is the sample variance of series j; m_j is the rank value of series j.

Carbon market liquidity is influenced by many factors. This section will introduce a multivariate statistic regressive method to investigate the influence of micro structural factors on liquidity. After analysis of characteristics and influencing factors of carbon market liquidity, we shall adopt ordinary linear Ganger causality test to find the causal relationship between EU carbon market liquidity ratio and Brent oil futures liquidity ratio, so as to provide a reference for better understanding of the interactions between carbon market and energy market.

9.3.2 Data sources and definitions

As analyzed above, transactions in ECX carbon market can largely reflect the market status of EU ETS. Based on the two phases (2005—2007 as Phase

I and 2008—2012 as Phase II) of EU ETS emission credits, we select several key carbon futures contract of ECX (expires in December of 2005, 2006, 2007, 2008 and 2009 respectively) and pick the day prices at Euro/ton of CO_2 from opening of carbon market from 22 April 2005 to the end of September 2007 as object for investigation. The price trend is shown in Figure 9.12 (Based on the data from ECX (2006), the results are calculated and shown in Figure 9.12). We found that there is large difference between carbon contract prices in two phases, especially after 2006, while carbon prices within the phase is rather consistent.

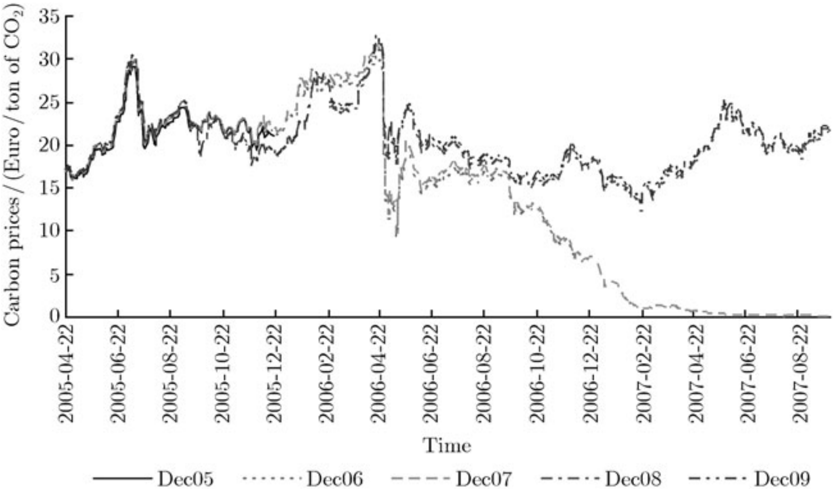

Figure 9.12 Trends of carbon prices in ECX (April 22, 2005—September 28, 2007)

Data Source: ECX (2006)

9.3.3 Empirical results and discussions

9.3.3.1 Statistical characteristics of carbon market liquidity

According to the Martin liquidity ratio equation above, we obtain daily liquidity of various futures contracts and then compute the average monthly and yearly liquidity ratios, which are shown in Figure 9.13 and Table 9.18 (Based on the data from ECX (2006), the results are calculated and shown in Figure 9.13 and Table 9.18).

With regard to the monthly carbon market liquidity, it is firstly observed from Figure 9.7 that the general trend of contract liquidity ratios in different phases is not so clear concerning different phases and contract liquidity within one phase does not show much consistency either, with many reciprocal chiasms. Secondly, the liquidity ratio of contract Dec06 is high in most trading days, following it is contract Dec08 which became major traded contract type, especially after 2006; contract Dec07 and Dec08 are relatively close; contract Dec09 shows lowest liquidity, leaving wide gap from other contracts but also demonstrating a rising pose, especially after 2006. This indicates that since the carbon futures market emerged contract Dec06 and Dec08 are most popular with active transactions and arouse sufficient confidence from participants, and that the market for contract Dec09 is far from mature. An important reason for it is that Phase I carbon market transactions happen in relatively stable and mature environment and encounter less uncertainty while carbon market development in Phase II are faced with many uncertainties, in addition to insufficient market expectation and confidence, which together lead to a weak market. Thirdly, we can see the rising trend in the overall EU carbon market liquidity. This is sufficient to approve that carbon market as a new futures market is becoming active and that its role in reaching the emission reduction goals of *"Kyoto Protocol"* already attracted wide attention from all walks of international community and its impacts are extending.

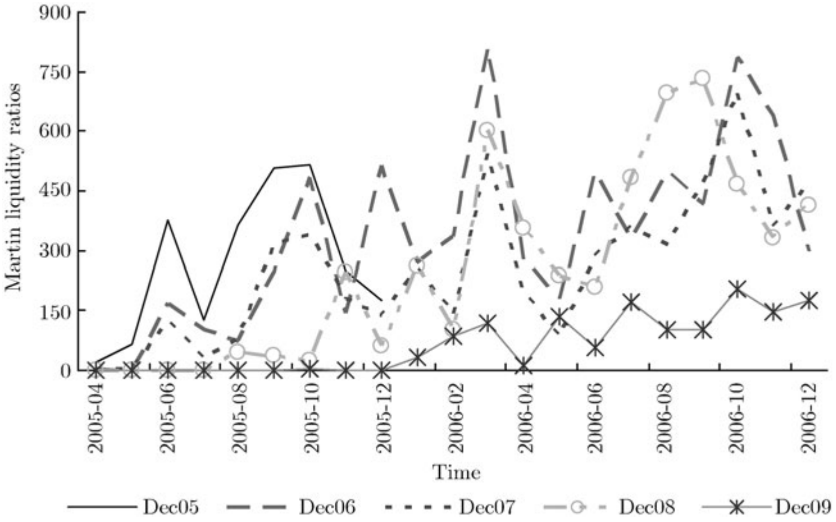

Figure 9.13 Monthly Martin liquidity ratios of different carbon contracts

[Data Source: ECX (2006)]

Table 9.18 gives the statistical results of yearly carbon market liquidities. We found that compared with 2005, liquidity ratios for all kinds of contracts in 2006 and 2007 are greatly increased, among which contract Dec08 shows the largest increase of 700% in 2006 (Contract Dec09 shows a large increase in 2006 too due to small transaction volume in 2005, but the absolute value of increase is still limited.); in 2007 contract Dec07 shows the largest increase of over 2700%. On the other hand, in 2005, contract Dec05 has the largest liquidity ratio and the farther the expiration date is the smaller liquidity ratio will be; in 2006, the trend in 2005 continues generally and the liquidity ratio of contract Dec07 is slightly smaller than that of contract Dec08. This explains that by the end of 2006 the primary contract in carbon market is still Dec08 and previous contracts while transactions of contracts after Dec08 lacks vitality and needs further cultivation.

Table 9.18 Daily Martin liquidity ratios of different carbon contracts by year

	Dec05		Dec06		Dec07		Dec08		Dec09	
Yean	Sample size	Mean	Sample size	Mean	Sample size	Mean	Sample size	Mean	Sample size	Mean
2005	167	297.40	175	210.25	175	148.94	175	51.37	175	0.41
2006	—	—	248	455.72	256	350.49	256	410.68	256	112.73
2007	—	—	—	—	193	9961.77	193	1933.67	193	931.29

Note: The sampling period in 2007 is from January to September.

Data Source: ECX (2006).

9.3.3.2 Expiration effects test of carbon market liquidity

Generally speaking, futures contract liquidity abides by the law of cyclical variation as it approaches the expiration month, which is called Samuelson hypothesis for futures contract. We investigated the expiration effect of contract Dec05 and Dec06 expiring in December 2005 and 2006 respectively①, and results are shown in Figure 9.14. We found that from the coming out to expiring of the contracts, the liquidities generally experienced three stages of low-high-low. During the initial period of listing, liquidities of two contracts are low and contract Dec05 transactions soon became active with rising liquidity, about 4 to 5 months later reaching the peak; for contract Dec06, its liquidity rose relatively slower, showing a trading peak in the beginning of 2006 and soon dived due to the incident of certified credit data, but after settlement of the incident its liquidity soared. 1 to 2 months before the delivery month, carbon futures contract liquidity appeared weak, especially contract Dec05, and showed obvious sinking trend. This is closely related to the strict trading system practiced before delivery month. Comparatively speaking, transactions of contract Dec06 are always active; although before delivery its liquidity slid down a bit it maintained a certain level of absolute value in

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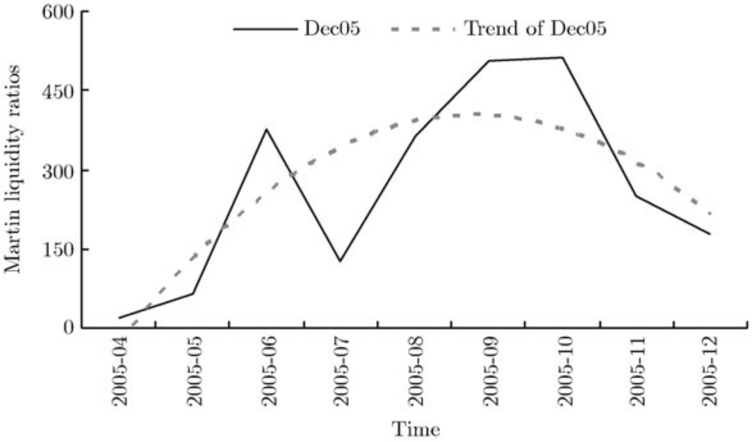
① By the end of 2006, only the two types of contracts are due among all the futures contracts investigated in this section.

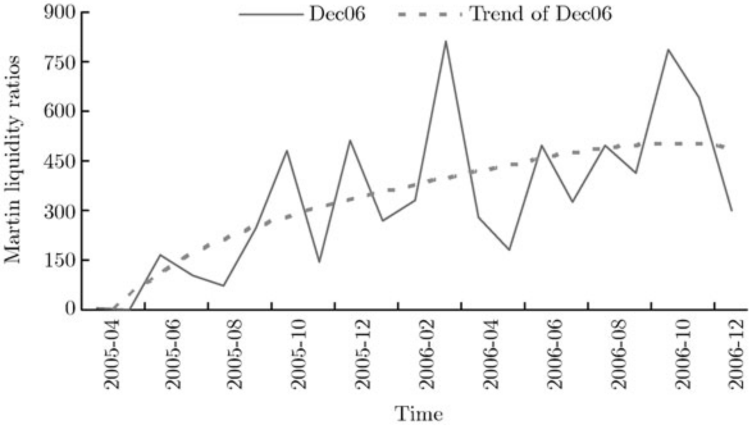
its liquidity. In general, European carbon futures contracts also demonstrate obvious expiration effects, just like other futures commodity.

9.3.3.3 Day-of-the-week effect test of carbon market liquidity

Day-of-the-week effect refers to the different characteristics expressed in futures contract liquidity on different days of the week; if the contract liquidity on certain weekday of a week is obviously higher than (or lower than) that of the other weekdays, we regard this contract possesses "weekday effect". In financial market, most common among the day-of-the-week effect is Monday effect and Friday effect, which combined together are called weekend effect. Causes of weekend effect might be measurement deviation or the fact



(a) Liquidity ratio and its trend for contract Dec05



(b) Liquidity ratio and its trend for contract Dec06

Figure 9.14 Liquidity expiration effects of Dec05 and Dec06 contracts that many unfavorable influencing factors are released during weekend; hence negative return appears every Monday. Of course, a possible reason might be that most investors have made investment decision for the next week during the weekend.

We first calculated the average liquidity ratios for various carbon futures contract from Monday to Friday (as shown in Table 9.19). Results show that liquidity ratios of Dec05 and Dec07 contracts are relatively higher on Monday and Tuesday, liquidity ratios of Dec06, Dec08 and Dec09 contracts are higher on Thursday and Friday than on other date, and that no contract shows higher liquidity ratio in the middle of the week. Therefore, the whole European carbon futures market does not have consistent day-of-the-week effect and some contracts may show similar day-of-the-week effect. Further research is needed to test whether such inference is correct.

