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Reconfiguration of Industrial Structure to Reduce GHG Emissions Based on an Input-Output Model

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Abstract

Due to the high speed of its economic development over the past 30 years, China has experienced energy development and increased energy usage. Having become the world's largest emitter of carbon dioxide, China has established a binding target which states that, in 2020, its carbon dioxide emissions per GDP will decrease to 40% to 45% of the 2005 level. This paper examines the actual potential for industrial structure adjustment from the perspective of carbon emission reduction in China's industry. Specifically, this paper investigates the change in the ratio of the output of a specific industry to the total industrial output, under three scenarios involving constraints on carbon emission reduction. Firstly, the energy-carbon-economy input-output (ECEIO) Table is designed and compiled. It connects the usage and consumption of energy by type and its embodied carbon emissions to industrial production and household consumption by the value and volume. Secondly, an optimal input-output model is established which combines the environmental system with the economic system, taking into consideration international trade. This enables precise accounting of the intensity of carbon emissions by industry and type based on the consumption of fossil energy, links to input and output of the economic system, and addresses the issue of industrial adjustment for reduction of carbon emissions. Thirdly, this model is applied to China's 2005 ECEIO table with 44 industries, to China's 2007 ECEIO table with 15 industries and to Shanghai's 2007 ECEIO table with 26 industries. The findings show that it is necessary to increase the output of high-tech industries and services with a low coefficient (intensity) of carbon emissions, for example mechanical devices and electricity generation as well as real estate, finance and other services. Moreover, industrial adjustment is sensitive to the energy structure, the speed of economic growth and the extent of carbon emission constraints. If the ratio of renewable energy is increased to change the structure of energy, the increase in industrial adjustment will rise with the increase in reduction of carbon emissions and with the decline in the speed of economic growth. Specifically, the small sector of heavy industry with high carbon emission coefficients should decrease its ratio of output to the total output. The degree of decline in the ratio of its output to the total output should increase with the increase in reduction of carbon emissions and with the decline in the speed of economic growth. Lastly, suggestions are given for industrial structure adjustment based on the calculated specific indicators to achieve emission reduction targets with less damage to optimal economic growth.

1. Introduction

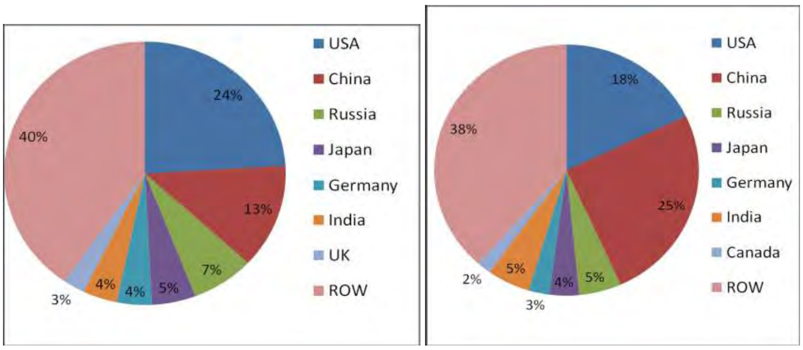
With the high speed of economic development and the population increase after China's reform and opening up, energy development and consumption have substantially grown, and carbon emissions have increased accordingly. According to the US Energy Information Administration (EIA) statistics, in 2007 China had 6.256 billion metric tons of carbon dioxide emissions (equivalent to 2.642 billion tons of carbon), accounting for 21% of the world's total emissions and surpassing the US as the world's largest emitter.[1] Under the pressure of international opinion and based on emission reduction requirements and its own development needs, China established a binding target stating that, in 2020, China's carbon dioxide emissions per GDP will have decreased to 40%-45% of the 2005 level and that China's proportion of non-fossil fuel consumption to total primary energy consumption will have declined to 15%. For the next few years, the coal consumption-based energy consumption structure will not change; therefore, adjustment of the industrial structure, improvement of energy efficiency and other methods will become the main ways to reduce carbon emissions.

The importance, necessity, difficulty and plausibility of China's reduction of carbon emissions can be analyzed from the aspect of the changing situation in international carbon emissions. From the US EIA statistics, the paper gives calculation of the ratio of the carbon dioxide emissions of six countries to the emissions of the largest emitter in the world, as shown as Figure 1.1. In 1995, China emitted 2.861 billion metric tons of carbon dioxide from energy consumption, which represented 12.9% of the world's carbon dioxide emissions, making it the second largest emitter in the world. Subsequently, its emissions rose to 7.707 billion metric tons in 2009, or 25.4% of world carbon dioxide emissions, making it the largest emitter in the world. Most of the other large emitters have decreased their carbon dioxide emissions. For example, the US, the world's largest emitter in 1995, discharged 5.319 billion metric tons, accounting for 24% of the world carbon dioxide emissions, and then slowly increased its emissions to 5.424 billion metric tons, or 17.9% of the world carbon dioxide emissions in 2009. The ratio of carbon emissions in Russia, Japan and Germany to the total carbon emissions of the world decreased respectively from 7%, 5% and 4% to 5%, 4% and 3% over the period from 1995 to 2009. India, as a developing country similar to China, increased its carbon dioxide emissions slowly, rising from 4% of the world emissions in 1995 to 5% of the world emissions in 2009.

From the US EIA statistics, Figure 1.2 shows the trend in carbon intensity using market exchange rates from 1995 to 2009 for seven countries which are the largest emitters in the world. China's carbon intensity was the second largest in the world before 2004, next to Russia, and became the largest in the world after 2004. It amounted to 3.053 metric tons of CO_2 per US$1,000 (at 2005 constant price, the same with below) in 1995, declined to1.935 metric tons per US$1,000 in 2001, and at last declined to 2.219 metric tons per US$1,000 in 2009. The decrease range from 1995 to 2009 (27.3%) was the second largest decline in carbon intensity in the world, next to Russia's 41.2% decline. India's carbon intensity declined from 1.925 metric tons per US$1,000 in 1995 to 1.406 metric tons per US$1,000 in 2009, down 27% from the 1995 figure. The other developed countries had the low carbon intensities which slowly declined as follow: in the US from 0.585 metric tons per US$1,000 to 0.421 metric tons per US$1,000, in Germany from 0.364 metric tons per US$1,000 to 0.269 metric tons per US$1,000, and in Japan from 0.274 metric tons per US$1,000 to 0.249 metric tons per US$1,000. China's difficulty with carbon emission reduction can be understood by comparing the target for carbon intensity reduction of 40%-45% within 15 years from 2005 to 2020 to the previous target of a 27.3% decrease within 14 years from 1995 to 2009.

Figure 1.1: The ratio of carbon emissions by country

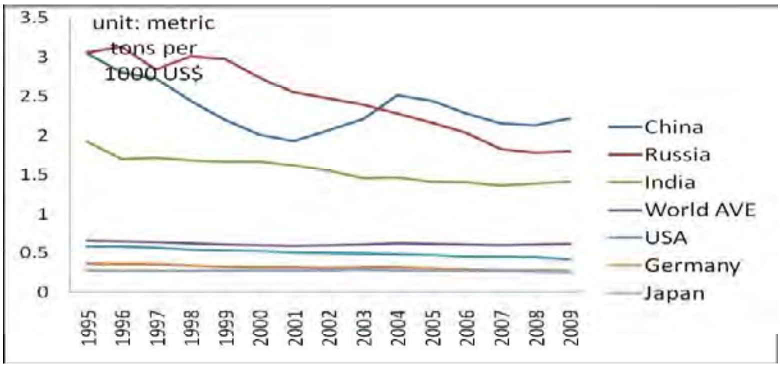
Carbon emissions in 1995 Carbon emissions in 2009



Source: US EIA statistics.

Based on the US EIA statistics, Figure 1.3 shows the carbon emissions by industry in different countries. Electricity and heat production is the industry with the largest ratio of carbon emissions in the whole carbon dioxide, which refers to those sourcing from the fossil energy consumption. According to the International Energy Agency (IEA), this ratio was 48.3% in China and 42.2% in the US in 2006. Manufacturing industries and construction are the industries with the second largest ratio in China, at 33.2% in 2006, while transport was the industry with the second largest ratio in the US, at 31.1% in 2006. Moreover, other sectors, including services and residential consumption, differed in China and the US, respectively, at 7.7% and 11.3%. The carbon intensity varied among the sectors.

Figure 1.2: Carbon intensity using market exchange rates

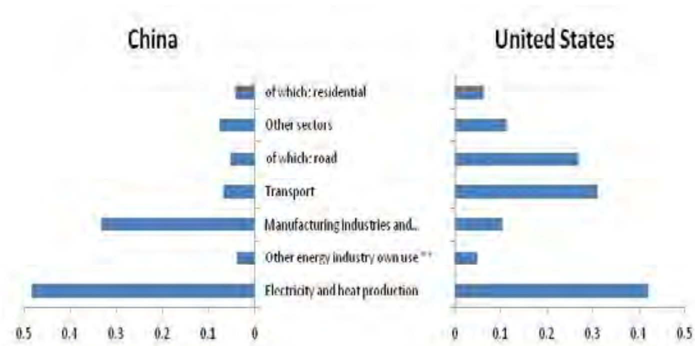


Source: US EIA statistics.

China is capable of creating a strategy for adjustment of industrial structure with the target of reducing carbon dioxide emissions. In general, there are three main ways to reduce carbon emissions, including restructuring industrial structure, reducing household energy consumption, and changing the energy structure. In China, coal consumption accounts for around 70% of all fossil energy, and this won't change dramatically in the long term. Chinese urbanization exceeds 50%, and the trend toward urbanization will cause an increase in energy consumption by urban households. These two facts necessitate the adjustment of the industrial structure. A strategy for industrial structure adjustment should be implemented without damaging economic growth.

To achieve the aim of reducing carbon emissions, how will China adjust its industrial structure? According to our computation shown in Figure 1.4, the main issue is the imbalance between the ratio of carbon emissions to the total carbon emissions and the ratio of output to the total output by industry (for industry classification, refer to Table A.5). Heavy manufacturing and transportation

Figure 1.3: Carbon emissions by industry

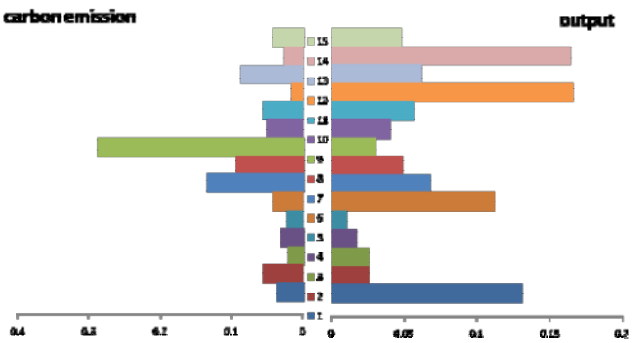


Source: IEA.

produced the largest percentage of carbon emissions; agriculture, food manufacturing, textiles, construction and commercial have the lowest ratio of carbon emissions. In contrast, construction, commercial, agriculture, energy and high technology had a comparatively large ratio of output; food manufacturing, wood processing, textiles and mining have a smaller ratio of output. In detail, looking at the top three carbon emitters among heavy industries, industry classification 9 (metal processing and manufacturing) industry classification 7 (chemical and pharmaceutical and medicine manufacturing), and industry classification 8 (building materials and non-metallic materials industry) accounted for 28.9%, 13.5% and 9.5%, respectively, of the total carbon emissions. Among services, industry classification 13 (transportation, storage, and information services) made up the next largest share (8.6%) of total carbon emissions. Among those industries with the least carbon emissions, industry classification 12 (construction) constituted 1.5% of the total carbon emissions; the light manufacturing, industry classification 3 (food manufacturing and tobacco processing), industry classification 5 (wood processing and manufacture of articles for culture, education and sport activities), and industry classification 4 (textiles, wearing apparel) made up 2.1%, 2. 2%, 3.2%, respectively, of the total carbon emissions; among services, industry classification 14 (wholesale and retail trades) accounted for 2.6% of carbon emissions; industry classification 1 (agriculture) comprised 3.7% of carbon emissions; the carbon emissions of industry classification 6 (petroleum processing, coking and nuclear fuel processing) made up 4.1%. However, the distribution of the ratio of carbon emissions is inversely related to the distribution of the ratio of output. The output of industry classification 12 (construction) comprised 16.6% of the total output, representing the largest ratio; the output of industry classification 14 (wholesale and retail trades) took second place, with 16.3%; the output of industry classification 1 (agriculture) took third place, with 13.1%, and the output of industry classification 6 (petroleum processing, coking and nuclear fuel processing) came in fourth place, with 11.2%. Among the industries with a comparatively small ratio of output, industry classification 9 (metal processing and manufacturing) ranked fifth, with 2.9% of total output, in contrast to its comparatively large ratio of carbon emissions. Light manufacturing in industry classifications 3, 4, and 5 had the smallest ratio of carbon emissions, at 2.5%, 1.6%, and 1.0%, respectively. The industry with the next smallest ratio was mining, in industry classification 2, which constituted 2.6% of carbon emissions. The industries with the smallest output ratio were those with the smallest carbon emission ratio. This implies the plausibility of an industrial adjustment strategy for decreasing the output of those industries with a high carbon emission ratio but a low output ratio (such as industry classification 9) and increasing the output of those industries with a low carbon emission ratio but a high output ratio (such as industry classifications 14, 12 and 7). However, to what extent the industry output will change should be determined based on more effective methods.

The aim of this paper is to design and compile an energy-carbon-economy input-output table and then to construct an optimal input-output model to address the potential of industrial adjustment for meeting the target for reduced carbon emissions. Since an adjustment of the industrial structure should not damage the economy, our objective is to maximize the GDP at the adjustment year. The ECEIO table associates industrial production and household consumption with fossil energy consumption and discharged carbon dioxide. Based on this table, the optimal model will include the objective for GDP and constraints on production and carbon emissions. The following Chapter presents the current research on a low carbon economy. Chapter 3 is concerned with the design of the energy-carbon-economy input-output table. The table links the production of each industry and consumption to fuel energy consumption as well as to the embodied carbon emissions. Based on this table, we present an optimal input-output model in Chapter 4 that maximizes the objective for GDP with the constraints on carbon emissions. This is used to investigate the adjusted industry structure and reduce carbon emission of each industry based on 2005 China ECEIO table with 44 industries aiming at the target of carbon emission reduction. Some scenarios that assume economic growth rate, energy structure change, and carbon emission constraints are presented to reconfigure the industry structure adjustment based on the 2007 China ECEIO table. The Chapter 5 gives the five factors of reduction of carbon emission intensity by Structure Decompose Analysis and then simulates the adjustment of industry structure of Shanghai based on 2007 Shanghai ECEIO table.

Figure 1.4 Comparison of carbon emissions and output by industry



Source: China's Energy Yearbook 2008, China's Input-Output Table 2007.

Note: For the industry classifications, refer to Table A.5.

2. Environment and economy input –output model

2.1 Present environment and economy model

The IPCC Fourth Assessment Report (http://www.ipcc.ch/ , IPCC-TAR 2001, Climate Change 2007: the AR4 Synthesis Report) condenses the international carbon emission forecasting model into two types, the top-down and the bottom-up The former can be used to describe the interactions between macroeconomic data, and also could be divided into a macroeconomic model(IPCC-AR5, The Fifth Assessment Report) and a CGE model (Pan & Zhen, 2008). The latter focuses on the analysis of micro data and technical data. We research the former model from the point of view of the macro economy to restructure industries and develop a low-carbon economy.

The CGE model is the most popular among the climate-energy-economy models. The model was developed by combining the energy model and economic model in 1980 and 1990 (Wang & Chen, 2005, Whalley & Wigle, 1991, Manne, 1999, Peck & Teisberg, 1992, Alcamo et al, 1994, Nordhaus & Yang., 1995, Capros & Mantzos, 2000, Jorgenson & Wilcoxen, 1993a, 1993b, Hazilla & Kopp, 1990). The issues analyzed by the model include the feedback effect of pollution on the economy(Vennemo, 1997), the effect of technical advantage on the cost of reduction of carbon emissions(Gerlagh & van der Zwaan,2003, van der Zwaan & Gerlagh, 2008), the influence of environmental tax and carbon tax on social welfare(Erickson & Jensen, 2000, Babiker, 2003), the cost of the "Kyoto Protocol" and loss in GDP. These researches were rarely involved in the adjustment of industrial structure for reduction of carbon emissions, and neither were China's researches. The Development Research Center of the State Council of China built the GAINS model(Amann et al., 2008) by analyzing the pollution control law in China, emission control technology, cost effective strategies, reduction of energy consumption, air quality control and reduction of greenhouse gas emissions, The Development Research Center also studied a multi-regional CGE model, addressing the policies for energy saving and environmental conservation with scenarios for energy tax and environment tax at the national level and by simulation of the policy effect. Their conclusion was that a different distribution of discharge rights would not bright out the efficiency variance in total, and the principle of per capita entitlement is superior to the principle of history(Li, & He, 2010).

