Article

Analysis of China's Carbon Emissions Base on Carbon Flow in Four Main Sectors: 2000–2013

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Abstract: Reducing carbon emissions is a major ways to achieving green development and sustainability for China's future. This paper elaborates the detailed feature of China's carbon flow for 2013 with the carbon flow chart and gives changing characteristics of China's CO_2 flow from the viewpoint of sector and energy during 2000 and 2013. The results show that (1) during 2000 to 2013, China's CO_2 emissions with the approximately growth portion of 9% annually, while the CO_2 intensity of China diminishes at different rates. (2) The CO_2 emissions from secondary industry are prominent from the perspective of four main sectors accounting for 83.5%. The manufacturing play an important part in the secondary industry with 45%. In which the "smelting and pressing of metal" takes up a large percentage as about 50% in manufacturing. (3) The CO_2 emissions produced by coal consumption is keep dominant in energy-related emissions with a contribution of 65%, while it will decrease in the future. (4) From the aspect of sector, the CO_2 emissions mainly come from the "electricity and heating" sector and the "smelting and pressing of metals" sub-sector. While it is essential and urgent to propose concrete recommendations for CO_2 emissions mitigation. Firstly, the progression of creative technology is inevitable and undeniable. Secondly, the government should make different CO_2 emissions reduction policies among different sectors. For example, the process emission plays an important role in "non-metallic mineral" while in "smelting and manufacturing of metals" it is energy. Thirdly, the country can change the energy structure and promote renewable energy for powering by wind or other low-carbon energy. Besides it, the coke oven gas can be a feasible substitution. Finally, policy maker should be aware of the emissions from residents have been growing in a fast rate. It is effective to involve the public in the activity of energy conservation and carbon emissions reduction such as reducing the times of personal transportation.

Keywords: China; sustainability development; carbon emissions; carbon flow; sectoral analysis

1. Introduction

In the past few years, environmental problems, particularly global warming, have captured both public and academic attention from all over the world. The highly intensive emission of greenhouse gases (GHGs) including carbon dioxide (CO_2) and methane (CH_4), which have been regarded as one of the important reasons for the global warming that has occurred since the Industrial Revolution, which has exerted profound impacts on global ecological and social-economic system [1]. According to the "5th Assessment Report of the Inter-governmental Panel on Climate Change (IPCC) ", the atmospheric concentration of CO_2 had risen to 391 mg/L by 2011, which were 40% increase over the figures before industrialization. The latest 30 years, that is, from 1983 to 2012 may be the hottest decades in the past 1400 years [2]. Meanwhile, China surpassed the United States in CO_2 emissions in 2008, having become the world's largest emitter and energy consume which makes China face more and more pressures on the control of its CO_2 emissions [3-7]. After four years, China's CO_2 emissions rapidly grew from 6.78 billion tons to 8.18 billion tons with an average

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annual growth rate of 4.81% [8]. It is increasing numbers and upward variation tendency that make it urgent and essential for policy-makers to make efforts. Thus, a study about the characteristic and variation trend of current carbon emission in China is extremely necessary. Besides it, to identify the emission source is of great importance to inform the policy designers for future mitigation and to realize a friendly environmental and sustainable development society in China [9].

China is now the world's largest consumer of primary energy and emitter of greenhouse gas emissions [10] .There has still much challenge for China's CO_2 mitigation. China produces 25% of global CO_2 emission [11] and consumes 20.3% of global primary energy [3]. Among CO_2 emission sources, 85% of China's emissions are contributed by energy usage in cities, which is higher than that of the USA (80%) or Europe (69%) [12,13]. Therefore, energy-related CO_2 emissions or emissions at city-level, province-level and national-level have been widely studied [4,14-16]. This paper is also at national-level, but analyze the feature of emission from four main sectors and four major energy types.

In order to provide detailed and straight insights for current situation of CO_2 emission, carbon flow chart is used. It is an intuitive and quantitative tool to show a whole picture of substances [16]. The approach of flow chart method has been increasing applied to study energy path and emission source of different countries at the regional or national scale [17-21]. Adopting this method Xie had conducted carbon flow chart for Shanghai in 2007 and found that 15.6% of coal was directly consumed in end sectors, which was not beneficial to energy saving and emission reduction [21]. Some scholars apply flow chart method to analyze the changing characteristics of China's carbon flow between 2008 to 2012, and make a conclusion that CO_2 flow carried by primary energy has significantly increased in 2012 [8]. However, these all most efforts about energy or energy-related CO_2 emissions were received to only adopt the IPCC approach in classification for CO_2 emissions, nor the changes that could realize the distinguish of CO_2 emissions.

