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China's Carbon Flow：2008-2012

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A B S T R A C T

As the world's largest CO_2 emitter, China's CO_2 emissions have become one of the most popular issues concerned by domestic and foreign researchers. Therefore, analysis of the current status of China's carbon emissions is very important. After drawing a chart of China's carbon flow in 2012, based on the IPCC carbon emission inventory method and China's energy balance table, this paper gives a detailed description of the current status of China's carbon flow and compares the changing characteristics of China's carbon flow between 2008 and 2012. The results show that 75.12% of total CO_2 emissions flow mainly into several sectors, such as ferrous sectors, and the chemical industry in the terminal sub-sectors. Although China's thermoelectric efficiency increased dramatically during past four years, emissions from the heat and power production sector are still increasing due to China's large demand for heat and power. In the ferrous metal and chemical industry sectors, CO_2 emissions are mainly energy-related, while in the non-metallic mineral sector, CO_2 emissions are mainly from process CO_2 emissions. In different terminal sub-sectors, the main carriers of CO_2 flow are different, thus, related CO_2 reduction policies should also be targeted. In addition, some valuable suggestions are given in this paper.

Key words: CO_2 flow chart; CO_2 reductions; China

1. Introduction

As global warming has become one of the most serious environmental problems worldwide, issues related to carbon dioxide (CO_2) emission have attracted close attention in the worldwide. Global warming is largely attributed to the effect of emissions of greenhouse gases, such as CO_2, from the combustion of fossil fuels (Yue-Jun Zhang, et al., 2014). According to several studies (BP, 2013; Zhu, et al., 2010; Hu and Lee, 2008; Li, 2010; Wang and Watson, 2010), China surpassed the United States in CO_2 emissions in 2008, becoming the world's largest emitter, which makes China facing more and more pressures on the control of its CO_2 emissions. After four years, China's CO_2 emissions rapidly grew from 6.78 billion tons to 8.18 billion tons, with an average annual growth rate of 4.81%. A series of questions should be answered for a clearer understanding of China's carbon emissions, such as how about the status quo of China's carbon emissions? Are there any changes during the past four years? Thus, an analysis of the changing characteristics of China's carbon emissions from 2008 to 2012 is necessary.

From the perspective of social system, carbon flow refers to the amount of CO_2 in theory, carried by different energy carriers such as coal and oil, and released in all aspects of the social system. It is a virtual concept, which can clearly describe the status of CO_2 emission in the human social systems. Carbon flow chart is a useful tool for research on the status of CO_2 emission (Li, 2006; Xie, 2009; Pei and Liao, 2014; Wei, et al., 2008). The authors (Mu and Li, 2013) analysed China's Carbon emissions for 2008 based on a more comprehensive and detailed carbon flow chart published in the journal of "Energy Policy". As a follow-up study, we draw China's carbon flow chart for 2012 in this paper, and compare the characteristics of its changes between 2008 and 2012. Different from other researches, CO_2 flow chart in this paper includes not only energy-related carbon emissions but also carbon emissions from production process, namely process CO_2 emissions. Methodology and main results are described in section 2 and 3. Finally, we conclude this study.

2. Methodology

For the calculation, we merge the sub-sectors classified in 2013 Energy Statistical Yearbook based on the classification method of IPCC2006, shown in table 1. In this paper, we take CO_2 emissions indirectly produced by heat and electricity consumptions of terminal sub-sectors as their indirect CO_2 emissions, which can be calculated based on energy processing and conversion data from energy balance table of China. Equivalently, indirect CO_2 emissions are those carried by different fossil fuels in theory, which are theoretically regarded as raw materials for electricity and heat production. After getting different amounts of fossil fuels with the equivalent heating value of electricity and heat produced, we can calculate CO_2 emissions carried by these fuels in theory. CO_2 emissions from "Energy processing and conversion sub-sector" only refer to the loss emissions during the process of energy production, that is, the difference value between its total CO_2 emissions and the indirect CO_2 emissions mentioned above. Analysis framework is shown in Figure 1.

2.1 CO_2 Accounting Method

1. Energy-related CO_2 emission

Energy-related CO_2 emissions are calculated according to Eq.(1). Total CO_2 emissions in the ith sector in period t is estimated based on energy consumption (E_{ij}^t), carbon emission factors (EF_j), and fraction of oxidizised carbon (O_j) by fuel j as follows:

$$CE_{i}^{t} = \sum_{j} CE_{ij}^{t} = \sum_{j} E_{ij}^{t} EF_{j} \left(1 - CS_{j}^{t}\right) O_{j} M \quad (1)$$

Where CS^{t}_{j} is the fraction of the jth fuel which is not oxidised as raw materials in year t.

Thus, total CO_2 emissions of all economy sectors at time t is,

$$CE^{t} = \sum_{i} \mathrm{CE}_{i}^{t} . \quad (2)$$

2. Process CO_2 emission

In this paper, four main industries, namely cement, lime stone, calcium carbide, iron and steel industry, are considered for calculating process CO_2 emissions. For the production of cement, lime and calcium carbide:

$$E_{CO2} = A \times F \quad (3)$$

For the production of iron and steel:

$$E_{CO2} = AD_{i} \times EF_{i} + AD_{d} \times EF_{d} + \left(AD_{r} \times F_{r} - AD_{s} \times F_{s}\right) M \quad (4)$$

The formula introduction and parameters are shown in table 2 and 3.

2.2 Data Sources

Data used in this paper are mainly from China Statistical Yearbook (CSY, 2010-2013), Chinese Energy Statistical Yearbook (CESY, 2010-2013), IPCC report (2006), and industry Statistics Yearbooks (2010-2013). Acronyms of classification are listed in table 4.