This research utilizes input-output analysis because it is the most effective system analysis method which associates industry production and consumption and then relates the value of the output of each industry to the volume of input energy of all types and discharged carbon dioxide. So, it can be applied in restructuring industrial output for the purpose of reducing carbon emissions. In the technical aspects, an input-output model has some advantages in application, as follow: 1) variables are endogenous, so output, value added and final demand are determined by the economic system itself and 2) models can be verified, and it is linear and easy to compute. If a suitable parameter and technology are set, it is easy to realize an adjustment of the industrial structure consistent with the carbon emission target.

Leontief (1970) first used the input-output model for analysis of environmental issues[22]. Since then, many economists have improved the theoretical research and application in the field of resources and environment (Lin & Karen, 1995). In analysis of the energy and carbon emissions, Miller and Blair applied an input-output model to analysis of energy consumption by the economic system induced by final demand(Miller & Blair, 1985). Lenzen (1998) estimated the greenhouse gases inherent in the initial energy embedded in goods and services;[25] Hawdon and Pearson (1995) showed the complex relation between energy, environment and economic welfare; Proops et al. (1993) demonstrated that changes in concentration of atmospheric carbon dioxide as well the changes in industrial structure would affect carbon emissions 20 years in the future. Recent studies use structural decomposition techniques and sensitivity analysis in their input-output analysis, building the relationship between carbon emissions and the industrial structure and economic development(Tarancón et al 2007, 2010). China's current research estimates the embodied carbon in international trade based on static analysis of the national input-output table(Qi et al, 2008, Yan & Yang, 2009), using an index decomposition analysis to study the factor of change of energy intensity(Wang,2003, Shi & Zhang, 2003). None of the above research precisely compiled an input-output table including the economic system, the energy consumption and discharged carbon dioxide. Inclusion of these items is crucial for addressing the adjustment of industrial structure aimed at reduction of carbon emissions. Chen Xikang, researcher at the Chinese Academy of Sciences, presented input-occupied-output (IOO) technology, applying it in energy, water, environment, education, international trade and many other fields(Chen & Guo). Xia (2010), and Chen & Guo (2005) designed an energy economy IOO table which combines the input-output table with the usage and consumption of energy by type. However, it focused on energy more than carbon emissions; moreover, it didn’t distinguish the carbon emissions discharged from energy of each type in each industry. Such detailed information is helpful in determining the difference in the intensity of carbon emissions by industry and reconfiguring the industrial structure.

There is a new development in the input-output model. The nonlinear and dynamic implications of the IOO technique were used for long-term forecasting and planning, making an outstanding contribution to the prediction of food output in China(Chen & Guo). The IOO model, combined with linear programming technologies, has been used to study China's industrial restructuring potential for the 2020 carbon intensity targets(Rose, 1996). The dynamic linear programming model of the Chinese economy is used to simulate the five strategies for stabilizing carbon dioxide emissions (Isard, 1956). The spatial input-output model provides a theoretical research framework for the inter-regional and industrial complexity relations (Zhang & Zhao, 2008, Pan & Li, 2007, Han et al, 2004, Peters et al, 2007). Peters et al. (2009) and Wiedmann et al. (2008) make use of the MRIO model analysis to show the effect of Chinese carbon emissions and British carbon emissions. Their research makes use of advanced techniques in addressing the industrial structure to reach the target for carbon emission reduction.

In this research, an energy-carbon-economy input-output Table was designed. It not only accounts for the usage and consumption of energy by type in each industry but also for the embodied carbon emissions from input of the energy industry, so as to enable computation of the intensity of carbon emissions in each industry from different types of energy and association of this to the development of the economy. The table can be viewed at the national level and the regional level. It is used to account for both the carbon emissions from the usage of energy and that from the consumption of energy. The former is more complete, but the latter produces no repeated computation, especially for regional carbon emissions. The intensity of carbon emissions of each industry can be accounted for per output and value added, and the energy type is considered in the computation of carbon emission amount and intensity. Based on the above account, the input-output model is combined with the optimal model to address the potential for industrial structure adjustment in China and Shanghai for achieving the target for reduction of carbon emissions. From the solution derived from the optimal model, some suggestions are put forth concerning how China can adjust the ratio of output in the energy, heavy, high technology and services industries and the potential of adjustment for reduction of carbon emissions. Using different growth speeds, energy structures and carbon emission constraints, several scenarios are posed to analyze the sensitivity to adjustment of the industrial structure in China and Shanghai.

2.2 The energy-carbon-economy input-output table

We designed and compiled an energy-carbon-economy input-output (ECEIO) table. It presents quantitative and valuable associations between the supply of various industries (including energy industry by energy type) and the demand of these industries and households as well as embodied carbon dioxide during production and consumption. The burning of fossil energy emits carbon, and 90% of the carbon emissions originate from fossil energy consumption. Since fossil energy of different types discharges carbon dioxide at different ratios, it is necessary to compile an energy-carbon-economy table, which shows how energy by type is produced and supplied by different energy industries and is consumed or used by different industries or consumers. The consumption and the usage of energy are respectively shown in this table because the former is composed of final consumption of fossil energy and the loss of energy, but the latter also includes transformation loss of energy. This table completely shows the usage and consumption of energy by type in each industry and its embodied carbon emissions, so as to enable computation of the intensity of carbon emissions in each industry (carbon emissions per GDP/output). The direct and indirect carbon emissions embodied in the production and consumption can be reflected through the input-output model with embodied carbon emissions, and further, an optimization input-output model can be developed to measure the potential capability of different industries.

The calculation of the carbon emissions in the ECEIO table involves two important issues. Firstly, carbon emissions in an industry are the sum of multiplication of the consumption or usage of energy by type in this industry with the corresponding coefficient of energy of this type. Most research does not distinguish the consumption of energy from the usage of energy, which is crucial to precisely account for carbon emissions. The consumption of energy by type accounted for in the ECEIO table is different from the total consumption of energy by type, which is an index in *China's Energy Statistics Yearbook*. The total consumption of energy by an industry refers to the total amount of energy which is used to produce the products of that industry. It includes the portion of energy purchased from another industry for final usage in production and the portion comprised of indirect consumption of energy, which is the secondary energy produced in and used by that industry itself and then input into that industry for final usage in production. In *China's Energy Statistics Yearbook*, the total consumption of energy in the chemical industry includes the purchased fuel oil and coking coal for production of chemical materials and the electricity, which is produced by the thermal power produced by the chemical industry and used or purchased by this industry itself. So, the total consumption of energy is equivalent to the usage of energy in the ECEIO table. The total consumption of energy is divided into final consumption of energy, processing and transaction of energy, and the loss of energy. The final consumption of energy refers to energy of all types purchased from other industries which is consumed directly in this industry for the production of products of this industry. The input and output transformation is the embodied energy in the secondary energy during input transformation. For example, the energy embodied in thermal power is transformed from the input of primary energy. The loss of energy is the actual loss of transformation during the secondary energy production. The consumption of energy in the ECEIO table is composed of the final consumption of energy and the loss of energy, but not the transformation of energy. The carbon emissions of each industry originate from the final consumption of energy, energy processing and transformation, and loss. The final consumption of energy includes the portion of energy used as raw material, not as burning fossil energy, which should be deduced from the energy used for carbon emissions in this industry. In the ECEIO table, we account for the consumption or usage of energy by type as the basis for calculation of the carbon emissions. Moreover, the carbon emissions originating from consumption of energy and that from usage of energy are both computed and compared. The former is mainly accounted for based on the final consumption of energy by type; the basis of the latter also includes the transformation of energy and the loss of energy. The advantage of the latter is that it is a more accurate and complete computation of carbon emissions. Because the energy transformed in thermal heat will be transported from a producing region to a demanding region, repeated computation can be avoided in the former, especially at the regional level.

Secondly, the carbon emission coefficient is different across energy types. For primary energy, carbon emission coefficient refers to the standards of US Oak Ridge National Laboratory (http://www.ornl.gov/) or *2006 IPCC Guidelines on National Greenhouse Gas Inventories (http://unfccc.int/)*. Here, we refer to the standards of the Development Research Center of the State Council of China. Secondary energy sources, such as electricity and thermal heat, are used for processing and transformation of the primary energy source, so its coefficient is decided by the composition coefficient of the primary energy source. This composition coefficient can be calculated using the transformation term of thermal power and heat in the Energy Balance Table in *China's Energy Statistics Yearbook*. Using the composition coefficient enables a more accurate method than the fixed coefficient used in other research or the coefficient computed according to the assumed input source. From the Energy Balance Table, the primary energy type input to thermal power (or heat) is multiplied its carbon emission coefficient and then the sum is divided by the output of thermal power (or heat). The resulting value represents more precisely the carbon emission coefficient of thermal power (or heat).

In the ECEIO table, energy of type is divided into primary energy and secondary energy. The energy type used as raw material is other coking products, other petroleum products, and so on. They should be deduced from the usage or consumption of energy when calculating the carbon emissions.

Input of energy by type is accounted for in the value and in the standard quantity (ton standard coal); the latter unit corresponds to the unit of the carbon emissions. This table connects the value of the economic system to the volume of consumed energy of type and embodied carbon emissions. We can calculate the direct and indirect consumption and usage of energy by type in each industry as well as the direct and indirect emitted carbon dioxide in products and in exports and imports.

The ECEIO table is shown in Table 2.1. The industries are classified into the energy industry and the non-energy industry. The energy industry consists of the primary energy industry and the secondary energy industry. The former includes (1) coal producing and selection, (2) oil producing and selection, and (3) natural gas producing and selection (4) hydro power and nuclear power, with the latter including (5) thermal power, (6) petroleum processing, (7) coking, (8) steam and heat water supply, and (9) gas supply. The energy industry can be classified into the fossil energy industry and the non-fossil energy industry as well as the renewable and non-renewable energy industry. The industry in (4) uses non-fossil energy and renewable energy; the other industries use fossil energy and non-renewable energy. Table A.1 shows all of the classifications of energy types, both in the ECEIO table and the input-output table. The energy type, affiliated industry and the carbon coefficient of the energy type are listed in Table A.2. Table A.3 presents the classification of 44 industries and two types of households in the ECEIO table.

Table 2.1 energy-carbon-economy input-output table

<table>
<tr><th colspan="5" rowspan="2">output
input</th><th colspan="2">Intermediate usage</th><th colspan="4">Final usage</th><th rowspan="2">Total output</th></tr>
<tr><th>Energy</th><th>Non-energy</th><th>Rural consumption</th><th>Urban consumption</th><th>Government consumption</th><th>…</th></tr>
<tr><td rowspan="20">Input</td><td rowspan="15">Intermediate input</td><td rowspan="10">Energy industry</td><td>Coal producing and selection</td><td>10^4 yuan</td><td>X^{EE}</td><td>X^{EN}</td><td colspan="4">F^{E}</td><td>X^{E}</td></tr>
<tr><td>Coal(usage/consumption)</td><td>ton/ton standard coal</td><td>X_u^{EE}</td><td>X_u^{EN}</td><td colspan="4">F_u^{E}</td><td>X_u^{E}</td></tr>
<tr><td>Carbon</td><td>metric ton</td><td></td><td></td><td colspan="4"></td><td></td></tr>
<tr><td>⋮</td><td>⋮</td><td>X_c^{EE}</td><td>X_c^{EN}</td><td colspan="4">F_c^{E}</td><td>X_c^{E}</td></tr>
<tr><td>Gas production and supplying</td><td>10^4 yuan</td><td></td><td></td><td colspan="4"></td><td></td></tr>
<tr><td>Gas(usage/consumption)</td><td>m^3/ton standard coal</td><td>X_c^{CE}</td><td>X_c^{CN}</td><td colspan="4">F_c</td><td>X_c</td></tr>
<tr><td>Carbon</td><td>metric ton</td><td>e_u^{e}</td><td>e_u^{n}</td><td colspan="4">e_u^{f}</td><td>e_u^{t}</td></tr>
<tr><td>Total usage of energy</td><td>ton standard coal</td><td>e_c^{e}</td><td>e_c^{n}</td><td colspan="4">e_c^{f}</td><td>e_c^{t}</td></tr>
<tr><td>Total consumption of energy</td><td>ton standard coal</td><td>c_z^{e}</td><td>c_z^{n}</td><td colspan="4">c_y</td><td>c^{t}</td></tr>
<tr><td>CO2 emissions</td><td>metric ton</td><td></td><td></td><td colspan="4"></td><td></td></tr>
<tr><td rowspan="4">Non energy industry</td><td>agriculture</td><td>10^4 yuan</td><td rowspan="5">X^{NE}</td><td rowspan="5">X^{NN}</td><td colspan="4" rowspan="5">F^{N}</td><td rowspan="5">X^{N}</td></tr>
<tr><td>⋮</td><td>⋮</td></tr>
<tr><td>⋮</td><td></td></tr>
<tr><td>The third industry</td><td>10^4 yuan</td></tr>
<tr><td colspan="2">Intermediate input in total</td><td>10^4 yuan</td></tr>
<tr><td rowspan="4">Value added</td><td colspan="2">Fix capital depreciation</td><td>10^4 yuan</td><td rowspan="4">V^{E}</td><td rowspan="4">V^{N}</td></tr>
<tr><td colspan="2">Remuneration of labor</td><td>10^4 yuan</td></tr>
<tr><td colspan="2">Tax and profit</td><td>10^4 yuan</td></tr>
<tr><td colspan="2">Value added in total</td><td>10^4 yuan</td></tr>
<tr><td colspan="3">Total input</td><td>10^4 yuan</td><td>X^{E}</td><td>X^{N}</td></tr>
</table>

Source: Designed and compiled by the author. The value part is from China's Input-Output Table; energy volume is from *China's Energy Yearbook*; carbon emission volume is computed from energy and the coefficient with reference to the Development Research Center of the State Council of China (DRCSCC).

Note: Energy value unit: 10^4 Yuan. Energy volume unit (physic quantity): metric ton (raw coal, crude oil, petroleum products, coking products); cubic meter (natural gas, oven gas, LPG); kWh (hydro, nuclear, and thermal power); and kJ (heat). Energy volume unit (standard unit): metric ton standard coal. Carbon dioxide unit: metric ton.

The rows of the ECEIO table reflect the usage and consumption of products of the energy industry and the non-energy industry. The output of energy of all types (X^E) meets the intermediate demand of the energy industry (X^{EE}), that of the non-energy industry (X^{EN}) and final demand (F^E). In contrast to the classic IO table, the product of energy of all types (X_u^E) is for the usage of the energy industry (X_u^{EE}) and that of the non-energy industry (X_u^{EN}) and the usage of household (F_u^E); the consumption of energy of all types (X_c^E) is consumed by the energy industry (X_c^{EE}) and by the non-energy industry (X_c^{EN}); and the embodied carbon emissions $X_c'^E$ originate from the consumption of energy in energy the industry ($X_c'^{EE}$) ,in the non-energy industry ($X_c'^{EN}$), and in household (F_c^E). In addition, the total usage of energy (e_u^t) is for usage in the energy industry (e_u^e) , in the non-energy industry (e_u^n), and in households (e_u^f), the total consumption of energy (e_c^t) is for the consumption in the energy industry (e_c^e), in the non-energy industry (e_c^n) , and in households (e_c^f), the total carbon emissions(c^t) originate from the consumption of energy in the energy industry (c^e), in the non-energy industry (c^n), and in households (c^f). The output of products of the non-energy industry (X^N) meets the demand of the energy industry (X^{NE}) and by non-energy (X^{NN}) and the final demand (F^N). The columns of the ECEIO table reflect the input of the energy industry and the non-energy industry. The total input of the energy industry (X^E) originate from primary input (V^E) and intermediate input of energy industry (X^{EE}) and intermediate input of the non-energy industry (X^{NE}).The total input of the energy industry (X^N) originates from primary input (V^N) and intermediate input of the energy industry (X^{NE}) and intermediate input of the non-energy industry (X^{NN}).The capital letters means the matrix, lower case letter means the vector, and apostrophe means transposition of vector. The ECEIO table is a mixture table, combining value and volume. The input of the energy industry is reflected in both value unit and quantitative value. The carbon emissions are reflected as quantitative value.