As liquidity ratios series show obvious non-normal characteristics, we cannot adopt variance analysis based on normal distribution to test day-of-the-week effect. This section, however, introduces Kruskal-Wallis nonparametric one-way variance analysis method to test the day-of-the-week effect for various carbon contract liquidities and the results are shown in Table 9.20. We found that, at significance level of 5% or even 10%, all carbon contracts should accept the original hypothesis, i.e. there is no obvious difference between liquidity ratios on different days of the week. This explains that differences of the daily liquidity ratios during the week are random and that EU carbon market liquidity does not show day-of-the-week effect. The most possible reason for such results is the immaturity of carbon market, which is expressed not only in inactive market transaction and small contraction volume, but also in the inconsistency between contraction volume and actual consumption volume. As for the big discrepancy in mean for some contracts (such as contract Dec09), it is caused by extrema of liquidity ratios due to absence of price change between trading days. This is a special case and should not be considered as typical of the whole transaction of this contract.

Table 9.19 Daily Martin liquidity ratios of different carbon contracts by weekday

Time	Dec05		Dec06		Dec07		Dec08		Dec09	
	Sample size	Mean	Sample size	Mean	Sample size	Mean	Sample size	Mean	Sample size	Mean
Mon.	32	478.44	81	366.24	119	2913.32	119	817.28	119	58.28
Tues.	34	311.68	86	286.93	127	3721.59	127	577.35	127	259.90
Wed.	34	342.44	86	337.62	127	3341.64	127	896.41	127	103.27
Thur.	34	245.51	86	440.87	127	3541.84	127	419.46	127	187.82
Fri.	33	114.23	84	339.53	124	2781.34	124	1206.67	124	1062.57

Table 9.20 Kruskal-Wallis Test for the day-of-the-week effect of liquidity

Carbon contract	Statistic KW	Degree of freedom	Significance probability
Dec05	2.575	4	0.631
Dec06	3.674	4	0.452
Dec07	4.548	4	0.337
Dec08	7.151	4	0.128
Dec09	6.962	4	0.138

Carbon market liquidity is influenced by many factors, including macroscopic factors like governmental macroeconomic policy and unexpected accident, as well as microscopic factors like carbon market maturity and market micro structure (in terms of market volume, position, price fluctuation rate, transaction turnover rate, etc.). Concerns about carbon market liquidity are always related to changes in these factors and efforts of increasing the liquidity should start from these aspects.

To sum up the discussions and analysis of the results of empirical research above, we come to some constructive suggestions about EU carbon market liquidity.

(1) For the general trend of carbon market liquidity, it is different from carbon prices trend; the liquidity ratios of carbon contract in different phases do not demonstrate obvious difference and liquidities of contracts in the same phase do not show consistency either. In particular, Dec06 and Dec08 contracts show higher liquidity ratios on most days, becoming the active contract type in the market, and contract Dec09 show lowest liquidity ratio. Moreover, we found a rising trend in the overall EU carbon market liquidity ratios. Although carbon market is an emerging futures market, transactions are becoming active and its influence is spreading.

(2) With regard to the expiration effect of carbon market, we found that carbon futures contract liquidities generally experienced three stages from their initial opening to expiration, i.e. low liquidity-high liquidity-low liquidity, showing obvious expiration effect. Carbon market transactions have the characteristics in other financial and futures commodity markets.

(3) With regard to day-of-the-week effect, we found that EU carbon market liquidity does not show notable day-of-the-week effect, i.e. no notable difference between the liquidity ratios on different days of the week exists and the existing liquidity ratios differences are limited and random.

Carbon market is a rising market with high potential. With the extending of its influence and the strengthening of the interactions between carbon market and energy market, carbon market shall attract focused attention due to its achievements in emission reductions and will play an important role in leading and promoting the development of energy market.

Generally speaking, there is long way to go for carbon market and much more efforts are needed in studies of carbon market. With regard to carbon market liquidity, we first need to design a better measuring method and instrument to precisely measure the liquidity, so as to provide reference for market trading and investors; we then need to pay attention to the major factors influencing carbon market liquidity, but owing to availability of data we haven't done any further discussion in this aspect yet. Finally, more attention are necessary in the interactions between carbon market and energy market, especially coal market and gas market; researches about the increasingly close relationship between them will forecast market behavior effectively and guide participants to avoid risks.

9.4 Socio-economic impacts analysis of CDM projects in China

Global warming has become the most serious challenge faced by human in the 21st century; to reduce the anthropogenic emission of greenhouse gases so as to alleviate global climate change has become a common responsibility and duty of all humanity. On February 16, 2005, *"Kyoto Protocol"* formally took into effect, which commenced the actual campaign of mankind to fight against global warming. Clean Development Mechanism (CDM) is one of the three flexible mechanisms in *"Kyoto Protocol"*. Through cooperation of CDM projects, developed countries can obtain the entire or partial of the Certified Emissions Reductions (CERs) produced in these projects and use the CERs to fulfill their quantized emission reduction duties under *"Kyoto Protocol"*; meanwhile, developing countries can gain additional funds and/or advanced environment friendly technologies so as to promote the sustainable development of the nations. Therefore, cooperation of CDM projects can globally reduce the total economic cost of achieving greenhouse gases emission reduction goals. In view of the high cost of GHG emission reduction in developed countries, CDM projects have become an important emission reduction instrument for developed countries to fulfill their duties of emission reductions. Many government agencies, funds and enterprises in developed countries tried to find a way of cooperating with developing countries in CDM projects, hoping to fulfill the quantized emission reduction goal set in *"Kyoto Protocol"* with lower cost. These efforts were actively responded by developing countries, who expected attract foreign investment and advanced technology via cooperation of CDM projects and at the same time provide informational support for future emission reductions strategy from the technological and economic perspectives. As of January 14, 2008, there were more than 40 countries that took part in CDM project cooperation in Executive Board (EB) and successfully registered 896 CDM projects. The emission reductions of these projects reached 188.48 million tons of CO_2/year. Currently, major CDM project host countries are China, India, Brazil and Mexico, among which China acts as the leading CERs producer (91.34 million tons of CO_2/year) and hosts 150 CDM projects.

At present, analysis of the influence of greenhouse gas emission reduction policy with Computable General Equilibrium (CGE) models, like MIT-EPPA, WorldScan, MS-MRT, GTEM, GEM-E3, has attracted attention from many scholars and research institutions abroad. Based on these models, Sp-inger (2003a) summarized a large body of relevant studies; additionally, a special issue about the impacts of *"Kyoto Protocol"* emission reduction mechanism was published by *Energy Journal* in 1999.

Manne and Richels (1999) used MERGE model to analyze the different situations with 15% of the global CDM project potential traded. Results showed that under the CDM scenario marginal abatement cost in 2010 will be decreased to USD 100/ton of carbon, under the scenario of global trading marginal abatement cost is USD 70/ton of carbon, and under the scenario of *"Kyoto Protocol"* emission reduction goals the US GDP will suffer 0.1% of loss without the flexible emission reductions mechanism but the loss will be half with the CDM mechanism. Bernstein et al. (1999) assumed by applying MS-MRT model that non-Annex I countries have 15% of the emission quota and results show that under CDM and global trading scenario marginal abatement cost is largely decreased in comparison with both the scenarios of no trading and trading between Annex I countries. Ellerman et al. (1998) hypothesized that all of the potential of CDM projects will be released with consideration of the additional cost of CDM projects. They used EPPA model and found that marginal abatement cost under CDM scenario is obviously lower than in the scenario of no trading and that the net profit for non-Annex I countries increases with the increase of CDM additional cost. Pan (2005), utilizing GEM-3 model, divided trading into free trade sector (energy and energy intensive sectors) and domestic trade sector with the hypothesis of regarding JI or CDM similar as ET but only free trade sector eligible for JI or CDM project cooperation. Bollen et al. (1999) modeled the CDM project in the form of investment with WORLD SCAN and hypothesized that investment does not influence all production capacity. The study covers only one type of CDM project and results show that greenhouse gases emission reductions under CDM will lead to global increase of greenhouse gas emissions if no greenhouse emissions quota is set for non-Annex I countries. Böhringer et al. (2003) utilized German CGE model and Indian MARKAL model to analyze the Indian power sector under CDM. Bréchet and Lussis (2006) used global equilibrium model and national equilibrium model to analyze the contribution of supply of and demand for CDM as an instrument to the climate policy in Belgium. Results show that CDM projects will reduce 21% of the CO_2 emission in Belgium in 2010 and decrease abatement cost.

All the above studies are based on the hypothesis that CDM is a trading mechanism with binding and that trading price is decided from market. Actually CDM is different from emission trading system in that CDM is developed on the basis of projects. Generally speaking, impacts of single project on macro economy are weak and unable to provide any reference for policy-making. In addition, CDM projects are different from carbon tax system and/or CO_2 emission trading system; the latter can be directly related to macro economy via commodity prices especially energy prices, while the former hasn't direct relationship with commodity prices in any way (Timilsina and Lefevre, 2000). Moreover, CDM projects are mostly bilateral projects, and the prices for CERs are normally decided in negotiation. Compared with CO_2 emission trading system, therefore, it is a twisted market; its prices do not reflect the supply and demand in the market either. The hypothesis of regarding CDM as ETS in above models can hardly reflect the impacts of CDM both developed and developing countries objectively. The study of Timilsina and Shrestha (2006) adopted a different approach. Starting with the supply and demand of energy, they modeled CDM projects with substitution of coal electricity for hydro electricity and analyzed the impacts of CDM projects on the macro economy of Thailand. Their analysis covers the impacts of the CERs, produced in small hydro electricity projects and with different prices, on the macro economy and sector development of Thailand. Results show that substitution of fossil energy electricity generation for small hydro power stations decreases GDP.

Most of the studies above used global or bi-national CGE model to analyze the global impacts of the three mechanisms in *"Kyoto Protocol"*, instead of the impacts of CDM on developing countries. However, due to the differences in manpower wages, industrial structure, and technology in each country as well as the differences in the number of CDM project and types in various countries, impacts on different countries are different. Therefore, impact analysis specific to developing countries are necessary.

Whether CDM is able to play an active role in achieving emission reduction goals of *"Kyoto Protocol"* and whether post-Kyoto protocol will be emission reductions mechanism largely depend on the current impacts of CDM projects on economy, society and environment both sides. And, how to objectively evaluate the economic, social and environmental impacts of CDM projects in China has become a hot and difficult subject for researchers.

China, as a key host country of CDM projects, has successfully registered a series of CDM projects related to renewable energy electricity and HFC, and the problem to be solved immediately is how to evaluate the impacts of these projects on the socio-economic development and environmental improvement in a scientific and objective manner? In the future work of CDM project development and selection, how to evaluate the impacts on sustainable development? As the largest developing country of the world, China owns a large potential CDM market, and how could China scientifically utilize international capitals and technologies to promote sustainable development via CDM projects? These problems have become important concerns of decision makers.

CGE (Computable General Equilibrium) models are normally applied in policy simulation to analyze the impacts of environmental policy/measure, revenue and/or foreign trade policies on national or regional (both intra-national and inter-national) GDP, resident welfare, industrial structure, labor income distribution, etc.; CGE models can be very effective in addressing the above issues. Therefore, CGE models addressing the above issues. Therefore, CGE models are theoretically very important and have real CDM projects in China. impacts of CDM projects in China. projects in China.

Some studies have it that China will be the largest the world (World Bank, 2004; Zhang, 2006); actually 2006); actually China already successfully registered a series of CDM projects, and the total CERs produced in China rank first in the world. But, how would these CDM projects and different CERs prices influence the society, economy and environment of China? How to evaluate the impacts of CDM projects on China's society and economy? So far there has been no related study.

Therefore, there is urgent need to conduct issues above with the idea of management science; it will not only of management science; it will not only help China further cooperate with other CDM projects and correctly understand the impacts of the projects, but also provide a theoretical model for the quantitative investigation of CDM projects, provide theoretical methods for objective evaluation of the projects' effects on promoting sustainable development, and provide scientific reference for decision makers in making some scientific and rational CDM project development plans.

9.4.1 CEEPA model with CERs prices

Based on the CGE models introduced in section 7.3, this chapter is an analysis of the impacts on macro economy exerted by the development of CDM projects related to biomass electricity generating, hydro electricity and wind electricity from the angle of energy supply. A hypothesis of this chapter is that CDM projects of biomass electricity generating, hydro electricity and wind electricity replace thermal electricity by 1% respectively.

According to Marrakesh Agreement, 2% of the total CERs are for international adaptation costs; in addition, there are other transaction costs for CDM projects like registration, verification and certification fees. And we suppose that 25% of total CERs is for transaction cost and adaptation fund, while the remaining 75% is surplus.