3. Results and Discussion

3.1 CO_2 flow chart of 2012

3.1.1 China's carbon flow increased significantly in these years

Based on data from “China’s Energy Statistical Yearbook”, we calculated the inventory of

China’s carbon flow for 2009-2012. We draw China's carbon flow chart for 2012 for analysis as shown in Figure 2, while carbon flow for other years are listed in Appendix A, B and C. In this paper we suppose CO_2 is “carried” by fossil fuels, electricity and heating power. Different colours represent different varieties of CO_2 carriers, and size of area represents the relative magnitude of CO_2 flow. Graph on the left is the CO_2 flowing into China's social system, which is carried by primary energy, including imported energy. Obviously, coal brings the maximum amount of CO_2 into China’s CO_2 flow system with a value of 6500.49 million tons, which accounts for 77.59% of the total primary CO_2 flow, decreasing 0.61 percents than that in 2008. The high percentage reflects the unitary structure of carbon emission in China, which is not conducive to CO_2 reduction. The middle part is the CO_2 flowing into energy processing and conversion sub-sectors. We can find that 96.73% of the CO_2 flow into energy processing and conversion sectors in 2012, in which the sub-sector of electricity and heat production occupies 3296.03 million tons, increased 27.96% in total than that in 2008. Above and below parts denote the outflow of CO_2 emissions from China's social and economic system, including exported CO_2, transmission and distribution loss emissions and conversion loss emissions. The right part is the CO_2 flowing to the terminal sub-sectors. After flowing through energy processing and conversion sector, 21.93% of China’s $CO_2$for 2012 leaves the system in the form of conversion loss emissions, while the remainder flows into terminal sub-sectors. Noteworthy, the conversion loss emissions of the sub-sector of electricity and heat production are huge, reaching up to 1752.39 million tons, accounting for 53.17% of the total CO_2 flowing into this sub-sector. This shows that efficiency of heat and electricity production in China should be improved greatly. There is a small amount flows out of the system in the form of exports and transmission and distribution losses, a total amount of which is 127.68 million tons in 2012, less than that in 2008. Although this part of CO_2 doesn't release into the environment, but it reflects the waste of energy fuels and should be reduced. In terminal sub-sectors, the CO_2 mainly flows into five main sub-sectors, that is, ferrous sector, chemical industry, non-metallic mineral sector, transportation sector, and residential sector, all of which accounts for 75.12% of the total CO_2 flow. The process CO_2 emissions in non-metallic mineral sector is maximum, reaching up to 624.17 million tons, accounting for 55.76% of its total CO_2 flow, followed by that in ferrous sector. From left to right, the CO_2 flow chart shows a clear and detailed circulation of carbon.

3.1.2 CO_2 emissions from terminal sectors differ greatly

Figure 3 shows the proportion of CO_2 emissions from terminal sub-sectors in 2012, which contains both energy-related CO_2 emissions and process CO_2 emissions. Clearly, the CO_2 flowing to ferrous metal sector is maximum, accounting for 26% of total terminal CO_2 emissions, followed by non-metallic mineral sector, accounting for 18%. CO_2 emissions from chemical industry, transportation and residential sectors are similar, all accounting for approximately 10% of total terminal CO_2 emissions. Obviously, these sectors absorb most of the carbon flow in China's carbon system, having the most significant impact on reduction of China's CO_2 emissions. In Figure 4, we find that energy-related CO_2 emissions from chemical industry sector, ferrous metal sector, and non-metallic mineral sector account for 97.31%, 85.02% and less than 50% respectively, their process CO_2 emissions sharing a high proportion. CO_2 emissions from these sub-sectors are the greatest, accounting for 56% of total CO_2 emissions from terminal sub-sectors. Due to the large base number, the process CO_2 emissions from these sectors are huge. Therefore,

CO_2 emissions from production process in some sectors should not be overlooked when we focus on reductions in energy-related carbon emissions.

3.2 Trend analysis from 2008 to 2012

3.2.1 Total Carbon emissions increased rapidly, especially from coal

Total CO_2 emissions from primary energy consumption increased nearly 21% from 2008 to 2012, with an average annual growth rate of 4.81% and an aggregate amount of 8.18 billion tonnes, as shown in Figure 5. From the perspective of primary energy carriers, there is little change in the structure of carbon emissions. The proportion of CO_2 emissions caused by coal consumption slightly decreased, remaining at approximately 80%, while the proportion of CO_2 emissions from oil and natural gas consumption both increased slightly. For indexes of per capita CO_2 emissions and CO_2 intensity, the basic trend has not changed: namely continuous growth in per capita CO_2 emissions and a decline in CO_2 intensity. The average annual growth rate of per capita CO_2 emissions increased by up to 5.04%, while carbon intensity decreased by 3.97% each year on average. Because of the large population base and rapid economic growth, China's CO_2 emissions will inevitably continue to rise in the future. The primary energy carbon flow refers to the CO_2 carried by primary energy, including that produced in China and imported from other countries. As shown in Figure 6, obviously, the flow of primary energy carbon has increased significantly in 2012 when compared to 2008, especially that carried by natural gas, which grew 71.30%. From the perspective of carbon flow structure, the primary energy carbon flow is still coal-based, with the proportion of the carbon flow carried by coal reaching 78%.The proportion of the carbon flow carried by crude oil remains unchanged, and that carried by natural gas drops one percentage point to 3%, which has a higher growth rate in the amount of emissions. Overall, coal is absolutely the main body in China's CO_2 emissions structure, and this feature will not change in the near future.

3.2.2 Reduction in loss emission flows

From figure 7, it's obvious that the CO_2 outflow of conversion loss emissions is the most significant, far more than other CO_2 outflows. The proportion of the CO_2 outflow caused by energy exports fell by 33.63% in 2012 compared to 2008, indicating that with the rapid increase of China's economy and energy consumption, the vast majority of China's primary energy carbon flows into China's social and economic system. Transmission and distribution losses are the components of the CO_2 flow carried by the primary energy that are lost in the process of energy transmission and distribution. Although this part of CO_2 is not emitted into the atmosphere because there is no combustion, it reflects the efficiency of the systems used to transport energy. In Figure 7, the amount of CO_2 lost to transmission and distribution is slightly smaller in 2012 than in 2008, showing an improvement in the efficiency of energy transportation. Conversion loss emissions denote the extra CO_2 emissions in the production process of secondary energy. We found that conversion loss emissions increased by 20.56% in the heat and power production sector shown in table 5, while the proportion of the conversion loss emissions to the sector's total CO_2 flow decreased from 56.13% to 53.17% as shown in Figure 7. This indicates that although energy processing efficiency increased, conversion loss emissions are still increasing due to the large demand for heat and power caused by China's economic development. Interestingly, the conversion loss emissions from the refining, coking and gas production sector decreased from

2008 to 2012, which reflects efficiency improvements in these two sectors that caused a reduction in the total amount of CO_2 in China.

3.2.3 Process CO_2emission flows increased rapidly

As shown in Figure 8, it's obvious that the process CO_2 emissions of all four main sectors have increased significantly. Process CO_2 emissions from cement industry in China are the largest in recent years, with total emissions researching 500 million tons, followed by iron and steel industry. However, from the perspective of emissions growth rate, iron and steel industry increases 10.33%, followed by calcium carbide industry at 8.25%. These four sectors are all basic industries in China, whose development will inevitably continue to cause the growth of process CO_2 emissions, particularly in the cement industry and iron and steel industry. We conducted a comparative study for the two major sources of CO_2 emissions, as shown in Figure 9. Both energy-related CO_2 emissions and process CO_2 emissions in China have greatly increased in recent years, especially process CO_2 emissions, which increased by an average of over 6% a year from 1994 to 2012, a higher average annual growth rate than energy-related CO_2 emissions. The proportion of process CO_2 emissions to total CO_2 emissions is stable at approximately 10%, which is an enormous amount in the context of the huge base of China's CO_2 emissions. Thus, policy makers should pay more attention to process CO_2 emissions.