The equations for economy system and carbon emissions in the ECEIO table are expressed as[1]:

$$x = Ax + f \tag{2.1}$$

$$x_c = I_c x + f_c \tag{2.2}$$

$$c^t = \tilde{i}_c X + c_y \tag{2.3}$$

Here, x is the column of output, $f = [F^E \; F^N]'$ is the final demand of kind. A is the direct coefficient matrix in input-output table in value, $A = \begin{bmatrix} A^{EE} & A^{EN} \\ A^{NE} & A^{NN} \end{bmatrix}$. The element $\{a_{kj}\} = \left\{ \frac{\bar{x}_{kj}}{x_j} \right\}$ is the product used in industry k for production of industry j, namely $A^{EE} = \{a_{kj}^{ee}\} = \left\{ \frac{\bar{x}_{kj}^{ee}}{x_j^e} \right\}$, $A^{EN} = \{a_{kj}^{en}\} = \left\{ \frac{\bar{x}_{kj}^{en}}{x_j^n} \right\}$, $A^{NE} = \{a_{kj}^{ne}\} = \left\{ \frac{\bar{x}_{kj}^{ne}}{x_j^e} \right\}$, $A^{NN} = \{a_{kj}^{nn}\} = \left\{ \frac{\bar{x}_{kj}^{nn}}{x_j^n} \right\}$. I_c is the coefficient matrix of carbon emission, i.e. the intensity of carbon emission. The element $\{i_{c\,kj}\} = \left\{ \frac{x_{c\,kj}}{x_j} \right\}$ is the carbon

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[1] Energy balance equations in the ECEIO model are as follows:

(1) Equation of usage of energy by type: $X_u^E = I_u^E X + F_u^E$ (2) Equation of consumption of energy by type: $X_c^E = I_c^E X + F_c^E$

(3) Equation of total usage of energy: $e_u^t = \tilde{i}_u X + e_u^f$ (4) Equation of total consumption of energy: $e_c^t = \tilde{i}_c^e X + e_c^f$

Here, I_u^E is the coefficient matrix of usage of energy, i.e. intensity of energy usage. The element $\{i_{kj}\} = \left\{ \frac{x_{u\,kj}^e}{x_j} \right\}$ is the usage of energy of type k for one unit of production of industry j; I_c^E is the coefficient matrix of consumption of energy, i.e. intensity of energy consumption. The element $\{i_{c\,kj}^e\} = \left\{ \frac{x_{c\,kj}^e}{x_j} \right\}$ is the consumption of energy of type k for one unit of production of industry j; $\tilde{i}_u^e$ is The coefficient vector of usage of energy, i.e. intensity of total usage of energy, the element $\{\tilde{i}_{kj}\} = \left\{ \frac{e_{u\,j}^e}{x_j} \right\}$ is the total usage of energy for one unit of production of industry j; $\tilde{i}_c^E$ is the coefficient vector of consumption of energy, i.e. intensity of final consumption of energy. The element $\{\tilde{i}_{c\,kj}^e\} = \left\{ \frac{e_{c\,j}^e}{x_j} \right\}$ is the final consumption of energy for one unit of production of industry j.

emitted by usage of energy of type k for one unit of production of industry j . $\tilde{i}_c$ is the coefficient vector of carbon emission, i.e. intensity of carbon emission. The element $\{\tilde{i}_{c\ kj}\} = \left\{\frac{c_j}{x_j}\right\}$ is the carbon emitted by usage of energy for one unit of production of industry j .

The usage of energy X_u^E consists of the consumption of energy X_c^E and the energy processing and transformation X_t^E and the energy loss X_l^E [2].

$$X_u^E = X_c^E + X_t^E + X_l^E \tag{2.4}$$

The burning activity of energy discharge carbon dioxide. The energy of different type emits the carbon dioxide at different emission rate. $x_{c\,kj}$ is the carbon dioxide origin from consumption of energy of type k in industry j , $x_{c\,kj} = d_k \times x_{c\ kj}^{E}$ [3]. Here d_k is the CO2 emission coefficient of type k [4]. It consistently link to the energy consumed unit of ton standard coal.

CO2 emission coefficient (d)=carbon embodied ×net thermal value×oxidation rate (2.5)

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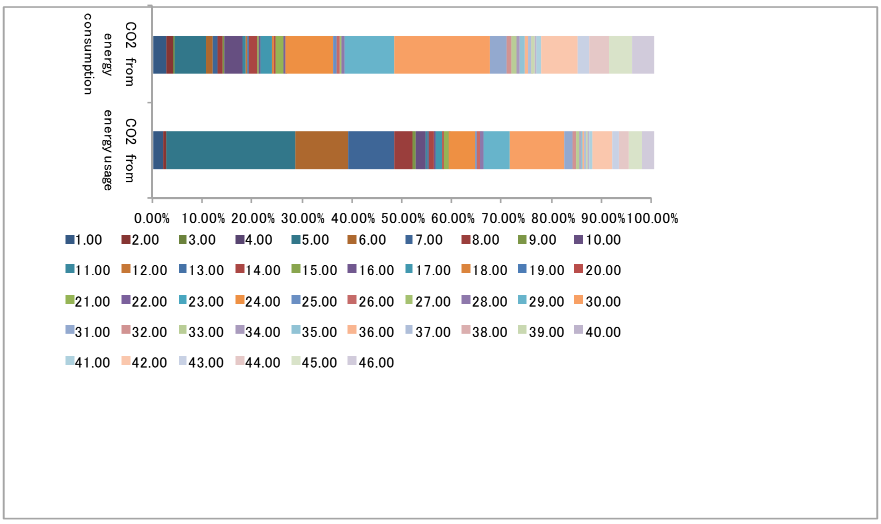
[2] The unit of usage of energy X_u^E, and consumption of energy X_c^E can be transferred to the standard unit (ton standard coal). The total energy usage and total energy consumption is the sum of usage and consumption of energy all types in an industry. $e_{u\,j} = \sum_{k=1}^{m} x_{u\,kj}$, $e_{c\,j} = \sum_{k=1}^{m} x_{c\,kj}^{e}$. Here, m is the number of energy industry.

[3] The sum of carbon dioxide emitted by consumption of energy of type k in industry j is the carbon emitted by consumption of energy in industry j , $c_{z\,j} = \sum_{k=1}^{m} x_{c\,kj}^{e}$

[4] Carbon emission coefficient is measured according to the equation and data in 《2006 IPCC Guidelines on National Greenhouse Gas Inventories》 . The carbon emission coefficients of energy by type are shown in table A.2. The thermal power or heat is computed by carbon emission of all input of energy by all types for one unit of the output of product of thermal power or heat according to the energy balance table of each year.

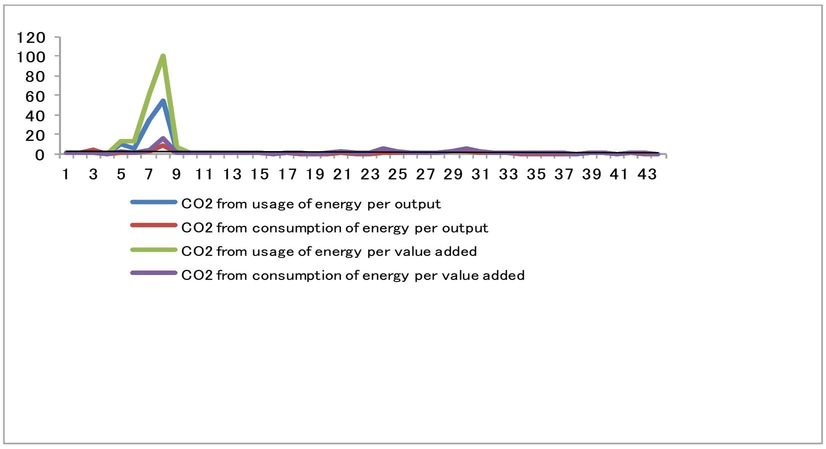
Carbon emission in 2005 is 2.6 billion metric tons from usage of energy and 1.3 billion metric ton from final consumption of energy. Figure 2.1 gives the carbon emission share of 44 industries, and rural and urban households. If transformation of energy is included in carbon emission, the industry with the largest share is the energy industry; otherwise, it is the heavy industries. The largest percentage of emission from usage of energy exits in industry 5 Production and Distribution of Thermal Power (25.6%), 6 Processing Petroleum (10.9%), 7 Coking (9.1%), 30 Smelting and Pressing of Ferrous Metals (10.8%), 42 Transportation, storage, Storage and Post (4.1%), 8 Production and Distribution of Heat Power (3.7%); The largest shares of emissions from final consumption of energy exits in industry 30 Smelting and Pressing of Ferrous Metals (19.4%), 29 Manufacture of Non-metallic Mineral Products (9.8%), 24 Manufacture of Raw Chemical Materials and Chemical Products (9.6%), 42 Transportation, storage, Storage and Post (7.3%), and 5 Production and Distribution of Thermal Power (6.3%).

Figure 2.1 Share of carbon emission by industry



As for carbon emissions intensity in 2005, production of 10,000 yuan worth of output produced 0.77 metric tons of carbon dioxide from energy usage and 0.43 metric tons from energy consumption; 10,000 yuan worth of value added generated 1.29 metric tons of carbon dioxide from energy usage and 0.72 metric tons from energy consumption. There are two notable characteristics in the carbon intensity of each industry shown in Figure 2.2. The first characteristic is that the energy industry has the largest carbon intensity, and the carbon intensity from energy usage is much larger than that from energy consumption. Looking at the industrial categories, 8 Production and distribution of heat power releases 53.98 metric tons of carbon dioxide from energy usage, 8.22 tons from consumption per 10,000 yuan of output, 100.45 tons from energy usage and 15.29 tons from energy consumption per 10,000 yuan of value added; 7 Coking releases 35.67 metric tons of carbon dioxide from energy usage 2.12 tons from consumption per 10^4 yuan of output, 61.91 tons from energy usage and 3.67 tons from energy consumption per 10^4 yuan of value added; (2)The heavy industry has the comparative large carbon intensity. 30 Smelting and Pressing of Ferrous Metals bring into 2.29 metric tons carbon dioxide from usage/consumption of energy for 10^4 Yuan output, and 5.41 tons from usage/consumption of energy for 10^4 Yuan value added.

Figure 2.2 Carbon intensity in 2005 (unit: ton/10^4 Yuan)[5]



[5] Carbon intensity unite: Metric tons carbon dioxide per 104 Yuan output Metric tons carbon dioxide per 104 Yuan value added

Energy industry:		
8 Production and Distribution of Heat Power:	53.98 (energy usage),	100.45(energy usage)
	8.22 (energy consumption)	15.29(energy consumption)
7 Coking:	35.67 (usage of energy)	61.91 (energy usage)
	2.12 (energy consumption)	3.67(energy consumption)
5 Production and Distribution of Thermal Power:	9.46(energy usage)	12.31 (energy usage)
	1.31 (energy consumption)	1.7 (energy consumption)
6 Processing Petroleum:	4.78 (energy usage)	12.72 (energy usage)
	0.36 (energy consumption)	0.95(energy consumption)
Heavy industry:		
30 Smelting and Pressing of Ferrous Metals:	2.29 (energy usage/consumption)	5.41 (energy usage/consumption)
29 Manufacture of Non-metallic Mineral Products:	1.22 (energy usage/consumption)	5.85 (energy usage/consumption)
24 Manufacture of Raw Chemical Materials and Chemical Products:	2.25(energy usage/consumption)	3.04(energy usage/consumption)

3. Reconfiguration of industrial structure to reduce GHG emissions in China

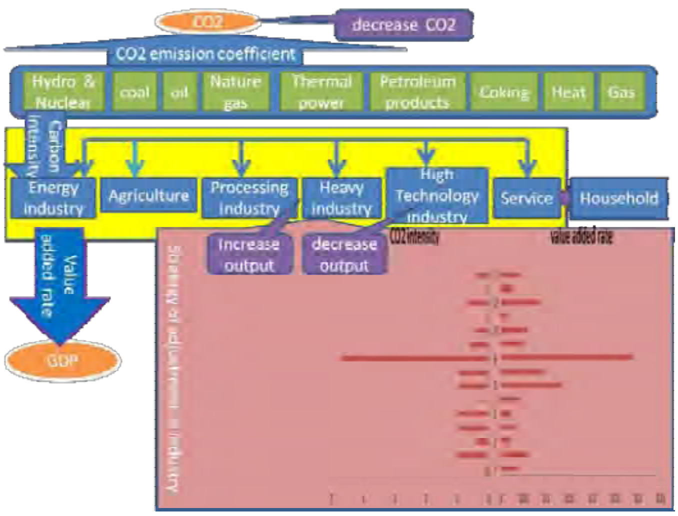
3.1. Mechanism of adjusting industrial structure to reduce carbon emissions

Industrial structure is adjusted to reduce the carbon emissions in total. The mechanism is preformed as shown in Figure 3.1. The energy system with 9 types of energy is associated with economy system with all kinds of industries and households. The carbon dioxide is emitted during the production of industry when using or consuming the energy of all types by different rate. If the industry structure is adjusted well, the carbon emission can be reduced without decrease of the total output or GDP. One the one hand, China reduces the output of industry with high carbon emission coefficient (heavy industry) and increases the output of industry with low carbon emission coefficient (high technology industry). The input of energy to heavy industry decrease, which further induce the energy input of other industries decreasing, so carbon emission decrease; while the input of energy to high technology industry increase, which further induce the energy input of other industries increasing, so carbon emission increase. The directly and indirectly carbon emission caused by the decrease in the output of heavy industry is more than the directly and indirectly carbon emission caused by the increase in the output of high technology. On the other hand, China reduces the output of industry with low total demand coefficient or low value added rate, and increases the output of industry with high total demand coefficient or high value added rate. It made the total output or GDP increase. The strategy of adjustment of industry structure has two effects. One is changing the energy input and reducing emitted carbon emission; another is changing the relationship of input and output among industries and increase the GDP or total output.

The strategy can be known through comparing CO2 intensity and value added share by the industries. Through the ECEIO table with 15 industries in 2007, we can find that services and agriculture have less CO2 intensity (1.37 ton per 1000 Yuan) and larger share of value added in output (3.7%). Heavy manufactures have the largest CO2 intensity as well as largest value added share (rate). For example, CO2 intensity of industry 9 Metal processing and manufacture was 47.21 ton per 1000 Yuan, that of industry 7 Chemical and Pharmaceutical and Medicine Manufacturing was 9.65 ton per 1000 Yuan, and that of industry 8 Building materials and non-Metallic Materials Industry was 9.41 ton per 1000 Yuan, the share of value added to output in these three industry were 28.9%, 13.5% and 9.4%. High technical manufacture, for example, industry 10 Mechanic, electronic equipment and other manufacturer, have less CO2 intensity, namely, 6.00 ton per 1000

Yuan, but comparative large value added share (rate), i.e. 5.0%; Light manufactures have comparative large CO2 intensity but less value added share (rate). CO2 intensity of industry 5 Wood processing and Manufacture of Articles for Culture, Education and Sport Activities, industry 4 Textile, Wearing Apparel, and industry 3 Food manufacture and tobacco processing were respectively 10.16 9.34 and 4.04 ton per 1000 Yuan, and the share of these industries were 2.2%, 3.2% and 2.1%. Energy industries, for instance, industry 6 Petroleum Processing, Coking and Nuclear Fuel Processing and industry 11 Electricity, heat power and water production and supply have comparative less CO2 intensity, i.e. 1.75 ton per 1000 Yuan and 4.75 ton per 1000 Yuan, as well as comparative less share of value added, i.e. 4.1% and 5.6%. However, industry 2, Mining, had comparative large CO2 intensity, i.e. 10.17 ton per 1000 Yuan and small share of value added, i.e. 5.5%.

Figure 3.1 Adjustment of industrial structure to reduce CO_2

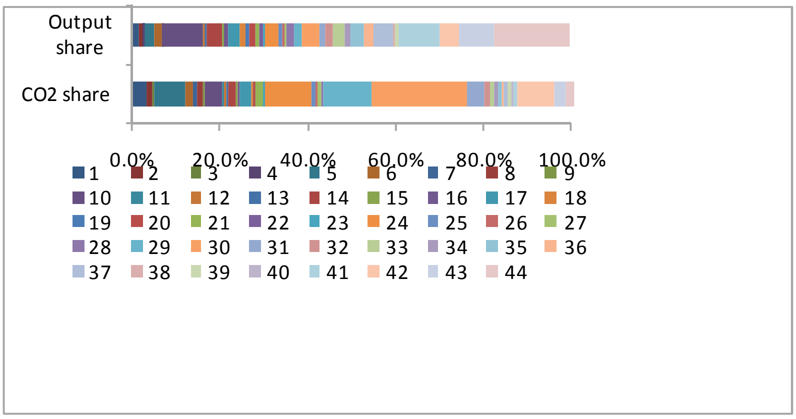


Note: the CO2 intensity and value added rate are obtained according the ECEIO table in 2007 with 15 industries.