In this paper, a carbon flow is adopted which combines the method of IPCC carbon emission inventory with classification of national economy industry published by National Bureau of Statistics of the People's Republic of China. It can provide a quantitative and intuitive study about the carbon emission path. What's more, the changes between 2000 and 2013 in China are also present. These will greatly contribute to clear understanding on emission status and policy-making for emission mitigation.

The paper is organized as follows: the classification and calculation methods of CO_2 emission are introduced in Section 2; Section 3 analyzes the characteristics in 2013 through carbon flow chart and measures the emissions in different sectors or energy types based above before results and conclusion are drawn in Section 4.

2. Materials and Methods

2.1. The Method for Classification of CO_2 Emissions

According to Greenhouse Gas Inventory of IPCC [22] and national economy industry in China, the CO_2 emissions sources is dividing into four main sectors shown in Table 1. Because manufacturing sector contains a huge amount of industries, it has sub-classifications shown in Table 2. As for energy type, it covers coal, coke, oil and gas. Fig 1 is show to summarize analysis framework of this paper.

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Table 1. The classification of CO_2 emission source

Sector	Sub-sector	Abbreviation
Primary industry	Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy	F
Secondary industry	Mining	M1
	Manufacturing	M2
	Electricity, heat, water production and supply	EHW
	Construction	C
Tertiary industry	Transportation, Storage, Post and Telecommunication Services	TSP
	Wholesale, Retail Trade and Catering Services	WRC
	Other service	OS
Civil department		Ci

Table 2. The sub-sector of Manufacture sector

Sector	**Sub-sector**	**Abbreviation**
Manufacturing	food, beverage, tobacco processing and production	FM
	Textiles and leather	TLM
	Chemical industry	CM
	Paper and printing	PPM
	Petroleum processing and coking	PCM
	Non-metallic mineral	NMM
	Smelting, pressing and manufacturing of metals	SM
	Wood processing	WM
	Transport equipment manufacturing	TM
	other manufacturing	OM

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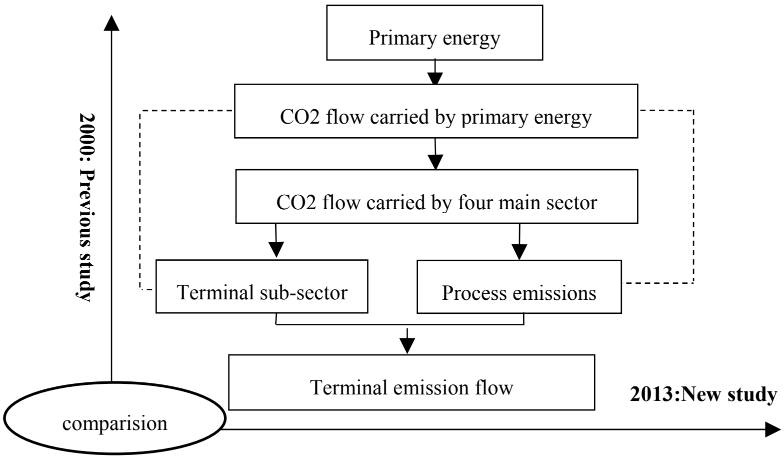

Figure 1. Framework of the paper

2.2. Formulas for Calculating CO_2 Emission

In this paper, CO_2 emissions of the energy-related [14] and the process are calculated. The growth and its rate are also considered.

The CO_2 emissions from fossil fuel combustion and industrial process [23] are calculation according to IPCC sectoral approach [22]. This way is also applied by other scholars[24-30].

