China's Carbon Flow: 2008-2012

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A B S T R A C T

In recent years, China's CO_2 emissions have become one of the hottest issues long-termly concerned by domestic and foreign researchers. After drawing China's carbon flow chart for 2012 based on IPCC carbon emission inventory method and China's energy balance table, this paper gives a detailed description of China's carbon flow for 2012 and compares the changing characteristics of China's carbon flow during 2008 and 2012. The results show that 75.12% of CO_2 flow mainly into several sectors such as ferrous sectors, chemical industry in the terminal sub-sectors; Although China thermoelectric efficiency 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 thermoelectric; CO_2 emissions are mainly from energy-related CO_2 emissions in ferrous metal and chemical industry sector, while that are mainly from process emissions in non-metallic mineral sector; In different terminal sub-sectors, main carriers of CO_2 flow are different, thus, CO_2 reduction policy should also be different. In addition, some valuable suggestions are given in this paper.

Key words: CO_2 flow chart; CO_2 reductions; changing characteristics; China

1. Introduction

In recent years, CO_2 emissions-related issues has been the focus studied by domestic and foreign scholars, as global warming has become one of the most serious environmental problems worldwide. Global warming is largely attributed to the effect of emissions of greenhouse gases (GHGs) such as CO_2 from the combustion of fossil fuels (Ke Wang, Yi-Ming Wei, 2013). According to the research (Jiangling Zhu, er al., 2010; Hu and Lee, 2008; Li, 2010; Wang and Watson, 2010; Wang etal., 2012), China’s CO_2 emissions has surpassed that of the United States in 2008, being the world's largest emitter. It’s a big challenge for the work of China’s carbon emissions reductions. Furthermore, with the growing emphasis on international environmental issues from public and government, China has already faced enormous pressures in the international negotiation on CO_2 emissions control and climate change mitigation (Ke Wang et al., 2013). After four years, China’s CO_2 emissions have rapidly grow from 6.78 billion tons to 8.18 billion tons, with an average annual growth rate of 4.81%. What is the status of China's CO_2 emissions now? What has changed? How to adjust CO_2 reduction policies? A series of questions should be answered for a clearer understanding of China's carbon emissions. Thus, analysis of changing characteristics of China’s carbon emissions from 2008 to 2012 is necessary. This is also the reason for writing this article.

Energy and carbon flow chart is a useful tool for the research of CO_2 emission status, and many institutions and scholars have done some valuable works on this subject (Garry, 2008; Lawrence Livermore National Laboratory, 2011; Osaka University: TsujiLabs, 2007; Environmental Data Compendium, 2003; Li,2006; Xie,2009; Mengling Pei, Hua Liao, Yi-Ming Wei,2014; Yi-Ming Wei, et al., 2008). The Authors (Hailin M, Huanan Li, 2013) analyzed China’s Carbon flow of 2008 based on a more comprehensive and detailed carbon flow chart published on journal of “Energy Policy”. In that paper, we analyzed the situation of China’s CO_2 emissions in

2008 and found some important conclusions, which proved our new proposed research methods and research findings are important. In this paper, we draw China's carbon flow chart for 2012 based on IPCC carbon emission inventory method and China's energy balance table, to reveal the characteristics of carbon flow and emissions in China, including not only energy-related carbon emissions but also carbon emissions from production process, namely process emission. In addition to a detailed description of China's carbon flow from 2008 to 2012, the paper also compares the changes between 2008 and 2012 in carbon emissions. It reflects the actual situation of China's carbon flow more comprehensively, providing an accurate and fundamental reference for policy-makings. The remainder of this paper is organized as follows. In the next section, the methodology calculating CO_2 emission of energy combustion and production process is discussed. Furthermore, we clarify the data used. The main results are presented in section 4. Finally, we conclude this study.

2. Methodology

In this paper, we not only consider the energy-related CO_2 emissions from the final subsectors, but also calculate the process CO_2 emissions which are emitted in the process of industry production. According to the classification from IPCC 2006, CO_2 emission sectors contain "Energy industry", "Industry and Construction", "Agriculture", "Transportation", "Service", "Resident" and "Other" sectors, in which "Energy industry" includes three subsectors namely "Electricity and heat production", "Petroleum processing, coking and nuclear fuel processing", "Gas production". "Industry" sector is divided into 41 sub-sectors in China's Energy Statistical Yearbook 2013, out of the three sub-sectors of the energy industries remaining 38 sub-sectors, but according to classification of IPCC2006, "industry and construction" sector is divided into 13 sub-sectors. We merge and organize the subsectors of "industry" sector in Energy Statistical Yearbook 2013 to the classification of IPCC2006, as shown in Table 1. Although the use of electricity and heat emits no CO_2, much CO_2 is produced in thermal power and heat generation. Based on fairness, we take the carbon emissions induced from electricity consumptions by terminal energy-use subsectors as their indirect CO_2 emissions. CO_2 emissions from "Energy industry" are the loss emissions during the process of energy production. Also, we calculate the process emissions from the four main sectors namely cement production, lime production, iron and steel production, calcium carbide production, while that from other sectors are ignored for their small amounts.

Table 1

Classification of this article

Sector code	**Sectors in IPCC classification**	**Sectors in National industry classification**
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.