3.2 Way to reduce carbon emissions

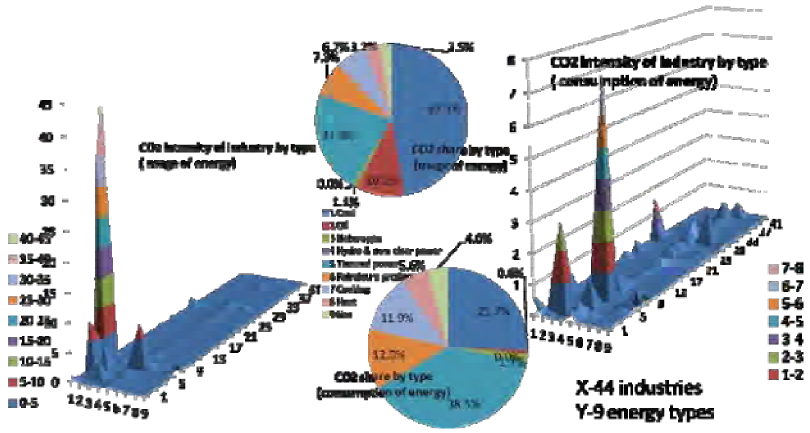
The ECEIO table shows that **reducing the carbon emission requires changing the industry structure.** We compare the CO2 share of each industry to all industries with the output share of each industry to the total output. Figure 3.2 shows the share of CO2 from final consumption of energy, and the output share of each industry to the total. On one hand, the heavy industry and energy industry take the large share of carbon emission from final consumption to that of all industries, but less share of value added to GDP. For example, 30 Smelting and Pressing of Ferrous Metals takes 21.8% of carbon emission and 3.6% of value added, 29 Manufacture of Non-metallic Mineral Products as 11% of carbon emission and 1.9% of value added, 5 Production and Distribution of Thermal Power as 7.2% of carbon emission 2.1% of value added in all industries. On the other hand, services and high technology industry take the large value added share but less carbon emission share. For example, 44 Real estate finance and other service takes 17.7% of value added to GDP and 4.5% of carbon emission in all industries, 43 wholesale and retail trades takes 7.8% of value added and 2.6% of carbon emission. 33 Manufacture of General Purpose Machinery as 1.1% of carbon emission, and 2.6% of value added; 34 Manufacture of Special Purpose Machinery has 0.7% of carbon emission and 1.6% of value added; 35 Manufacture of Transport Equipment has 1.1% of carbon emission and 3.1% of value added; 36 Manufacture of Electrical Machinery and Equipment has 0.6% carbon emission and 2.3% of value added; 37 Manufacture of Communication Equipment Computers and Other Electronic Equipment has 0.8 of carbon emission and 4.1% of value added. Reduction of carbon emission can be realized through increase the output of high technology industry with less carbon emission, and decrease the output of heavy industry and energy industry with high carbon emission.

Figure 3.2: CO_2 share and value added share of each industry



Reducing the carbon emissions requires changing structure of energy input by industry. Among the all types energies, the hydro power and new clear power do not emit carbon emission, fossil energy emit carbon dioxide with different rate. The output requires different amount input of energy by type, emitting different amount of carbon dioxide. According to Figure 3.3, the carbon emission from the usage of energy has 47.3% from coal, 10.2 from oil, 1.1% from nature gas, 21.6% from thermal power; the emission from the consumption of energy has 38.5% from thermal power, 25.7% from coal, 12% from petroleum product and 11.9% from coking. Reduction of carbon emission requires deducing the input of energy of type with high carbon emission coefficient and increasing input of energy of type with low carbon emission coefficient. Figure 3.3 shows the carbon emission coefficient of each industry by energy type. Comparing to other energy, coal and thermal power emit at largest extent of carbon emission for 10000 Yuan output of secondary energy industry. coal emit 43.4 tons carbon for 10000 Yuan output of 8 Production and Distribution of Heat Power, 34.6 tons carbon for 7 Coking, 8.1 tons carbon for 10000 Yuan output of 5 Production and Distribution of Thermal Power, 2.2 tons carbon for 10000 Yuan output of Gas from usage of energy. Thermal power emit 7.3 ton carbon for 10000 Yuan output of 8 Production and Distribution of Heat Power, 1 ton carbon for 10000 Yuan output of 5 Production and Distribution of Thermal Power from both usage and consumption of energy. Among the non-energy industry, the carbon emission coefficient in heavy industry is comparative large. Coal emit 1.5 ton for 10000 Yuan output of 29 Manufacture of Non-metallic Mineral Products, coking 1.2 tons carbon for 30 Smelting and Pressing of Ferrous Metals, thermal Power emit 0.8 ton carbon for 10000 Yuan output of 31 Smelting and Pressing of Non-ferrous Metals, 0.5 ton in 29 Manufacture of Non-metallic Mineral Products, 0.5 ton in 30 Smelting and Pressing of Ferrous Metals. On contrary, the hydro power and new clear power has no carbon emission. Oil and nature gas has the low carbon emission. The carbon emission coefficient of oil and nature gas in high technology industry and service is the lowest. It is below 0.1 ton carbon for thousand Yuan of output in 44 Real estate finance and other service, 43 wholesale and retail trades 33 Manufacture of General Purpose Machinery 34 Manufacture of Special Purpose Machinery 35 Manufacture of Transport Equipment 36 Manufacture of Electrical Machinery and Equipment 37 Manufacture of Communication Equipment Computers and Other Electronic Equipment. The reduction of carbon emission can be realized through deduce the input of coal and thermal power in energy industry and heavy industry, and increase the input of oil and nature gas in high technology industry and service.

Figure 3.3: Carbon dioxide shares by type and carbon intensity of industry by type



Notes:
Left chart-the CO2 intensity of 44 industries by 9 types of used energy;
Right chart-the CO2 intensity of 44 industries by 9 types of consumed energy;
The above pie chart-CO2 share by 9 types of used energy;
The below pie chart-CO2 share by 9 types of consumed energy;
X axle - 44 industries (classification refers to Table A. 3);
Y axle - 9 energy types (classification refers to Table A.2).
Data source: 2005 ECEIO table

3.3 Potential for adjustment of industrial structure to reduce carbon emissions

The paper researches on the potential of structure adjustment on the reduction of carbon emission. China can improve the percentage of its industry with low carbon emissions to achieve lower total carbon emissions of the whole country. Industrial structure adjustment causes a change in the ratio of different industrial outputs in the national economy and results in a change in the amount of carbon dioxide produced by the whole economy. A suitable research method is to connect input of various kinds, including energy, to the output of various industries in the national economy. The output of each industry corresponds to the carbon dioxide released by consumption of fossil energy. We use the carbon coefficient to reflect the relation between the output of various industries and carbon dioxide emissions. In the future, changes in the industrial structure in developing country will be massive. The ratio of Chinese gross domestic production in three industries was 10.3：46.3：43.4 in 2009, meanwhile, the sum of the GDP of the first industry and the second industry was 19.3 trillion Yuan， second to the US and superior to Japan. The productivity of the primary industry is low, the secondary industry has high pollution and high emissions, and the tertiary industry has a low carbon emission coefficient and high profit. Assuming that the GDP of China in 2020 will be close to that of the US, the production of various industries will be adjusted to reduce the output of industries with high emissions and increase the output of industries with low emissions so as to reduce the emissions of the whole country.

Assumed constraint of carbon emission, the research presents an optimal model to address the adjustment of industry structure, and potential of the reduction of carbon emission. The adjustment of industry structure refers to the difference of output of various industries at present structure and that of optimal structure. We produce the scenarios for reduced carbon emissions permitted, and find that the potential capability vary from the various industries. It is defined as the difference between the outputs of each industry at present and that of an optimal structure given carbon emission constraints. The negative figures refer to the potential capability for output to decrease, and positive figures refer to the potential capability for output to increase. If potential capability is larger, then the given industry has more space to be improved or optimized so that the contribution of this sector is larger; if the potential capability is smaller, then the industry has less space to be improved or optimized so that the contribution of this industry is smaller. The potential capability for adjustment of industrial structure is shown as,

$$\Delta s_j = s_j(t) - s_j(0) \qquad (3.1)$$

$[s_j] = [x_j / x]$ refers to the ratio of output x_j of industry j to the total output x, $s_i(t)$ and $s_j(0)$ respectively reflect the optimal industry structure of industry j and initial industry structure of industry i. The penitential of the reduction of carbon emission of each industry is

$$\Delta \mathrm{c_j}/\mathrm{c_j}(0) = (\mathrm{c_j}(\mathrm{t}) - c_j(0))/c_j(0) \qquad (3.2)$$

$c_j(t)$ and $c_j(0)$ is the difference of carbon emission after and before optimization.

3.4 Optimal input-output model

The carbon emission is produced by fossil energy consumption; other non-fossil energy consumption and ecology activity don't produces dioxide carbon. Here the carbon emission from consumption of energy is computed. Target of reduction of carbon emissions are classified into two types: reduction of carbon intensity and reduction of absolute amount of carbon emission. At present, China promise the first type of reduction target. Three scenarios are set corresponding to three constraints of carbon intensity, each of which has three constraints of amount of carbon emission assumed three growth rates. The scenarios are shown as table 3.1[6].

Table 3.1 Index of intensity of carbon emissions and carbon emissions per year (%)

Scenario 1			Scenario 2			Scenario 3		
$\Delta\tilde{i}_c$	φ	ϕ	$\Delta\tilde{i}_c$	φ	ϕ	$\Delta\tilde{i}_c$	φ	ϕ
-5.93	9	2.53	-6.35	9	2.08	-6.76	9	1.63
	8	1.60		8	1.14		8	0.70
	7.5	1.12		7.5	0.67		7.5	0.23

Notes: $\Delta\tilde{i}_c$ Change rate of carbon intensity, φ Growth rate of GDP, ϕ Change rate of carbon amount

From the ECEIO table and scenarios, this paper builds the optimization input-output model. The objective is to maximize the GDP from input-output equation; the constraints are input-output equations, carbon emission constraints, and economic growth.

6 China presents the target of decreasing the intensity of carbon emission as that China's carbon dioxide emissions per GDP in 2020 decreased to 40% -45% compared with 2005's, and in 2020 our nation's non-fossil fuels declined to 15% around proportion in primary energy consumption. Define intensity of carbon emission (i) equal to the total amount of dioxide carbon produced by energy consumption (c^t) divided by national production amount (gdp), then the intensity of carbon emission is $i = c^t / gdp$ and the reduction of intensity of carbon emission over 15 years is $\Delta\tilde{i}_c(15) = -\frac{c^t(15)/gdp(15) - c^t(0)/gdp(0)}{c(0)/gdp(0)} \times 100\% \in (40\%,45\%)$. We assumes target of reducing the intensity of carbon emission is consist in the whole country, then intensity of carbon emission in average of 15 year from 2005 to 2020 is reduced arrange from (-6.76%, -5.93%). The process of computing low bound and up bound of them are express as $\sqrt[15]{(1-40\%)} - 1 = -6.76\%$ and $\sqrt[15]{(1-45\%)} - 1 = -5.93\%$ .In order to analysis in more detail, we add the mean value of target of carbon emission, then the index of target of carbon emission intensity has high value（5.93%）, middle value（6.35%）, and low value（6.76%）as three scenarios. Assume growth rate per year of GDP as three cases, namely quick growth rate of GDP（9%）, normal growth rate（8%） and slow growth rate（7.5%）, we obtain the three cases of the change in the amount of carbon emission under the condition of each scenario of the intensity of carbon emission

$$
\text{object} : \max o'(I-A)x
$$

$$
s.t.\begin{cases}
Ax + y + p - m \le x & \text{(I)Input-output balance constraints} \\
\widetilde{i_c}\ x + c_Y \le \phi \times c^t(0) & \text{(II)Emission reduction targets constraints} \\
\hat{V}x \ge \varphi \times gdp(0) & \text{(III) Economy growth constraint} \\
x^l \le x \le x^u & \text{(IV)The upper and lower bounds of output} \\
p^l \le p \le p^u & \text{(V) The upper and lower bounds of export} \\
m^l \le m \le m^u & \text{(VI) The upper and lower bounds of import}
\end{cases} \tag{3.2}
$$

The model is express in equation 3.2. It including (1) objective, that is maximum of GDP; (2) input-output balance equation, namely the output of various industries meet demand, final demand, import and export; (3) Emission reduction constraints, which is the amount of carbon emission at most; (4) economic growth constraints, which is the amount of GDP at lest; (5) the up and low bound of output. (3) and (4) are set according to three scenarios in Table 3.1. φ is the growth rate of GDP per year, and ϕ is growth rate of carbon emission per year. A Stands for direct consumption coefficient matrix in the input-output tables, x is that the output vector, y is the vector of final demand of households, o' is price vector as the format of unit row vector, p and m are respectively exports and imports vector, $\widetilde{i_c}$ is the vector of intensity the carbon emission by industry, c_y is carbon emission for household, $c^t(0)$ is the total carbon emission at the initial time, $\hat{V}$ is diagonal matrix of value added rate, GDP is the gross domestic production at initial time. The subscript l and superscript u are lower and upper bounds respectively. The up bound of output is 125% output of past year (Rose et al, 1996). There are no low bound for production and export, and no up bound for import (ten Raa et al, 2010).

We use the optimal model to calculate the optimal industry structure of China. Assumed the original economy taking structure in 2005, the model is applied to find how the industry structure be arranged to realize 6.35% of reduction of the carbon emission intensity next year (the middle level among 3 scenarios), equivalent to 1.14% of increase of the amount of carbon emission next year if GDP increase by 8% (scenario 2). Here the coefficient A, $\widetilde{i_c}$, $\hat{V}$ are from the 2005 China ECEIO table. We take the carbon $c^t(0)$ and $gdp(0)$ in 2005, and up bound of the output and export is

125% of output and export in 2005. The 2005 China ECEIO table applied here only account the carbon emission from the final consumption of energy. The table has 44 industries, classified as Table A. 4.

3.5 Potential for structural adjustment and carbon reduction

Table 3.2 Potential adjustment of industrial structure and reduction of carbon emissions

Industry	ΔS_j	$\Delta C_j / C_j(0)$	Industry	ΔS_j	$\Delta C_j / C_j(0)$	Industry	ΔS_j	$\Delta C_j / C_j(0)$
1	-0.39%	-8.70%	16	0.04%	33.75%	31	-0.61%	-19.75%
2	0.07%	33.75%	17	0.20%	33.75%	32	0.14%	33.75%
3	0.01%	33.75%	18	0.09%	33.75%	33	0.21%	33.75%
4	0.04%	33.75%	19	0.06%	33.75%	34	0.11%	33.75%
5	-0.98%	-19.75%	20	0.08%	33.75%	35	0.23%	33.75%
6	0.14%	33.75%	21	-0.38%	-19.75%	36	0.21%	33.75%
7	-0.09%	-19.75%	22	0.04%	33.75%	37	0.36%	33.75%
8	-0.02%	-19.75%	23	0.03%	33.75%	38	0.05%	33.75%
9	-0.05%	-19.75%	24	-0.53%	-19.75%	39	0.06%	33.75%
10	0.51%	33.75%	25	-0.19%	-19.75%	40	0.01%	33.75%
11	0.02%	33.75%	26	-0.18%	-18.76%	41	0.55%	33.75%
12	0.02%	33.75%	27	0.11%	33.75%	42	0.32%	33.75%
13	0.03%	33.75%	28	0.23%	33.75%	43	0.44%	33.75%
14	0.24%	33.75%	29	-1.01%	-19.75%	44	1.15%	33.75%
15	0.05%	33.75%	30	-1.45%	-19.75%			

Notes: The carbon emission increases by ΔC=1.4 million ton carbon dioxide (carbon emission intensity decrease 6.35% per year). ΔS_j is the ratio of industry to total output. $\Delta C_j / C_j(0)$ means the change in the amount of carbon emission. Positive (+) means increase, and minus (-) means decrease. Computation from optimal input-output table based on 2005 ECEIO table.

The optimal adjustment of industrial structure and potential of carbon emissions has the same change direction, shown as table 3.2. *The output and carbon emissions decrease in energy industry and heavy industry with high carbon emission coefficient.* These industries include 1 Mining and Washing of Coal 5 Production and Distribution of Thermal Power, 7 Coking, 8 Production and Distribution of Heat, 9 Production and Distribution of Gas, 21 Manufacture of Paper and Paper Products, 24 Manufacture of Raw Chemical Materials and Chemical Products, 25 Manufacture of Medicines, 26 Manufacture of Chemical Fibers, 29 Manufacture of Non-metallic Mineral Products, 30 Smelting and Pressing of Ferrous Metals, 31 Smelting and Pressing of Non-ferrous Metals.

Meanwhile, the output of 29 Manufacture of Non-metallic Mineral Products, 30 Smelting and Pressing of Ferrous Metals, and 5 decrease at the largest extend, about 1% of the original output. The carbon emission of 1 Mining and Washing of Coal decrease 8.7%; the carbon emission of other industries decreases by 19.75%. *On contrary, the output and carbon emission increase in the rest of industries, especially services and high technology industry, including energy industry with low carbon emission coefficient*. The carbon emission all increase by 33.75% for all of these industries. The output increase at largest extent in the service, (i.e. 44 Real estate finance and other service, 43 wholesale and retail trades, 42 Transportation, storage, Storage and Post), high technology industry (i.e. 37, Manufacture of Communication Equipment, Computers and Other Electronic Equipment 35 Manufacture of Transport Equipment, 36 Manufacture of Electrical Machinery and Equipment, 33manufacture of General Purpose Machinery), and processing industry (i.e. 14 Manufacture of Foods, 28 Manufacture of Plastics), and 41 Construction, 10 Agriculture.

3.5 .1 Industrial structure adjustment of 3 scenarios

We set three scenarios of target of carbon emission intensity by high target, middle target and low target, and each of them with three cases of economy growth rate as 9%, 8% and 7.5%, corresponding 9 cases of constraints of carbon emission amount. Industries are cut to 15 in the ECEIO table in 2007.