2.2.1. Energy-related CO2 Emission

Eq.(1) is used to calculate the fossil fuel-related CO_2 emissions. Where the subscripts i and j denote the i th sector and the j th fuel respectively; the CE_{ij} designates the CO_2 emission of different sectors and energy types; AD_{ij} represents the adjusted energy consumption; NCV_j refers to the net calorific value of different energy types; EF_j is the carbon emission factor of the fuel; O_j means the fraction of carbon oxidized of fuel.

$$CE_{ij} = AD_{ij} \times NCV_j \times EF_j \times O_j, i \in [1,4], j \in [1,17] \quad (1)$$

Therefore, the total energy-related CO_2 emission in the year t is accumulated by all economy sectors from 1 to 4 as following:

$$CE^t = \sum_i CE_i^t \quad (2)$$

The parameters instruction in Eq.(1) and Eq.(2) is shown in Table 3.

Table 3. Carbon emission factor (EF) and fraction oxidized (O) of fuel

No.(s)	Fuel	NCV(KJ/Kg)	EF(t C/TJ)	O(%)
1	Raw coal	20 908	25.8	0.9
2	Anthracite	34 000	27.4	0.94
3	Bitumite	29 000	26.1	0.93
4	Lignite	12 187	28	0.96

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5	Washed coal	26 344	25.41	0.93
6	Coke	28 435	29.5	0.93
7	Coke oven gas	17 084	13.58	0.98
8	Other coking products	38 052	29.5	0.93
9	Crude oil	41 816	20	0.98
10	Fuel oil	41 816	21.1	0.98
11	Gasoline	43 070	18.9	0.98
12	Diesel oil	42 652	20.2	0.98
13	Kerosene	43 070	19.6	0.98
14	LPG	50 719	17.2	0.98
15	Refinery gas	46 055	18.2	0.98
16	Other petroleum products	35 125	20	0.98
17	Natural gas	38 979	15.3	0.99

2.2.2. Process CO_2 emission

For the non-mental product, the process emissions is present as Eq. (3):

$$CE_m = AD_m \times EF_m, m \in [1,3] \tag{3}$$

The instructions of formula (3) is in Table 4.

Table 4. The instruction in formula (3) (Unit: *t* CO_2/*t*)

m	Sub-sector	AD	EF
1	Cement production	Net production of cement clinker expect production from carbide slag	0.538
2	Lime production	Production of lime	0.683
3	Calcium carbide production	Production of calcium carbide	1.154

2.2.3. The change in CO_2 emission

The change in CO_2 emissions from period *t* to *T* can be formulate as follows:

$$C_\Delta = C_T - C_t \tag{4}$$

$$r_\Delta = (C_T / C_t - 1) \times 100\% \tag{5}$$

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Where C_{Δ} stands for the change in carbon emissions from period t to period T, r_{Δ} refers to the changes in percentage form.

2.3. Data sources

The data in this paper are prior to the adoption of official statistics, such as "China Statistical Yearbook", "Chinese Energy Statistical Yearbook", "IPCC report (2014) ", and "Industry Statistics Yearbooks". Some data used in this paper are from National Bureau of Statistics of the People's Republic of China.

3. Results and Discussion

3.1. CO_2 flow chart of 2013

Based on data calculated above, it is easy to draw the CO_2 flow in 2013. It is clear to suppose fossil fuels as CO_2 source and denote these with different colors. At the same time, the scale of the rectangle represents the magnitude of CO_2 flow in Fig 2.