2.1 Research Framework

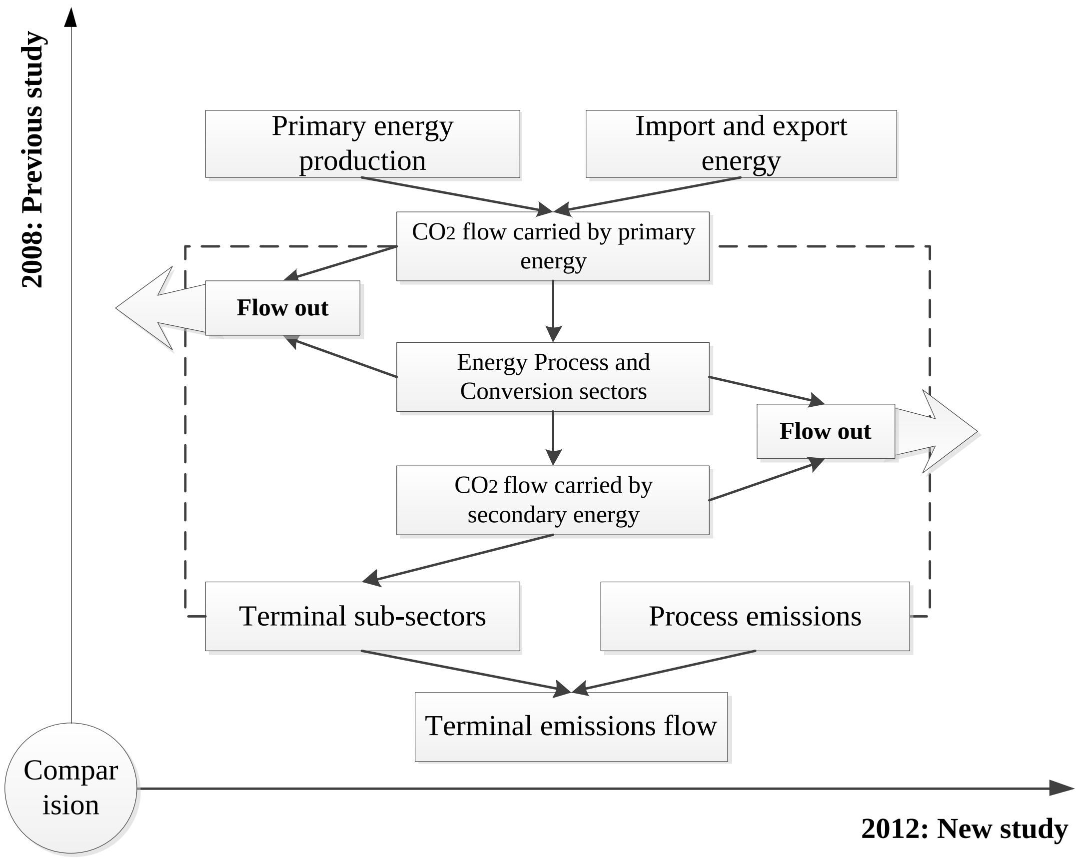

Fig.1. Framework of this study

The framework of this paper is shown as figure 1. Firstly, we sort energy balance table, final energy consumption by industry sector table and industry capacity data of major sectors of China in 2012. Then, CO_2 flows of different sectors are calculated according to the formula above. After that, we draw China's carbon flow chart of 2012. Based on the above research, we analyze the changing characteristics of China's carbon flow from 2008 to 2012, not only from the point of view of amount of emissions, but also from the perspective of emission structures.

2.2 CO_2 Accounting Method

Formula involved in this article has been described in our previous article (Hailin Mu, Huanan Li,2013), here only for a brief introduction. Energy-related CO_2 emission is calculated according to Eq.(1), which is given by IPCC. The total CO_2 emission in the *i*th sector is estimated based on energy consumption, carbon emission factors (*EFs*), and the fraction of oxidized carbon by fuel as follows:

$$CE_{\mathrm{i}}^{\mathrm{t}} = \sum_j CE_{ij}^t = \sum_j E_{ij}^t EF_j \left(1 - CS_j^t\right) O_j M \tag{1}$$

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

$$CE^{\mathrm{t}} = \sum_{\mathrm{i}} \mathrm{CE}_{\mathrm{i}}^{\mathrm{t}} . \tag{2}$$

Process emissions are mainly from the production of cement, lime stone, calcium carbide, iron and steel, while emissions from other industries can be ignored. For production of cement, lime and calcium carbide, CO_2 emissions can be calculated as follows,

$$E_{CO2} = A \times F \tag{3}$$

For production of iron and steel,

$$E_{CO2} = AD_i \times EF_i + AD_d \times EF_d + \left(AD_r \times F_r - AD_s \times F_s\right) M \tag{4}$$

Formula introduction is shown in table 2. Specific parameters in the formula please refer to our previous article.

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
AD_i	consumption of lime stone in iron and steel sector
EF_i	emission factor of lime stone as solvent consumption
AD_d	consumption of dolomite in iron and steel sector as solvent
EF_d	emission factor of dolomite as solvent consumption
AD_r	amount of pig iron for steelmaking
F_r	average carbon rate of pig iron for steel making
AD_s	amount of steel production
F_s	average carbon rate of steel products

2.3 Data Sources

Data used in this paper are mainly from China Statistical Yearbook (CSY, 2013), China Energy Statistical Yearbook (CESY, 2013), report of IPCC (2006), industry Statistics Yearbooks 2013. The acronyms of classification are listed in table 3.