CDM project surplus:

$$\mathrm{CDMREV} = \mathrm{CERp} \times \left(\mathrm{TPOL}^{0}_{\mathrm{CO_2}} - \mathrm{TPOL}_{\mathrm{CO_2}}\right)$$

Here, CERp is the price of certified emission reductions; $\mathrm{TPOL}^{0}_{\mathrm{CO_2}}$ and $\mathrm{TPOL}_{\mathrm{CO2}}$ are CO_2 emissions under BAU (Business-As-Usual) scenario and policy simulation scenario respectively.

CERs price is an important variable. As currently there is no price on a uniform global basis, the general CERs price of the CDM projects registered by EB is USD 3—5/ton of CO_2. In order to analyze the socio-economic impacts of CERs prices, we suppose CERs price to be USD 3—50/ton of CO_2, which reflects the fact that CERs price of CDM project is decided by both parties of the transaction.

The 75% of surplus from increase of CDM projects will increase government revenue. To keep government revenue constant, the increased revenue is returned to residents in this report.

9.4.2 Macro impacts of renewable electricity CDM project

Based on the CEEPA model, we come to some conclusions as follows.

9.4.2.1 Impacts of renewable power generation CDM projects on GDP

It can be found from Figure 9.15 that biomass electricity, wind electricity and hydro electricity CDM projects have a negative influence on actual GDP, among which the GDP loss caused by hydro electricity CDM project is obviously lower than that caused by wind electricity and biomass electricity CDM project. Actual GDP loss from biomass electricity CDM project is largest, and the wind electricity CDM project goes in between the other two. Moreover, GDP loss increases with rise of CERs price, which is consistent to the results of the analysis done by Timilsina and Shrestha about the impact of hydro electricity CDM project on social economy in Thailand (Timilsina and Shrestha, 2006). As the GDP analyzed in this report is the actual GDP described with expenditure approach, in which GDP is composed of total consumption, total investment and net export and the model adopts law of closure in balance of trade, i.e. foreign savings is exogenously given, net export is constant; and actually total consumption and total investment are the major factors influencing GDP. Hence we remain focusing our analysis on total investment and total consumption.

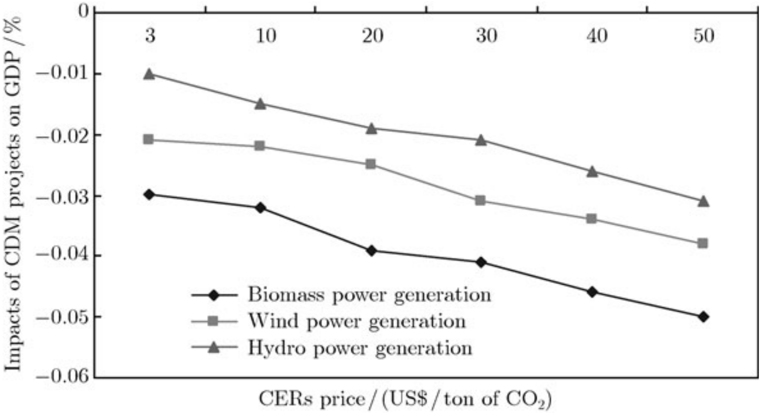


Figure 9.15 Impacts of renewable power generation CDM projects on GDP

9.4.2.2 *Impacts of renewable power generation CDM projects on total investment*

From Figure 9.16 we may see that the total investment of biomass

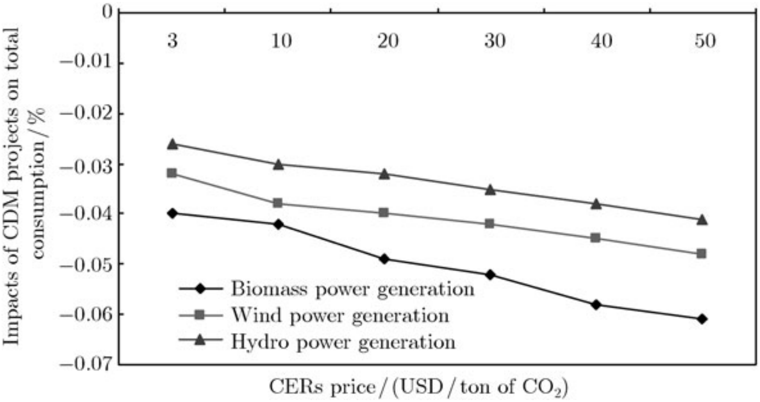


Figure 9.16 Impacts of renewable power generation CDM projects on total investment

electricity, wind electricity and hydro electricity CDM projects is obviously lower than in the BAU scenario, among which the hydro electricity CDM projects show smallest decrease, biomass electricity CDM projects show largest decrease and wind electricity CDM project is in between. And, it decreases with the rise of CERs price. This is because the total investment in this model is obtained from endogenous conversion of total savings. The major components of total savings are enterprise saving, private saving and government saving. Since renewable energy power generation is a capital-intensive technology, substitution of thermal power generation for this technology means increase in demand for capital by electric power sector. This will somewhat lower the average capital return rate and demand for labor in comparison with under the BAU scenario and in turn lowers the gross profit of enterprise; it therefore causes decrease in enterprise saving.

9.4.2.3 Impacts of renewable power generation CDM projects on total consumption

According to Figure 9.17, the total consumption of biomass electricity, wind electricity and hydro electricity CDM projects increase in comparison with under the BAU scenario, which is opposite to the results in section 7.3. Increase in total consumptions caused by biomass electricity and hydro electricity CDM projects are relatively larger and increase with the rise of CERs price. This is because government consumption in this model is exogenously given according to law of closure and total consumption is mainly influenced by resident consumption. Resident consumption has a dominant position in total consumption. On the one hand, residents may receive allowance from CDM project surplus to increase their income; on the other hand, rural

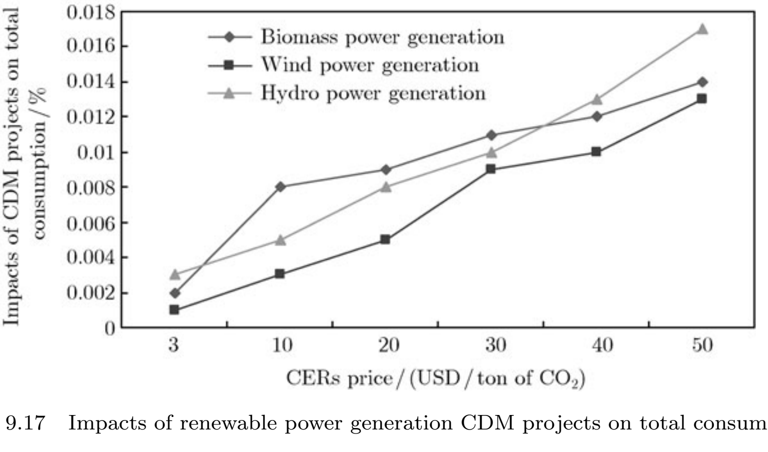


Figure 9.17 Impacts of renewable power generation CDM projects on total consumption

residents may receive profit from biomass electricity project. Therefore, resident consumption is relatively increased in comparison with under the BAU scenario and it increases with the rise of CERs price.

The negative pulling force of total investment is obviously higher than the positive pulling force of it, and therefore actual GDP is lower than that under the BAU scenario. At the point of CERs price USD 50/ton of CO_2, the GDP loss caused by biomass electricity, wind electricity and hydro electricity CDM projects are 0.05%, 0.038% and 0.031% respectively.

9.4.2.4 Impacts of renewable power generation CDM projects on CO_2 emissions

According to Figure 9.18 we find that the impact of CDM project substituting thermal power generation for renewable power generation by 1% is 0.96%—1.04%, among which hydro electricity CDM projects bring about largest 1.04% of CO_2 emission reductions, wind electricity CDM projects bring about 1.02% and biomass electricity projects bring about 0.97% of reductions. And, CERs price has the least impact.

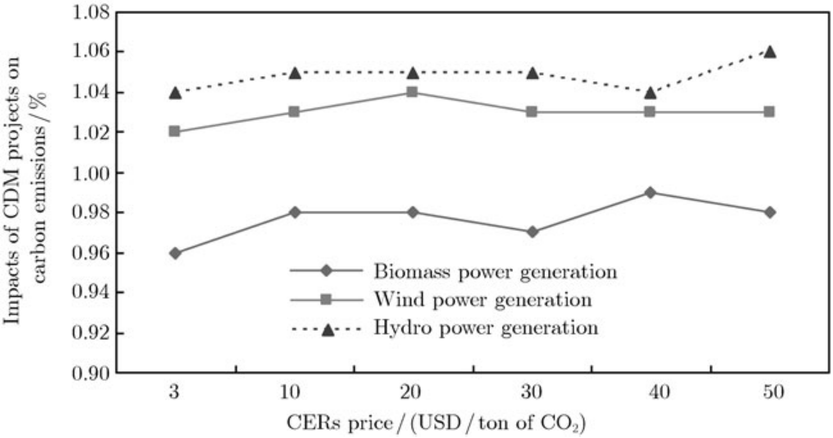


Figure 9.18 Impacts of renewable power generation CDM projects on CO_2 emissions

9.4.3 Impacts of renewable electricity CDM project on energy intensive sectors and energy sectors

This section analyzes the impacts of biomass electricity, hydro electricity and wind electricity CDM projects on energy intensive sectors and energy sectors at the CERs price point of USD 20/ton of CO_2.

9.4.3.1 Impacts of renewable electricity CDM project on outputs of energy intensive sectors and energy sectors

According to Figure 9.19 we find that all renewable electricity CDM projects cause decrease of outputs in both energy intensive sectors like iron and steel, building materials, chemical engineering, non-ferrous metal, paper manufacturing, etc., and energy sectors like coal mining, oil drilling, gas exploitation, petroleum processing, power industry, etc. Coal mining industry suffers the largest impact. With regard to the impacts of the three types of renewable power generation CDM projects on various sectors, biomass electricity CDM projects exert the largest impact, since the costs of biomass power generation is higher. Therefore, CDM project surplus may be used to subsidize energy intensive sectors.

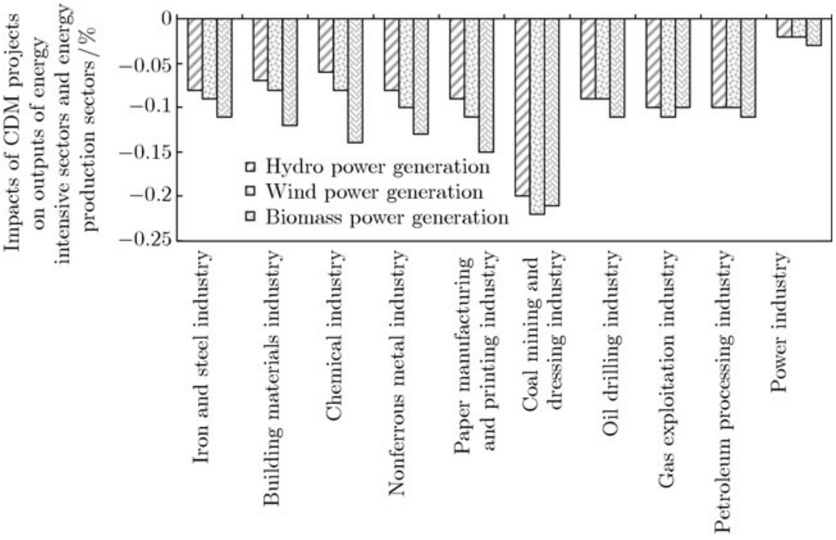


Figure 9.19 Impacts of renewable electricity CDM projects on outputs of energy intensive sectors and energy production sectors

9.4.3.2 Impacts of renewable electricity CDM project on product prices of energy intensive sectors and energy sectors

According to Figure 9.20, all the renewable power generation CDM projects cause increase of product prices in energy intensive sectors like iron and steel, building materials, chemical engineering, non-ferrous metal, paper manufacturing, etc., among which the price increase in iron and steel and chemical engineering sectors appears the largest. Impacts on energy production sectors vary, but are generally small. Hydro electricity CDM project will cause price decrease in coal mining, oil drilling, gas exploitation and petroleum processing industries by 0.010%, 0.001%, 0.001% and 0.001%, respectively; product prices in electric power sectors increase by 0.18%. Wind electricity CDM project cause price decrease in coal mining industry by 0.02%; and for other energy production sectors product prices increase by 0.001%, 0.001%, 0.002% and 0.200% respectively. Biomass electricity CDM project causes price increase in coal mining, oil drilling, gas exploitation, petroleum processing and electric power sector by 0.001%, 0.002%, 0.004%, 0.002% and 0.250% respectively.