3.2.4 Changing trends of CO_2 emission structures of terminal sub-sectors are very different

In this paper, CO_2emission structure denotes the proportion of sub-sector's CO_2 emissions to the total terminal CO_2 emissions, including both energy-related and process CO_2 emissions. It's obvious that there are nine departments whose CO_2 emission structures increased as shown in

Figure 10. The structures of ferrous metal industry and transportation sector have the greatest growth with percentages of 1.2% and 0.86%.In sectors with decreasing CO_2emissions structure, the non-metallic mineral and mining (excluding fuels) sectors are most representative, with percentage declines of 1.38% and 0.60%. In recent years, resource depletion accelerated with the rapid economic development in China. Therefore, development of related industries is also restricted. The changing trends of CO_2 emissions structure of these industries also prove this phenomenon. Different carriers of CO_2 emissions can reflect CO_2 emission structure and energy use of each sub-sector. From table 6, the CO_2 flows of eight sub-sectors in the total of eighteen terminal sub-sectors, such as non-ferrous metals and transport equipment, are mainly from their indirect emissions, while seven sectors are mainly carried by coal. This shows that saving energy through electricity and coal is equally important for CO_2 reduction in terminal sub-sectors. The CO_2 flow carried by coking products in the ferrous metal industry is the most significant, thus, targeted CO_2 reduction policies are essential in this sector. From the viewpoint of structural changes, proportions of CO_2 flows carried by coal in most sub-sectors decreased between 2008 and 2012, meaning that traditional coal resources are increasingly being replaced by other energies in terminal sub-sectors. The proportions of CO_2 flows carried by petroleum products in agricultural and residential sectors increased while declining in other sectors, which reflect that the usage of petroleum products in some terminal sub-sectors is gradually restricted. Notably, the proportions of CO_2 flows carried by electricity increased between 2008 and 2012 in all sectors, indicating that electricity has been applied more and more widely.

4. Conclusions and Policy Implications

After drawing China's carbon flow chart for 2012, this paper gives a detailed description of

China’s carbon flow for 2012 and compares the changing characteristics of China’s CO_2 flow during 2008 and 2012. The specific conclusions derived from the present study can be listed as follows:

(1) Coal and oil are main CO_2 carriers in China, which accounts for 97% of the total CO_2 flow. In the terminal sub-sectors, 75.12% of the CO_2 flow mainly into several sectors such as ferrous sectors, chemical industry.

(2) For the comprehensive indexes of per capita CO_2 emissions and CO_2 intensity, basic trend has not changed, that is, continuous increase in per capita CO_2 emissions and decline in CO_2 intensity, while there is a little change in the structure of carbon emissions.

(3) Although the efficiency of energy processing and conversion in China increased dramatically during past four years, the conversion loss emissions of the heat and power production sector are still increasing due to the large demand for heat and power with China's economic development.

(4) CO_2 emissions are mainly from energy-related CO_2 emissions in ferrous metal and chemical industry sector, while that are mainly from process CO_2 emissions in non-metallic mineral sector. In different terminal sub-sectors, main carriers of the CO_2 flow are really different, thus, CO_2 reduction policies should also be targeted.

From the results of this paper, we present the following policy recommendations. Firstly, characteristics of CO_2 emission of different sectors are very different and China's CO_2 emissions system is very complex. Therefore, CO_2 reduction policies should be distinguished among different sectors. More stringent targets for CO_2 emission reductions should be set in the sectors with large CO_2 flows, such as the energy conversion sectors. CO_2 reductions in these sectors will have an important and positive impact on China's overall CO_2 reductions. Strengthening the implementation of CO_2 reduction measures in the terminal sub-sectors with large CO_2 flows, such as the ferrous metal, chemical industry, non-metallic mineral, transportation and residential sectors, will also play a positive role in CO_2 reductions. Second, CO_2 reduction policies for different CO_2 carriers should be different. For example, major carbon flow carriers of different terminal sectors are very different: some sectors have coal as the main carrier, while some have electricity. Therefore, detailed and targeted reduction policies and measures differentiating different CO_2 carriers will be more effective. Third, process CO_2 emissions in the cement industry and iron and steel sectors are abundant and growing rapidly. Therefore, the development of alternative raw materials should be strengthened, and appropriate policies should be made for CO_2 reductions in the production processes of these two sectors. Finally, in the structure of CO_2 emissions in terminal sectors, policy makers should focus on the sectors that have fast growth in the proportion of CO_2 emissions, such as the ferrous metal and transportation sectors, analyse the reason for the accelerated growth of CO_2 emissions, and make appropriate countermeasures in a timely fashion.