Table 3

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-sector includes processing conversion sub-sectors and terminal sub-sectors, all of which are terminal sub-sectors except energy industries belong to processing conversion sub-sectors.

3. Results and discussion

3.1 CO_2 flow chart of 2012

3.1.1 China's carbon flow increased significantly in these years

Through calculating based on data of "China's Energy Statistical Yearbook (2010-2013)", we calculated the inventory of carbon flow of 2009, 2010, 2011 and 2012. There are no big differences in carbon flow diagrams, so we only drew the 2012 carbon flow chart for analysis. We got CO_2 flow chart of China in 2012 as shown in Figure 2. Different colors represent different varieties of energy carrier, and the type of area represents the relative magnitude of the CO_2 flow in figure 2. Graph on the left is the carbon emissions carried by the primary energy flowing into China's socio-economic system, including that by energy imports. The middle part is CO_2 flow to the energy conversion sectors, while the right part is the CO_2 flow to the end-use sectors. In the above and below of this chart are the outflow of CO_2 emissions from socio-economic system, including the export CO_2 flow, Transmission and distribution losses flow and conversion loss emissions. From left to right, the CO_2 flow chart shows a clear and detailed carbon circulation of 2012 in China's social and economic system. Since CO_2 flow chart of 2008 has been described in our previous article (Huanan Li, Hailin Mu,2012), thus, no introduction here.

Overall, CO_2 flows into our social and economic system are mainly carried by coal and oil, accounting for about 97% of the total CO_2 flow. Then, 96.73% of CO_2 flow into the energy processing and conversion sectors, while a small amount flow out of the system in the form of export and transmission and distribution losses. After flowing through processing and conversion sector, 21.93% of CO_2 flow are out of the system in the form of conversion loss emissions, while the remaining flowing into the terminal sub-sectors. In terminal sub-sectors, CO_2 flow mainly into several sectors like ferrous sectors, chemical industry, non-metallic mineral, transportation, resident, which accounting for 75.12% of the total carbon flow.

The inventory of carbon flow of 2009, 2010, 2011 are listed in Appendix A,B,C.