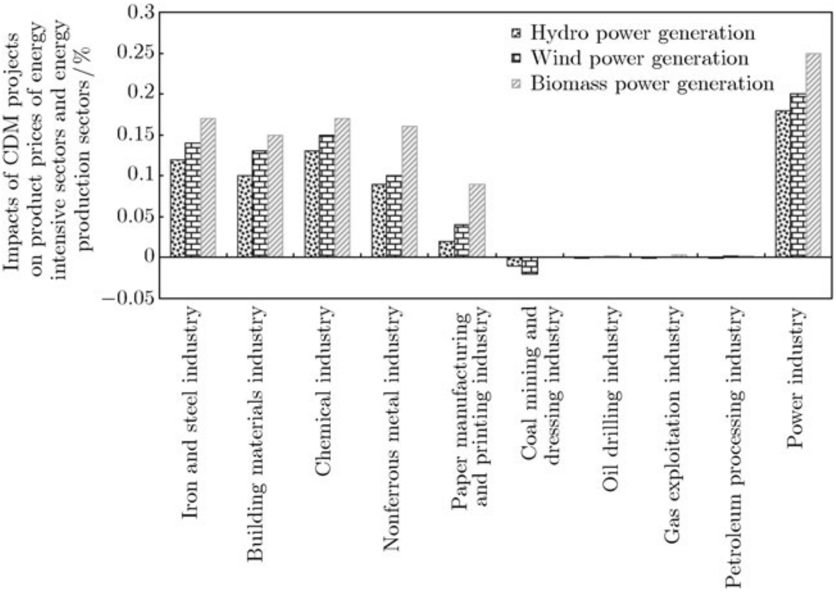


Figure 9.20 Impacts of renewable electricity CDM projects on product prices of energy intensive sectors and energy production sectors

9.4.4 Regional impacts of CDM projects

According to the PDD of renewable energy projects in China, CDM projects can increase local revenue, create new job opportunities, promote local economy, and build up the ability of the locality by means of technical transformation; the projects may utilize energy source more effectively and make use of waste materials for power generation, thus improving the efficiency of resource utilization; they can also reduce emissions of air pollutant like SO_2, NO_x and dust, improve water quality and decrease the demand for organic oxygen, thus protecting nature and forest vegetation.

For example, Ningxia Yinyi wind electricity CDM project produces 104GWh power annually on average, presumably saving 34,600 tons of standard coal. This means a decrease of 352 tons of SO_2, 400 tons of NO_x, 480 tons of granule and 9000 tons of coal cinder. In addition, it is expected that ① the project reduces 98,200 tons of CO_2 equivalent annually; ② the project will contribute to the development of wind power generation in Ningxia Hui Autonomous Region and even the whole of China; ③ it reduces emissions of other pollutant from thermal power generation; ④ construction and maintenance of the project create job opportunities; and ⑤ the project somewhat relieved local poverty.

Another example, Gansu Xiaogushan hydro electricity CDM project produces 357GWh annually on average, presumably reducing 3,129,000 tons of CO_2. And, the project brings the benefits of ① increasing energy consumption, reducing load shedding in several poorer villages nearby and improving conditions of housing, education, health and public facility for local residents; ② promoting the development of local electric industry; ③ increasing job opportunities and local income (installation of the project creates 3000 job opportunity, operation of the project need 100 regular staff), and improving technical level of local people; ④ improving local traffic situation; and ⑤ improving local energy utilization efficiency.

One more example, Heilongjiang Tangyuan County biomass electricity CDM project produces 124GWh annually on average, presumably reducing 184,000 tons of CO_2e. And the project can ① utilize local agricultural resources comprehensively, setting an example for comprehensive utilization of biomass energy in China; ② increase job opportunities, relieve poverty, and increase the income of local residents who can sell stalk; and ③ help with the environmental improvement, not only reducing emissions of greenhouse gases and SO_2 but also avoiding burning of agricultural residual and reducing air pollution.

Based on the research above, we may come to the following conclusions:

(1) At different CERs price levels, CDM projects of biomass power generation, wind power generation and hydro power generation all result in decrease of total investment and increase of total consumption; and as the negative pulling force on total investment is larger than the positive pulling force on total consumption, actual GDP suffer losses too. At the CERs price level of USD 50/ton of CO_2, actual GDP losses resulted from biomass electricity,

wind electricity and hydro electricity CDM projects are 0.05%, 0.038% and 0.031% respectively. In terms of CO_2 emission reductions, hydro electricity CDM project brings about 1.04%, wind electricity CDM project brings about 1.02% and biomass electricity CDM project brings about 0.97%.

(2) From the angle of sector division, renewable power generation CDM projects will result in decrease of outputs and increase of product prices in energy intensive sectors; and biomass electricity projects demonstrate the largest impact.

(3) From the angle of regional division, renewable power generation CDM projects will bring about multiple benefits, demonstrating a long-term obvious positive effect on economic growth and the improvement of local living conditions.

These conclusions are drawn based on a static CGE model. In order to further analyze the long-term impacts of CDM projects, a dynamic CGE model will be developed, so that the socio-economic impacts from CDM projects related to renewable power generation and energy utilization improvement as well as other CDM projects can be analyzed from a long-term perspective.

9.5 Challenges of international carbon market development

Although international carbon market shows fast development, it still faces series of challenges. We start with discussions about the uncertainties of long-term development of the entire carbon market and then analyze the challenges of international carbon market from two aspects of quota based carbon market (represented by EU ETS) and project based carbon market (represented by CDM).

9.5.1 Uncertainty of long-term development of international carbon market

(1) Despite the fast development of carbon market, it is noted that the transaction volume is still limited in comparison with the actual world emissions. And, carbon market liquidity is not sufficient to make direct connection with energy market and financial market. At present, given the development of carbon market, it did not change the structure of energy consumption of the world or key regions to large degree. Take Europe for example. Coal is the kind of fossil fuel with the highest emission density, but as international

oil and gas prices were kept rising in recent years while coal prices relatively lower, plus the low cost of CO_2 emissions and weak binding force, coal power generation industry is still progressing rapidly.

(2) It is uncertain as to how the international carbon market will be after 2012. As *"Kyoto Protocol"* only provides provisions on greenhouse gases emission reduction duties for 2008—2012, the emission reductions in international carbon market are mainly the quantized emission reduction goals fulfilled by developed countries. There is currently not any agreements concerning the framework of emission reductions after 2012, and hence the international carbon market after 2012 shows much uncertainty.

(3) There is currently no global transaction rule for carbon market, which is divided into standardized and non-standardized parts. In the standardized market, emission right trade at reasonable transaction value helps achieve established emission reduction goals, but this requires policy makers to establish rational emission reduction goals and allocate appropriate quantity of carbon credits. The efficiency of market operation depends to a great extent on rationalization of policy. Market operation also requires accurate forecasting of economic growth, impact assessment of technological improvement and establishment of strict system of transaction rules and monitoring. In the non-standardized voluntary carbon market, lack of applicable standards and higher risks presents many defects of market operations. Another influence source of carbon market is participation of many small funds and/or enterprises, which have their own anticipation of the rapidly developing carbon market and hope to gain long-term benefits from investment. Considering the variables in carbon market, such behavior can be regarded as gambling.

9.5.2 Challenges of the development of EU carbon market

(1) EU ETS concentrates only on CO_2 emissions, leaving emissions of other greenhouse gases aside; while other greenhouse gases emissions occupies 20% of the total greenhouse gas emissions in EU, therefore, the scheme has only limited influence on fulfilling the Kyoto goals. Besides, there is large internal diversity within each nation. In France, for example, the greenhouse gases emissions from the sectors covered by ETS only occupy 20% of its total emissions, while the percentage is 69% in Estonia (IEA, 2005).

(2) EU ETS covers only 45% of the CO_2 emissions in EU and there are many more CO_2 emissions not considered. The scheme covers almost 12,000 emission facilities in about 25 countries of EU, including refineries, coking plants, power plants with over 20 MW capacity, steel works,

cement plants, glass works, ceramic factories as well as pulp and paper mills. But, there are still 55% of CO_2 emissions not included in the trading scheme.

(3) EU ETS works only in certain sectors with CO_2 emissions, which makes other sectors uninvolved in the scheme which grows faster and further imposes difficulties in coordinating balanced development of all sectors. Especially, traffic sector already aroused wide discussions. The traffic sector is not covered in the ETS and will probably not be covered in Phase III (before 2013); whereas it is a large source of emission and a sector that deserves focused emission reduction operations.

(4) EU ETS market and the National Allocation Plan (NAP) of each member country do not necessarily bring future investment towards low-carbon economy, though it is one of the important goals of EU ETS. During 2005—2008, the Phase I NAP was generally over-allocated and consequently Germany as a leading emission source tried to focus on carbon intensive industries in Phase II NAP, such as coal electricity facilities, instead of low-carbon industries.

(5) Irrationality of NAP results in many uncertainties for long-term effect of EU ETS. The over-allocation of EU ETS in Phase I not only failed to make a contribution to achieving Kyoto goals or assisting effectively carbon market to develop and grow, but also paid the cost of "learning by doing" and added uncertainty in succeeding NAP for member countries. The member countries are unwilling to change the NAP, together with the invalidity of ETS price signal, which makes the long-term effects of ETS full of uncertainty.

(6) Compared with the emission reduction commitment of *"Kyoto Protocol"*, the contraction value of EU ETS is very low. Although the monthly volume is growing, it does not exceed the 1.6% of allocated quota in Phase I (Kaasik, 2006).

9.5.3 Challenges of the development of CDM market

With regard to CDM market, although the market is developing well, there are still some uncertainties for future development.

(1) As the two large CO_2 emission countries, whether or not China and India make the commitment to the binding emission reduction duty will directly influence the transactions in global CDM market.

(2) It is difficult to improve energy utilization efficiency and to finance for fuel switching projects.

The major reasons for such difficulty lie in the fact that renewable energy development and energy efficiency improvement projects are capital intensive investment, which require large amount of initial capital investment and last for a long period. Such projects have low investment return rate and lacks competitiveness. Meanwhile, these projects produces less CERs and single project has small impact on achievement of the Kyoto goals for a developed country.

(3) The methodology of CDM projects and the procedural complexity and difficulty together increase costs of transaction.

On the one hand, CDM projects have complicated rules and require multiple methodologies, which require computation of the data line, additionality, project boundaries, leakage, etc., but availability of such data is difficult and current methodology needs improvement; especially energy efficiency improvement projects, difficulties in methodology and monitoring seriously obstruct development of such projects in large amount. On the other hand, examination and approval of CDM projects require complicated procedures of examining and approval by relevant departments of the developing country and registration in UN. The shortest time spent in examination and approval of a project is 3—6 months while complicated procedures may bring uncertainty to final results. But whether registration is successful or not, initial designing and advertising costs at least need USD 100,000. Besides, due to the "additionality", most CDM projects are not byproducts; instead, CERs can be traded only after investment, which may turn to be waste if final result of the examination and approval procedures is uncertain.

(4) CDM project management in developing countries needs to be improved.

Although many countries have established relevant CDM project management institutions, there is no clear division of which institution is in charge of what approval/assessment responsibilities concerning CDM projects, like introduction of energy utilization technology, environment improvement, impacts on economy and employment, etc.

(5) Low CERs price and cutthroat price competition in seller's market restricted enthusiasm.

Current CDM projects are basically buyer's market, and enterprises of developing countries show weak bargaining power. As people get to know CDM projects better and more and more enterprises take part in market transaction as suppliers, carbon prices will be further depressed and expected benefits will shrink with large amount. Meanwhile, according to the Linking Directive of EU ETS, CERs can be used to redeem emission reduction commitment, i.e. CERs are completely negotiable in EU ETS. Currently there is large difference between EUAs prices and CERs prices; purchased CERs produced in CDM projects can be very profitable through EUAs trading. Therefore, buyer's market does not want to see over-rising of CERs prices or trend of equivalent CERs and EUAs prices.

(6) Buyers of CDM projects prefer to low-cost and large-emissions projects.