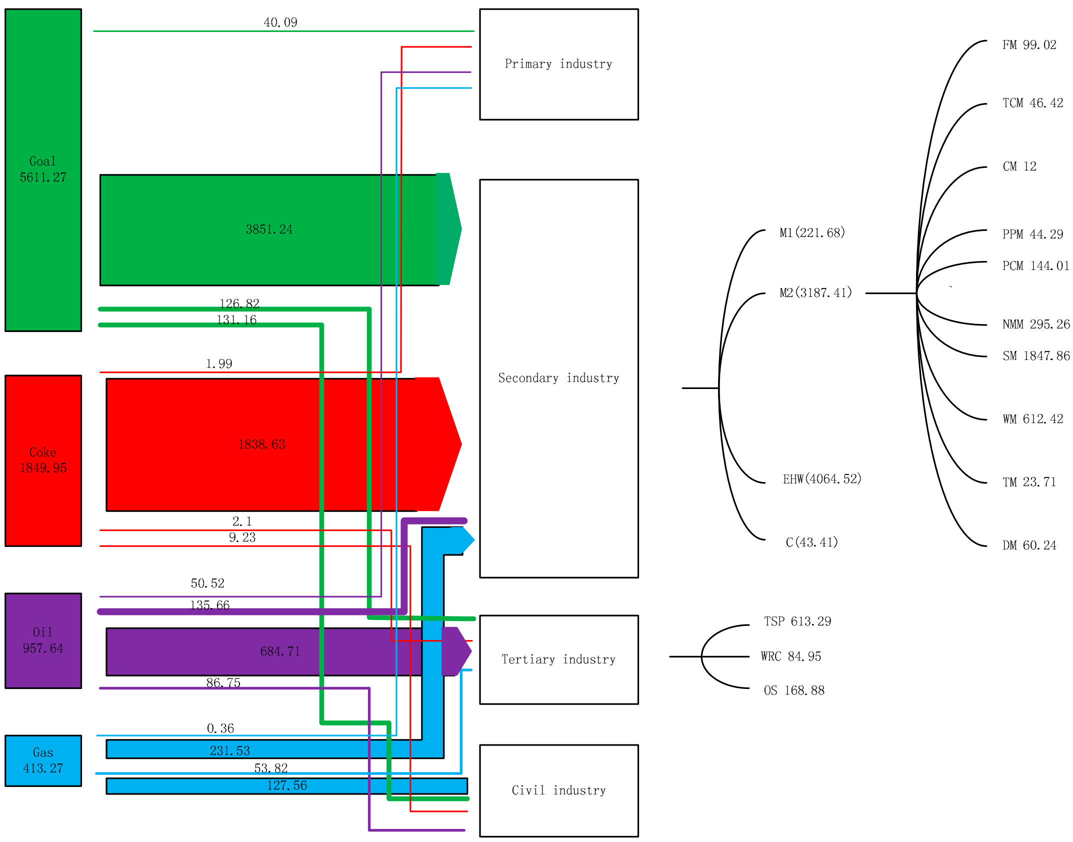

Figure 2. China's CO_2 flow chart in 2013

Graph on the left is the CO_2 flowing into China's industrial system, which is carried by primary energy. Apparently, coal is the mainstream in CO_2 flowing which accounts for 59% of the total with a share of 5 611.27 million tons, decreasing 0.03 percent than that in 2000. This unitary structure of primary energy is not positive in CO_2 mitigation, which makes change its structure and seek replacement more emergent. The middle part is the CO_2 flowing into four main industries. It is significant to find that the 85% of the total CO_2 flows into the secondary industry, in which the coal is the major source with the percent of 71 decreasing 3% compared with 2000 followed by coke taking up 24%, decreasing 8% with comparison of 2000. Besides, 71% of the CO_2 carried by gas flows into the tertiary industry and 31% of the oil goes into the civil department. Adjustment on these huge flows will work greatly for reducing CO_2 emissions. The right part is the CO_2 flowing to the terminal sub-sectors. The amount of CO_2 flowing into "electricity and heating sector" and the "manufacturing" sector in secondary industry is huge, reaching up to 4 064.52 million tons and 3187.41 million tons respectively. In addition, the "smelting and pressing of metals" sub-sector and the "non-metallic mineral" sub-sector among these sub-sectors involve a big share of CO_2 flowing in manufacturing which is 1 847.86 million tons and 295.26 million tons. Noteworthy, there has a considerable percentage of the "transportation, storage and post" sector in tertiary industry with a proportion of 71%, which has decreased 6% than that in 2000. There will be more efficient on carbon reduction if the government make more effect on these specific sectors.

3.2. Trend analysis from 2000 to 2013

Based on the method mentioned in section 2, China's total CO_2 emissions and CO_2 intensity from 2000 to 2013 is show in Fig 3.