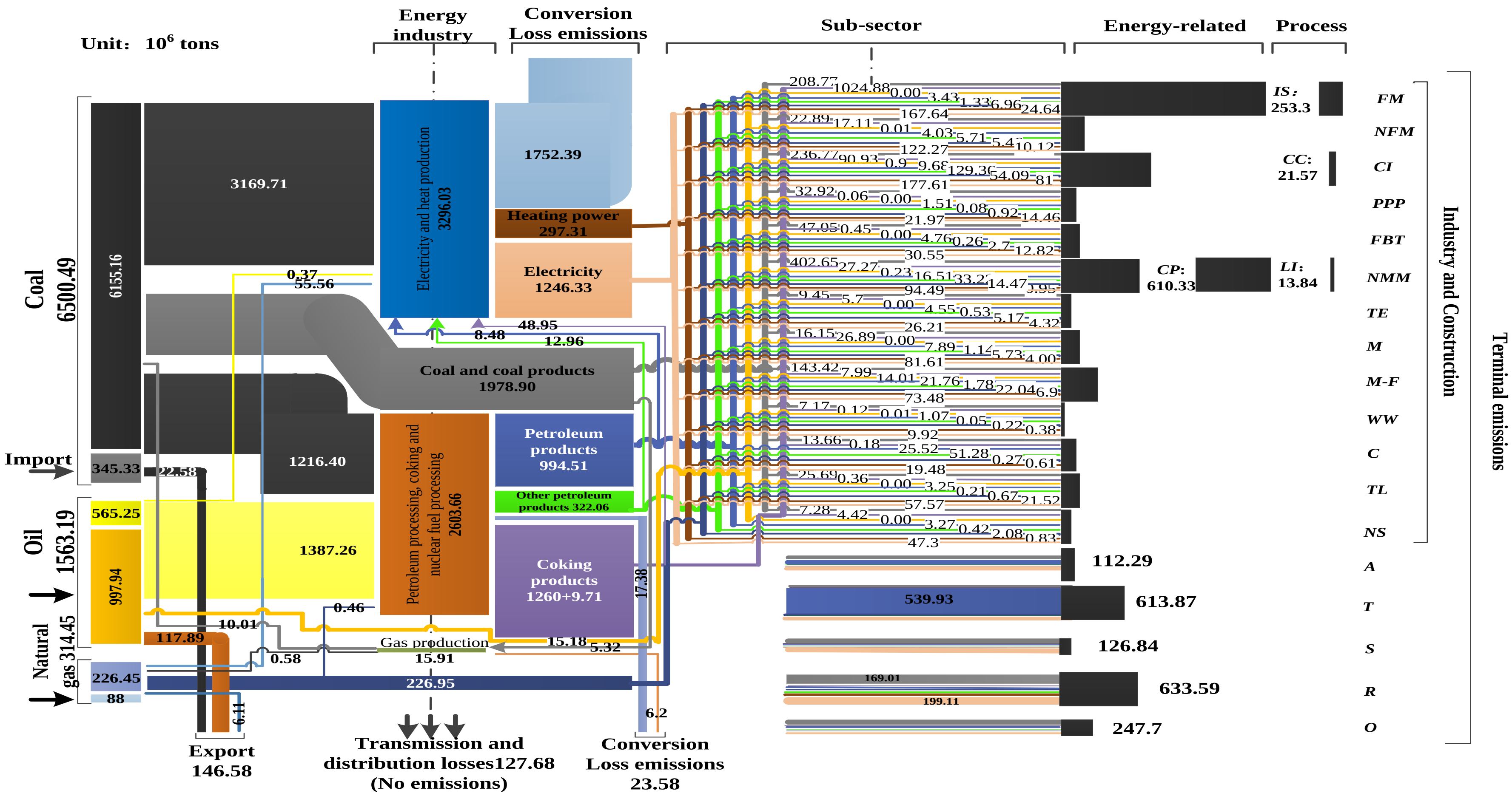

Fig. 2 Carbon dioxide flow for 2012

3.1.2 CO2 emissions from terminal sectors are greatly different

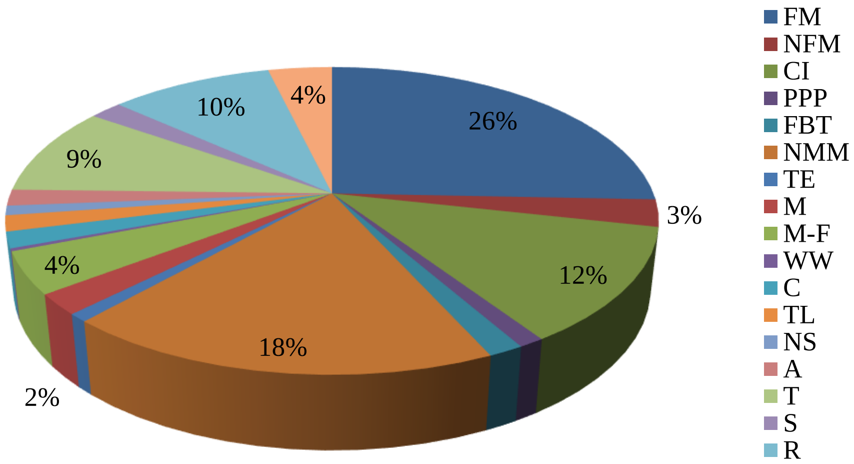

Fig.3. Comparison of CO_2 emissions from terminal sectors in China in 2012

Figure 3 shows the proportion of the CO_2 emissions flow from terminal sub-sectors by 2012 which contains both energy-related CO_2 emissions and process CO_2 emissions. It's clearly that the CO_2 flows in ferrous metal sectors is the most significant, accounting for 26% over the total terminal CO_2 emissions, followed by non-metallic mineral, accounting for 18% of total terminal CO_2 emissions. CO_2 emissions from chemical industry, transportation and resident sectors are similar, all accounting for around 10% to the total terminal CO_2 emissions. These five sectors absorb most of the carbon flow in China's carbon system, which affect China's CO_2 reduction most significantly.

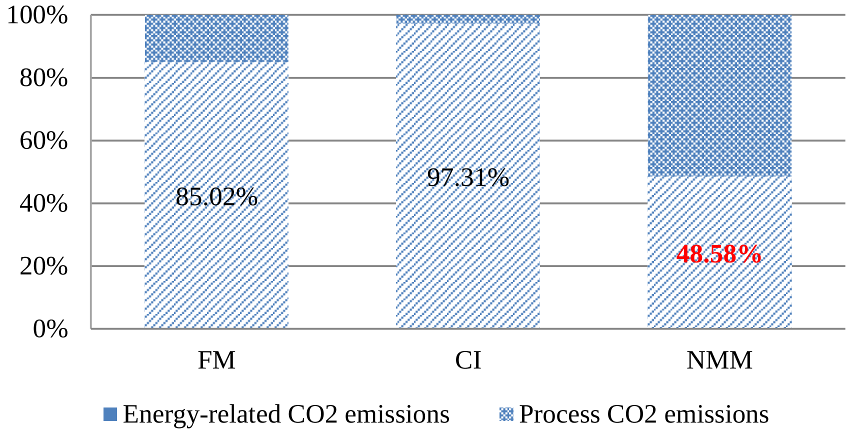

Fig.4. Comparison of energy-related and process CO_2 emissions in some sectors in 2012

We can also find that the CO_2 emissions are mainly from energy-related CO_2 emissions in ferrous metal and chemical industry sector, as shown in figure 4. However, CO_2 emissions are mainly produced by process of production in non-metallic mineral sector, which accounting for more than 50% to the total CO_2 emissions. Thus, CO_2 reduction policies on non-metallic mineral sector should be paid more attention. Process CO_2 emissions of non-metallic mineral sector are mainly from the production of cement and clinker, research and development on replacement materials of cement production will play a very important role in its CO_2 reduction.

3.2 Trend analysis from 2008 to 2012

China's carbon emissions presents a number of new features, not only on the amount, intensity, as well as changes in the structure of the emissions from 2008 to 2012. Here, we analyze the changing trend of China’s carbon flow during 2008 and 2012 based on previous research results and the above conclusions, expecting to find some new results.