We list the 9 case of potential of 15 industries adjustment in the table 3.3. The most industries increased in their output ratio to total output. High technology industry and service increase largest. For example, mechanical, electronic equipment manufacturer has the largest increase, range from 1.72% to 1.85%, real estate, finance and other service has the second largest increase, from 1.17% to 1.26%. Only heavy industries with high carbon emission coefficient, 9 metal processing and manufacturer, decrease the industry structure, ranging from -8.74% to -8.13%. *The increase range of industries output became larger as the constraints of carbon emission tighter, or as the economy growth rate slower*. At the same level of 9% growth rate of GDP, 10 mechanical, electronic equipment manufacturer increases industry structure by 1.72% with the carbon constraint increase by 2.53 ton carbon in scenario 1, increases industry structure by 1.74% with carbon constraint increase by 2.08 ton carbon in scenario 2, and increases industry structure by 1.77% with carbon constraint increase by 1.63 ton carbon dioxide in scenarios 3. At the scenario 1, the industry's structure increases by 1.72%, 1.77% and 1.80 with the economy growth rate as 9%, 8% and 7.5%.

Similarly, the structure of industry 9 decreases by 8.13% with carbon constrain increase of 2.53 ton carbon dioxide, by 8.25% with carbon constrain increase of 2.08 ton carbon dioxide, and by 8.37% with carbon constraints increase of 1.63 ton carbon dioxide. In scenario 1, the carbon emission constraint decreases as 5.93%, the structure of industry 9 decreases respectively as 8.13%， 8.38% and 8.50% with the economy growth rate as 9%, 8% and 7.5%.

Table 3.3 China's potential adjustment of industrial structure (no energy structure change)

ΔS_j	Scenario 1(low:-5.93%)			Scenario 2(middle:-6.35%)			Scenario 3(high:-6.76%)		
ΔC GDP	2.53 9%	1.60 8%	1.12 7.5%	2.08 9%	1.14 8%	0.67 7.5%	1.63 9%	0.70 8%	0.23 7.5%
1	0.54%	0.55%	0.56%	0.55%	0.56%	0.57%	0.55%	0.57%	0.58%
2	0.32%	0.33%	0.34%	0.33%	0.34%	0.34%	0.33%	0.34%	0.34%
3	0.46%	0.47%	0.48%	0.47%	0.48%	0.49%	0.47%	0.49%	0.49%
4	0.48%	0.49%	0.50%	0.48%	0.50%	0.50%	0.49%	0.50%	0.51%
5	0.28%	0.29%	0.30%	0.29%	0.30%	0.30%	0.29%	0.30%	0.31%
6	0.23%	0.24%	0.24%	0.23%	0.24%	0.25%	0.24%	0.25%	0.25%
7	0.68%	0.70%	0.71%	0.69%	0.71%	0.72%	0.70%	0.72%	0.73%
8	0.25%	0.26%	0.26%	0.25%	0.26%	0.27%	0.26%	0.27%	0.27%
9	-8.13%	-8.38%	-8.50%	-8.25%	-8.50%	-8.62%	-8.37%	-8.61%	-8.74%
10	1.72%	1.77%	1.80%	1.74%	1.79%	1.82%	1.77%	1.82%	1.85%
11	0.37%	0.38%	0.39%	0.38%	0.39%	0.39%	0.38%	0.39%	0.40%
12	0.69%	0.71%	0.72%	0.70%	0.72%	0.73%	0.71%	0.73%	0.74%
13	0.47%	0.48%	0.49%	0.47%	0.49%	0.49%	0.48%	0.49%	0.50%
14	0.48%	0.49%	0.50%	0.49%	0.50%	0.51%	0.49%	0.51%	0.52%
15	1.17%	1.20%	1.22%	1.18%	1.22%	1.24%	1.20%	1.24%	1.26%

Notes: The industry is classified as China's ECEIO table in 2007(industry classification refers to Table A 5). Computation from optimal input-output table based on 2007 China ECEIO table.

Table 3.4 China's potential capability of industrial structure (energy structure change)

ΔS_j	Scenario one*			Scenario two*			Scenario three*		
ΔC	2.53	1.60	1.12	2.08	1.14	0.67	1.63	0.70	0.23
GDP	9%	8%	7.5%	9%	8%	7.5%	9%	8%	7.5%
1	0.44%	0.45%	0.46%	0.45%	0.46%	0.47%	0.45%	0.47%	0.48%
2	0.26%	0.27%	0.28%	0.27%	0.28%	0.28%	0.27%	0.28%	0.29%
3	0.37%	0.39%	0.40%	0.38%	0.39%	0.40%	0.39%	0.40%	0.41%
4	0.39%	0.40%	0.41%	0.39%	0.41%	0.42%	0.40%	0.42%	0.42%
5	0.23%	0.24%	0.25%	0.24%	0.24%	0.25%	0.24%	0.25%	0.25%
6	0.19%	0.20%	0.20%	0.19%	0.20%	0.20%	0.20%	0.20%	0.21%
7	0.55%	0.58%	0.59%	0.56%	0.59%	0.60%	0.57%	0.60%	0.61%
8	0.20%	0.21%	0.22%	0.21%	0.22%	0.22%	0.21%	0.22%	0.22%
9	-6.62%	-6.87%	-7.00%	-6.74%	-6.99%	-7.12%	-6.86%	-7.11%	-7.24%
10	1.40%	1.45%	1.48%	1.42%	1.48%	1.50%	1.45%	1.50%	1.53%
11	0.30%	0.31%	0.32%	0.31%	0.32%	0.32%	0.31%	0.32%	0.33%
12	0.56%	0.58%	0.59%	0.57%	0.59%	0.60%	0.58%	0.60%	0.61%
13	0.38%	0.39%	0.40%	0.39%	0.40%	0.41%	0.39%	0.41%	0.42%
14	0.39%	0.41%	0.41%	0.40%	0.41%	0.42%	0.40%	0.42%	0.43%
15	0.95%	0.99%	1.00%	0.97%	1.00%	1.02%	0.99%	1.02%	0.104

Notes: The industry is classified as China's ECEIO table in 2007 (industry classification refers to Table A 5). Computation from optimal input-output table based on 2007 China ECEIO table.

We compute the potential adjustment of industrial structure with the energy structure change, shown in Table 3.4. The energy structure change refers to the change in the ratio of non-fossil energy to the consumption of first primer energy by 15% between 2005 and 2020. It can be seen that non-fossil energy consumption increased by 5.4%. In this case, the potential adjustment of industrial structure has the same direction of change as in the previous case in Table 3.3, but a small range of increase and decrease. Firstly, we focus on an industry with an increase in structure, the high technology industry with low carbon emissions, particularly the mechanical devices and electronic equipment industry, in which the increase had the largest range at 1.4%-1.53%, and real estate, finance and other service industries, in which the range of increase was the second largest at 0.95%-1.04%. Among the industries with an increase in output, their increase range became larger as the carbon emissions became tighter. For example, the industrial structure of the mechanical devices and electronic equipment manufacturing industry increased at a rate of 1.4%, 1.42% and 1.45% for carbon emission constraints at 2.53, 2.08 and 1.63 tons of carbon dioxide. These three constraints are respectively corresponding to a decrease in carbon emission intensity by 5.93% (Scenario 1), a decrease in carbon emission intensity by 6.35% (Scenario 2), and a decrease in carbon emission intensity by 6.76% (Scenarios 3), assumed all at 9% economic growth rate. For economic growth rates at 9%, 8% and 7.5%, carbon emission constraints decrease 5.93% per year, and the industrial structure increases 1.4%, 1.45% and 1.48%, respectively. For industries with a high carbon emission coefficient, the output should decrease. The largest adjustment occurs in the industries with a high carbon coefficient, such as metal processing and manufacturing, where it decreases by 6.62% to 7.24%. The industrial structure decreases at 6.62%, 6.74% and 6.86% with the carbon constraint at 2.53, 2.08 and 1.63 tons of carbon dioxide, which are corresponding to three Scenarios at the same growth rate (9%). The industrial structure decreases to 6.62%, 6.87% and 7%, respectively, when constraints on carbon emissions decrease by 5.93% with an economic growth rate at 9%, 8% and 7.5%, respectively.

3.5.2 Summary and policy suggestions

China makes the obligation of carbon emissions. The most important policy to reduce the carbon emission is to adjust the industry structure, namely change the ratio of output of industry to the total output. The industry strategy should make out according to development of economy, the situation of the industries structure and their coefficient of carbon emission of industries. So the energy-carbon-economy input-output table should be design to combining the economy system and environment system. The table is composed of the value part from input-output table, and volume part, accounting the usage and consumption of energy by type in each industry and embodied carbon emission.

According to the ECEIO table, the carbon emission of with is from consumption of consumption, an optimal input-output table is built up, maximizing the GDP, considering the input and output equations, constraints of carbon emission, to address the adjustment of industry structure and potential reduction of carbon emission at the target of carbon emission with being harm to economy. Based on 2007 China ECEIO table with 44 industries, we set the intensity of carbon emission decreased by 6.35%, namely carbon emission increased by 1.14 % if GDP growth rate as 8%, the result shows that China should decreases the ratio of output of energy industry and heavy industry, increases the ratio of output of high technology and services. The former has high carbon emission but low contribution to GDP, and the latter has low carbon coefficient but high contribution to GDP. In detail, the output and carbon emission decrease in energy industry and heavy industry with high carbon emission coefficient, such as 29 Manufacture of Non-metallic Mineral Products, 30 Smelting and Pressing of Ferrous Metals. On contrary, the output and carbon emission increase in high technology industry and services with low carbon emission coefficient, for example, 44 Real estate finance and other service, 43 wholesale and retail trades, 37 Manufacture of Communication Equipment, Computers and Other Electronic Equipment 35 Manufacture of Transport Equipment.

We find the range of industry structure is more sensitive to growth rate than the constraints of reduction of carbon emission. Then computations are made on 3 scenarios on the target of intensity of carbon emission at 3 cases of growth speed, namely 9 cases of amount of carbon emission. Comparing the different growth speed in the same scenario, it finds that industry structure adjustment should be at larger ranger if growth rate is small. China faces more pressure on the economy development. From JPMorgan, there will be a downturn in growth rate to 7.7%. China should decrease heavy industry more, and increase the high technology industry more, such as decrease in the 9 metal processing and manufacturer around 0.4%, and increase in Mechanic, electronic equipment and other manufacturer around 0.1% from the growth rate 9% to 7.5%. Comparing 3 scenarios at the same growth rate, it finds that industry structure adjustment should be at larger range if constraints of carbon emission are tighter. But the change of ranger is less than the range of changing growth rate, for example, a decrease in the 9 metal processing and manufacturer around 0.2%, and an increase in Mechanic, electronic equipment and other manufacturer around 0.05% from the scenario 1 to scenario 3.

Those research results will give a reference for the government to make plan of industry adjustment to realize the target of carbon emission without being harm to economy. Some suggestion is given about how China adjust the ratio of output in energy industry, heavy industry, high technology and services and the potential of adjustment for reduction of carbon emission. Under different growth speed, energy structure, carbon emission constraints, several scenarios are given to analyze the sensitivity of carbon emission constrains, energy structure, and growth speed in adjustment of industry structure in China.

4 Reconfiguration of industrial structure to reduce GHG emissions in Shanghai

In the target of reduction of carbon emission in China, there are two points to be deserved to pay attention, one is that China is a developing country, first, it sets the target of reducing carbon emission intensity, different with the target of reducing absolute amount of carbon emission; second, economic development and energy utilization are different across the provinces and industries in China, therefore, assignment of target of carbon emissions intensity to each province and each industry according to local development characteristics become important issues that central and local governments are concerned about. Therefore, we need to study factors of changes of carbon emissions intensity in each province and then study on how to address the industry structure to reduce GHG Emission so as to put forward policy suggestions that are suitable for regional development of low-carbon economy. This chapter is divided into two parts. The first part analyzis the factors of change in carbon intensity in Shanghai by the method of structural decomposition analysis (SDA), and the second gives the optimal structure of Shanghai for the target of reducing carbon emissions.

4.1 Structural decomposition analysis of carbon emissions intensity in Shanghai

4.1.1 Literature on SDA of carbon emissions

Most studies on Structural Decomposition Analysis (SDA) focused on researching the factors of changes of the absolute amount of carbon emissions (Peter et al, 2007, Lenzen, 2004), however, China's carbon emissions goal is dropping the intensity rather than a decline in absolute amount of carbon emission. The existing research about carbon emissions intensity merely is to compare China's carbon emissions intensity with other countries ' from the point view of the whole country (He, 2004), or involve a single industry, for example, the influence of energy consumption changes of electricity industry on carbon emissions intensity (Zhang, 2009). An index decomposion analysis of factors of change of carbon intensity was given on the contributed shares of carbon emissions intensity and industry share in changes of carbon emissions intensity in 6 big industries from provincial level. (Yue, 2010). However, there are limitations in the above research as follows: (1) Data are sourced from the energy balance table, of which the industries are classified roughly and less; (2) Although it is easy to obtain the data of annual variable for dynamic study by index decomposition analysis (IDA) (Ang, 2000,2004), but the different of industries of great amount cannot be linked to each other, and it cannot form comprehensive index which reflects industry structure, consumption structure and technological progress. We can only isolated consider decreasing factors of each industrial energy intensity or the carbon intensity, which are so-called efficiency factors, and study the change of proportion of the industrial output value in the output of the whole economy, which are so-called structure factors. However, the factors influencing carbon emissions intensity in a region are very complex, the carbon intensity change is the result of joint action of a comprehensive adjustment of industrial structure, energy efficiency changes of the industry (technological progress) and the changes of consumption in total and in structure, therefore, we need to study carbon emissions intensity factors change from the point of view of comprehensive influence of overall change of industry structure and consumption structure changes.

This section attempts to analyze factors of carbon emissions intensity changes in Shanghai by a method that can understand the influences of consumption pattern change of each industry and resident on carbon emissions from the point view of structural analysis. Structural decomposition analysis is currently widely used as an effective quantitative analysis tool in the field of the input-output analysis. It has outstanding advantage in describing the structure factor of change of time series. The basic idea of this method is to decompose the change of dependent variable into various change of relevant independent variable to measure the contribution of each independent variable to dependent variable. At present, the SDA model has been used widely in each domain of economic system, such as energy (Lin & Polenske, 1995; Dietzenbacher & Stage, 2006), economic growth (Dietzenbacher & Los, 1998; Liu and Saal, 2001), the price mechanism changes (Fujikam & Milana, 2002), international trade (Hitomi et al. 2000), waste pollution (Mark de Haan 2001, Kagawa & Inamura, 2004), etc. In spite of China's literature to analyze energy intensity change in the SDA (Wang, 2003, Zhang, 2004, Xia, 2010). There is no literature that studies provincial carbon emissions intensity changes through SDA. The study (Li, 2004, Dietzenbacher & Stage, 2006) give the method of factor decomposition method of various kinds, and its application, including the addition decomposition method, multiplication decomposition method, and division decomposition method. The last method suits for analyzing the variable factors of carbon emission intensity as the form of division. This paper use the division method as the same as Xia (2010) and Dietzenbacher & Stage (2006) ,which is based on multiplication decomposition method, to measure the amount of carbon emission and carbon emission intensity of 25 industries, and then decompose the decline of carbon emission intensity from 2002 to 2007 in Shanghai into the following five factors: total amount of final demand (GDP), and structure factor of final demand, full demand factor caused by technology change, the change factor of energy consumption or input caused by industry structure adjustment and household consumption pattern. In this way, we can use two-pole method to reflect the balanced change in average from the basic term to the report term, and then put forward the policy suggestion.

4.1.2. The factor of decline of carbon emissions in Shanghai

Carbon emissions intensity is the carbon emission per GDP. According to Shanghai's 2002 and 2007 input-output table and Shanghai's "the table of energy balance", the carbon emission intensity decreased 21% from 2002 to 2007. Analyzing its change need consider not only the change in the amount of carbon emission and GDP in Shanghai, but also some internal factors, such as industry structure, consumption structure, and energy consumption structure, etc.

First, it focuses on influence of GDP or final demand on carbon emission. Shanghai's GDP nearly reached 0.15 billion in 2009. No matter GDP and GDP per capita (11320 US$) are the highest in the China (Chinese National Bureau of Statistics, http://www.stats.gov.cn). Moreover, the GDP growth rate of Shanghai since 1992 is higher than China's average level. If we consider the three component of GDP, consumption demand rises gradually but its share in GDP declines by a small amount; investment steadily increase and it still is the main drive of the growth of GDP; the net export tends to increase. Then we consider the type of consumption product in various components. Among consumption of various products, there are a great increase in high technology industries and various modern services. We investigate the influence on carbon emission of increase in GDP, GDP component and the change in consumption structure. In the value input-output table, they are embodied as final demand and final demand structure. The former is GDP, of which the components are consumption demand, investment demand and net export. The latter is the product or investment required by three type of demand.