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Figures

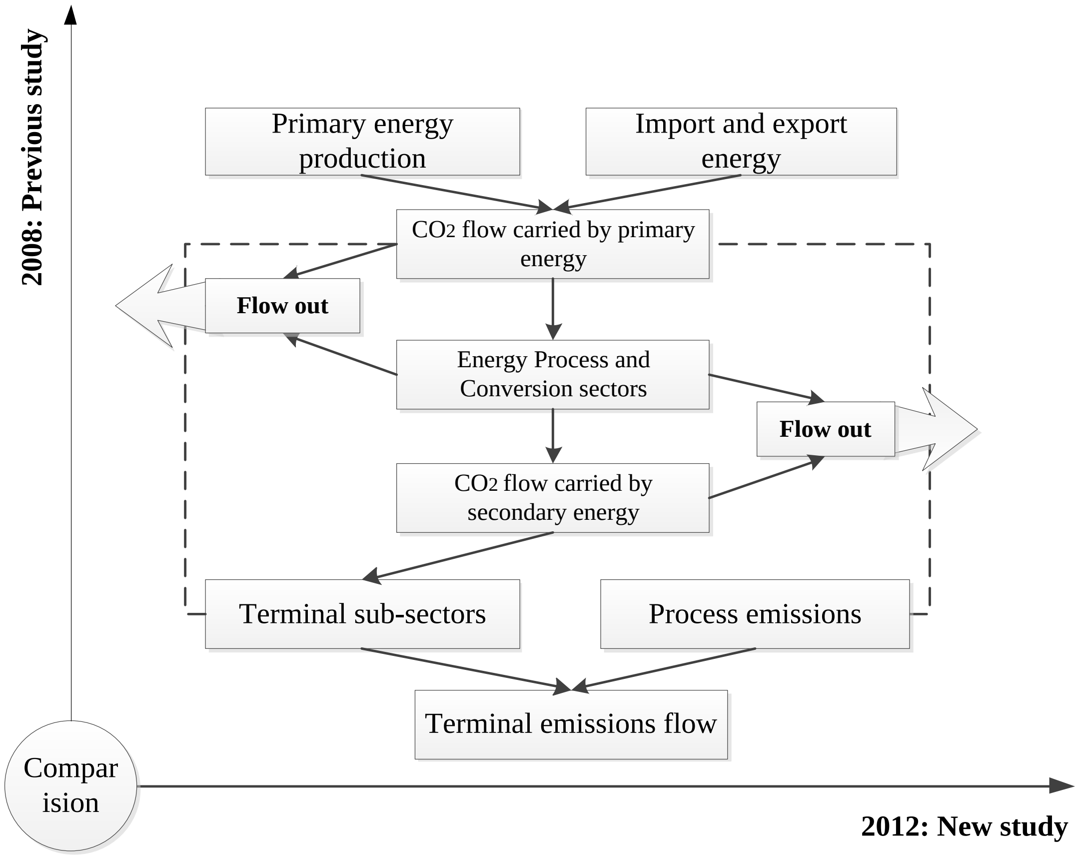

Fig. 1. Framework of the research

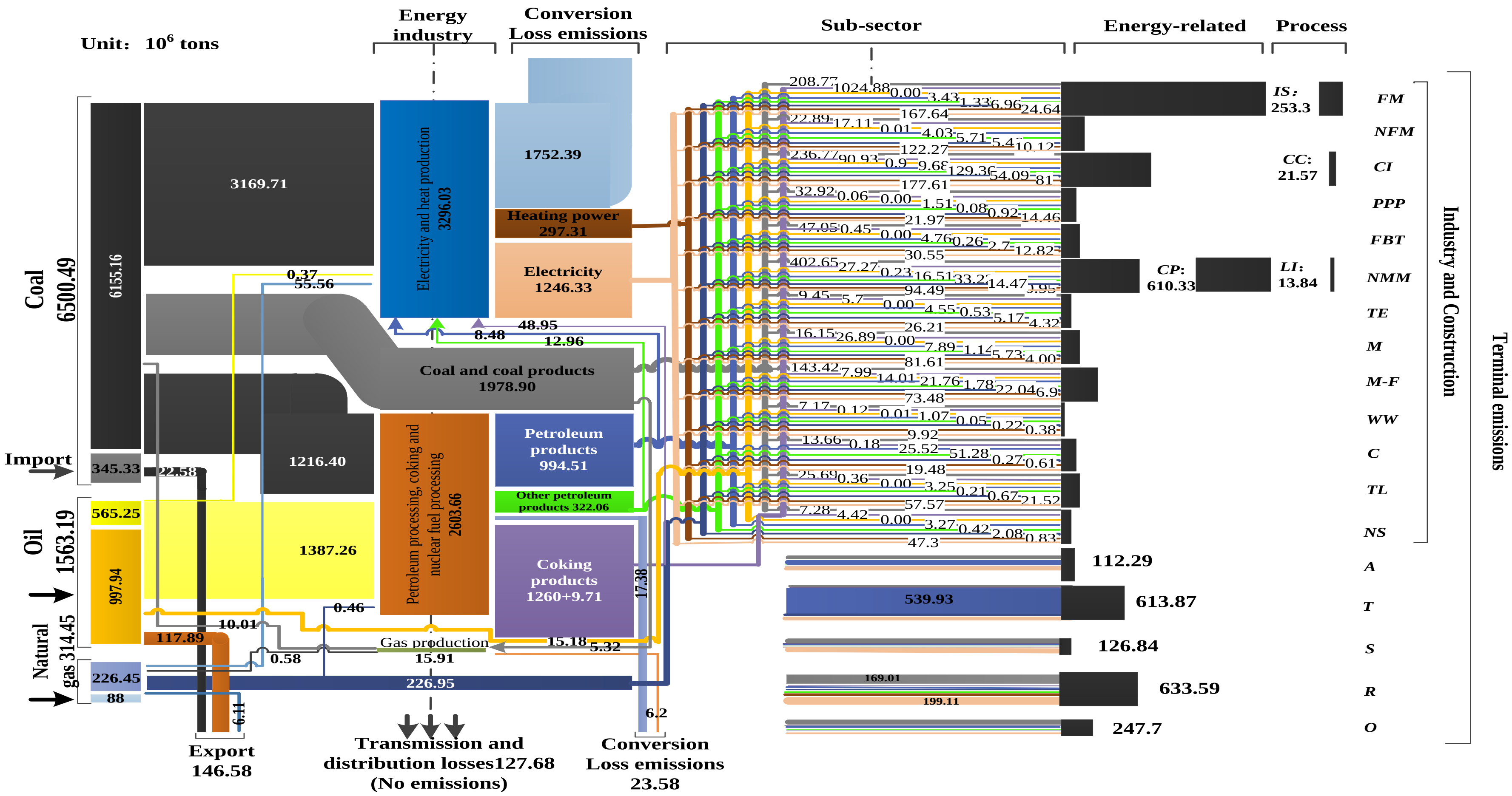

Fig. 2. China's CO_2 flow chart for 2012

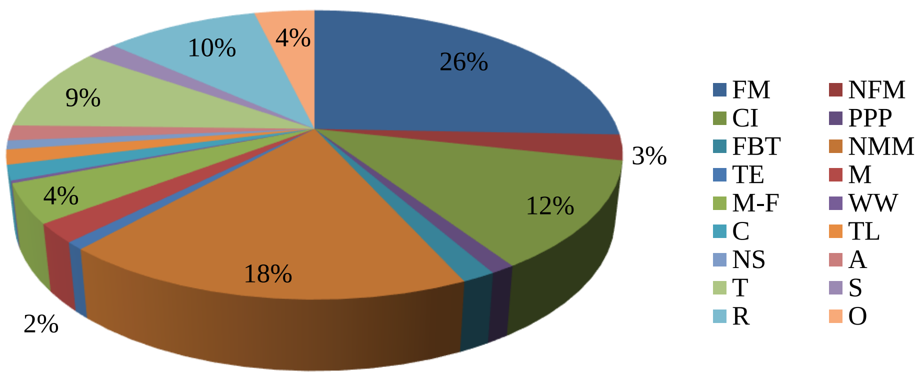

Fig. 3. Comparison of CO_2 emissions from terminal sectors in China in 2012

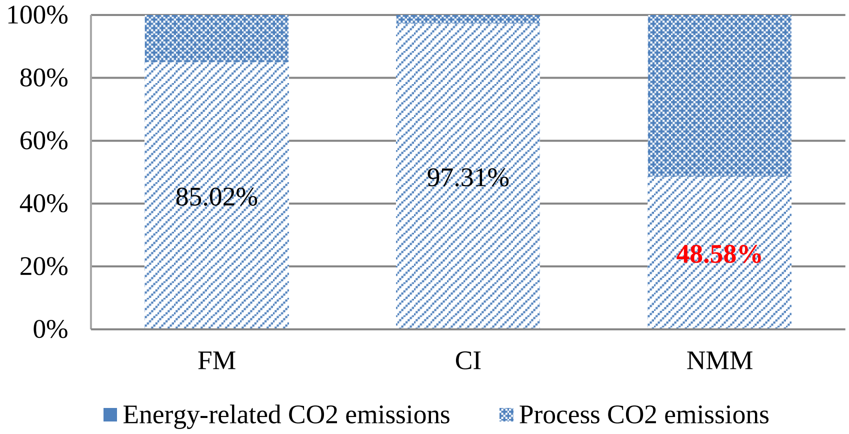

Fig. 4. Comparison of energy-related and process CO_2 emissions in three sectors in 2012