3.2.1 Total Carbon emissions increased rapidly, especially that carried by coal

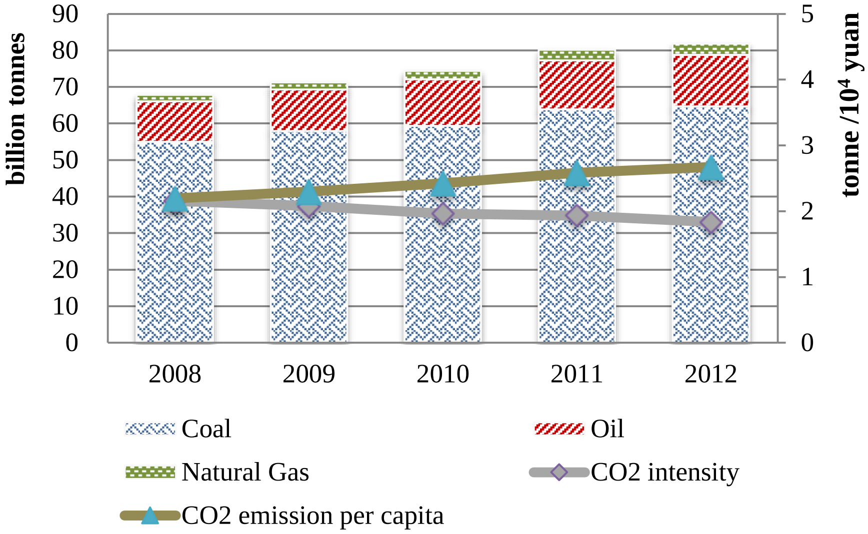

Fig.5. Status of China's carbon emissions

Figure 5 shows the changes of CO_2 emission-related indicators in China from 2008 to 2011. Total CO_2 emissions from primary energy consumption increased nearly 21% during the past four years, with an average annual growth rate of 4.81% and amount of 8.18 billion tonnes. There is a little change in the structure of carbon emissions, of which the proportion of CO_2 emissions caused by coal consumption reduced with stable, maintaining at about 80%, and the proportion of carbon emissions from oil and natural gas consumption increased slightly together. For the comprehensive indexes of per capita CO_2 emissions and CO_2 intensity, basic trend has not changed, that is, continued growth in per capita CO_2 emissions and decline in CO_2 intensity. Average annual growth rate of per capita CO_2 emissions average annual raised by up to 5.04%, while carbon intensity decreased by 3.97%. Because of the large population base and economic aggregate, China's CO_2 emissions will continue to rise inevitably in the future.

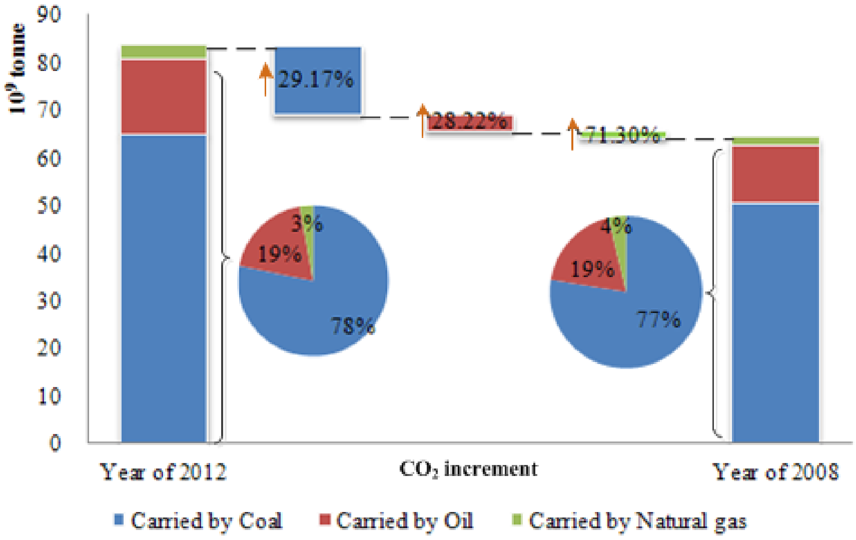

Fig.6. Situation of primary energy CO_2 flow flowing into China's carbon system

Figure 6 compares the variation of primary energy carbon flow that flowing into China's carbon emissions system between 2008 and 2012. Here the primary energy carbon flow refers to the CO_2 amount carried by primary energy, including both primary energy produced in China and imported. Obviously, primary energy carbon flow in 2012 has significantly increased compared to that in 2008, especially that the carbon flow carried by natural gas grew 71.30%, far higher than that by coal and crude oil. From carbon flow structure, the primary energy carbon flow is still coal-based, and the proportion of carbon flow carried by coal increased one percentage point in 2012 than in 2008, reaching 78%. Carbon flow carried by crude oil remains unchanged, and the proportion of carbon flow carried by natural gas is reduced by one percentage point to 3%. Although primary energy carbon flow carried by natural gas has a higher growth rate, due to the large proportion of carbon by coal, the proportion of carbon flow by natural gas is decreasing year by year. This is inconsistent with our view that the proportion of carbon flow by crude oil and natural gas should increase because the proportion of their energy consumption is increasing.