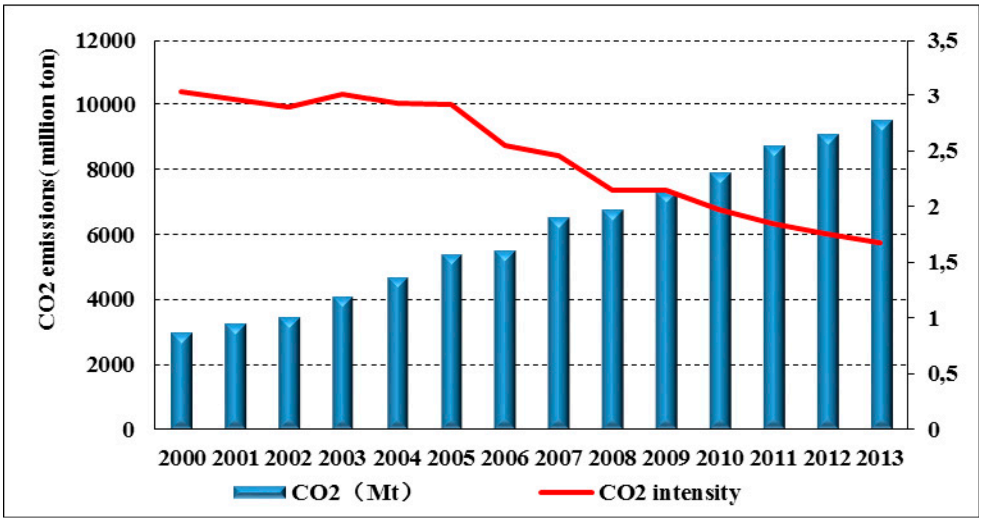

Figure 3. China's total CO_2 emission and CO_2 intensity during 2000 to 2013

There is a substantial growth of CO_2 emission from 3 003.43 million tons to 9 534.22 million tons, with an annual growth rate of 9.46% from 2000 to 2013. When in 2003, 2004, 2005, 2007 and 2011, it has a greatly increase due to the developing secondary industry. Apparently, the CO_2 intensity in China declines continuously during 2000 to 2013, whereas the slightly increase in 2003 probably be caused by the rapid expansion of infrastructures requiring the operation of energy-consuming industries [15]. It is obvious to find that the intensity of CO_2 has a stable drop rate since 2009 with about 6% yearly. China's government has been promoting technical innovation and other efficient measures presently to reduce CO_2 emission, which contributes to making CO_2 intensity downward steadily. It is worth mentioning that the total emission will continue to increase in a long time because of the developmental industrialization and urbanization in China.

3.2.1. Emissions of Different Sectors

In order to present sectoral contribution clearly, there are four main sectors of China's CO_2 emission as section 2 mentioned shown in Fig 4.

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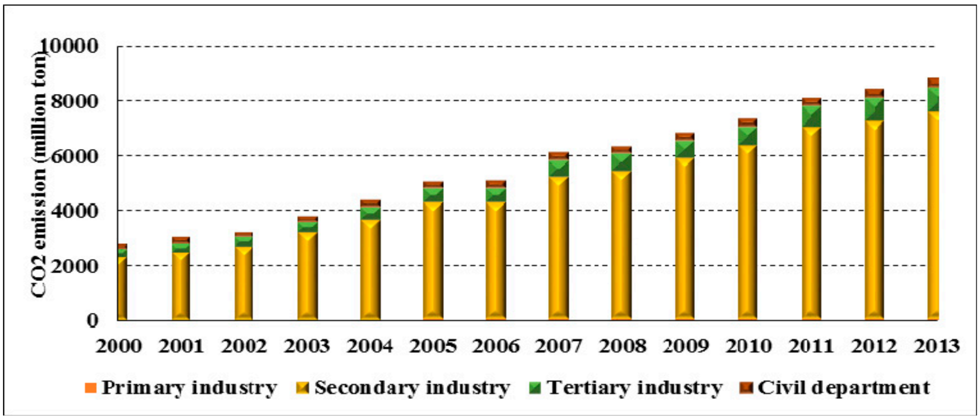

Figure 4. China's CO_2 emissions in four main sectors from 2000 to 2013

The CO_2 emission of secondary industry ranks first, ranging from 2 299 million tons to 7 517 million tons and accounting for 83.5% of the total CO_2 emissions on average, followed by tertiary industry and civil department. Primary industry have the smallest CO_2 emissions. Noteworthy, the secondary industry has the highest growth rate of 9.62% on average, followed by tertiary industry and civil department with increase percentage of 8.30% and 8.15% respectively annually. The primary industry similarly has the lowest growth percentage of 6.23%. It is clear that taking some actions on secondary industry would contribute effectively to CO_2 emissions mitigation. The civil department also should be consider seriously such as making some changes on human lifestyle [31]. It is necessary to subdivide the secondary industry due to its huge amount and varied sectors. Fig 5 (a. b. c. d) present the proportion of different sectors as mining, manufacturing, electricity and heating, and construction mentioned in Table 1 in 2000, 2004, 2008 and 2013.