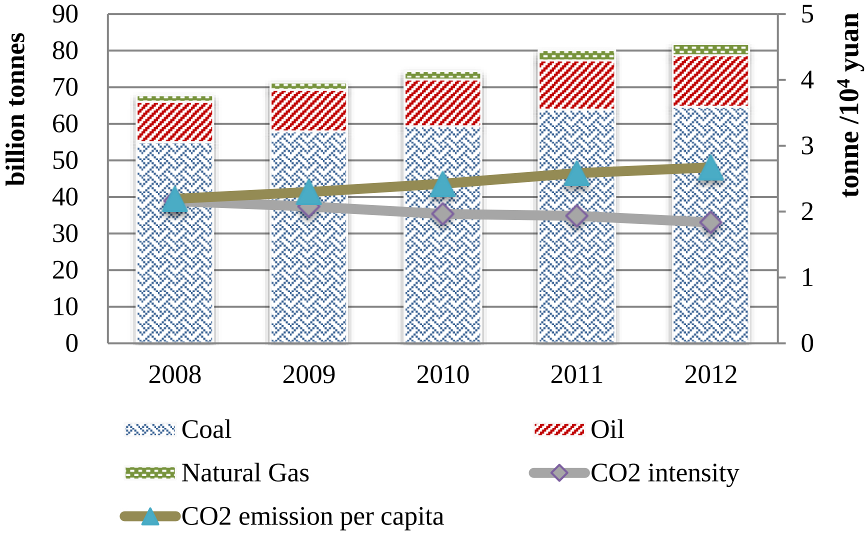

Fig. 5. Indicators of China's energy-related carbon emissions

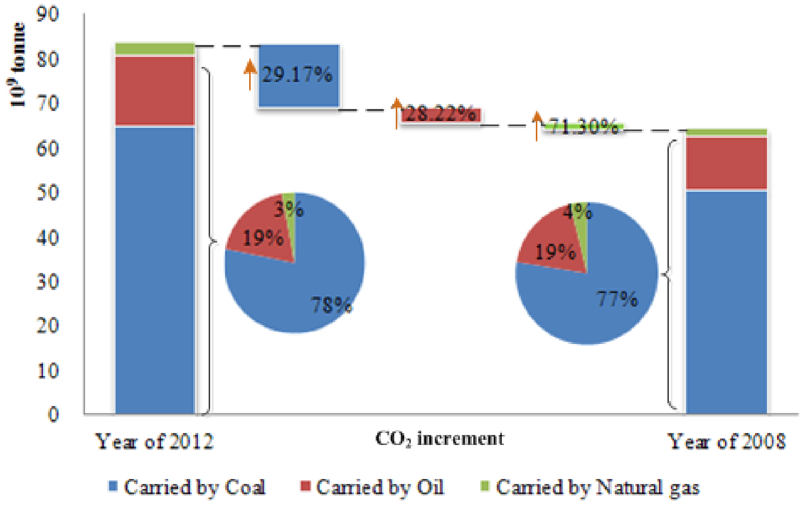

Fig. 6. Changes in the CO_2 flowing into China's carbon system carried by primary energy

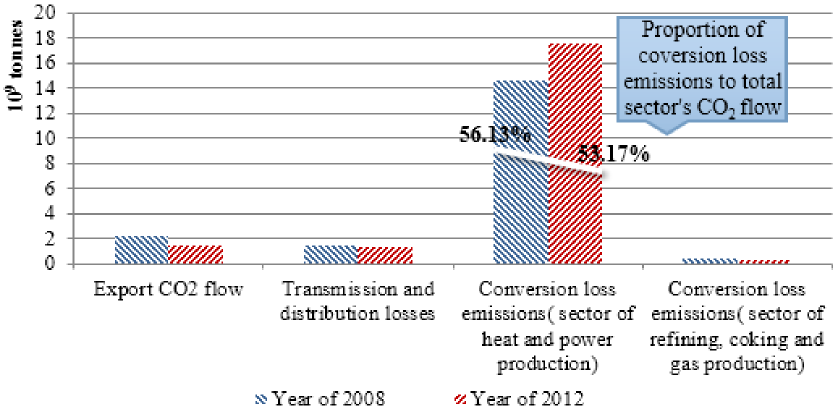

Fig. 7. Comparison of the CO_2 outflow between 2008 and 2012.

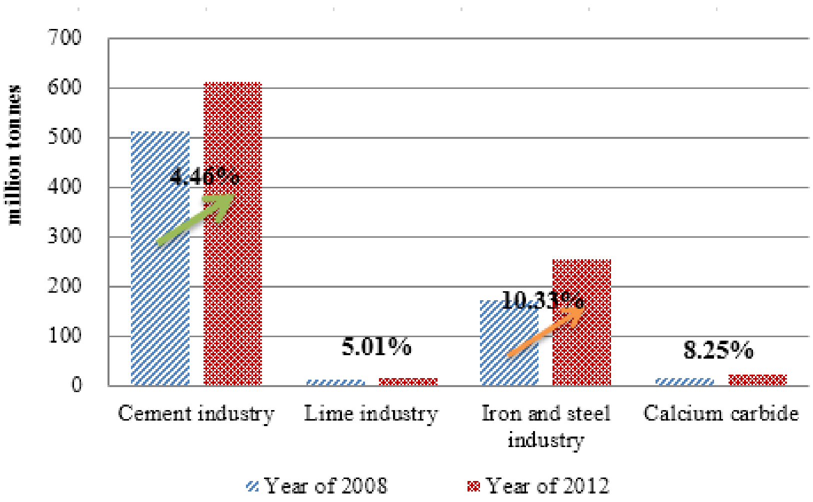

Fig. 8. Comparison of process CO_2 emissions between 2008 and 2012.