3.2.2 Loss emissions flows have some reduction

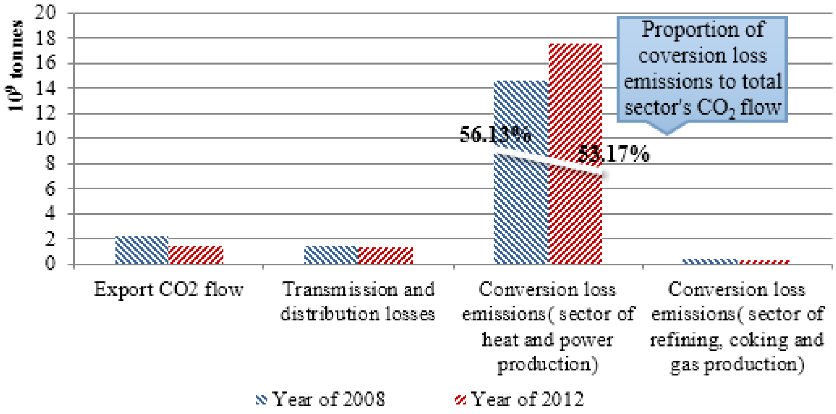

Fig.7. Comparison of expert CO_2 flow and loss emissions flow between 2008 and 2012.

As seen from figure 7, the amount of CO_2 in the outflow caused by energy exports reduced by 33.63% in 2012 compared to in 2008, indicating that the vast majority of China's primary energy carbon flows into China’s the production and construction systems with the increase in China's economic development and energy consumption. Transmission and distribution losses mean the CO_2 carried by primary energy missing in the process of energy transmission and distribution. Although this part of CO_2 emissions doesn’t spread into the atmosphere because of no combustion, but it reflects the efficiency of energy transport systems from the other hand. From figure 7, the amount of transmission and distribution losses is slightly lower in 2012 than in 2008. In the case of growing of total carbon flow, the transmission and distribution losses have decreased, showing the energy efficiency of transport has improved. Conversion loss emissions indicate the extra CO_2 emissions due to the production of secondary energy. We can find that the conversion loss emissions increased by 20.56% in 2012 than in 2008 in the sector of heat and power production as shown in table 4, while the proportion of its conversion loss emissions to total sector's CO_2 flow decreased from 56.13% to 53.17%. This indicates that although China thermoelectric efficiency 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 thermoelectric with China's economic development growth. Noteworthy, the conversion loss emissions of refining, coking and gas production sector decreased during 2008 and 2012 which reflects that efficiency improvement in these two sectors achieved amount CO_2 reduction.

Table 4

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%

3.2.3 Press emission flows increased rapidly

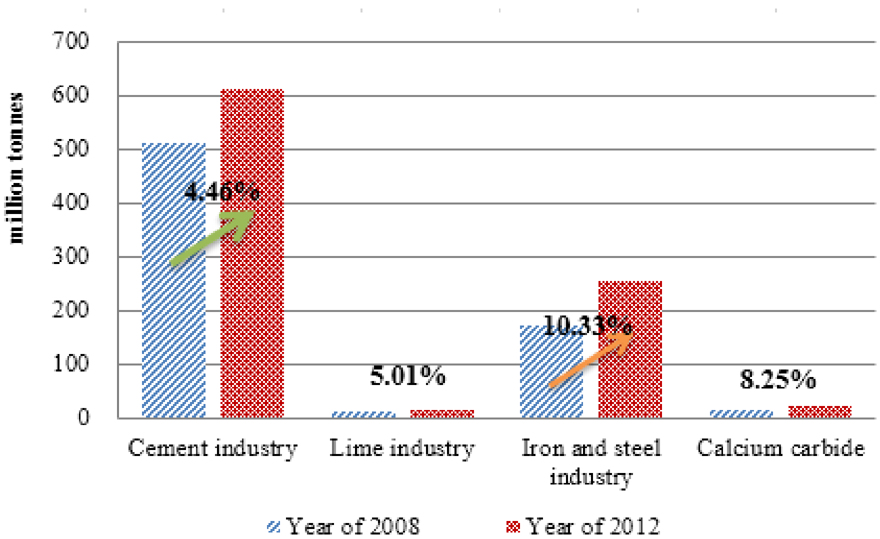

Fig.8. Comparison of process emissions between 2008 and 2012.

Figure 8 compares process emissions flow of major industries between 2008 and 2012. Process emissions mainly refer to the non-combustion CO_2 emissions during the production of some industries. It's obvious that process emissions from all four main sectors namely cement production, lime production, iron and steel production, calcium carbide production have increased significantly, with total growth of 4.46%, 5.01%, 10.33% and 8.25% respectively. These four sectors are the base industry of the national economy, which development will inevitably continue to cause the growth of process emissions, particularly the sectors of cement production, iron and steel production.

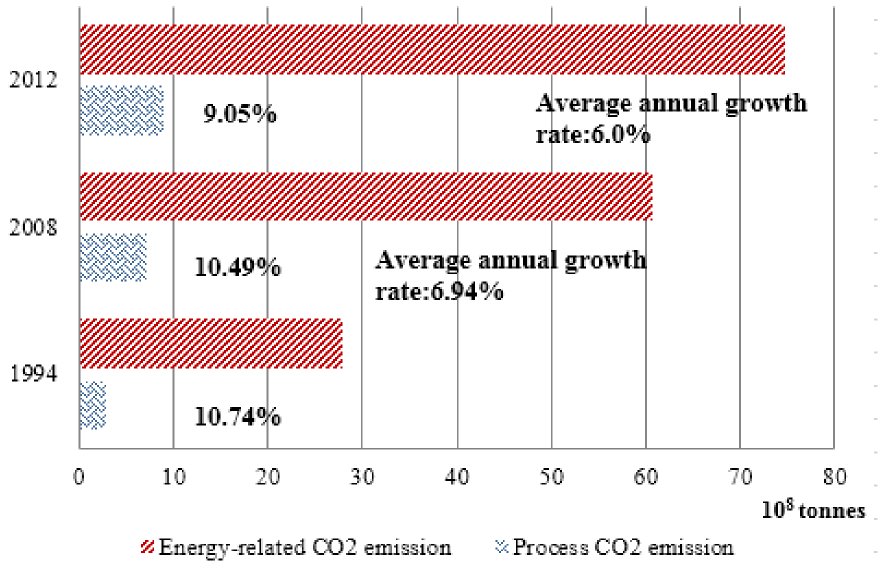

Fig.9. Comparison of energy-related and process CO_2 emissions in recent years.