In terms of the supply structure in global carbon market, the commitment of developed countries to *"Kyoto Protocol"* and the demand for emission reductions gave impetus to global carbon market with the preference to development of fast-production, low-risk and large-quantity CDM projects related to fluorinated hydrocarbon and N_xO emissions. Supply of non-CH_4 and non-CO_2 emission reductions projects occupies over 50% of total supply; these gases carry higher potential of warming effect, but only need general equipment and technology to process, besides, initial input is less and incremental cost of emission reductions is relatively lower.

9.6 Conclusion

In this chapter, surrounding the issues about the origin of international carbon market, the relationship between international carbon market and carbon dioxide emission reductions, mechanism of different carbon markets and market transaction, through empirical research, we discussed the recent development of international carbon market and its socio-economic impact in China, and indicated the uncertainty and challenges in the future of international carbon market.

We have come to the following conclusions:

(1) The emergence of *"Kyoto Protocol"* provides conditions for introducing market tools into the field of greenhouse gases emission reductions.

The emergence of international carbon market is based on two reasons, principle of common but different responsibility and emission reduction cost differences between different country/region.

(2) International carbon market is growing rapidly with promising prospect, but there are heavy tasks for relevant system establishment.

Carbon market under *"Kyoto Protocol"* is the part unit in global carbon market. According to the *"Kyoto Protocol"*, international carbon market can be divided into two categories based on transaction type: project-based market (such as CDM, JI) and quota-based market (such as IET), which demonstrates different characteristics in terms of transaction cost and management. Quota-based carbon market developed fast, but with many challenges, and its functions need to be strengthened. For example, the transaction environment of EU ETS is far from perfect and it faces many challenges before a prosperous development. Project-based market also saw a fast growth, with Japan and UK as major buyers while China and India as major CERs sellers.

(3) In EU carbon market, the market function of price discovery for futures trading is waiting to play; energy prices are not yet the dominant factors influencing carbon price volatility; establishment of market system and transaction environment needs to be enhanced.

Our research results indicate that both the long-term and short-term interactions between energy prices and carbon prices in Europe are not fully demonstrated; and the influence of abnormal weather or government emission reductions policy on carbon market on traders' expectations, there might even be negative correlation inconsistent to intuitive logical reasoning.

(4) European carbon market liquidity shows similar characteristics as ordinary financial market, but with unobvious day-of-the-week effect.

In terms of general trend, it can be found that the EU carbon market liquidity is different from carbon prices trend; the liquidity ratios of carbon contracts in different phases do not demonstrate obvious difference and liquidities of contracts in the same phase do not show consistency either. Secondly, with regard to the expiration effect of carbon market, we found that carbon futures contract liquidities generally experienced three stages from their initial opening to expiration, i.e. low - high - low liquidity, showing obvious expiration effect. Carbon market transactions have the characteristics in other financial and futures commodity markets. Besides, as for the day-of-the-week effect, it can be discovered that EU carbon market liquidity does not show significant day-of-the-week effect, i.e. no notable difference between the liquidity ratios on different days of the week exists and the existing liquidity ratios differences are limited and somewhat random.

(5) The renewable power generation CDM projects in China will result in actual GDP loss; but in terms of different regions, these projects produce multiple benefits.

In addition to carbon market, we also analyzed the socio-economic and regional impacts of renewable power generation CDM projects in China. Results show that at different CERs price levels, CDM projects of biomass power generation, wind power generation and hydro power generation all result in decrease of total investment and increase of total consumption; and as the negative pulling force on total investment is larger than the positive pulling force on total consumption, actual GDP suffer losses too. At the CERs price level of USD 50/tCO_2, actual GDP losses resulted from biomass electricity, wind electricity and hydro electricity CDM projects are 0.05%, 0.038% and 0.031% respectively. But, in terms of CO_2 emission reductions, hydro electricity CDM project brings about 1.04% reductions, wind electricity CDM project brings about 1.02% reductions and biomass electricity CDM project brings about 0.97% reductions.

From the angle of sector division, renewable power generation CDM projects will result in decrease of outputs and increase of product prices in energy intensive sectors; and biomass electricity project demonstrate largest impact.

However, from the angle of regional division, renewable power generation CDM projects will bring about multiple benefits, demonstrating long-term obvious positive effects on economic growth and the improvement of local living conditions.

As renewable energy CDM projects have negative influence on actual GDP and outputs in energy intensive sectors, such negative influence may not last for a long time. Therefore, to make our study thorough and sound and hence to provide comprehensive policy support, it is necessary to conduct further research in the following two aspects: ① establishment of dynamic CGE model and analysis of socio-economic impacts of CDM projects related to renewable power generation, energy efficiency improvement and other fields from the long-term angle; and ② analysis of impacts of profit allocation mechanism of different CDM projects, for example, allowance allocated to renewable power generation projects or energy intensive sector will change their potential socio-economic impacts.

In summary, although EU carbon market has already attracted and will continue to attract wide attention, it is still not mature and perfect in general. On the other hand, there is much room for global CDM project development; and to achieve emission reduction goals at minimum cost has become a common understanding (Zhuang Guiyang, 2007). China already became and will continue to be the major CDM cooperation country. Moreover, establishment of carbon market brings about obvious profits for all countries of the world. However, the appearance and activity of carbon market did not change the structure of energy consumption of the world or in major regions, and in the long run, its development still faces large challenges.

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Chapter 10

Outlook of CO_2 Abatement in China

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In accordance with the above analysis and the economic development level of China, we can conclude that: the current status of CO_2 emissions of China can be classified into *survival-based emissions.* And China needs to coordinate between economic development and CO_2 emission reduction, which means that China needs to slow down the increasing rate of CO_2 emissions in major emission-intensive sectors, increase the proportion of renewable energy consumption, optimize the economic structure and energy consumption structure, strengthen the R&D and introduction of GHG emission reduction technologies, and further improve the energy utilization efficiency while maintaining the pace of economic growth.

Analysis of this chapter will focus on:

- How will the key driving forces of China's CO_2 emission change in the future?
- How will China's future CO_2 emission develop?
- What are the measures for China to control its CO_2 emissions?
- In order to maintain economic growth whilst control CO_2 emissions, what policy recommendations can be provided?

10.1 Main driving forces of CO_2 emissions in the procedure of urbanization and industrialization in China

In accordance with the development goal of "quadrupling the per capita GDP of the year 2000 by 2020 on basis of structure optimization, economic performance improvement, consumption reduction and environment protection", people's living standard will be improved substantially, the urbanization process will speed up, the household electric appliance consumption will grow rapidly, and the automobile will become affordable for more and more families, hence resulting in the increase in energy consumption by households. "To fundamentally realize industrialization in China by 2020" implies that the manufactural scale will still go on expanding. Meanwhile, the booming development of urbanization will also greatly drive the development of service industry and transport industry. Therefore, energy consumption from production will also increase dramatically in this period, and CO_2 emissions from energy consumption will increase unavoidably.

Firstly, China is divided into eight macro economic regions, i.e., Northeast (NE), Beijing-Tianjin (BT), Northern Coastal (NC), Eastern Coastal (EC), Southern Coastal (SC), Central (C), Northwest (NW) and Southwest (SW) (as indicated in Figure 10.1; owing to the lack of corresponding input and out-

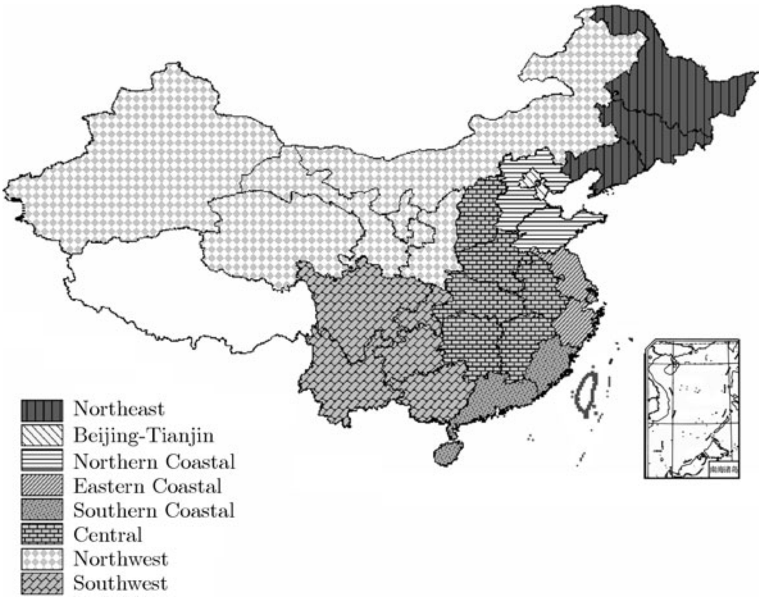

Figure 10.1 Map of China with the eight economic regions

put data, Tibet and Taiwan is not included in this study). The Northwest and Southwest regions constitute the West Region, which is line with the extension laid out in the state West Development Strategy. Four sectors are considered in each region, i.e. agriculture, manufacturing, construction and service (including freight transportation, communication, commerce, catering and non-material production industry).

The empirical study indicated in Chapter 3 has proved the great impacts of population, economy, technology and urbanization on CO_2 emissions. Therefore, on basis of scientific analysis, we have set up four scenarios of China's future economic development, population growth, urbanization rate and technological advancement (as indicated in Table 10.1).

Table 10.1 Scenarios

Scenario	Description
BAU (Business-as-usual)	Given the macroeconomic development in recent years, it is assumed that average economic growth during 2005—2010 will be the arithmetic average of values indicated in the"11th Five-Year Plan" of all regions. The economy will maintain comparatively quick growth during 2010—2030, with the growth rate dropping year after year. The population and urbanization will grow at a moderate rate. The technology will also grow at a moderate rate and achieve the national energy-saving layout.
L (Low economic growth)	Assume that a variety of risks and challenges will result in the drop of economic growth rate, which will be lower than the rate under the reference scenario. Meanwhile, the urbanization process will advance at a lower rate.
H (High economic growth)	Assume a higher economic growth rate on basis of scenario BAU.
HP (High economic growth + High population)	Assume a higher population growth rate on base of scenario H.
HT (High economic growth + High technology)	Assume technology achieves greater improvement on base of scenario H.

Developments of the major driving forces are set as follows.

10.1.1 Economic growth

Three possible economic growth scenarios are given in Table 10.2.

Table 10.2 Forecast of China's rate of economic growth in the coming 20 years (%)

Scenario	2005—2010	2010—2015	2015—2020	2020—2030
Reference scenario	10.1	8.5	7.5	6.5
Scenario L	9.0	7.5	6.5	5.5
Scenario H	10.5	9.5	8.5	7.5

We believe that the annual average economic growth rate of each region during 2005—2010 just complies with the 11th Five-year Plan of that region. Although eventually the growth rate of each region is quite possible to surpass the planned value, the weighted mean value of regional economic growth is always higher than the national growth rate (because of the scope of statistics and human factors). According to the experience of the 10th Five-year Plan, the average of the regional planned growth rates will be the relatively more accurate expectation of the national GDP growth. Scenario L and scenario H will be adjusted by 1 percentage point respectively on the basis of the reference scenario. According to the experience of industrialized countries, with the rapid economic growth in China, the growth rate will slow down gradually. For reasons given above, we established the scenarios of economic growth during 2010—2030, and also assumed that the economic growth in different regions will be getting close to each other gradually and taking on the characteristics of convergence to some extent.

10.1.2 Population growth

This model has referred to the forecasts of China's future population changes, which are given in "*Strategic Study Report on National Population Development*" (National Population Development Strategic Research Team, 2007) (see Table 10.3).

Table 10.3 Forecast of regional population development (100 million)

Scenario		Northeast	Beijing-Tianjin	Northern Coast	Eastern Coast	Southern Coast	Central	North-west	South-west
2020	Medium	1.20	0.32	1.81	1.63	1.61	3.89	1.38	2.67
	High	1.23	0.33	1.84	1.66	1.64	3.97	1.41	2.72
2030	Medium	1.24	0.33	1.85	1.68	1.67	3.98	1.42	2.73
	High	1.27	0.34	1.90	1.72	1.71	4.09	1.46	2.80

10.1.3 Urbanization level

Since 1996, the urbanization process of China steps up distinctively. However, the current urbanization level is still on the low side. In accordance with the population scenarios and the related urbanization files of China, the scenarios of China's future urbanization processes are accordingly given in Table 10.4.