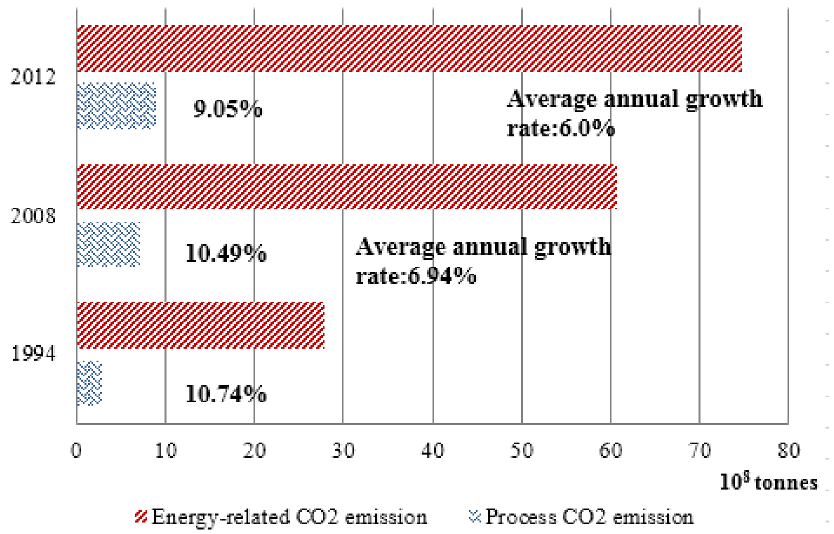

Fig. 9. Comparison of energy-related and process CO_2 emissions in recent years.

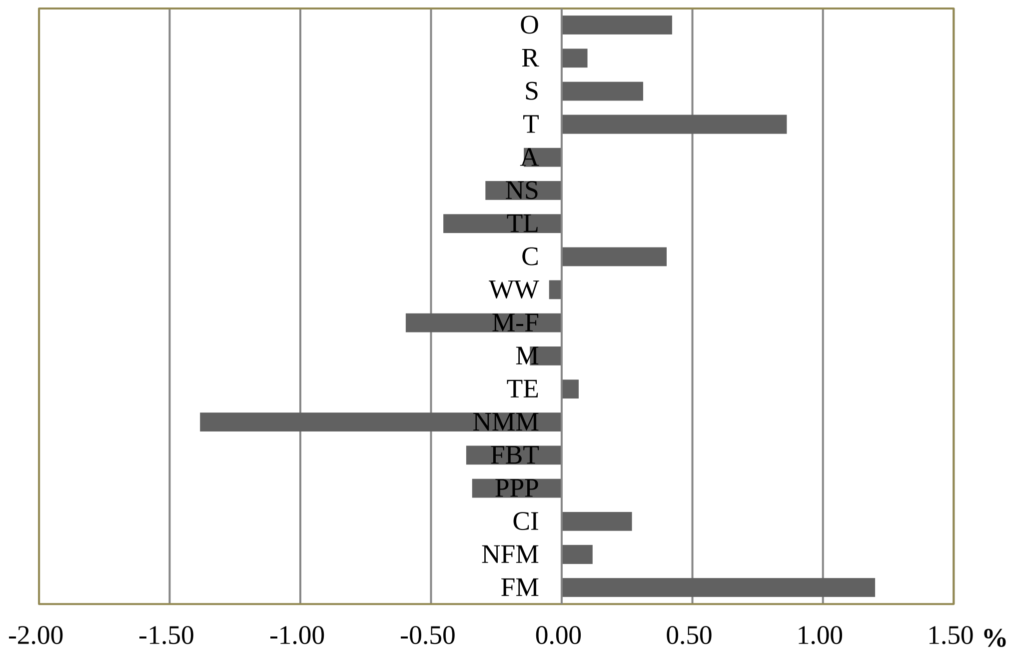

Fig. 10. Comparison of the structure of terminal CO_2 emissions between 2008 and 2012.

Table 1

Classification in this article

Sector code	Sub-sectors in IPCC classification	Sub-sectors in China's Energy Statistical Yearbook
1	Black metal	Smelting and Pressing of Ferrous Metals.
2	Non-ferrous metals	Smelting and Pressing of Non-ferrous Metals.
3	Chemical industry	Manufacture of Raw Chemical Materials and Chemical Products; Manufacture of Medicines; Manufacture of Chemical Fibers; Manufacture of Rubber and Plastics Products.
4	Pulp, paper and print	Manufacture of Paper and Paper Products; Printing and Reproduction of Recording Media.
5	Food processing, beverages and tobacco products	Processing of Food from Agricultural Products; Manufacture of Foods; Manufacture of Liquor, Beverages and Refined Tea; Manufacture of Tobacco.
6	Non-metallic mineral	Manufacture of Non-metallic Mineral Products.
7	Transport equipment	Manufacture of Automobiles; Manufacture of Railway, Ship, Aerospace and Other Transport Equipments.
8	Machinery	Manufacture of General Purpose Machinery; Manufacture of Special Purpose Machinery; Manufacture of Electrical Machinery and Apparatus; Manufacture of Computers, Communication and Other Electronic Equipment; Manufacture of Measuring Instruments and Machinery.
9	Mining (excluding fuels)	Mining and Washing of Coal; Extraction of Petroleum and Natural Gas; Mining and Processing of Ferrous Metal Ores; Mining and Processing of Non-Ferrous Metal Ores; Mining and Processing of Nonmetal Ores; Support Activities for Mining; Mining of Other Ores.
10	Wood and wood products	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products; Manufacture of Furniture.
11	**Construction**	**Construction**
12	Textiles and leather	Manufacture of Textile; Manufacture of Textile, Wearing Apparel and Accessories; Manufacture of Leather, Fur, Feather and Related Products and Footwear.
13	Non-specific industry	Manufacture of Articles for Culture, Education, Arts and Crafts, Sport and Entertainment Activities; Manufacture of Metal Products; Other Manufacture; Utilization of Waste Resources; Repair Service of Metal Products, Machinery and Equipment; Production and Supply of Water.