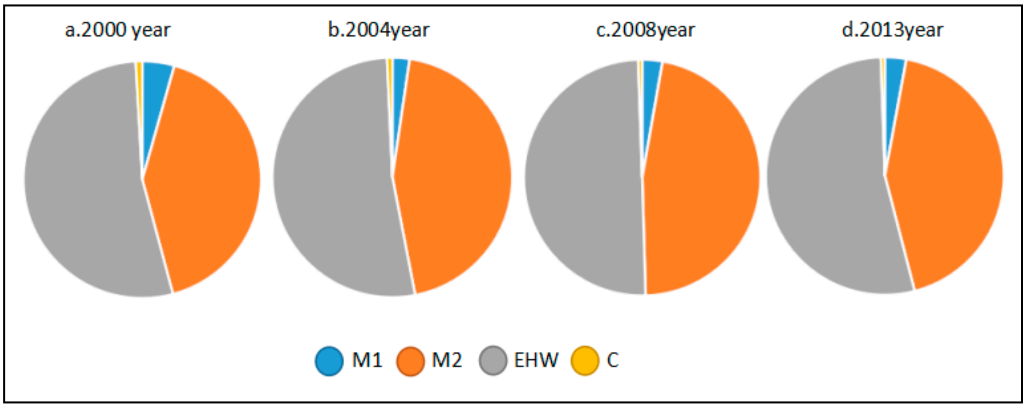

Figure 5. The sectors of secondary industry in 2000, 2004, 2008, 2013

The "Electricity and heating" sector apparently emits maximum with proportion of 50% over the total emissions on average from the aspect of secondary industry, following by the "manufacturing" with percentage of 45% and the "mining". The construction is the lowest. The structure of secondary industry is almost invariable during 2000 to 2013 from these pies. Mining has declined a little due to the promotion of conserving resource and the close focus on environmental problems. Because of the increasing huge demand on electricity, the "electricity and heating" is the primary source that contributes to the secondary industry's CO_2 emissions averagely. This shows that reduce emissions through the "electricity and heating" is equally important for reduction on the "manufacturing" sector. The innovative technology is strongly supposed to be apply to the "electricity and heating" sector.

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China's government has been paying more attention to the "manufacturing" sector recently and it is devoting to making it a powerful country on manufacture industry. Among the 10 sub-sectors of manufacturing defined in Section 2, the "smelting and pressing of metals" sub-sector produces the most CO_2 that it generates average 51.2% of the manufacture emissions during 2000, 2008 and 2013 chosen in Fig 6. Obviously, the "smelting and pressing of metals" sub-sector definitely decides whether the carbon emission trend of the "manufacturing" sector is upward or not at some extent, but it will not decline greatly in a short time owing to China's booming economical construction. The flourishing housing industry causes the "non-metallic mineral" and the "wood processing" sectors increased continuously. When the construction and real estate reaches a satisfactory situation, it will cut down or remain a stable stage. The emissions of other eight sub-sectors have almost no change.

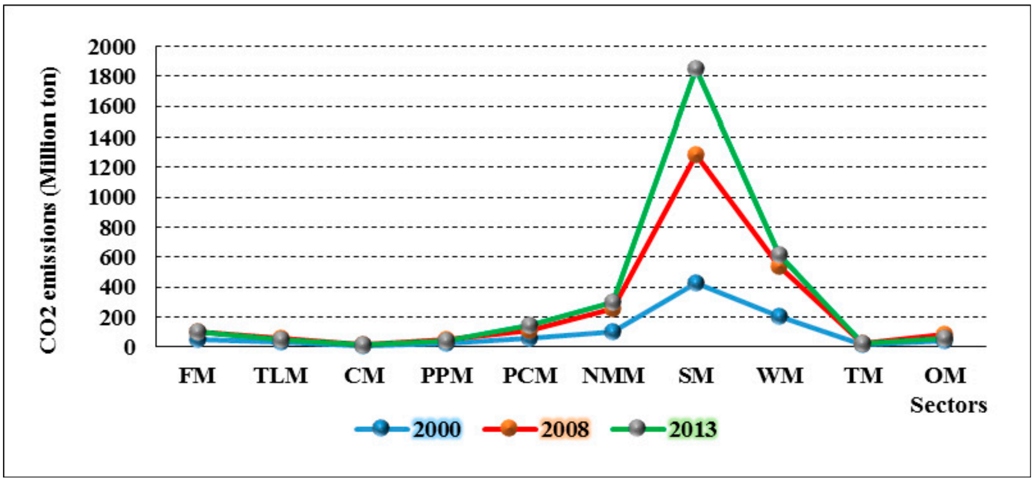

Figure 6. The CO_2 emissions of sub-sectors in manufacturing during 2000, 2008 and 2013