Table 10.4 Forecast of regional urbanization rate (%)

Scenario		Northeast	Beijing-Tianjin	Northern Coast	Eastern Coast	Southern Coast	Central	North-west	South-west
2020	Medium	55.21	84.77	56.54	66.45	62.13	48.55	45.31	42.55
	Low	56.25	86.37	57.61	67.70	63.30	49.47	46.16	43.35
2030	Medium	58.19	90.62	62.87	72.15	66.87	53.88	49.40	47.02
	Low	59.69	92.97	64.50	74.02	68.60	55.27	50.67	48.23

10.1.4 Technology advance

This model has set up two possible technical developing scenarios (as indicated in Table 10.5), and assumed that the speed of technical advancements is the same among all regions.

Table 10.5 Improvement potential of sectoral final energy use efficiency

Scenario	Description
Medium	The efficiency of energy utilization meets the goal of National Energy-Saving Layouts (see Annex 3) in line with which the efficiency values for 2030 are also planned.
High	The efficiency of energy utilization achieves better than the planned goals. The improvement rate of final energy use efficiency in both years is 5% higher than the existing goal.

10.2 China's future CO_2 emissions

The base-year data of regional GDP, population, urban/rural per capita income and urbanization rate are derived from *"Historical Data on China's Gross Domestic Product* 1952—2004" (Department of National Accounts, National Bureau of Statistics, 2007) and the related provincial data of 1997 as given in "1949—2000 *China Statistical Data Compilation"* (Department of Comprehensive Statistics, National Bureau of Statistics, 2005). The values are all at constant prices of 1997. Given the difference between the input-output accounting and general national economic accounting and the difference between the aggregation of provincial values and the national value, we hereby deflate the data of aforesaid regions, so that they can be compatible with the national scope.

The base-year final demand matrix, interregional trade coefficient matrix and the multiregional direct consumption coefficient matrix are obtained by adjusting the 8-sector basic matrix from the multi-regional input-output tables of China for the year 1997 (State Information Center, 2005). From the MRIO data we could also identify regional urban- and rural-household aggregate consumptions, which are combined with regional population and urbanization rates to obtain the base-year regional per capita consumption by urban and rural residents.

The base-year data of energy consumption per unit output and residential energy consumption per capita could be obtained as follows: adjusting and integrating the energy balance of each province or municipality from the *"China Energy Statistical Yearbook"* (National Bureau of Statistics, 2001), total sectoral energy consumption, as well as aggregate residential energy consumptions of urban and rural residents for each region, could be obtained. The base-year data of energy consumption per unit output could be obtained by dividing total sectoral energy consumption with the corresponding sectoral total output from the MRIO tables. Base-year residential energy consumption per capita could be obtained by dividing regional aggregate residential energy consumptions of urban and rural residents with the corresponding base-year regional urban and rural population, respectively. The future urban and rural income elasticities are acquired through a modification of the work of Hubacek and Sun (2001).

10.2.1 Total emissions continue growing

Figure 10.2 illustrates the results of total CO_2 emissions under different scenarios. The nationwide CO_2 emissions will be 2.19—2.87 billion tons of carbon and 2.49—3.96 billion tons of carbon respectively in 2020 and 2030.

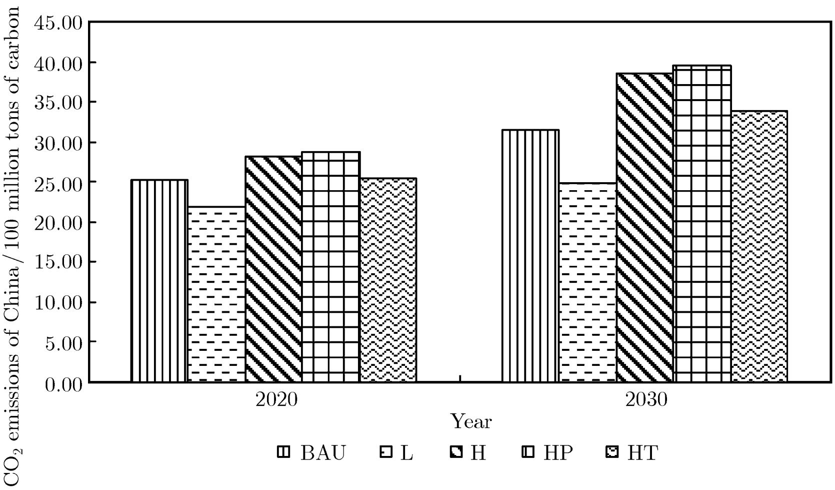

Figure 10.2 Total CO_2 emissions of China in 2020 and 2030 under different scenarios

Under the BAU scenario, the nationwide CO_2 emissions will be 2.52 billion tons of carbon and 3.15 billion tons of carbon respectively in 2020 and 2030. On basis of the BAU scenario, if the annual growth rate of GDP increases by 0.80% and 1.00% respectively during 2005—2020 and during 2020—2030

(Scenario H), then the nationwide CO_2 emissions will increase by 291 million tons of carbon and 707 million tons of carbon respectively in 2020 and 2030. When the economy grows rapidly, if the control over population growth is slackened, i.e. the annual growth rate of population during 2005—2020 and during 2020—2030 will increase by 0.14% and 0.06% (Scenario HP), then compared with the BAU scenario, the increment of nationwide CO_2 emissions in 2020 and 2030 will increase to 349 million tons of carbon and 810 million tons of carbon respectively. On the contrary, if efforts are also made to promote technical advancements besides rapid economic growth, so that the improvement rate of regional final energy use efficiency of each sector is 5% higher than the existing energy conservation goal (Scenario HT), then the increment of nationwide CO_2 emissions will decrease to 170 million tons of carbon and 240 million tons of carbon in 2020 and 2030 respectively when compared with the BAU scenario.

10.2.2 Per capita CO_2 emission will continually increase while still lower than the current level of developed countries

According to our analysis, the per capita CO_2 emission will reach 1.51—1.94 tons of carbon/capita and 1.67—2.59 tons of carbon/capita respectively in 2020 and 2030. In 2005, the per capita CO_2 emission of OECD countries was 3.01 tons of carbon/capita. It is obvious that China's future per capita CO_2 emission level will still be lower than the current level of developed countries. Figure 10.3 and Figure 10.4 respectively shows the results of regional per capita CO_2 emissions in 2020 and 2030. It can be seen that the per capita emissions of Southern Coastal region and Southwest region are apparently lower than the national average; those in Central region

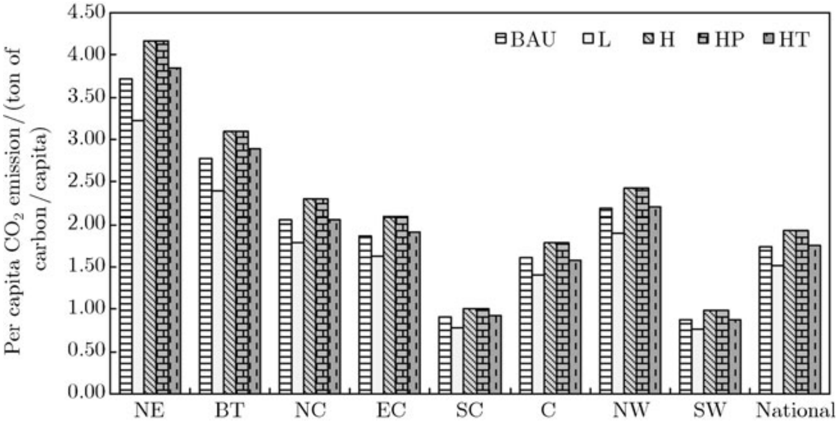

Figure 10.3 Regional per capita CO_2 emissions for year 2020

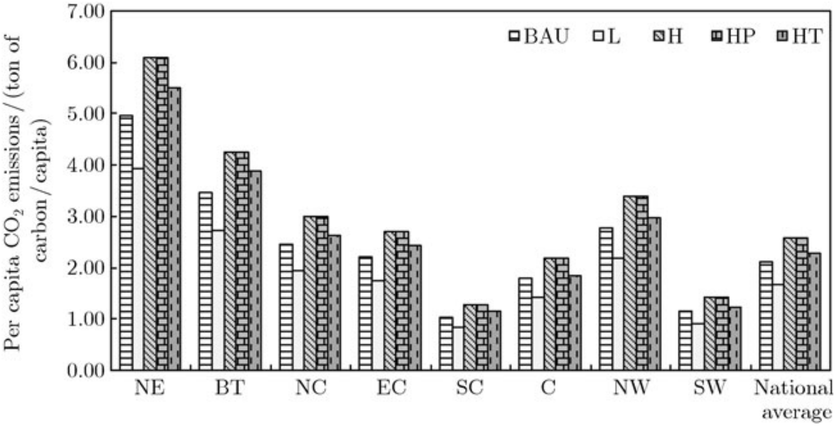

Figure 10.4 Regional per capita CO_2 emissions for year 2030

are slightly lower than the national average, and those of other five regions are all higher than national average, with the two highest per capita emissions appearing in Northeast region and Beijing-Tianjin region.

10.2.3 CO_2 emissions in Central China occupies the largest share

Regional CO_2 emissions for year 2020 and 2030 are presented in Figure 10.5 and Figure 10.6, respectively.

In both analysis years, all regions reach their highest CO_2 emissions in scenario HP. In all scenarios the highest emission appears in the central region. In BAU scenario, the CO_2 emissions of the central region account for 24.8% and 22.6% of nationwide CO_2 emissions in 2020 and 2030 respectively.

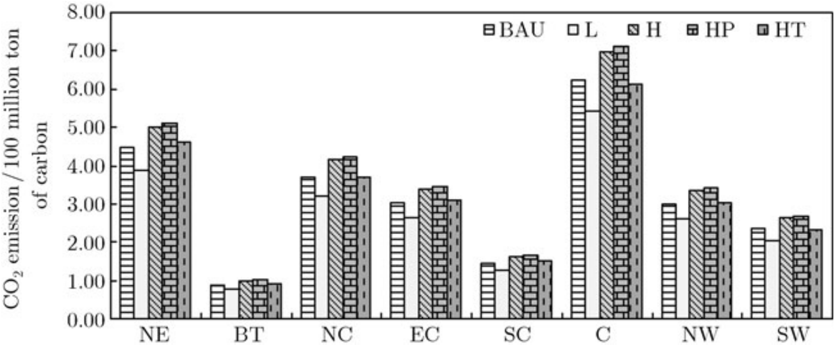

Figure 10.5 Regional CO_2 emissions for year 2020

10.2.4 Obvious difference existing among CO_2 emission intensities

Table 10.6 shows the results of CO_2 emission intensities under each scenario.

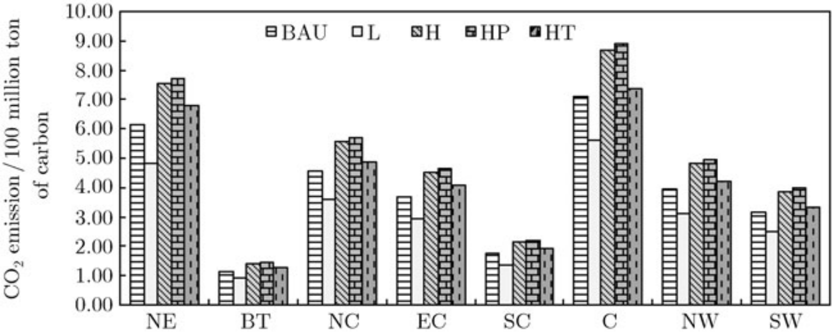

Figure 10.6 Regional CO_2 emissions for year 2030

Table 10.6 CO_2 emission intensity in different scenarios

(ton of carbon/10^4 RMB)

Scenario	1997	2020	2030
BAU	1.260	0.520	0.346
L	1.260	0.521	0.347
H	1.260	0.519	0.346
HP	1.260	0.530	0.355
HT	1.260	0.469	0.304

In both analysis years, Scenario HT is characterized by the lowest CO_2 emission intensity, while Scenario HP is featured by the highest CO_2 emission intensity. Generally speaking, the CO_2 emission intensity is declining under all scenarios.