Table 2

Symbol introduction in formulas

Item	Illustration
i	industrial sector
j	fuel kind
t	year
CE^{t}_{ij}	CO_2 emission of the *i*th sector based on fuel type j in year t
E^{t}_{ij}	total energy consumption of the *i*th sector based on fuel type j in year t
EF_j	the carbon emission factor of the *j*th fuel (t C/TJ)
CS^{t}_{j}	the fraction of the jth fuel which is not oxidized as raw materials in year t
O_j	the fraction of carbon oxidized of fuel *j*
M	the molecular weight ratio of carbon dioxide to carbon (44/12)
E_{CO2}	process CO_2 emissions
A	production amount in different sectors(cement production, lime production, calcium carbide production)
F	emission factor, for cement production (0.538 t/t), lime production (0.683 t/t), calcium carbide production (1.154 t/t)
AD_i	consumption of lime stone in iron and steel sector
EF_i	emission factor of lime stone as solvent consumption (0.43 t/t)
AD_d	consumption of dolomite in iron and steel sector as solvent
EF_d	emission factor of dolomite as solvent consumption (0.474 t/t)
AD_r	amount of pig iron for steelmaking
F_r	average carbon rate of pig iron for steel making (4.1%)
AD_s	amount of steel production
F_s	average carbon rate of steel products (0.248%)

Note: Parameters are from IPCC.

Table 3

Carbon emission factors (*EF*) and fraction of carbon oxidized (*O*).

Fuel	*EF* (t C/TJ)	*O*	Fuel	*EF* (t C/TJ)	*O*
Raw coal	25.8	0.9	Fuel oil	21.1	0.98
Anthracite	27.4	0.94	Gasoline	18.9	0.98
Bitumite	26.1	0.93	Diesel oil	20.2	0.98
Lignite	28	0.96	Kerosene	19.6	0.98
Moulded coal	33.6	0.9	NGL	17.2	0.98
Washed coal	25.41	0.93	LPG	17.2	0.98
Coke	29.5	0.93	Refinery gas	18.2	0.98
Coke oven gas	13.58	0.98	Other petroleum products	20	0.98
Other coking products	29.5	0.93	Natural gas	15.3	0.99
Crude oil	20.1	0.98			

Note: Parameters are from IPCC.

Table 4

The acronyms of classification [a]

Source	Sector	Sub-sector [b]	Abbreviation
Energy -related	Energy industry	Electricity and heat production	*EH*
		Petroleum processing, coking and nuclear fuel processing	*PCN*
		Gas production	*G*
	Industry and Construction	Ferrous metal	*FM*
		Non-ferrous metal	*NFM*
		Chemical industry	*CI*
		Pulp, paper and print	*PPP*
		Food processing, beverages and tobacco products	*FBT*
		Non-metallic mineral	*NMM*
		Transport equipment	*TE*
		Machinery	*M*
		Mining (excluding fuels)	*M-F*
		Wood and wood products	*WW*
		Construction	*C*
		Textiles and leather	*TL*
		Non-specific industry	*NS*
	Agriculture		*A*
	Transportation		*T*
	Service		*S*
	Resident		*R*
	Other		*O*
Process	Non-metallic mineral	Cement production	*CP*
	Non-metallic mineral	Lime industry	*LI*
	Chemical industry	Calcium carbide	*CC*
	Ferrous metal	Iron and steel industry	*IS*

Note: [a] the table is same as "Table 1" in the reference (Hailin M, Huanan Li, 2013), for this is the follow-up study of that paper .[b] Sub-sectors of energy industry belong to energy processing and conversion sub-sector, while all other sub-sectors are terminal sub-sectors.

Table 5

Comparison of conversion loss emissions between 2008 and 2012

Year	Conversion Loss Emissions					
	EH		*PCN*		*G*	
2008	1453.55	up	23.33	down	15.3	down
2012	1752.39	20.56%	17.38	25.50%	6.2	59.48%

Table 6

Comparison of CO_2 flows carried by different fuels between 2008 and 2012

Sector	**Direct emissions**			**Indirect emissions**
	Coal	**Coking Products**	**Petroleum Products**	**Electricity**
Total	***31.26-25.83***	21.53-21.29	15.37-15.42	20.45-23.59
FM	12.96-14.53	***74.09-71.31***	0.69-0.24	10.54-11.63
NFM	18.56-12.20	12.86-9.12	3.95-2.15	***55.72-65.18***
CI	***36.19-30.34***	12.53-11.65	3.59-1.24	20.43-22.76
PPP	***58.15-45.77***	0.29-0.08	4.02-2.10	23.17-30.54
FBT	***59.50-47.72***	0.70-0.45	6.06-4.83	22.07-30.99
NMM	***77.32-68.27***	2.42-4.62	5.30-2.80	11.99-16.02
TE	27.81-16.89	9.83-10.18	13.84-8.14	***36.46-46.87***
M	19.09-11.26	15.42-18.75	11.34-5.50	***45.89-56.91***
M-F	***52.68-49.22***	2.00-2.74	7.43-7.47	20.52-25.22
WW	***49.03-37.84***	0.59-0.63	7.82-5.69	37.92-52.38
C	16.91-12.30	0.45-0.16	***27.58-22.99***	17.34-17.55
TL	38.06-23.51	0.26-0.32	5.67-2.98	***38.24-52.68***
NS	21.04-11.09	4.50-6.74	8.43-4.99	***62.98-72.10***
A	29.54-28.81	1.55-0.00	**39.68-41.93**	29.04-28.87
T	2.83-1.73	0.00-0.00	**89.27-87.96**	4.10-4.77
S	39.93-34.37	0.80-0.20	11.16-11.10	***38.20-42.70***
R	***33.72-26.67***	2.26-0.87	8.69-12.53	27.97-31.43
O	18.96-16.74	0.20-0.09	39.43-36.47	***34.72-39.86***

Appendix A：Carbon Flow of Terminal Sub-sectors and Process Emissions of China in 2009