3.2.2. Emissions of different energy types

Fig 7 (a, b, c, d) shows the proportion of energy for the energy-related CO_2 emissions inventory in 2000, 2005, 2010 and 2013 respectively. There are four energy type as coal, coke, oil and gas. Clearly, the CO_2 emissions carried by coal is maximum, accounting for 65% on average, followed by coke, accounting for 18.5%. The others take up 16.5% approximately in total. Coal is the largest primary energy source in China. More than 65% of the total energy used in China comes from coal [11].

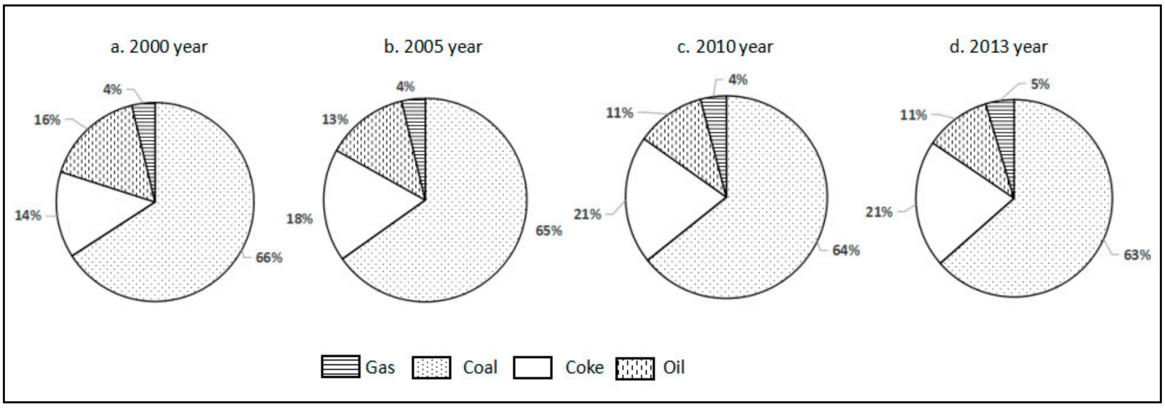

Figure 7. CO_2 emissions from four energies in 2000, 2005, 2010, 2013

From the perspective of primary energy carriers, the structure of their emission has little change. Obviously, the emissions caused by coal and combustion of coal products slightly diminished. Although the decreased percentage is small averagely, there is still a big amount of

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emissions reduction because of its huge base number. While the CO_2 emissions produced by coke and natural gas both increasing a little. It will have some efficient to promote coal mineral harness movement and encourage industries to adopt renewable alternative energy.