Figure 10.7 and Figure 10.8 illustrate the results of regional CO_2 emission intensities for year 2020 and 2030, respectively. It can be seen that, under the assumption of uniform rates of technological improvement for all regions, up to year 2030 there will be distinct differences among regional emission

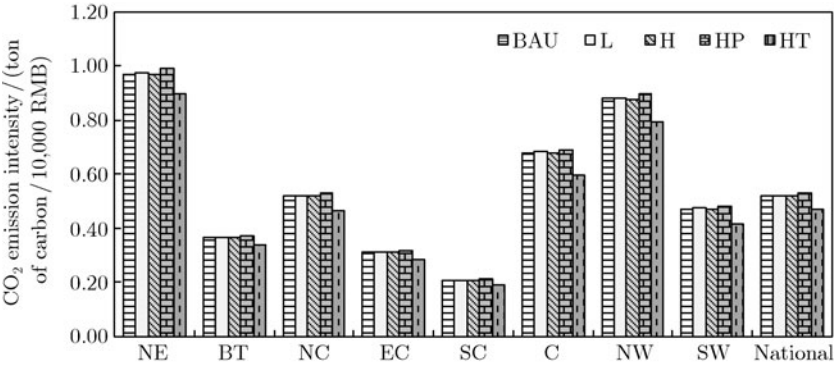

Figure 10.7 Regional CO_2 emission intensity for year 2020

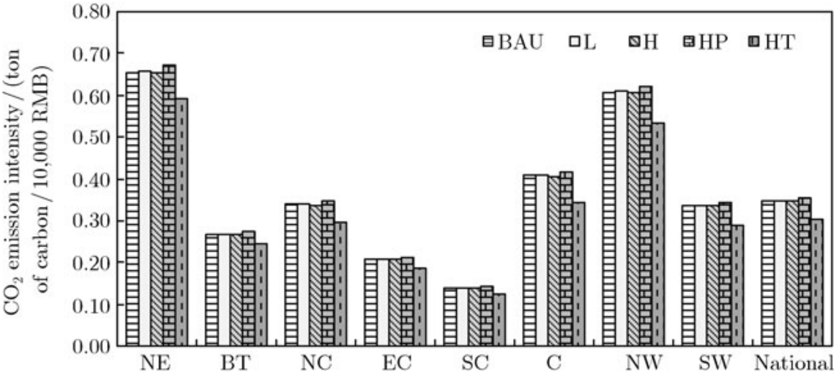

Figure 10.8 Regional CO_2 emission intensity for year 2030

intensities. In all scenarios in the two analysis years, the regions whose emission intensities are higher than the corresponding national average include: Northeast, Central and Northwest. The highest emission intensities correspond to Northeast, closely followed by Northwest. The lowest emission intensities correspond to Southern Coastal in both analysis years.

Given the different regional emission intensities, the inter-regional commodity transfers may raise nationwide CO_2 emissions while shortening the supply-demand gap of the importing region. Therefore, continuing efforts should be taken to advance the improvement of final energy use efficiency in each region, especially to accelerate the improvement in Central and Northwest as much as possible, so as to promote CO_2 emission reduction at the national level.

10.2.5 Huge shifting emission among regions

CO_2 emissions taking place in any region result directly or indirectly from the final demand of the region itself or from other regions. Figure 10.9 and Figure 10.10 show the difference between CO_2 emissions driven by each region and those generated by that region in 2020 and 2030 respectively. CO_2 emissions driven by any region refer to the emissions produced either inside the region or in other regions in order to satisfy the final demands in that region. That is, it excludes the CO_2 emissions attributing to the region's exports, while it includes the emissions taking place in other regions, but resulting from the satisfaction of imports of this region. A positive relative error implies that emissions driven by a region are larger than those it generates, and vice versa.

It can be seen from Figure 10.9 and Figure 10.10 that in both analysis years, the relative errors clearly exist in most regions. The regions with emissions driven by them being higher than those they generate include Beijing-Tianjin region, Eastern Coastal region, Southern Coastal region and two western regions, with the largest positive relative error corresponding to Beijing-Tianjin in both analysis years (30%—32% and 22%—24% in 2020 and 2030 respectively). Among all the regions with negative relative negative errors, Northern Coastal has the lowest errors in both analysis years. Emissions driven by this region are about 25% lower than those it generates in year 2020, and 24% lower than those it generates in year 2030. The summation of all positive errors reflects the scale of emission shifting among regions. The results of this model show that: the inter-regional shifting scale hits 116—154 million ton of carbon in 2020 and 142—227 million ton of carbon in 2030.

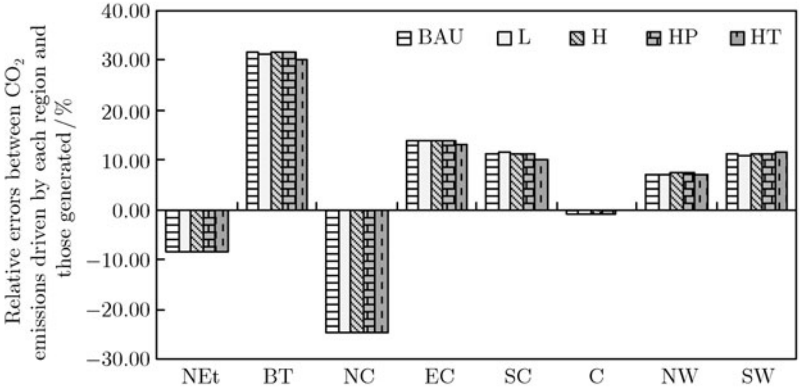

Figure 10.9 Relative errors between CO_2 emissions driven by each region and those generated by that region for year 2020

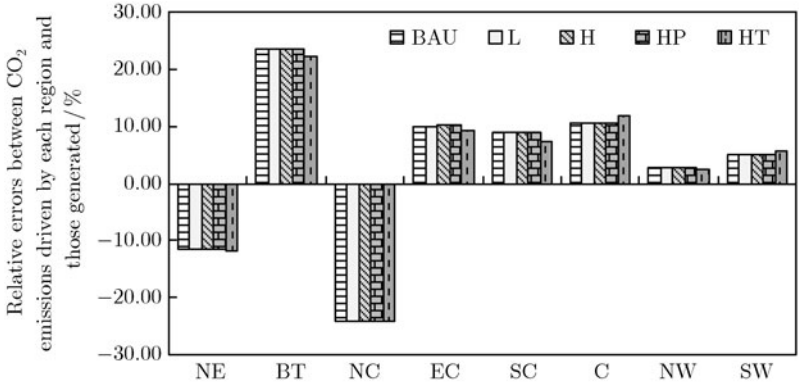

Figure 10.10 Relative errors between CO_2 emissions driven by each region and those generated by that region for year 2030

These results indicate that, the inter-regional trade will result in the apparent emission shifting among regions and hence there existing obvious relative error between emissions driven by one region and those emitted by that region, which implies different identifications of a region's emission obligation may incur evidently different impacts on that region that when performing environmental policy reform. The principles of emission responsibility identification would be one of the most important determinants of whether the policy goal of certain taxing scheme could realize. Therefore, in the future when performing environmental policy reform, careful decisions should be made about for which kind of emissions a regional is supposed to be responsible.

10.3 Pathway of CO_2 abatement in China

Based on the studies of the above chapters, we believe that China's CO_2 emission strategy should follow the fundamental principle of "technology priority, diverse development and economic security", with the major measures for emission reduction shown as follows.

10.3.1 Optimizing economic structure and energy structure as the long-term strategy of CO_2 abatement

It is hard to change the coal-dominant primary energy structure of China in the short run. With per capita GDP exceeding USD 1,000 and the economy entering a new phase of booming development, the proportion of heavy and chemical industry will increase, the energy intensity will rise, and the energy consumption will grow quickly. Therefore, China's GHG emissions will be characterized with huge total emissions, quick growth rate and high CO_2 emission intensity, resulting in the fact that the mitigation of CO_2 emissions through structural optimization will be faced with both great potential and great challenge.

Since 1980s, despite the booming economic growth, the CO_2 emission intensity has been dropping constantly, with reduction rate even surpassing those of major developed countries at their take-off stage. What are the driving factors of such quick reduction? Can we further predict that China's energy intensity will keep dropping quickly in the future? The causes for the continual drop of CO_2 emission intensity in the final energy use of China's production sectors has been quantitatively analyzed with this model. The results have proven that it is hard for China's CO_2 emission intensity to maintain quick drop in the future.

Analysis of the CO_2 emission intensity variation in the final energy use of material production sector and the CO_2 emissions indicate that: the current variations in China's industrial structure and final energy use structure are not favorable for the reduction of CO_2 emission intensity and have offset the partial functions of energy intensity. Therefore, the industrial structure and the final energy use structure of the material production sector should be adjusted, especially for those of the secondary industry. However, the growth in the added values of the ferrous metal smelting and processing industry and the non-ferrous metal smelting and processing industry has resulted in the increase of industrial CO_2 emissions by 56.21 million ton of carbon. Therefore, mitigation emphasis should be put upon these energy-intensive sectors, and the export of CO_2 intensive products should be reduced properly.

For such energy intensive sectors as chemical feedstock and product manufacturing industry and non-metallic mineral product industry, priority should be given to introducing advanced technologies, updating and lagged production techniques and further improving energy efficiency, so that the energy intensity of these sectors can catch the advanced international standards. Exports of these products should be properly reduced while imports should be properly increased. End-use consumption of renewable energies in these sectors should be promoted through preferential measures such as incentive fiscal and tax policies, so as to orient the final energy use structure toward the direction favorable for CO_2 emission reduction.

The coal-fired power generation technology should be improved; such clean energies as wind power and hydropower should be well promoted. Meanwhile, the power loss incurred during power transmission/distribution should also be reduced, as well as the CO_2 emission intensity of electricity sector.

Clean and low-carbon industrial final energy use should be promoted, and the efficiency of electricity use should be improved. Efforts should be made to reinforce energy conservation and implement energy conservation audit system. Some industrial sectors should commit to a certain energy saving goal so as to reduce CO_2 emissions.

10.3.2 Guiding household consumption style to reduce CO_2 emissions

According to our study, population will contribute to the most of CO_2 emissions of China. This means that the number of population and the production and living patterns of residents will have the greatest influence on CO_2 emissions. Therefore, controlling population growth and properly guiding residents' ways of production/living can effectively reduce CO_2 emissions in China. As a matter of fact, the direct and indirect influence of residents on CO_2 emissions accounted for 40% of total primary energy-related CO_2 emissions during 1992—2002. The indirect CO_2 emissions resulted from the foodstuff, dressing, household appliances and services accounted for over 50% of total indirect CO_2 emissions. Housing is the greatest carbon-intensive behavior. The enlargement of the consumption scale of urban and rural residents, the growth of urban population and the upgrade of household consumption structure are the major causes for the growth of household CO_2 emissions. However, the reduction of energy intensity has more or less moderated the growth speed of energy consumption.

Furthermore, according to the results of CO_2 emissions in year 2020 and 2030 produced by CEDAS model, if the control over population growth is slackened when the economy grows rapidly, i.e. the annual average growth rate of population during 2005—2020 and during 2020—2030 increases by 0.14% and 0.06% respectively (Scenario HP), then compared with the BAU scenario, the increment of nationwide CO_2 emissions in 2020 and 2030 will enlarge to 349 million ton of carbon and 810 million ton of carbon respectively. Therefore, through properly guiding household consumption pattern toward low-energy-consumption and low-emission pattern, household CO_2 emissions can be mitigated to a great extent.

10.3.3 Improving structure of international trade to lower embedded CO_2 emissions

In recent years, China's foreign trade continues to maintain positive growth momentum. In 2005, the total volume of China's foreign trade hit RMB 11,690 billion, ranking top 3 in the world, with 53.6% of which coming from export. Therefore, the export trade has played a very important role in the economic development of China. However, since a majority of export commodities are energy-intensive products, China's export products have generated substantive CO_2 emissions during processes such as production and transportation.

Our study shows that, the direct and indirect CO_2 emissions caused by export products in 1997 and 2007 both had accounted for over 30% of primary energy related CO_2 emissions. This means that about 1/3 of primary energy related CO_2 emissions in China are generated from satisfying the production and living activities in other countries. The greatest CO_2 emissions come from the commodity export of machinery manufacturing industry, energy exploitation industry, textile industry and chemical industry, which accounted for 73.40% and 77.32% of CO_2 emissions from commodity export respectively in these two years.