Unit: Million tons

Terminal sub-sector		Coal	Coking produ	Crude oil	Refined oil	Other petroleum	Natural gas	Heat	Electricity	Total
Energy-related CO_2 emissions	*EH*	59.64	0.79	0.02	4.14	0.10	0.10	4.90	90.34	160.03
	PCN	28.76	12.01	4.31	9.73	149.44	4.45	23.67	15.21	247.59
	G	1.57	1.01	0.01	0.42	0.97	0.48	0.25	2.25	6.95
	BM	171.72	893.82	0.00	5.81	1.11	4.06	18.24	128.72	1223.4
	NFM	27.28	23.09	0.02	4.80	4.14	1.45	6.90	82.48	150.15
	CI	224.78	72.93	5.56	19.34	62.21	37.95	57.06	131.48	611.30
	PPP	45.37	0.20	0.01	2.66	0.17	0.34	11.53	18.11	78.39
	FBT	58.92	0.56	0.01	6.11	0.46	1.06	10.54	22.88	100.54
	NMM	430.31	16.42	0.27	23.97	5.25	9.65	0.95	68.07	554.89
	TE	11.84	4.75	0.00	5.14	0.54	2.62	2.19	18.10	45.18
	M	23.78	24.80	0.01	14.11	1.50	4.08	4.46	57.95	130.70
	M-F	141.12	4.63	14.71	18.51	2.04	19.71	3.67	56.41	260.80
	WW	8.88	0.10	0.01	1.36	0.04	0.17	0.57	7.27	18.40
	C	12.37	0.16	0.00	21.14	34.19	0.21	0.57	13.51	82.15
	TL	41.51	0.28	0.02	5.70	0.20	0.36	17.59	43.49	109.15
	NS	13.29	3.23	0.01	5.72	0.74	0.60	0.82	44.72	69.11
	A	30.71	1.28	0.00	40.08	0.13	0.00	0.07	30.09	102.36
	T	12.46	0.02	0.00	408.11	1.69	17.62	1.32	19.75	460.98
	S	38.35	0.74	0.00	11.08	1.96	5.18	3.02	36.40	96.73
	R	170.11	10.05	0.00	50.02	46.38	38.41	59.52	155.99	530.48
	O	37.87	0.30	0.00	67.74	1.51	5.11	6.29	70.11	188.94
Process emissions	*CI*	537.06				*IS*	191.55			
	LI	12.00				*CC*	17.17			

Appendix B：Carbon Flow of Terminal Sub-sectors and Process Emissions of China in 2010

Unit: Million tons

Terminal sub-sector		Coal	Coking produ	Crude oil	Refined oil	Other petroleum	Natural gas	Heat	Electricity	Total
Energy-related CO_2 emissions	*EH*	56.43	0.52	0.01	2.42	0.13	0.15	6.03	99.87	165.55
	PCN	25.24	13.31	2.99	7.32	151.69	6.74	26.23	18.10	251.63
	G	1.25	0.77	0.00	0.18	0.83	0.70	0.32	2.65	6.69
	BM	191.05	902.43	0.01	4.21	1.30	4.39	21.99	147.65	1273.0
	NFM	24.17	17.71	0.02	5.40	6.55	1.95	8.63	100.18	164.60
	CI	216.52	60.20	6.63	16.52	82.94	40.13	66.32	145.01	634.27
	PPP	39.80	0.09	0.00	2.51	0.13	0.49	13.43	20.20	76.65
	FBT	51.21	0.39	0.00	6.30	0.50	1.28	11.56	25.21	96.45
	NMM	397.30	15.79	0.07	21.32	35.35	9.15	1.18	78.39	558.56
	TE	11.34	4.89	0.01	5.56	0.71	2.75	2.74	25.30	53.29
	M	23.10	23.68	0.02	14.24	1.60	5.18	5.45	70.55	143.80
	M-F	134.43	5.84	14.57	18.65	1.97	22.57	4.36	62.12	264.51
	WW	7.72	0.09	0.01	1.56	0.05	0.14	0.58	8.22	18.37
	C	13.04	0.17	0.00	24.45	61.80	0.25	0.59	15.47	115.76

	TL	34.70	0.41	0.00	5.51	0.19	0.43	19.50	48.60	109.35
	NS	10.89	2.73	0.01	5.37	0.76	0.96	1.06	54.12	75.90
	A	31.97	1.34	0.00	42.37	0.14	0.11	0.08	31.26	107.27
	T	11.21	0.00	0.00	448.08	1.82	20.83	1.46	23.52	506.91
	S	36.64	0.21	0.00	12.34	2.25	5.89	3.47	41.36	102.16
	R	171.71	8.49	0.00	59.95	45.19	49.06	59.88	164.07	558.34
	O	36.60	0.30	0.00	75.56	1.58	5.62	6.69	78.50	204.85
Process emissions	*CI*	561.48				*IS*	212.13			
	LI	12.61				*CC*	18.64			

Appendix C：Carbon Flow of Terminal Sub-sectors and Process Emissions of China in 2011

Unit: Million tons

Terminal sub-sector		Coal	Coking produ	Crude oil	Refined oil	Other petroleum	Natural gas	Heat	Electricity	Total
Energy-related CO_2 emissions	*EH*	44.14	0.59	0.00	2.33	0.43	0.12	5.49	122.03	175.12
	PCN	23.37	17.31	2.08	6.13	158.50	12.90	27.43	19.44	267.16
	G	1.00	0.43	0.00	0.16	0.36	1.04	0.38	2.89	6.25
	BM	202.00	1004.3	0.01	3.20	2.07	6.13	23.92	168.03	1409.6
	NFM	25.22	17.40	0.02	4.68	5.73	2.98	10.01	112.11	178.14
	CI	231.87	78.97	2.49	11.76	127.20	50.38	74.23	159.53	736.44
	PPP	38.07	0.08	0.00	1.78	0.09	0.67	14.28	21.86	76.83
	FBT	50.39	0.52	0.00	5.15	0.28	1.83	12.47	27.75	98.39
	NMM	421.95	20.71	0.06	18.69	32.67	13.66	1.09	93.42	602.24
	TE	10.40	5.09	0.00	5.40	0.68	3.94	3.15	27.58	56.24
	M	21.45	31.56	0.01	9.76	1.32	6.01	4.47	79.46	154.04
	M-F	135.45	8.14	11.10	22.01	1.93	21.27	5.84	71.88	277.62
	WW	7.64	0.07	0.00	1.16	0.06	0.21	0.46	9.03	18.63
	C	14.48	0.14	0.00	25.62	46.32	0.28	0.55	18.31	105.69
	TL	30.31	0.41	0.00	4.20	0.17	0.54	18.97	52.21	106.82
	NS	9.71	2.86	0.00	3.73	0.64	1.28	1.01	57.00	76.22
	A	33.47	1.55	0.00	44.90	0.17	0.12	0.08	32.43	112.72
	T	11.41	0.00	0.00	484.89	1.88	27.47	1.77	27.16	554.59
	S	41.32	0.53	0.00	13.03	2.14	7.27	3.82	48.12	116.24
	R	174.61	7.05	0.00	71.07	49.84	57.16	62.22	179.93	601.89
	O	39.10	0.34	0.00	85.20	1.70	5.87	7.22	88.14	227.58
Process emissions	*CI*	585.91				*IS*	232.71			
	LI	13.22				*CC*	20.10			