Second, we probe into the influence on carbon emission of production consumption and household consumption. There is a rapid development in finance, real estate, modern logistic, information services and professional services, from less than in 1978 to 53.7% in 2008. The manufacture has been optimized and updated. Electronic information, automobile, petrochemicals and fine chemical, high-quality steel, complete sets of equipment, biological medicine, etc, accelerate its speed of development. The proportion of six pillar industries in the city industrial value increases from 30% in the early 1990s to above 60% at current. These industries have low energy consumption, and tend to consume petroleum with lower carbon emissions coefficient instead of coal with high carbon emissions coefficient. In addition, for this decade, the urbanization level and households' living level in Shanghai rise up rapidly. The urbanization level became the highest in the China and reach 88.7% in 2007 (Chinese National Bureau of Statistics, http://www.stats.gov.cn). Households require the working, living and travelling with higher and higher standard, which caused the household consumption increasing, such as at aspect of lighting and heating in architecture and landscape architecture. What is the influence of this kind of production energy and household energy consumption on the carbon emission intensity? It is reflected as the extended volume part of input-output table, i.e. carbon emission part caused by production consumption of energy and household consumption of energy, hence two types of coefficients.

Last, we look at the influence on the carbon emission of industry structure and technology progress in Shanghai. Since 1992, the ratio of tertiary industry rise from 31.9% in 1990 to 53.7% in 2008, and start to form the growth pattern accelerated by the secondary industry and tertiary industry. Capital factor input speed up to change the traditional industries and develop the new emerging industry, and increase the capital intensity degree. Shanghai makes industry adjustment and updating and technology progress as the drive, fully takes the advantage of technology, finance, market, management and increase process to enhance the scale economic profit and export-oriented economy quality. This pattern will bring affect on carbon emission intensity. The technology progress is shown as full demand coefficient in input-output table.

Therefore, we investigate the change of the final demand (GDP), final demand structure, carbon emission coefficient during intermediate process, carbon emission coefficient for final demand, and full demand coefficient on carbon emission.

4.1.3 Method and data

When this paper measures carbon emissions intensity, carbon emissions refers specifically carbon dioxide that fossil fuel discharges, fossil energy's mining and utilization is the main source of greenhouse gases, 61.4% of the overall greenhouse gases (in which carbon dioxide accounted for

77%) from energy use. Carbon dioxide discharged from fossil fuel not only includes carbon dioxide emission from terminal energy consumption in production process but also the emissions of households' energy consumption. While Peters et al (2007) and the most other literatures only compute the former. In order to fully reflect the two aspects of carbon emissions, carbon emissions in the extended part of input-output table here include two parts, carbon emissions from consumption of energy of different kinds in the intermediate production process and carbon emissions from households' energy consumption.

$$C = C_{in} + C_y \tag{4.1}$$

Here, C is total column of carbon dioxide energy consumption discharges, C_{in} is carbon dioxide emissions coefficients of energy consumption of each industry in intermediate production process. It is actual the energy input structure and energy consumption of various industries. C_y is carbon dioxide emissions coefficients of energy consumption of each industry for the final demand. It reflects the energy usage by various consumers, such as household, government, and foreigner or other provinces.

As for the intermediate production process, the following equation connect the carbon emission amount to the full demand coefficients and final demand,

$$C_{in} = cX = cLY \tag{4.2}$$

c is real carbon emissions coefficient matrix, expressed as carbon emissions for per unit of output due to energy of all kinds in various industries, the element c_{ij} is expressed as carbon dioxide discharged by the energy of type i (standard coal) for one unit of output in industry j, X is output vector in value, Y is final demand vector in value. $L = (I - A)^{-1}$ is full demand coefficient matrix, so-called Leontief inverse matrix. It reflects the amount of total input for one unit of final demand, including energy input and non-energy input, and it also reflect the technical progress. Introducing the coefficients is to measure the carbon emission discharged by energy for products and service in the chain of production. So we can account the total carbon emission discharged for increase in the consumption of a production or service, which is difference with the direct carbon emission due to consumption of energy. This coefficient is important for measure the effect of technology progress and industry structure adjustment in developing country on reduction of carbon emission.

Final demand F refers to the part which does not enter the intermediate process. It is decomposed into the consumption, capital formation, import, export, and other item, etc, which are expressed as column vector $Y_{fc}, Y_s, Y_x, Y_i, Y_\varepsilon$. The sum of each column is corresponded to the total final demand of different kinds, i.e. f_c, f_s, f_x, f_i, f_ε, which compose the row vector of final demand F' or the element of diagnose matrix of $\hat{F}$. B is the matrix of structure coefficient of the final demand, namely $B = [Y_{fc}, Y_s, Y_x, Y_i, Y_\varepsilon]\hat{F}^{-1}$. The elements b_{ij} refer to the proportion of products of industry i in the final demand of type j . Let $Y = BF'$ .So the final demand is classified into the change of final demand in structure and that of final demand in total, to verify whether we can reduce the pressure of target of reduction of carbon emission in developing country through increase the final demand.

According to the above deduction, we get the vector of carbon emission during intermediate production as following:

$$C_{in} = cLBF \tag{4.3}$$

The vector of carbon emissions caused by energy consumption for the final demand is

$$C_y = huF \tag{4.4}$$

h is the vector of carbon emissions caused by energy consumption for final demand

$$h = [c_{fc}, c_s, c_x, c_i, c_{1\varepsilon}]\hat{F} \tag{4.5}$$

Corresponding to the input-output table in value, c_{ifc} , c_{is} , c_{ix} , c_{ii} , c_{iz} respectively refer to amount of carbon dioxide discharged by energy of different kind for final demand (consumption, the capital formation and total import, export and other items), c_{ifc} is carbon emissions generated by energy consumption of household, including urban and rural residents' energy consumption, such as carbon dioxide generated by lighting, heating, refreezing, fuels. In input-output table, capital formation refers to fixed capital such as mechanism and construction, while energy cannot be expressed as capital goods, so we regard c_{is} as null. We do not distinguish energy import with energy of local production, and consider the energy export not as carbon emission generated in local. We also not consider error term. Thus c_{is} , c_{ix} , c_{ii} , c_{iz} is empty. u is diagonal matrix composed of 1 and 0. 1 is shown in the diagonal of matrix which is corresponding to the consumption of household, and 0 is the other term of final demand.

This paper aims to do structural decomposition analysis of carbon emissions intensity. Therefore, it first calculates total carbon emissions, and then calculates carbon emissions intensity, finally, does structural decomposition by using the multiplier method . The expression of the total carbon emissions is

$$TC = cLBF + hcF \tag{4.6}$$

One of the prerequisite of structural decompose is that the factors are independent with each other, therefore, in order to avoid the correlation of added value and intermediate input coefficient, GDP is measured by the final demand rather than added value. Supposed λ is unit row vector for summation of the five compositions of final demands, according to the input-output table, the expression of the GDP is,

$$GDP = \lambda F \tag{4.7}$$

So carbon emissions intensity I is

$$I = TC / GDP = \frac{cLBF + hcF}{\lambda F} \tag{4.8}$$

From this equation, total carbon emissions intensity change can be decomposed into the result of joint action of the change of five factors—the change of carbon emissions coefficient during intermediate production (c), the change of full demand coefficient (L), the change of final demand structure (B), the change of final demand (F), the change of carbon emission coefficient during final demand (h). To illustrate the indeed means of above factors. The carbon emission coefficient during intermediate production and that during final demand can reflect completely that the different action of usage of energy during the intermediate production and during final demand. The change of full demand coefficient is the total input for one unit of final demand, which comprehensively reflects the efficiency and industry structure. The final demand in total and the final demand in structure reflect the reality effect of GDP.

Carbon emission intensity is represented as carbon dioxide emission per unit of GDP, so it is two variables' division. It is necessary to use multiplier decomposition method with division format. It is comprehensive method of addition decomposition method (Dietzenbacher & Los, 2000, Li 2004), multiplication decomposition method (Dietzenbacher & Stage, 2006), and multi-factor general decomposition method (Xia, 2010). According to the multiplication decomposition method with the division format, the dependent variable can be decomposed into multiplier format of several factors' changes. With a certain condition, we can determine the degree of influence of each factor. Decomposition result is equal to multiply of several changes of independent variable, and the expectation of influence of each factor is equal to geometric mean of different decomposition ways. Influence value of the change of each factor is expressed as comprehensive changing rate of the independent variables to the dependent variable; it is relative influence degree, corresponding to the difference between the numerator and the denominator of change rate, expressed as absolute influence values of the independent variable to the dependent variable. According to number (n) of the factors there are $n!$ kinds of decomposition ways, here we use two polar solution of multiplication decomposition method (Dietzenbacher & Stage, 2006), it is to do a decomposition respectively according to the base period and report period, calculate the average value of two polar solution as decomposition value , to study factors of change of carbon emissions intensity in Shanghai, because it is constant with calculated results of most methods, and it is able to truly reflect the direction and degree of the changes of factors.

We calculate the changes of carbon emissions intensity from base period to report period, regarding report period as the benchmark, the first polar solution of SDA decomposition of the energy intensity is

$$\frac{I_{11}}{I_{10}} = \frac{(c_1 L_1 B_1 + h_1 u)F_1}{(c_0 L_1 B_1 + h_1 u)F_1} \times \frac{(c_0 L_1 B_1 + h_1 u)F_1}{(c_0 L_0 B_1 + h_1 u)F_1} \times \frac{(c_0 L_0 B_1 + h_1 u)F_1}{(c_0 L_0 B_0 + h_1 u)F_1}$$

$$\times \frac{(c_0 L_0 B_0 + h_1 u)F_1}{(c_0 L_0 B_0 + h_0 u)F_1} \times \frac{(c_0 L_0 B_0 + h_0 u)F_1}{(c_0 L_0 B_0 + h_0 u)F_0} \times \frac{\lambda F_0}{\lambda F_1} \qquad (4.9)$$

Regarding based period as the benchmark, so we get

$$\frac{I_{01}}{I_{00}} = \frac{(c_1 L_0 B_0 + h_0 u)F_0}{(c_0 L_0 B_0 + h_0 u)F_0} \times \frac{(c_1 L_1 B_0 + h_0 u)F_0}{(c_1 L_0 B_0 + h_0 u)F_0} \times \frac{(c_1 L_1 B_1 + h_0 u)F_0}{(c_1 L_1 B_0 + h_0 u)F_0}$$

$$\times \frac{(c_1 L_1 B_1 + h_1 u)F_0}{(c_1 L_1 B_1 + h_0 u)F_0} \times \frac{(c_1 L_1 B_1 + h_1 u)F_1}{(c_1 L_1 B_1 + h_1 u)F_0} \times \frac{\lambda F_0}{\lambda F_1} \qquad (4.10)$$

Then carbon emissions intensity change can be decomposed into multiplication of five changing factors, that is

$$\frac{I_1}{I_0} = \frac{(1.1)}{(1.1)'} \times \frac{(1.2)}{(1.2)'} \times \frac{(1.3)}{(1.3)'} \times \frac{(1.4)}{(1.4)'} \times \frac{(1.5)}{(1.5)'} \qquad (4.11)$$

Among them, $(1.1)/(1.1)'$ refers to the change amount of carbon emission intensity when merely changing the carbon emission coefficients during intermediate production but other factors not changing, $(1.2)/(1.2)'$ refers to the change amount of carbon emission intensity when merely changing the full demand coefficients but other factors not changing, $(1.3)/(1.3)'$ refers to the change amount of carbon emission intensity when merely changing the final demand structure but other factors not changing, $(1.4)/(1.4)'$ refers to the change amount of carbon emission intensity when merely changing the carbon emission coefficient during final demand but other factors not changing, and $(1.5)/(1.5)'$ refers to the change amount of carbon emission intensity when merely changing the final demand but other factors not changing7.

[7] $(1.1) = \sqrt{(c_1 L_1 B_1 + h_1 u)F_1 \times (c_1 L_0 B_0 + h_0 u)F_0}$, $(1.1)' = \sqrt{(c_0 L_1 B_1 + h_1 u)F_1 \times (c_0 L_0 B_0 + h_0 u)F_0}$: the factor of carbon emission coefficient during intermediate production; $(1.2) = \sqrt{(c_0 L_1 B_1 + h_1 u)F_1 \times (c_1 L_1 B_0 + h_0 u)F_0}$, $(1.2)' = \sqrt{(c_0 L_0 B_1 + h_1 u)F_1 \times (c_1 L_0 B_0 + h_0 u)F_0}$: the factor of technology change (or the factor of change of full demand coefficient); $(1.3) = \sqrt{(c_0 L_0 B_1 + h_1 u)F_1 \times (c_1 L_1 B_1 + h_0 u)F_0}$, $(1.3)' = \sqrt{(c_0 L_0 B_0 + h_1 u)F_1 \times (c_1 L_1 B_0 + h_0 u)F_0}$: the factor of change of final demand structure ; $(1.4) = \sqrt{(c_0 L_0 B_0 + h_1 u)F_1 \times (c_1 L_1 B_1 + h_1 u)F_0}$, $(1.4)' = \sqrt{(c_0 L_0 B_0 + h_0 u)F_1 \times (c_1 L_1 B_1 + h_0 u)F_0}$:

Here, we define two indexes, influence values of independent variables on the dependent variables, and contribution rate of independent variables to the dependent variables. The former reflects comprehensive change rate of independent variable comparing to the dependent variable, namely the number of five indexes in formula (11), the multiplier of which equal to the decline rate of carbon intensity. If influence value is more than 1, it is said that the change of this factor has action on the increase of carbon emissions intensity, if it is less than 1, which means the change of this factor has action on the decline of carbon emissions intensity.

The latter reflects the absolute influence values of independent variables on the dependent variable, corresponding to ratio[8] of the difference between the numerator and the denominator of each factor in formula (11) to difference between the numerator and the denominator of dependent variable. Its meaning is the portion of the difference of the original intensity with the intensity, which has a change of merely one factor but other factors stable, to the difference of the original intensity without any change with the intensity with five factors changing. This portion may be far away from ±100%. If Contribution rate is positive, it reflects that the direction of the change of factor is consistent to the direction of the change of carbon emissions intensity, if contribution rate is negative, it means the opposite direction. The value has no specific meaning, but it can reflect the extension of variation of one factor change comparing to the variation of all factors change. Through comparing the ratios of change of carbon emission intensity respectively caused by one of factors to the change of carbon emission intensity simulate caused by five factors, we can know which factor is more important.

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the factor of change of carbon emission coefficient during final demand;

$(1.5)=\sqrt{(c_0L_0B_0+h_0u)F_1\times\lambda F_0\times(c_1L_1B_1+h_1u)F\times\lambda F_0}$, $(1.5)'=\sqrt{(c_0L_0B_0+h_0u)F_0\times\lambda F_1\times(c_1L_1B_1+h_1u)F_0\times\lambda F_1}$: the factor of change of final demand. The two sets of equation respectively reflect the change of factor in report period and in basic period.

[8] Change's difference of dependent variables is

$I'=(1.1)\times(1.2)\times(1.3)\times(1.4)\times(1.5)-(1.1)'\times(1.2)'\times(1.3)'\times(1.4)'\times(1.5)'$,So the ratio of change's difference of dependent variables and change's difference of independent variables respectively refer to : $((1.1)-(1.1)')/I'$, $((1.2)-(1.2)')/I'$, $((1.3)-(1.3)')/I'$, $((1.4)-(1.4)')/I'$, $((1.5)-(1.5)')/I'$,it reflects contribution rate of five factors .

Data of the above five factors sources from two kinds of tables: the first source is the Shanghai input-output table in 2002 and in 2007. The final demand is divided into eight categories: 1) rural consumption, 2) urban consumption, 3) the government's consumption; 4) fixed capital formation; 5) increasing inventory, 6) export, 7) import, 8) other. The second source is to volume data9 of "the Shanghai industrial and transportation's energy statistical yearbook". We calculate the carbon emission amount according to "the energy balance table" and "the table of terminal energy consumption of industries by sector", the sectors of which are coordinate with the sectors in input-output table. In order to combine physical table data, we will divide input-output table into 25 industries, including former nine energy industries: coal, crude oil, natural gas, water electricity (including nuclear power) for primary energy industries; Thermal power and oil products (including fuel oil, petrol, diesel and kerosene), coke, thermal and gas and other energy belong to the second energy industries. The consumption of primary energy industries and non-energy industries in physical part of the table takes the aggregate form of terminal consumption and loss, secondary energy departments use aggregate form of terminal consumption, loss and intermediate input-transformation.

4.1.4 Discussion

According to the compiled 2002 and 2007 mixed energy - carbon - economic input-output table in Shanghai, then by using the structural decomposition technique(Structural Decomposition Analysis), we can decompose index that affects its carbon emissions intensity into: carbon emissions coefficient in intermediate production, full demand coefficient, the final demand structure coefficient, the final demand, carbon emissions coefficient during final demand, and see the calculation results from Table 4. 1.