From the perspective of total CO_2 emissions, both the total energy-related CO_2 emissions and process emissions are greatly increased in recent years, as shown in figure 9, China's total energy-related carbon emissions with an average growth rate of over 6% during 1994 and 2012. However, proportion of process CO_2 emissions on total CO_2 emissions decreased gradually, but relatively stable at about 10%, which is also a huge amount because the huge base of china's CO_2 emissions. Thus, policy makers should pay more attention to the process CO_2 emissions, encouraging technological innovation of related industries and accelerating the development of alternative raw materials.

3.2.4 Structure changing trend of terminal CO_2 emissions are very different

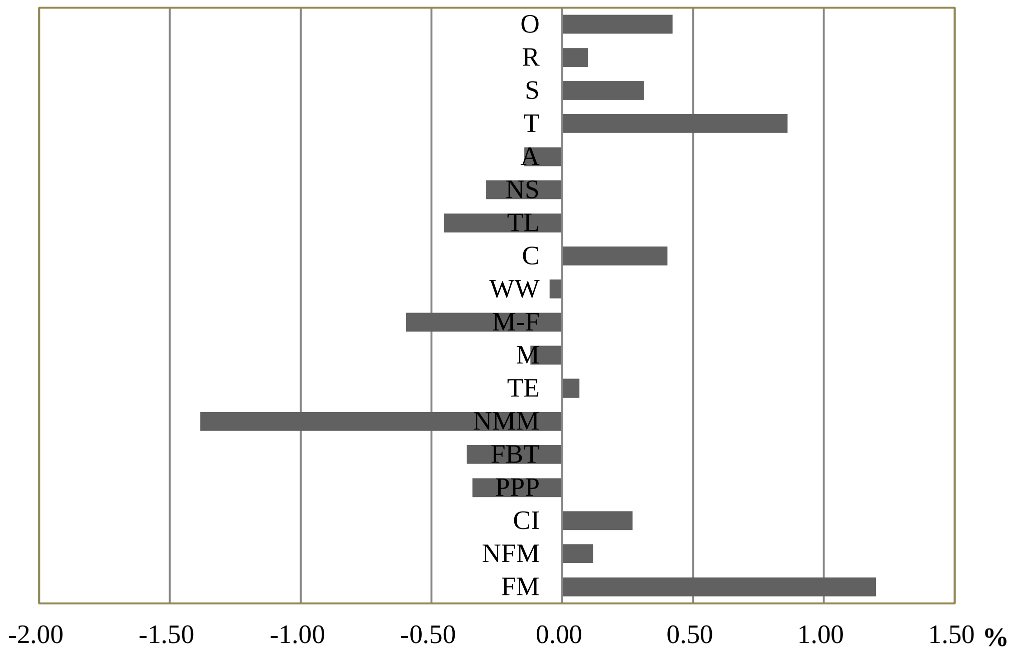

Fig.10. Comparison of structure of terminal CO_2 emissions between 2008 and 2012.

Figure 10 describes change trend of structure of terminal CO_2 emissions between 2008 and 2012. Structure indicates the proportion of CO_2 emissions to the total terminal CO_2 emissions including both energy-related and process CO_2 emissions. As shown in the figure, it's obvious that there are nine departments with increased proportions while nine with decreased proportions. During 2008 and 2012, proportions of ferrous metal and transportation sector to the total terminal CO_2 emissions make maximizing growth with growth percentages of 1.2, 0.86 respectively. In the context of economic slowdown in the world, the Chinese government proposed a 4 trillion bailout plan in 2008, mainly for urbanization and infrastructure construction, which caused a rapid growth in ferrous metal manufacturing and transportation development scale, also brought an increase in carbon emissions of these two industries. In the decreased sectors, non-metallic mineral and mining (excluding fuels) sectors are most representative, with decline percentages of 1.38, 0.60

respectively. In recent years, resources depletion accelerated with the rapid economic development in China, therefore, the development of related industries are also restricted. The changing trend of proportions of sectors' CO_2 emissions also proved this phenomenon.

