Influencing Factors of CO_2 Emissions in China's Manufacturing ——An Analysis Based on Manufacturing Structural Changes

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Abstract. Identifying the main influencing factors of carbon emission change in manufacturing is essential for making sound mitigation policies and boosting China to achieve emission peak early. Classifying manufacturing industry into high-, medium- and low-energy consumption categories, this paper employed LMDI approach to decompose energy-related carbon emissions in China's manufacturing from 1992 to 2012 into five driving factors. The results show that: (1) During the periods of 1996-2002, 2002-2007 and 2007-2012, the annual growth rate of manufacturing carbon emissions is 1.84%, 17.45% and 5.72% respectively. (2) Manufacturing value-added is the primary positive driving factor of carbon emission change, whose contribution rate to manufacturing carbon emissions ranges from 92.95% to 345.59%. Energy intensity is the leading negative driving factor, whose contribution rate is from -3.95% to -216.43%. (3) Manufacturing structure is generally a negative driving factor dominated by high energy consumption industries, such as Chemistry, Non-metallic mineral products and Metal smelting.

Introduction

Chinese government announced to peak CO_2 emissions around 2030 and make maximum efforts to peak early in *U.S.-China Joint Announcement on Climate Change* in November 2014. Acted as the primary industry in China's ecnomy, manufacturing is one of main sources of carbon emissions. From 1992 to 2012, its value-added accounted for about 30%-35% of China's GDP, while its energy-related carbon emissions (direct fossil fuel emissions plus indirect electricity emissions) accounted for about 60%-70% of national emissions[1]. It is essential for China to identify the key factors of carbon emission change in manufacturing to achieve its commitment. As the world's factory, China holds a wide range of manufacturing industries, including not only high energy consumption industries such as Metal smelting and Non-metallic mineral products, but also low energy consumption industries like Food manufacturing and tobacco processing. Besides the influence of value-added, energy intensity and energy structure, manufacturing structural change probably have a great impact on China's crabon emissions.

Logarithmic mean Divisia index (LMDI) is a widely used method for studying influencing factors of pollutant emissions and energy use change[1]. Liu et al. [2] and Yang and Chen [3] identified main factors responsible for China's industrial CO_2 emission (ICE) using LMDI, showing that industrial activity is the main driving force of ICE. Ren et al. [4] used LMDI to find the nature of factors that influence energy-related industrial CO_2 emission change in China's nine economic regions.

Concerining studies about China's manufacturing, based on extended Kaya identity, Ren et al. [5] investigated influencing factors of China's manufacturing carbon emissions from 1996 to 2010. Ang and Pandiyan [6] studied the effects of manufacturing internal structures. Using LMDI, Sun [7] quantitatively analyzed main factors that influenced CO_2 emissions of 30 sectors in manufacturing from 2003 to 2008. It shows that energy intensity caused by technical progress is the primary reason

[1] It is calculated by the authors according to *China energy statistical yearbook*. Refer to *methods and data* section for details.

for carbon reduction of all sectors. Liu et al. [8] explored the factors to the change of the energy-related carbon emissions from manufacturing sector based on LMDI method and Tapio decoupling model, indicating the intra structure effect on carbon emission change was relatively weak. These studies did not classify manufacturing to high-, medium- and low-energy consumption and their analysis on manufacturing structure change are limited.

In this paper, we adopt LMDI, incorporating manufacturing structural change, to decompose the driving factors of energy-related carbon emissions in China's manufacturing from 1992 to 2012, and to identify main factors that influence emission change.

Methods and data

The Classification of Manufacturing Structure. According to *Chinese national industries classification standard* (GB/T4754-2011), manufacturing includes 30 sectors. We regroup manufacturing into 14 sectors to maintain a unified statistical caliber with energy consumption data. Based on energy intensities of sectors (refer to Table 1), manufacturing industry is divided into three categories, involving high-, medium- and low-energy consumption manufacturing. The energy intensity of each sector is the mean of energy consumption per unit of value-added between 1996 and 2011 (tons of coal-equivalent/million yuan, in 2005 comparable price).