10.3.4 Strengthening self-innovation of technology to mitigate CO_2 emissions effectively

IGCC and NGCC now have entered into the stage of commercial demonstration and may accomplish the overall optimization of energy conservation and emission reduction. The thermal power plants are the major CO_2 emission sources in the world. Such emerging power generation technologies as IGCC and NGCC can well improve power generation efficiency and substantially decrease CO_2 emissions. They are considered as the important technological options to reduce global CO_2 emissions. The combination of IGCC/NGCC with CCS can even accomplish near-zero CO_2 emissions of thermal power plants. The energy resource endowments of China have determined that the coal-dominant energy structure will remain unchanged in quite a long time in the future. Being applicable to the situations of China, IGCC has great potential for development. However, with a high construction cost, the IGCC power station is still staying at the primary stage of commercial operation. With technical advancements and efficiency improvement, IGCC will have a broad prospect for application in China.

The power generation efficiency and emission reduction potential of NGCC power stations are even higher than that of IGCC power stations. However, the power-generation costs of NGCC rely excessively on the price of natural gas. Therefore, with the continual growth of international oil/gas price, there exist many uncertainties in the power-generation costs of NGCC. In particular, since the natural gas resources are not abundant in China, the NGCC technology should be developed moderately.

CCS has obvious emission mitigation effect. It may realize near zero emissions. CCS is considered to be “one of options for mitigating climate change” in the IPCC special report 2005. The key feature of CCS is to perform carbon capture and storage aiming at large emission sources. It can effectively control and reduce the CO_2 emissions from large emission sources such as thermal power plants. Boasting great potential for emission reduction, CCS can help reduce more than 1/3 of global CO_2 emissions by 2050. CCS is currently on the way toward commercialization in some developed countries. Despite the high costs of CCS, such approaches as EOR/EGR can help reduce costs. However, the application of CCS will also result in the increase of energy consumption. Therefore, in order to enable large scale deployment of CCS, the emission reduction costs of this technology should be reduced as fast as possible.

Renewable energies could mitigate CO_2 emissions effectively with long term abatement potential. Utilization of renewable energy can realize zero emissions. It is one of relatively mature technologies which can be scaled-up developed and capable of reducing CO_2 emissions effectively. Renewable technology includes hydropower, wind power, solar power and biomass power, etc. The renewable energies are developing swiftly in China, with some technologies reaching or approaching the level of commercialized development. Considering no matter the aspect of resource, technology or industry, the renewable energy has great potential for large-scale deployment. Along with the gradual optimization of China's energy consumption structure, the share of renewable energy will become higher and higher. Therefore, in the long term, the development and application of renewable energy utilization technologies will play a very important role in energy conservation and emission reduction.

10.3.5 Balancing positive and negative impacts of carbon tax

The results of our model show that the variation of GDP is sensitive to the setting of tax schemes. If there is no tax relief or subsidy for any sector (scheme S1), the GDP loss caused by carbon taxing will be obvious. For example, in the 10% reduction case, the GDP loss caused by scheme S1 will be 0.74%, which will severely affect the realization of overall objectives of China's economic construction.

However, the negative impact of carbon tax on the economy, and on the energy and trade intensive sectors, could be alleviated through properly relieving or subsidizing production sectors. The Denmark pattern, which completely exempts energy and trade intensive sectors and subsidizes all the un-exempted sectors, is a relatively ideal scheme. By utilizing the carbon tax revenue to reduce indirect tax, this scheme can completely eliminate the negative impact of carbon tax on GDP, employment and total consumption. Compared with the other schemes, this scheme has obvious advantages in stimulating total investment and improving energy structure. As for the effect on protecting energy- and trade-intensive sectors, this scheme could entirely remove the negative impact of carbon tax on the total output and export of these sectors, and could increase the profit of Iron and Steel industry, building materials industry, chemical industry and Non-ferrous Metals industry. In the 10% reduction case, the profit loss of paper industry caused by this scheme is only some 0.06 percent, which is smaller than the 1.46%—2.41%

caused by the other three schemes. This scheme can completely eliminate the intersectoral transfers, thus having obvious advantage in policy feasibility when compared with the other schemes. However, one of the major weak points of this scheme is that it would strongly weaken the mitigation effects of exempted sectors. The result of sectoral CO_2 emissions shows that, emissions by the exempted sectors under this scheme will rise instead of reduction in comparison to the baseline level. Therefore, during practical application, the Denmark approach should be further referred to, and the exempted sectors should commit themselves to qualified energy saving or emission mitigating measures defined by the government.

10.3.6 Participating and improving international carbon market actively

The establishment of international carbon market has greatly promoted the cooperation between developed countries and developing countries on CO_2 emission reduction. Although China is a leading project cooperator in the global CDM market, the buyers favor low-cost projects with the greatest emission reduction force. Therefore, such a fact has largely inhibited the development of capital-intensive projects of renewable energy and energy efficiency improvement.

In the carbon trading market, starting from the future prices, our study shows that neither the long-term nor the short-term interactions between the European energy price and carbon price are fully displayed. Plus the impact of unusual weather or the emission reduction policy of the government on the prospect of the carbon traders, such interaction could even be negatively correlated and run against the intuitive logical inference. It can be seen that the futures trading in the carbon market has not yet given full play to the marketing function of price discovery, also the energy price has not yet become the dominant factor affecting the trend of carbon price. The construction of related market systems and trading environment should be reinforced.

Despite the booming development of international carbon market, it is noted that the emergence and heating-up of carbon market is not able to obviously change the energy consumption structure of the world or those of major regions. Taking Europe as an example, although the coal is the fossil fuel with highest emission intensity, the coal-fired power generation industry is still experiencing rapid development as a result of the swift growth of international oil/gas price in recent years, as well as the low coal price and low carbon price. Furthermore, despite the satisfactory development of carbon market, its influence is still very limited. On the one hand, its trading volume is still very limited compared to the real emissions of the world; on the other hand, the liquidity of the carbon market is not sufficiently enough, and is not directly and apparently correlated to the energy market and finance market.

10.4 Policy implications

Global climate change is one of the most complicated problems faced by human being up to present, as well as the greatest challenge to energy development. The ultimate measure to address the issue of climate change is to reduce the anthropogenic GHG emissions, especially CO_2 emissions from the process of energy production and consumption. Thus the international community is making efforts to find out more effective (or maybe more rigid) emission reduction actions at the post-Kyoto age. On the other hand, emissions will not only relate to the living environment of human being, but also directly influence the modernization and sustainable development process of developing countries. Therefore, the control of GHG emissions will not only relate to the field of science and technology, but also relate to broader fields such as society, economy, politics and international relation. China should, from the view of a responsible country and the stand on sustainable development, give systematic consideration to socio-economic development and GHG emission mitigation and take well-defined strategies and effective measures to resolve the problem of global climate change. On the one hand, China should contribute to the mitigation of climate change by cooperating with the international community; on the other hand, China should endeavor for more favorable development spaces during its modernization process, so as to achieve the double-dividend of economic development and environmental protection.

According to the research findings of previous chapters, the following policy recommendations are provided.

10.4.1 Guiding GHG mitigation in the national energy strategy

Greenhouse gases are mainly generated during the process of energy production, consumption and utilization. Emission reduction will directly influence the quantity of fossil fuel consumption or the way of consumption. At the present time, no matter what their position is in the climate negotiation, the issue of emission reduction has all be reflected in the energy strategy of a majority of countries. No matter how historical responsibilities are identified, China's development cannot repeat the energy consumption pattern of developed countries causing unlimited CO_2 emissions. Therefore, we need make early preparations and plans to include the emission reduction concepts and measures into the long-term energy development strategy and meet energy needs with the lowest environmental cost, so as to accomplish the goal of a stable, diverse, clean and sustainable energy supply.

10.4.2 Accelerating the R&D of low carbon technologies

Currently, climate change has become the new driving force of energy technology development, with low-carbon energy technology becoming one of important directions for energy technology development. In order to slow down the increase of fossil fuel consumption and improve energy efficiency, priorities should be given to the development and selection of clean coal, natural gas, renewable energies and new energy technologies. Especially, for renewable energies, emphasis should be given to the development, promotion and utilization of wind power, solar energy and biomass energy. Researches on CCS should be carried out continuously. The corresponding road map and implementation strategy should be developed, and a clean energy utilization road with Chinese characteristics should be laid out through combining independent development with introduction and digestion.

International experiences indicate that: supports from the government and environmental policies are the key factors guiding the development of energy technology. Efforts should be made for demand pulling and policy guidance, and the systematized arrangement and innovation capacity building of the technology R&D system should be reinforced, so as to achieve a breakthrough in the low-carbon energy technology.

10.4.3 Optimizing the industrial structure and energy consumption structure

The above analysis indicates the great potential of industrial structure and energy consumption structure for emission reduction. Structural adjustment would be necessary to accomplish certain emission reduction goal. High attention should be paid to industrial structure and energy consumption structure in China, which are showing the trend toward carbon-intensive development in recent years,

In respect of industrial structure, the proportion of secondary industries should be controlled, especially the growth rate of energy- and carbon-intensive heavy and chemical engineering industries. The share of emission-intensive products in export trade should be reduced. As for energy structure, the proportion of nuclear power and renewable energy should be gradually increased. Meanwhile, efforts should be made to develop clean coal power generation technologies and promote such clean energies as wind power and hydropower. The power loss incurred during power transformation/transmission and the CO_2 emission intensity of electricity sector should also be reduced.

The final energy use structure should be adjusted. For such energy-intensive sectors as chemical feedstock and product manufacturing industry and non-metallic mineral product industry, priority should be given to the introduction of advanced technologies, upgrade and retrofit of lagged production techniques and the further promotion of energy efficiency, so that the energy intensity of these sectors can reach the advanced international standards.

Clean and low-carbon industrial end-use energy consumption should be promoted, whilst importance should be attached to the increase of CO_2 emission intensity with the increase in the proportion of electricity. If the power utilization efficiency cannot offset its high CO_2 emissions, the cost of electrification will be the increase of CO_2 emissions. Therefore, the policy to adjust the industrial end-use energy consumption structure should be implemented together with the policy to reduce CO_2 emission of the electricity industry.

10.4.4 Accelerating the import of advanced energy technologies through international mechanism

Three mechanisms orienting emission reduction and cost-cutting have been developed internationally. Although there are still some uncertainties on the future mechanisms, the basic framework is positive and will definitely be improved and strengthened in the future. When applying these mechanisms, emphasis should be put upon the introduction, absorption, promotion and innovation of technologies, as well as upon the integrated planning and the connection of technological chains.

Meanwhile, China should participate in the stipulation, improvement and implementation of rules. A group of special talents who are familiar with international rules and energy related technologies should be cultivated. Chance should be seized to promote the introduction and application of advanced energy technologies, which should be integrated with the independent innovation of energy technologies.

10.4.5 Strengthening socio-economic impacts analysis of mitigation policies

Compulsory emission reduction will have certain adverse impacts on economic development and energy consumption. The cost of emission reduction varies from country to country which are at different development stages.

China is currently in the process of industrialization and modernization, and the cost of emission reduction is far higher than that of developed countries. Such a process will go on in the near future. Therefore, scientific researches should be strengthened to figure out the socio-economic impacts of emission reduction policies, which will on the one hand provide quantitative support for the planning of scientific emission reduction strategy and on the other hand provide scientific references for fairly developing international emission reduction policies and allocating emission reduction obligations.

10.4.6 Enhancing the propaganda of the efforts on GHG mitigation

Currently, most consumers do not have a good understanding of the important significance of emission reduction and the connection between daily consumption behavior and emission reduction. Besides policy guidance, related propaganda should be promoted and the enthusiasm of enterprises should be stimulated, so as to guide the consumption behavior of residents and develop an atmosphere of energy conservation, energy efficiency improvement and GHG emission reduction.

The core of international negotiation on emission reduction is justice. Developing countries are faced with greater difficulties and more restrictive factors during emission reduction. In such a circumstance, China has made good efforts to mitigate climate change. Efforts and achievements of China should be publicized internationally to build the image of a responsible developing country and seek for the understanding and support from international community.

We believe that, as long as the strategy is proper and the measures are effective, China will become a model developing country seeking for low-carbon development under the framework of sustainable development.

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