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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 CO2 flow from the viewpoint of sector and energy during 2000 and 2013. The results show that (1) during 2000 to 2013, China’s CO2 emissions with the approximately growth portion of 9% annually, while the CO2 intensity of China diminishes at different rates. (2) The CO2 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 CO2 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 CO2 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 CO2 emissions mitigation. Firstly, the progression of creative technology is inevitable and undeniable. Secondly, the government should make different CO2 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 (CO2) and methane (CH4), 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 CO2 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 CO2 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 CO2 emissions [3-7]. After four years, China’s CO2 emissions rapidly grew from 6.78 billion tons to 8.18 billion tons with an average
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 is 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.
Table 1. The classification of CO₂ emission source

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

Table 2. The sub-sector of Manufacture sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Sub-sector</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing</td>
<td>food, beverage, tobacco processing and production</td>
<td>FM</td>
</tr>
<tr>
<td></td>
<td>Textiles and leather</td>
<td>TLM</td>
</tr>
<tr>
<td></td>
<td>Chemical industry</td>
<td>CM</td>
</tr>
<tr>
<td></td>
<td>Paper and printing</td>
<td>PPM</td>
</tr>
<tr>
<td></td>
<td>Petroleum processing and coking</td>
<td>PCM</td>
</tr>
<tr>
<td></td>
<td>Non-metallic mineral</td>
<td>NMM</td>
</tr>
<tr>
<td></td>
<td>Smelting, pressing and manufacturing of metals</td>
<td>SM</td>
</tr>
<tr>
<td></td>
<td>Wood processing</td>
<td>WM</td>
</tr>
<tr>
<td></td>
<td>Transport equipment manufacturing</td>
<td>TM</td>
</tr>
<tr>
<td></td>
<td>other manufacturing</td>
<td>OM</td>
</tr>
</tbody>
</table>
2.2. Formulas for Calculating CO₂ Emission

In this paper, CO₂ emissions of the energy-related [14] and the process are calculated. The growth and its rate are also considered.

The CO₂ 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 CO₂ emissions. Where the subscripts \( i \) and \( j \) denote the \( i \) th sector and the \( j \) th fuel respectively; the \( CE_{ij} \) designates the CO₂ emission of different sectors and energy types; \( AD_j \) 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.

\[
CE_{ij} = AD_j \times NCV_j \times EF_j \times O_j, i \in [1,4], j \in [1,17] \tag{1}
\]

Therefore, the total energy-related CO₂ emission in the year \( t \) is accumulated by all economy sectors from 1 to 4 as following:

\[
CE' = \sum_i CE_i \tag{2}
\]

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

<table>
<thead>
<tr>
<th>No.(s)</th>
<th>Fuel</th>
<th>NCV(KJ/kg)</th>
<th>EF(t C/TJ)</th>
<th>O(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raw coal</td>
<td>20 908</td>
<td>25.8</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>Anthracite</td>
<td>34 000</td>
<td>27.4</td>
<td>0.94</td>
</tr>
<tr>
<td>3</td>
<td>Bitumite</td>
<td>29 000</td>
<td>26.1</td>
<td>0.93</td>
</tr>
<tr>
<td>4</td>
<td>Lignite</td>
<td>12 187</td>
<td>28</td>
<td>0.96</td>
</tr>
</tbody>
</table>
2.2.2. Process CO₂ emission

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

\[ CE_m = AD_m \times EF_m, m \in [1,3] \]  

(3)

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

<table>
<thead>
<tr>
<th>( m )</th>
<th>Sub-sector</th>
<th>AD</th>
<th>EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cement production</td>
<td>Net production of cement clinker expect production from carbide slag</td>
<td>0.538</td>
</tr>
<tr>
<td>2</td>
<td>Lime production</td>
<td>Production of lime</td>
<td>0.683</td>
</tr>
<tr>
<td>3</td>
<td>Calcium carbide production</td>
<td>Production of calcium carbide</td>
<td>1.154</td>
</tr>
</tbody>
</table>

2.2.3. The change in CO₂ emission

The change in CO₂ emissions from period \( t \) to \( T \) can be formulate as follows:

\[ C_\Delta = C_T - C_i \]  

(4)

\[ r_\Delta = \left( \frac{C_T}{C_i} - 1 \right) \times 100\% \]  

(5)
Where \( C_{\Delta} \) stands for the change in carbon emissions from period \( t \) to period \( T \), \( r_{\Delta} \) 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](https://example.com/figure2.png)

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 3,187.41 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](attachment:image.png)

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.
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 has the smallest CO$_2$ emissions. Noteworthly, 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.
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 CO2: 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 CO2 emissions of sub-sectors in manufacturing during 2000, 2008 and 2013](image)

3.2.2. Emissions of different energy types

Fig 7 (a, b, c, d) shows the proportion of energy for the energy-related CO2 emissions inventory in 2000, 2005, 2010 and 2013 respectively. There are four energy type as coal, coke, oil and gas. Clearly, the CO2 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. CO2 emissions from four energies in 2000, 2005, 2010, 2013](image)

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
emissions reduction because of its huge base number. While the CO₂ 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.

![Energy-related and process CO2 emissions from 2000 to 2013](image)

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

In addition to energy-related emissions, industrial processes also contribute to total CO₂ 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 CO₂ 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 CO₂ emissions with an approximately growth proportion of 7% annually, while the CO₂ intensity of China diminishes lastly at different rates during 2000 to 2013 and it still decreases in the future.

(2) The CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions mitigation. Firstly, the progression of creative technology is inevitable and undeniable, which makes the CO₂ intensity constantly decrease. It is necessary and essential for China to offset CO₂ 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 CO2 emissions flow. Secondly, the government should make different CO2 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 CO2 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.

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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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