As shown in Fig.1, energy intensities of high-, medium- and low-energy consumption manufacturing decreased from 4.70, 1.30 and 0.83 tons of coal-equivalent/million yuan in 1996 to 3.52, 0.88 and 0.50 in 2011, demonstrating an average annual decline rate of 7.9%, 2.8% and 2.2% respectively. High-energy consumption manufacturing dominanted the decreasement.

Table 1 Classification of manufacturing structure

Manufacturing Structure	Sectors Included	Energy Consumption Intensity[tons of coal-equivalent/million yuan]
High-energy Consumption Industry	Petroleum processing, coking and nuclear fuel processing	4.115
	Chemistry	3.419
	Non-metallic mineral product	3.959
	Metal smelting	5.070
Medium-energy Consumption Industry	Textile	0.889
	Garment, leather, down and Products	0.786
	Paper, printing and stationery manufacturing	1.508
	Rubber and plastic products	0.890
	Other manufacturing (including recovery of waste materials)	1.427
Low-energy Consumption Industry	Food manufacturing and tobacco processing	0.685
	Wood processing and furniture manufacturing	0.560
	General and special equipment manufacturing	0.642
	Transportation equipment manufacturing	0.649
	Electrical, electronics, instrumentation and culture, office machinery manufacturing	0.363

LMDI Decomposition Model. LMDI decomposition model with manufacturing structural change is shown as Eq.1:

$$C_{manu} = \sum_a C_a = \sum_a QS_a I_a F_a \,. \tag{1}$$

Where C_{manu} is the total carbon emissions of manufacturing; a is the manufacturing categories (high-, medium- and low-energy consumption manufacturing); C_a is the carbon emissions of category a; Q is manufacturing value-added; S_a is the proportion of the value-added of category a to the manufacturing value-added (hereby referred to as manufacturing structure); I_a is the energy intensity of category a; F_a is the carbon emissions per unit of energy consumption of category a, reflecting the energy consumption structure.

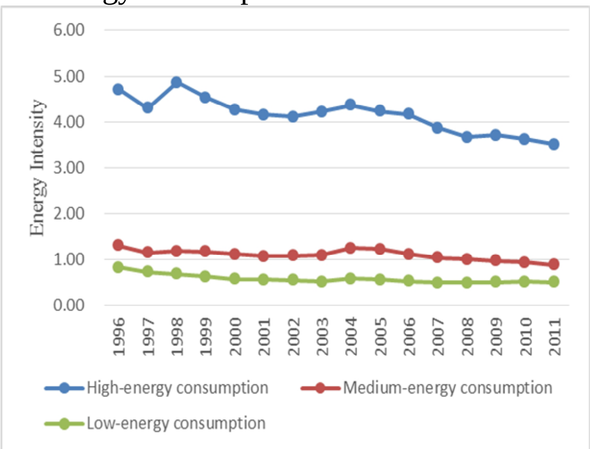

Fig.1 The change of energy intensity of China's manufacturing from 1996 to 2011[tons of coal-equivalent/million yuan]

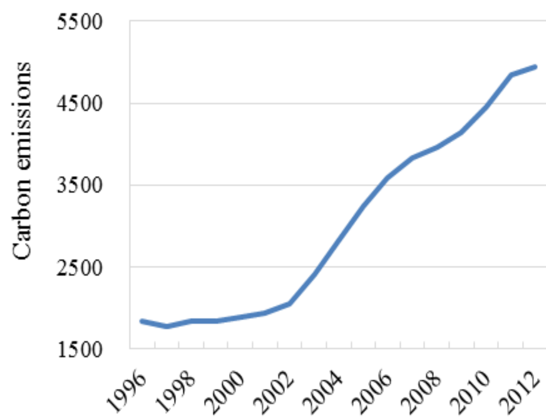

Fig.2 The increase of energy-related manufacturing carbon emissions in China from 1996 to 2012 [$MtCO_2$]