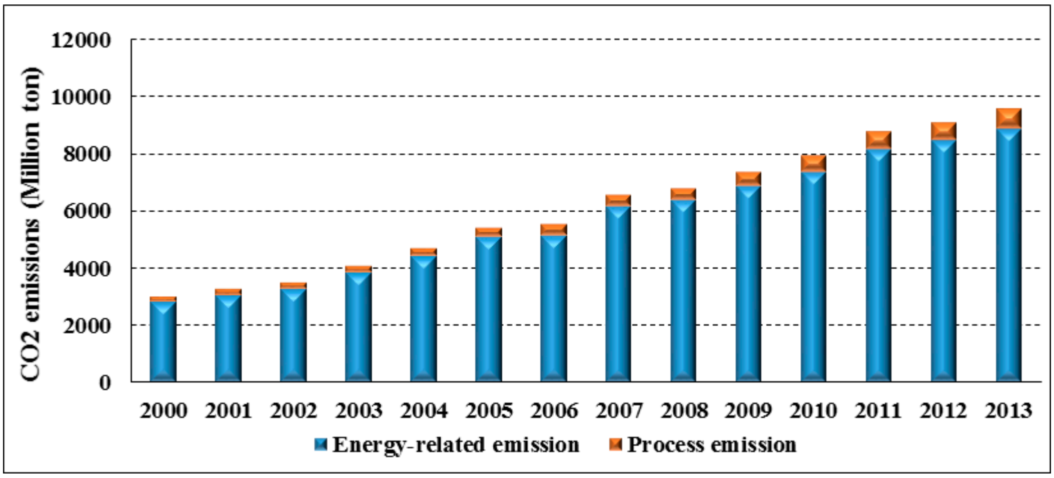

Figure 8. Energy-related and process CO2 emissions from 2000 to 2013

In addition to energy-related emissions, industrial processes also contribute to total CO_2 emissions shown in Fig 8 with a percentage of 6.36% on average. It increased slightly due to the large quantities of manufacturing industries in China such as the "non-metal mineral sector" and the great production of cement, iron and steel. The emissions of industrial process should be giving preference by Chinese government.

4. Results and conclusion

This paper elaborates the detailed feature of China's carbon flow for 2013 with the carbon flow chart and gives changing characteristics of China's CO_2 flow from the viewpoint of sector and energy during 2000 and 2013. Based on the findings presented above, the specific results are follows:

(1) There remains a upward trend in China's CO_2 emissions with an approximately growth proportion of 7% annually, while the CO_2 intensity of China diminishes lastly at different rates during 2000 to 2013 and it still decreases in the future.

(2) The CO_2 emissions from secondary industry are prominent from the perspective of four main sectors that accounts for 83.5%. The “manufacturing” plays an important part in the secondary industry with 45%, in which the "smelting and pressing of metal" takes up a large percentage as about 50% in manufacturing.

(3) Although its total amount is small at present, the growth rate of civil department reaches up about 8% that should be pay more attention to.

(4) The CO_2 emission produced by coal consumption keeps dominant in energy-related emissions with a contribution of 65%, while it will decrease in the future. Apart from this, the process emissions has a considerable growth speed of 11%.

(5) From the aspect of sectors, the CO_2 emissions mainly come from the "electricity and heating" sector and the "smelting and pressing of metals" sub-sector, meanwhile the "non-metallic mineral" and the "wood processing" sectors occupy a string proportion.

According to the results of this paper, it is essential and urgent to propose concrete recommendations for CO_2 emissions mitigation. Firstly, the progression of creative technology is inevitable and undeniable, which makes the CO_2 intensity constantly decrease. It is necessary and essential for China to offset CO_2 intensity with its rapid development of economy, thus the government should take a series of actions to encourage innovation on techniques and management level then apply it immediately to the industrial sectors with a huge CO_2 emissions flow. Secondly, the government should make different CO_2 emissions reduction policies among different sectors. For example, the process emission plays an important role in "non-metallic mineral" while in "smelting and manufacturing of metals" it is energy. Thirdly, because the secondary industry has a great share of the total emission and is the pillar of China's economy, it is necessary to adjust its structure such as focusing on manufacturing and adopting the clean energy. In addition, coal is still a main source of CO_2 emission. It is not reliable to shut down all coal mineral and alter it at once but the country can change the energy structure and promote renewable energy for powering by wind or other low-carbon energy. There has a finding that the combustion of coke oven gas has little emission with the same amount, which is twice or even more three times lower than the others. It will feasible to make full use of coke oven gas than coal. Finally, policy maker should be aware of the emissions from residents have been growing in a fast rate. It is effective to involve the public in the activity of energy conservation and carbon emissions reduction such as reducing the times of personal transportation.

Acknowledgments

This research are supported by funding from Cultivating program of excellent innovation team of Chengdu University of Technology (KYTD201406); Resources and the Environment Strategy Research Team of Sichuan's High Level Social Science Research Team (2015-2017); Accounting and evaluation of carbon dioxide emission inventory in Sichuan: Sichuan Social Science Association planned project (SC16TJ006).

Author Contributions

All authors have made a significant contribution to this research. Minxi Wang and Xin Li conceived and designed the experiments; Xiandan Cui collected data and information; Minxi Wang provided methods and processed data; Xin Li analyzed the data Xiandan Cui wrote the paper.

Conflicts of Interest

The authors declare no conflict of Internet.

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