[9] We calculate carbon emissions according to the energy balance table and industrial terminal consumption of each industry table。

Table 4.1 influence values of factor on carbon emissions intensity from 2002 to 2007[10]

Influence factors	Final demand changes	Final demand structure	Full demand coefficient	carbon emissions coefficient in intermediate production	carbon emissions coefficient during final demand	The Change of carbon emissions intensity
Influence value	1.223	0.733	1.334	0.664	0.988	0.786
Contribution rate	-243%	280%	-147%	204%	6%	-

Shanghai's carbon emissions intensity decrease from 2002 to 2007, the intensity in 2007 is 78.6% that of 2002. After analyzing the factors, we can obtain the following results:

Among the factor which has negative action on the decrease of carbon emission intensity, we get tow findings special. First, there is no influence of GDP increase on the carbon emission intensity. It is different with the present opinion (Yu et al,2011). However, the influence factor is the change of composition of GDP (final demand), namely composition of consumption, investment and net export. Because when we decomposing the factor of carbon emission, the final demand vector in numerator can be divided by GDP value and became the composition of final demand. The influence of final demand composition is 122.3%, it means that the change of final demand composition will accelerate the increase of carbon emission intensity by 122.3%; the contribution rate of final demand is -243%, and it means the final demand composition will cause the increase of carbon emission intensity, which is opposite to the decline of carbon emission intensity because of the change of all factors, and the former is the latter -243%. Shanghai is the region with the largest GDP and rapidest growth rate in China; as well it is the region with highest urbanization in China. Among the various final demand, household consumption increase rapidly 88% in 2007 comparing to that in 2002, government consumption and citizen household consumption increase respectively by 99.5% and 86.4%, quite larger than the growth of rural household consumption. 96.2% of the growth of household consumption is caused by the citizen household consumption; it shows that high urbanization in Shanghai result in the growth of household consumption so as to increase the carbon emission intensity dramatically.

[10] Among influence values in Table 1, carbon emissions intensity change is formula(11), reflecting degree of carbon emissions intensity change from 2002 to 2007 ,former respectively are $((1.1)-(1.1)')/I'$, $((1.2)-(1.2)')/I'$, $((1.3)-(1.3)')/I'$, $((1.4)-(1.4)')/I'$, $((1.5)-(1.5)')/I'$ in formula(4.11).

Second, the change of full demand cause the growth of the carbon emission intensity by 133.4%, and the ratio of the increase of carbon emission intensity caused by this factor to the decrease of carbon emission intensity caused by the change of all factors is -147%. It is consistent to the result of structure decomposition analysis of energy intensity by Xia (2010). The full demand coefficient reflects the total input amount for one unit of final demand, and it embodies comprehensively the index of efficiency and structure. Although the industry structure of Shanghai has update comparing to that of inland developing province, it still exist the problems of non scale economy growth in developing country, such as low efficiency, high cost and great consumption, low product quality, the serious redundant construction, etc. the proportion of second industry in Shanghai is lower than national level, but its growth is still far larger than developed countries, especially high energy-consuming industries such as building materials, steel, nonferrous metal, chemical etc. And some high carbon emissions industry, such as building industry, exist the problem of serious repetitive construction, China is the country which has the largest amount of new buildings in the world every year, annual 2 billion square meters of newly-built area, is equivalent to consume 40% of the world's cement and steel, this only lasts 25-30 years. The full demand coefficients in these high carbon emissions industries are quite high, increase of demand causes increase in the full demand of iron ore, the electric power, cement, gas, instruments and other products in production process, vigorous development of energy-intensive and low level enterprise reduce the technical level of the whole industry, causing tremendous energy waste, also causing the increase of carbon emissions intensity of the whole economy. In the future Shanghai can reduce full demand coefficients in these industries with high carbon emissions through two ways. The first way is to new material with small consumption instead of previous materials with large consumption to reduce carbon emissions intensity, the second way is to reduce material consumption coefficients by technical progress and enhancing management level.

Among the factors which cause the decrease of carbon emission intensity, the change of final demand structure, the influence value and contribution rate of carbon emission coefficient during intermediate production are quite larger than those of carbon emission coefficient during final demand. In detail, the importance of factor of final demand in structure is larger than the factor of carbon emission coefficient during intermediate production. Because the influence value of carbon emission coefficient during intermediate production on the intensity of carbon emission is 66.4%, which is smaller than the influence value of final demand in structure, but the contribution rate of the former factor is 280%, larger than the contribution rate of the latter factor, namely 204%. Therefore, in order to reduce the carbon emission intensity, local government should emphasis on final demand structure besides the industry structure adjustment, it is consistence with the opinion of Peters et al (2007). From the point view of final demand structure, Shanghai's final demand consumption with largest amount of and increase in the products and services are the other services (20%), agriculture (8.8), food manufactures and tobacco processing (1.8%), information equipment, computer and other electric equipment (1%). Those industries have low energy consumption and low carbon emission. Thus the change of consumption structure will affect on the decline of carbon emission intensity.

As to the energy input, factor of carbon emission coefficient during intermediate production is far larger than the coefficient during final demand. The contribution rate of the former is 34 times of that of the latter. On one side, in the production process, the coefficient is embodied as substitution effect, namely substituting the fossil energy by renewable energy. If the nature gas, petrol with low carbon emission is substituted by coal with higher carbon emission, the intensity of carbon emission in total will decrease. On the other side, Shanghai's economy developed with high-speed in post-industrialization stage from 2002 to 2007, it is reflected in the actual efficiency effect of the technical progress in the aspect of reduction of energy input per unit of output on the decrease of carbon emissions. It is embodied in the following aspect. Traditional heavy industries with high carbon emissions gradually withdraw from Shanghai, and high-tech industries with low carbon emissions increase rapidly, such as communication equipment, computer and other electronic equipment industry etc, and financial sector, shipping industry, modern logistics and professional service and other tertiary industry expand rapidly. Moreover, the contribution of carbon emissions coefficient changes in the final demand stage is small, because household energy consumption structure is comparatively fixed; energy demands by heating, lighting, refreezing, fuel are comparatively fixed, so the substitutability is poor.

The contribution rate of the factor of change of carbon emission coefficient during intermediate production is comparatively large, but lower than the contribution rate of the factor of change of final demand, and the factor of change of final demand structure. It is different with the traditional opinion that emphasizing on industry adjustment to reduce the carbon emission [18]. Our research shows that it is necessary to focus on the adjustment of final demand structure. While the importance of industry structure adjustment exist when comparing to the energy consumption in the final demand stage.

4.1.5 Policy suggestions

The section, at first at the provincial level, studies on the factors of decrease of Shanghai' carbon emission intensity from 2002 to 2007. By using structural decomposition analysis (SDA), it integrates the change of intensity of carbon emission of 25 industries into five factors: carbon emissions coefficient in intermediate production, carbon emissions coefficient during final demand, full demand coefficient, the final demand structure, the final demand composition (GDP). Its contributions are as follows: First, it takes the local (Shanghai) decrease of carbon emissions intensity as purpose. Second, it focuses on the decrease of carbon emissions intensity, instead of amount of carbon emission, to decompose their factors, which more fit Chinese current target of reduction of carbon emissions. Third, it accounts carbon emissions, which not only include carbon emissions in the intermediate production process, but also carbon emissions in final consumption stage. Fourth, it pays more attention to the comprehensive analysis of influence of industrial structure and consumption structure on the decrease of carbon intensity.

Different from the traditional point of view, the finding of this research is that, in the period from 2002 to 2007, GDP growth is not the reason to reduce carbon emissions intensity in Shanghai. The key factor is the change of the structure factor. To reduce the influence of urbanization on the increase of carbon emission, it is necessary to increase the proportion in GDP of value added of the following industries, i.e. other services, communication equipment, computer and other electronic equipment industry which have less energy consumption, lower carbon emissions. Although the proportion of the secondary industry to the total industry in Shanghai is lower that the level of China, the secondary industry with high full demand coefficient has serious problem in high energy consumption, low efficiency and serious repetitive construction, which results in difficulties in decreasing carbon emissions intensity in Shanghai, so it is necessary to further accelerate technical progress and to improve the management efficiency. The carbon emission coefficient in intermediate production process is very important to the decrease of carbon emissions intensity, far more than the role of change of carbon emissions coefficient in the final consumption phase, thus, Shanghai should put forward the industrial policies in the future which is to change energy consumption structure through the adjustment of industrial structure so as to reduce carbon emissions intensity.

4.2 Adjustment of Industrial Structure in Shanghai

Shanghai is the developed region in China. Its GDP and other social developing index reach the level of China in 2030. From the international comparison, the industry structure and energy consumption patter in Shanghai approach to that of developed countries, such as Japan. The carbon intensity of Shanghai trends to decline. According to our computation, the intensity of carbon emission from final consumption of energy decreased from 0.385 ton carbon per 10000 Yuan output in 2002 to 0.190 ton carbon per 10000 Yuan output in 2007, 50% of the former. The absolute amount of carbon emission increased from 36 million metric ton in 2000 to 65.67 million metric tons in 2008. Although the absolute amount of carbon emission increase all the time, the growth rate in 2008 has decline from 10% in 2004 and 2005as the highest rate to the level of 2000, i.e. 5%. In the future 10 year, there is a decrease in the growth rate of absolute amount of carbon emission. The 12^{nd} 5 year plan made the target of saving energy of 31 provinces, which is classified into 5 type regions. Shanghai, Jiangsu, Zhejiang, and Guangdong is the first type of region with the most rapidly decline rate of energy consumption per GDP. In those regions, the comparative index, the carbon intensity target, is transferred into the absolute index, the target of absolute carbon emission, when assuming the growth rate of GDP. In some site, such as Guanzhou, Shanghai, the target is set for the reduction of absolute carbon emission, not only the reduction of carbon intensity. The target of carbon emission is divided into two types, first, the total carbon emission target according to the national average level, second, the target of absolute reduction of carbon emission according to the European Union’s growth rate level and carbon reduction target.

For the target of carbon emission reduction, the adjustment of industry structure and improve the energy efficiency is the main patter to make use at present. It is because among the total carbon emission, the carbon emitted in the production is the more important factor than the carbon emitted directly from consumption. In Shanghai, the former exceed much more than the latter in 2007, taking over 90% of the total carbon emission. Among the carbon emission in production, the carbon emission in manufactures takes 60.6%, and that in services takes 29.8%. In the manufactures, the industries with high carbon emission are, in decline sequence, Smelting and Pressing of Ferrous Metals with 31%, Petroleum Processing, Coking and Nuclear Fuel Processing with 19%, Chemical and Pharmaceutical and Medicine Manufacturing with 15%. They are the resource industries and heavy industry. The carbon coefficient, namely the carbon emission per unit of output, differs from industries. Thus Shanghai should adjust the industry structure and energy consumption to reduce the carbon emission, instead of reducing the carbon emission in the same ratio. At the same time, the adjustment of industry structure in Shanghai should fit to the industry strategy of Shanghai. Shanghai has finish the industrialization, it is import for Shanghai to cultivate the industry competitive advantage, speed up the development of industry, enlarge the industry scale, and form the industry growth pole.

The target of carbon emission is divided into carbon intensity and carbon emission amount, here the carbon intensity referring to the carbon emission per GDP. Therefore, the target of carbon intensity can be transferred to carbon emission amount when assumed growth rate o GDP. According to the target China promise at present, there is an increase in the amount of carbon emission at the forecasted GDP. The situation of Shanghai development and the international standard are referred to set a decreased target of amount of carbon emission, which can be transferred to a rigid carbon intensity target when assuming GDP growth rate of Shanghai. It is tighter than national average standard. Shanghai do not take the obligate of absolute reduction of carbon emission, however, this reference is given for the decision of reduction policy in the future.

Four scenarios are set as Table 4.2. The first three scenarios are set according to national average standard, which is corresponding to high, middle and low level of carbon intensity within the reduction target of carbon emission China promise in Copenhagen conference. From the forecast growth rate of GDP, there are 9 cases of constraints of amount of carbon emission, the method of determination are the same as Chapter 3. The forth scenario is absolute reduction target of carbon emission referring to the international standard. European Union presented the target of 20%-30% reduction in 2020 comparing to the level of 1990, namely 0.74% -1.18% reductions per year. However, Shanghai growth rate reach 7.5%-9%, much higher than the growth rate of European countries. According to OECD and IMF, the European growth rate was 1% and 1.75%, so the target of reduction of carbon emission is set as one third of the standard of European Union, reduction per year within the range of (0.25%，0.39%). So Shanghai reduction target of absolute carbon emission amount is 0.4%[11]. In order to comparing to national average level, this constrain is reversed to the target of carbon intensity. The four scenarios are shown in Table 4.2. Here the carbon emission is origin from energy activity, not from the material usage and biology activity.

Table 4.2 Index of intensity of carbon emissions and carbon emissions per year (%)

Scenario 1			Scenario 2			Scenario 3			Scenario 4		
Intensity of carbon emission	Growth rate of GDP (m)	Total amount of carbon emission (r)	Intensity of carbon emission	Growth rate of GDP (m)	Total amount of carbon emission (r)	Intensity of carbon emission	Growth rate of GDP (m)	Total amount of carbon emission (r)	Intensity of carbon emission	Growth rate of GDP (m)	Total amount of carbon emission ( )
-5.93	9	2.53	-6.35	9	2.08	-6.76	9	1.63	-9.14	9	-0.4
	8	1.60		8	1.14		8	0.70	-8.30	8	
	7.5	1.12		7.5	0.67		7.5	0.23	-7.44	7.5	

Note: scenarios is computed according to the balance of growth

We give the industry adjustment based on Shanghai's ECEIO table in 2007. We make use of Shanghai ECEIO in 2007 to address the optimal industry structure. The industry is shown in appendix. The first three scenarios on constraints are decreased intensity of carbon emission, but the increased amount of carbon emission. The constraint in scenario 4 is decreased absolute amount of carbon emission which is made according the standard of European reduction standard.

[11] Shanghai reduction of carbon emission per year is set as one third of European Union standard. European Union reduction of carbon emission per year (0.74% -1.18%). Then the range of shanghai reduction target per year (0.25%，0.39%)

0.74%×(1/3)=0.25%, 1.75%×(1/3）=0.39%

So we set Shanghai reduction constrain is 0.4%.

Table 4.3 Shanghai's potential adjustment of industrial structure

ΔS_j	Scenario 1			Scenario 2			Scenario 3			Scenario 4
GDP	9%	8%	7.5%	9%	8%	7.5%	9%	8%	7.5%	
ΔC	0.025	0.016	0.011	0.021	0.011	0.007	0.016	0.007	0.002	-0.004
1	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
2	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
4	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
5	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
6	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
7	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
8	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.8%	-0.7%
9	-0.8%	-1.2%	-1.5%	-1.0%	-1.5%	-1.7%	-1.2%	-1.7%	-2.0%	-2.3%
10	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%	-0.3%
11	-1.9%	-1.9%	-1.9%	-1.9%	-1.9%	-1.8%	-1.9%	-1.8%	-1.8%	-1.8%
12	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
13	0.5%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.7%
14	0.5%	0.6%	0.6%	0.5%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
15	0.3%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
16	1.1%	1.2%	1.2%	1.1%	1.2%	1.3%	1.2%	1.3%	1.3%	1.3%
17	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
21	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
22	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
23	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.6%
24	-2.2%	-2.2%	-2.2%	-2.2%	-2.2%	-2.1%	-2.2%	-2.1%	-2.1%	-2.1%
25	0.4%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
26	1.8%	2.0%	2.0%	1.9%	2.0%	2.1%	2.0%	2.1%	2.2%	2.2%

Note: The industry is classified as Shanghai's ECEIO table in 2007 (industry classification refers to Table A 6). Shanghai's ECEIO table in 2007 is compiled according to the 2007 Shanghai input-output table and Shanghai statistic Bureau. Computation from optimal input-output table based on 2007 Shanghai ECEIO table.

Shanghai's optimal adjustment of industry structure is shown in Table 4.3. The services and the high technology increase their output at the largest degree, for example, 26 Real estate finance and other service as 1.8%-2.2%, 16 Manufacture of Communication Equipment, Computers and Other Electronic Equipment as 1.1%-1.3%, 13 Manufacture of General Purpose and Special Purpose Machinery as 0.5%-0.7%, 14 Manufacture of Transport Equipment as 0.5%-0.6%, 25 wholesale and retail trades as 0.4%-0.5%, 15 Manufacture of Electrical Machinery and Equipment as 0.3%-0.4. On contrary, the heavy industry and processing industry decrease their output at largest degree. In detail, 24 Transportation, storage, Storage and Post decrease by 2.1%-2.2%, 11 Smelting and Pressing of Ferrous Metals decrease by 1.8%-1.9%, 9 Chemical and Pharmaceutical and Medicine Manufacturing and 8 Petroleum Processing, Coking and Nuclear Fuel Processing, decrease by 0.8%-2.3%, 4 Manufacture of Textile decrease by 0.3%, and 10 Building materials and non-Metallic Materials Industry decreased by 0.3%.