The change of manufacturing carbon emissions for a period of time could be calculated by Eq.2:

$$\Delta C_{manu} = C_{manu}^{T} - C_{manu}^{0} = \Delta C_{mQ} + \Delta C_{mS} + \Delta C_{mI} + \Delta C_{mF}. \tag{2}$$

Where ΔC_{manu} is the change of manufacturing carbon emissions; C_{manu}^{0} and C_{manu}^{T} are the manufacturing emissions in initial and final stage, respectively; ΔC_{mQ} is the emission change caused by the change of manufacturing value-added; ΔC_{mS} is the emission change caused by the manufacturing structure change; ΔC_{mI} is the emission change caused by the change of energy intensities of three manufacturing categories; ΔC_{mF} is the change of emissions caused by the change of energy consumption structures of all manufacturing categories.

The impacts of all factors in Eq. (2) on manufacturing carbon emissions can be calculated by Eq. 3 [9]:

$$\Delta C_X = \sum_a \frac{C_a^T - C_a^0}{\ln C_a^T - \ln C_a^0} \ln\left(\frac{X_a^T}{X_a^0}\right). \tag{3}$$

Where ΔC_X is the emission change induced by Q, S_a, I_a or F_a; X_a^0 and X_a^T are the starting and ending value of Q, S_a, I_a or F_a of a period.

Data. The sectoral value-added of manufacturing from 1992 to 2007 is collected from *China Statistical Yearbook*. National Bureau of Statistics of China had stopped publishing sectoral value-added data since 2008, so we calculate the data based on the growth rates of industry sectoral value-added published by National Bureau of Statistics of China. The price index method is used to adjust the value-added in current year price to that in 2005 comparable price.

The data of manufacturing energy consumption comes from *China energy statistical yearbook*. Among them, The data from 1996 to 1999 is updated according to *China energy statistical yearbook 2009*, and the data from 2000 to 2012 is updated according to *China energy statistical yearbook 2014*. Manufacturing carbon emissions are calculated with IPCC (2006) reference method [10].

Results and discussions

Overall Analysis of Influencing Factors. According to the growth rate of manufacturing energy-related carbon emissions in China from 1996 to 2012 shown in Fig.2, we can divide whole period into three stages. The carbon emission increase slightly with the annual growth rate of 1.84% from 1996 to 2002, while the next period from 2002 to 2007 rise up dramatically with the annual rate of 17.45%. After 2007, the growth rate of carbon emissions is declining gradually, with an average annual growth rate of 5.72%.

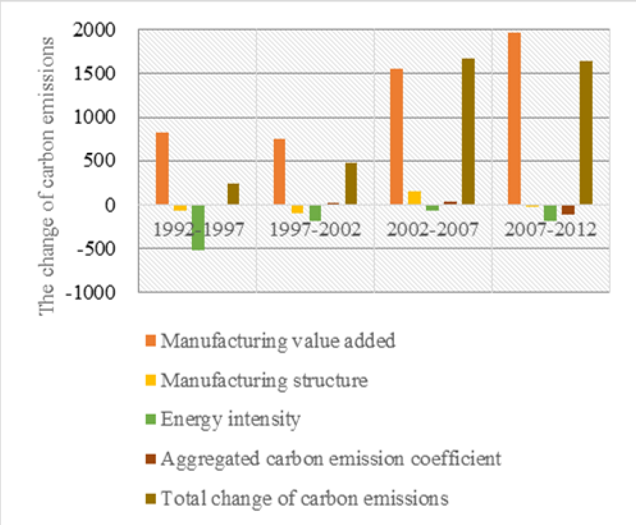

Fig.3 Influencing factors of CO_2 emission change in China's manufacturing [$MtCO_2$]