Table 5

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***

In our carbon flow system, CO_2 is carried by different fuels in different sectors. The changing trend of CO_2 emissions by different fuels can reflect the structure of sectors' CO_2 emissions and energy use. Using electricity does not emit CO_2, but for fairness, CO_2 emissions caused by electricity production are considered as the indirect carbon emissions of end-use sectors in this paper. As seen in table 5, CO_2 flows of eight sectors such as non-ferrous metals, transport equipment and non-specific industry are mainly from their indirect emission, that is, electricity consumption in the eighteen terminal sectors, while seven sectors' CO_2 flows are mainly carried by coal. This shows that energy saving of electricity and coal is equally important for CO_2 reduction in the end-use sectors. CO_2 flow carried coking products in ferrous metal industry is the most significant, thus, targeted CO_2 reduction policies is essential in the sector. CO_2 flows mainly carried by petroleum products are only in sectors of construction, agriculture and transportation. From the viewpoint of structural changes, proportions of CO_2 flow carried by coal in most sectors decreased during 2008 and 2012 except in ferrous metal industry, which means that the traditional coal resources are increasingly being replaced by other species of energy in end-use sectors. Proportions of CO_2 flows carried by petroleum products in sectors of agriculture and resident increased during 2008 and 2012 while these in other sectors are declined, which reflects the scale of the usage of petroleum products in end-use sectors is gradually restricted. The most notable is that, proportions of CO_2 flows carried by electricity increased during 2008 and 2012 in all sectors, indicating that electricity has been applied more and more widely, thereby reducing indirect CO_2 emissions caused by electricity consumption and loss emissions caused by electricity production will play a very important role in China's CO_2 reduction work.

4. Conclusions and Policy Implications

4.1 Conclusions

After drawing China's carbon flow chart for 2012 based on IPCC carbon emission inventory method and China's energy balance table, 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) China's CO_2 flow chart of 2012 shows a clear and detailed carbon circulation of 2012 in China's social and economic system. CO_2 carried by coal and oil accounts for 97% of the total CO_2 flow, then, 96.73% of total CO_2 flowing into China's energy processing and conversion sectors, while a small amount flowing out of the system in the form of export and transmission and distribution losses. 21.93% of CO_2 is out of the system in the form of conversion loss emissions. In the terminal sub-sectors, 75.12% of 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, continued growth in per capita CO_2 emissions and decline in CO_2 intensity, while there is a little change in the structure of carbon emissions. Because of the large population base and economic aggregate, China's CO_2 emissions will continue to rise inevitably in the future.

(3) Primary energy carbon flow in 2012 has significantly increased compared to that of 2008, especially that the carbon flow carried by natural gas grew 71.30%, far higher than that by coal and crude oil. From carbon flow structure, the primary energy carbon flow is still coal-based, and the proportion of carbon flow carried by coal increased one percentage point in 2012 than in 2008, reaching to 78%.

(4) Vast majority of China's CO_2 carried by primary energy flows into China's the production and construction systems. Although China thermoelectric efficiency 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 thermoelectric with China's economic development growth. Noteworthy, the conversion loss emissions of refining, coking and gas

production sector decreased during 2008 and 2012 which reflects that efficiency improvement in these two sectors achieved amount CO_2 reduction.

(5) Process emissions from all four main sectors namely cement production, lime production, iron and steel production, calcium carbide production have increased significantly during 2008 and 2012. CO_2 emissions are mainly from energy-related CO_2 emissions in ferrous metal and chemical industry sector, while that are mainly from process emissions in non-metallic mineral sector.

(6) Proportions of ferrous metal and transportation sector to the total terminal CO_2 emissions make maximizing growth with growth percentages of 1.2, 0.86 respectively during 2008 and 2012, due to the "4 trillion bailout plan" proposed by Chinese government in 2008 mainly for urbanization and infrastructure construction. In different terminal sub-sectors, main carriers of CO_2 flow are different, thus, CO_2 reduction policy should also be different.

4.2 Policy Implications

In recent years, China's CO_2 emissions have become one of the hottest issues long-termly concerned by domestic and foreign researchers. Under the background of international economic crisis, China's "four trillion" economic stimulus plan and energy saving and emissions reduction policy, there is a new change in the characteristics of China's CO_2 emissions since 2008. Therefore, the research on these new changes will have a positive significance to policy making. From the results of this paper, we present the following policy recommendations. Firstly, characteristics of CO_2 emission of different sectors are quite different and should be distinguished on the policy making because of China's CO_2 emissions system is very complex. More stringent targets for CO_2

emission reduction policies should be developed in the sector with large CO_2 flow, especially energy conversion sectors, carbon reduction in which will have a very important and positive impact on China's overall CO_2 reduction. Strengthening implementation of CO_2 reduction measures in the terminal sub-sectors with large CO_2 flow such as ferrous metal, chemical industry, non-metallic mineral, transportation and resident will also play a positive role in CO_2 reduction; Secondly, 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 taking coal as main carrier while some electricity. Therefore, detailed and targeted reduction policies and measures differentiating different CO_2 carriers will be very effective; Thirdly, CO_2 process emissions from cement industry, iron and steel sectors is abundant and growing rapidly, therefore, development of alternative raw materials should be strengthened, and appropriate policies should be made for CO_2 emissions from the production process of these two sectors; Finally, in the structure of the CO_2 emissions of terminal sectors, policy makers should focus on the sectors with fast growth of proportion of CO_2 emissions, such as ferrous metal and transportation sector, analyzing the reason for the accelerated growth of emissions, and timely developing appropriate countermeasures.

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

Terminal sub-sector		Coal	Coking products	Crude oil	Refined oil	Other petroleum products	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	1223.48
	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 products	Crude oil	Refined oil	Other petroleum products	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	1273.04
	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 products	Crude oil	Refined oil	Other petroleum products	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	1004.32	0.01	3.20	2.07	6.13	23.92	168.03	1409.67
	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			