4.3 Summary and policy suggestion

In this section of chapter 4, we, first at level of province, investigate the factors of decreasing Carbon Emission Intensity in Shanghai from 2002 to 2007. By structural decomposition analysis method, it integrates the change of carbon emission intensity of 25 industries into 5 factors: final demand (GDP) composition, final demand in structure, carbon emission coefficients during intermediate production, carbon emission coefficient at procedure of final demand, and full demand coefficient. We can get the value of influence of five factors on the decrease of carbon emission intensity and the rate of contribution of five factors to the decline of carbon emission intensity. It finds that final demand in structure, namely the final demand for products or services of different kinds, is the most important factor for the decrease of carbon intensity. This factor has the largest influence value 0.733%, which means the change of final demand in structure will cause the decrease of carbon emission intensity by 0.733%, and the largest contribution rate 280%, which means the decrease amount of carbon emission intensity by final demand in structure is 280% of the decrease of carbon emission intensity by all five factors. The influence value of final demand composition, namely household consumption, government consumption, investment and net export, etc., is 1.223%, which means final demand composition will cause the increase of carbon emission intensity by 1.223%, and the contribution rate of final demand is -243%, which means the increase amount of carbon emission intensity by final demand is 243% of the decrease of carbon emission intensity by all factors. Different from the other literature, the growth of GDP won’t decrease the Carbon emission intensity of Shanghai, it will decrease through the change of final demand for the products of different types, but it increase through the change of composition of GDP. So it is necessary to enlarge the proportion of consumption of service and high technology products with low carbon emission coefficients so as to decrease the carbon emission intensity. In addition, the influence value of change of carbon emission coefficients during intermediate production is larger than that of carbon emission coefficients during the household consumption, so it is necessary to pay more attention to the industries structure adjustment aiming at changing the structure of energy consumption. Last but not least, as to the secondary industries with high full demand coefficient, their efficiency should be improved for potential of decline of carbon emission intension.

Based on 2007 ECEIO table of Shanghai with 26 industries, the adjustment of industry structure is made on four scenarios of carbon emission. Scenario 4 is the decreased absolute amount of carbon emission which is made according the standard of European reduction standard. The services and the high technology increase their output at the largest degree, for example, 26 Real estate finance and other service as 1.8%-2.2%, 16 Manufacture of Communication Equipment, Computers and Other Electronic Equipment as 1.1%-1.3%, 13 Manufacture of General Purpose and Special Purpose Machinery as 0.5%-0.7%, 14 Manufacture of Transport Equipment as 0.5%-0.6%, 25 wholesale and retail trades as 0.4%-0.5%, 15 Manufacture of Electrical Machinery and Equipment as 0.3%-0.4. On contrary, the heavy industry and processing industry decrease their output at largest degree. In detail, 24 Transportation, storage, Storage and Post decrease by 2.1%-2.2%, 11 Smelting and Pressing of Ferrous Metals decrease by 1.8%-1.9%, 9 Chemical and Pharmaceutical and Medicine Manufacturing and 8 Petroleum Processing, Coking and Nuclear Fuel Processing, decrease by 0.8%-2.3%, 4 Manufacture of Textile decrease by 0.3%, and 10 Building materials and non-Metallic Materials Industry decreased by 0.3%.

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Supplements

S.1 Compiling the table of usage and consumption of energy in the ECEIO table

The table of usage and consumption of energy is the base of compiling ECEIO table. The usage of energy is the sum of the final consumption, the energy of processing and transformation, and the loss of energy from the point of view of input. Because the energy of the intermediate transformation is classified into thermal power, heating supply, coal washing, coking, petroleum refineries, gas works, and briquettes according to the secondary energy production technical, total energy consumption by industry is computed as the sum of the final consumption of energy by industry, and the intermediate transformation according to the different production technical. The term "2.Input(-) & Output (+) of Transformation" in "China's energy balance table" gives the consumption of energy by type during the process of "thermal power, heating supply, coal washing, coking, petroleum refineries, gas works(Coke input (-)), and briquettes". Taking thermal power for example, many types of energy are input into the production of thermal power, the sum of input energy of types is the total input of energy in the thermal production. The final consumption plus loss, and the energy of the transformation of corresponding energy in the term "thermal power, heating supply, coal washing, coking, petroleum refineries, gas works, and briquettes", form the table of "final consumption + loss + loss of transformation", namely the table of energy consumption. The term "3.loss" in "China's energy balance table" gives the loss of energy by type. This part of energy can be assigned by the ratio of final energy consumption into various industries, including the consumption of rural and urban household. Let loss $E^d = [E_1^d, E_2^d, \cdots, E_{10}^d]$, ratio of final consumption of energy by type $\delta_{10\times m} = [\delta_1, \delta_2, \cdots, \delta_m]$, here $\delta_i = [\frac{m_i}{\sum m_i}]$, m_i is the amount of energy of final consumption by industry. The energy consumption by industry is

$$M' = M + E^d \times \delta \tag{5.1}$$

The energy consumption by input method is

$$E_c = S + M' = M + S + E^d \delta \tag{5.2}$$

Table of energy usage and consumption can be accounted through combining “China’s energy balance table” with “final energy consumption by industrial sector”. This is the core to calculate the carbon emission. The part of matrix of energy’s usage and consumption among the energy industries in 2005 is shown as Table 2.2. This table gives the quantitative amount of usage of energy and consumption of energy. The consumption of energy of each type in each energy industry is obtained from “final energy consumption by industrial sector” in 2005. In secondary energy industry, the transformation from energy of each type and loss from “China’s energy balance table” in 2005 is added into the consumption of energy of each type. The sum is the usage of energy of this type. The consumption of energy is noted in blank. Similarly, from the “final energy consumption by industrial sector” in 2005, the table of energy consumption among the non-energy industries and households can be obtained, which are the same with energy usage among these industries. These tables can be compiled as standard unit (10^4 ton standard coal).

S.2 Table of carbon emissions in the ECEIO table

We compile the part of carbon emission in ECEIO table. It is obtained from the usage and consumption of energy. Carbon Emission Caused by the consumption of energy excludes the consumption of energy for materials because the part of energy is not burnt and not bring into carbon emission. The carbon emission of industry j by energy type k, $x_{c\,kj}$, can be calculate as

$$x_{c\,kj} = d_k \times (x^e_{c\,kj} + x^e_{t\,kj} + x^e_{t\,kj} - x^e_{mkj})$$

The carbon emission can be accounted completely according to the usage of energy excluding the part of energy as material. To avoid repeated computation, the carbon emission of industry j by energy type k is accounted base on the final energy consumption

$$x_{c\,kj} = d_k \times (x^e_{c\,kj} - x^e_{mkj}) \qquad (5.3)$$

The carbon emission of industry j is $c_j = \sum_{k=1}^{n} x_{c\,kj}$. The carbon emission coefficient $i_{c\,kj}$ is carbon emission emitted by energy type k for output of industry j $i_{c\,kj} = x_{c\,kj} / x_j$. The carbon emission intensity has two kinds, (1) the CO2 per output of industry j, $i_{c\,j}$, is the carbon emission directly emitted for the one unit of output in industry j, $i_{c\,j} = c_j / x_j$; and (2) CO2 per value added , i_j , is the carbon emission directly emitted for the one unit of value added in industry j , $i_j = c_j / v_j$.

Appendix

Table A.1 The energy usage and consumption among energy industries in 2005

	1	2	3	4	5	6	7	8	9
1 Coal(104 ton)	9165.28 （4583.17）	125.02	9.50	0.00	105673.95 （2410.461）	51.48	32744.86 （1077.8）	13788.25 （246.25）	1354 (77.04)
2 Oil (104 ton)	0.00	522.36	8.18	0.00	21.45 (0.17)	29195.18 (154.67)	0.00	0.33 (0.002)	0.26
3 Nature Gas(108 Cu. M3)	1.71	0.30	56.15	0.00	31.97(0.45)	3.49	11.27	23.17(0)	8.84 (4.59)
4 Hydro & Nuclear Power (108 kW•h)	106.54	65.78	3.86	565.43	0.00	56.49	0.16	103.66	5.40
5 Thermal Power(108 kW•h)	481.58	297.33	17.46	0.00	2555.89	255.37	0.72	468.56	24.39
6 Petroleum Product(104 ton)	89.44	224.60	28.59	0.00	1579.71 (106.21)	293.68	39.26	174.91 (3.08)	27.71 (13.32)
7 Coking(104 ton)	34.55	0.27	0.01	0.00	4.87	0.00	61.71	0.88	229.51 (1.6)
8 Heat(104 million KJ)	297.91	5242.08	0.00	0.00	10572.66	25843.93	2922.81	3.54	220.01
9 Gas(108 Cu. M3)	3.64	0.00	0.01	0.00	167.92 (1.24)	0.00	48.92	95.09 (0.04)	10.98
Total usage	5587.99	1762.37	797.12	694.91	76982.01	43483.16	29352.42	11231.86	1677.39
Total consumption	4285.23	1760.32	797.12	694.91	5541.45	1984.62	1839.60	900.16	381.22

Table A.2: The classification of energy types

Energy	Industry in ECEIO table	Industry in input-output table
Raw Coal, Cleaned Coal, Other Washed Coal	Mining and Washing of Coal	Mining and Washing of Coal
Crude Oil	Extraction of Petroleum	Extraction of Petroleum and Natural Gas
Nature Gas	Extraction of Natural Gas	Extraction of Petroleum and Natural Gas
Hydro Power and Nuclear Power	Production and Distribution of Hydro Power and Nuclear Power	Production and Distribution of Electric Power and Heat Power
Thermal Power	Production and Distribution of Thermal Power	Production and Distribution of Electric Power and Heat Power
Gasline, Kerosene, Diesel Oil, Fuel Oil, other Petroleum Product	Processing of Petroleum, Processing of Nuclear Fuel	Processing of Petroleum, Processing of Nuclear Fuel
Coke, Other Coking Products	Coking	Coking
Heat	Production and Distribution of Heat Power	Production and Distribution of Electric Power and Heat Power
Coke Oven Gas, LPG, Refinery Gas, Other Gas	Production and Distribution of Gas	Processing of Petroleum, Processing of Nuclear Fuel, Coking, Production and Distribution of Gas

Table A.3: The carbon coefficient of energy types

	Energy	carbon emission coefficient(10^4 t)	
		DRCSCC	IPCC
1.Mining and Washing of Coal	Raw Coal	0.7476	0.7559
	Cleaned Coal	0.7476	0.7559
	Other Washed Coal	0.7476	0.7559
2.Extraction of Petroleum	Crude Oil	0.5825	0.5857
3.Extraction of Natural Gas	Nature Gas	0.4435	0.4483
4.Production and Distribution of Thermal Power*	Thermal Power	2.1114	
5.Processing of Petroleum, Processing of Nuclear Fuel	Gasline	0.5825	0.5538
	Kerosene	0.5825	0.5714
	Diesel Oil	0.5825	0.5921
	Fuel Oil	0.5825	0.6185
	other Petroleum Product	0.5825	0.5857
6.Coking	Coke	0.7476	0.855
	Other Coking Products	0.7476	0.6449
7.Production and Distribution of Heat Power*	Heat	0.9966	
8.Production and Distribution of Gas	Coke Oven Gas	0.7476	0.3548
	Other Gas	0.7476	0.3548
	LPG	0.5825	0.5042
	Refinery Gas	0.5825	0.4602

*the coefficient of thermal power and heat is accounted according to the energy balance table of 2005. The development research center of the state council of China (DRCSCC)

Table A.4: **industry classification in the ECEIO table**

	Industry		Industry
1	Mining and Washing of Coal	19	Manufacture of Leather, Fur, Feather and Related Products
	Raw Coal (104 ton/104 ton standard coal)	20	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products and Manufacture of Furniture
2	Extraction of Petroleum	21	Manufacture of Paper and Paper Products
	Crude Oil (104 ton/104 ton standard coal)	22	Printing, Reproduction of Recording Media
3	Extraction of Natural Gas	23	Manufacture of Articles For Culture, Education and Sport Activity
	Nature Gas (108 Cu. M3/104 ton standard coal)	24	Manufacture of Raw Chemical Materials and Chemical Products
4	Production and Distribution of Hydro Power and Nuclear Power	25	Manufacture of Medicines
	Hydro Power and Nuclear Power (108 kW•h/ 104 ton stand coal)	26	Manufacture of Chemical Fibers
5	Production and Distribution of Thermal Power	27	Manufacture of Rubber
	Thermal Power (108 kW•h/ 104 ton stand coal)	28	Manufacture of Plastics
6	Processing of Petroleum	29	Manufacture of Non-metallic Mineral Products
	Petroleum Product(104 ton/104 ton standard coal)	30	Smelting and Pressing of Ferrous Metals
7	Coking	31	Smelting and Pressing of Non-ferrous Metals
	Coking Products(104 ton/104 ton standard coal)	32	Manufacture of Metal Products
8	Production and Distribution of Heat Power	33	Manufacture of General Purpose Machinery
	Heat (104 million KJ/104 ton standard coal)	34	Manufacture of Special Purpose Machinery
9	Production and Distribution of Gas	35	Manufacture of Transport Equipment
	Gas (108 Cu. M3/104 ton standard coal)	36	Manufacture of Electrical Machinery and Equipment
10	Agriculture	37	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
11	Mining and Processing of Ferrous Metal Ores	38	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work
12	Mining and Processing of Non-Ferrous Metal Ores	39	Other Manufacturing
13	Mining and Processing of Nonmetal Ores and Mining of Other Ores	40	Production and Distribution of Water
14	Manufacture of Foods	41	Construction
15	Manufacture of Beverages	42	Transportation, storage, Storage and Post
16	Manufacture of Tobacco	43	wholesale and retail trades
17	Manufacture of Textile	44	Real estate finance and other service
18	Manufacture of Textile Wearing Apparel, Footware, and Caps	45	Rural households
		46	Urban households

Table A.5: Classification of industry in China's optimal industrial structure

	Industry		Industry
1	Agriculture	9	Metal processing and manufacture
2	Mining	10	Mechanic, electronic equipment and other manufacturer
3	Food manufacture and tobacco processing	11	Electricity, heat power and water production and supply
4	Textile, Wearing Apparel	12	Construction
5	Wood processing and Manufacture of Articles for Culture, Education and Sport Activities	13	Transportation, storage, and information service
6	Petroleum Processing, Coking and Nuclear Fuel Processing	14	wholesale and retail trades
7	Chemical and Pharmaceutical and Medicine Manufacturing	15	Real estate finance and other service
8	Building materials and non-Metallic Materials Industry	16	Household's final demand/ Total industry

Energy industry: (2), (6), (11); Non energy industry: (1), (3), (4), (5), (7), (8), (9), (10), (12), (13), (14), (15)..

Table A.6: Classification of industry in Shanghai's optimal industrial structure

No.	Industry	No.	Industry
1	Agriculture	14	Manufacture of Transport Equipment
2	Mining	15	Manufacture of Electrical Machinery and Equipment
3	Food manufacture and tobacco processing	16	Manufacture of Communication Equipment, Computers and Other Electronic Equipment
4	Manufacture of Textile	17	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work
5	Manufacture of Textile Wearing Apparel, Footware, Leather, Fur, Feather and Related Products	18	Manufacture of Artwork and Other Manufacturing
6	Wood processing and Manufacture	19	Recycling and Disposal of Waste
7	of Articles for Culture, Education and Sport Activities	20	Production and Supply of Electric Power and Heat Power
8	Petroleum Processing, Coking and Nuclear Fuel Processing	21	Production and Supply of Gas
9	Chemical and Pharmaceutical and Medicine Manufacturing	22	Production and Supply of Water
10	Building materials and non-Metallic Materials Industry	23	Construction
11	Smelting and Pressing of Ferrous Metals	24	Transportation, storage, Storage and Post
12	Metal processing and manufacture	25	wholesale and retail trades
13	Manufacture of General Purpose and Special Purpose Machinery	26	Real estate finance and other service

Energy industry: (2), (8), (20), (21); non-energy industry: (1), (3), (4), (5),(6), (7), (9), (10),(11), (12), (13), (14), (15), (16), (17), (18), (19), (22), (23), (24), (25), (26).

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Xue Fu obtained a Ph.D. degree in input-output analysis from the Academy of Mathematics and System Science (AMSS) and had the associate professor position since 2006 in Jiangxi Uinversity of Finance and Economy and Shanghai Normal University. Then she began to carry out research on the reduction of carbon emissions using an input-output model. During the first two years after obtaining her doctorate, she has hosted several projects involving environment and economics. She gradually focused on sustainability science using mathematical models, particularly the input-output model. In 2003, she started Ph.D. research on a dynamic input-output model at AMSS, engaging in a number of important national projects. In 2005, she attended the Complex Systems Summer School sponsored by the Santa Fe Institute. After receiving a Ph.D. in 2006, she obtained a Bernoulli scholarship from the University of Groningen to work with Prof. Erik Dietzenbacher and Dr. Bart Los. In 2010, she was granted a project from the National Social Science Foundation, titled "Dynamic Programming of the Industrial Structure of a Low-Carbon Economy based on a Multiregional Input-Output Model" and a project from the China Scholarship Council, titled "A Low-Carbon Economy and Regional Industrial Structure Achieved by Means of an Input-Output Model", and she was sent to the University of Maryland in the US, where she was supervised by Prof. Klaus Hubacek. She also took part in a key grant project of the National Social Science Foundation titled "Research on the Strategy of Low-Carbon Development during China's Urbanization" and went to IDE-JETRO in Japan to research "Reconfiguration of Industrial Structure to Reduce GHG Emissions Based on an Input-Output Model".