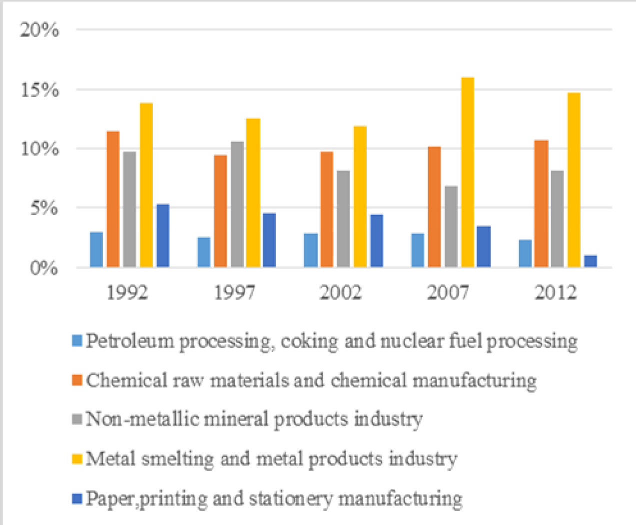

Fig.4 Value-added share of major sectors to manufactring

From Fig.3, manufacturing value-added is the primary positive driving factor of carbon emission change during the above four periods in 1992-2002, with contribution rates of 345.6%, 160.0%, 92.9% and 120.1% respectively. The main negative driving force is energy intensity, whose contribution portions are -216.4%, -40.5%, -11.5% and -3.9% during the four periods respectvely. From 1992 to 2012, manufacturing structure acts as the positive contribution to carbon emissions in most time except for 2002-2007, in which time China's industrialization centered on heavy industry. Aggregated carbon emission coefficient (reflecting energy structure) has little impact on carbon emission change during 1992 to 2007, while it becomes main negative driving force which is only second to energy intensity during 2007 to 2012.

Impact of Manufacturing Value-added. Manufacturing value-added, the main positive driving force for carbon emission change, lead to the increase by 831.01 $MtCO_2$ in 1992-1997 and 748.16 $MtCO_2$ in 1997-2002. The result of slowdown in increment is probably caused by Southeast Asian Financial Crisis broken out in 1997, resulting in the decline in China's domestic and export demand regarding manufacturing. From 2002 to 2007, the increment in carbon emissions caused by manufacturing value-added is 1561.31 $MtCO_2$, incresing by 108.66% compared with last period. There are two reasons: firstly, the exports of manufacturing increase significantly with China's accession to WTO. Secondly, the rapid urbanization characterized by prosperous real estate has promoted high-energy consumption manufacturing. From 2007 to 2012, the growth rate of China's manufacturing value-added slows down, but still maintain a relatively high speed. During this period, the carbon emission change caused by manufacturing value-added is 1973.46 $MtCO_2$, increasing by 26.40% than last period.

Impact of Manufacturing Structure. Table 2 shows that high-energy consumption manufacturing plays a leading role in carbon emission change, whose contributions are -88.44 and -104.93 MtCO_2 during 1992-1997 and 1997-2002 respectively. As for specific sectors, the proportion of value-added of Chemistry, Non-metallic mineral products and Metal smelting to whole manufacturing value-added are showing downward trends (Fig. 4), thus slowing down the growth of manufacturing carbon emissions (Table 3). During 2002-2007, the proportion of Metal smelting value-added increase significantly, promoting an increment in carbon emissions of 321.84 MtCO_2, thereby, the overall effect of manufacturing structure during this period is positive. During 2007-2012, medium- and low-energy consumption manufacturing (for example, paper, printing and stationery manufacturing) play an increasing important role in carbon reduction, leading to a negative effect on whole carbon emissions during this period. The results above show that China's manufacturing structure is improving gradually.

Table 2 The impacts of manufacturing structure change on CO_2 emissions [MtCO_2]

Classification	1992-1997	1997-2002	2002-2007	2007-2012
High-energy Consumption	-88.44	-104.93	202.01	8.73
Medium-energy Consumption	5.64	-12.23	-53.29	-59.35
Low-energy Consumption	13.06	22.71	2.08	25.03
Sum	-69.74	-94.45	150.80	-25.59

Table 3 The impacts of value-added share change of major sectors on CO_2 emissions [MtCO_2]

Sector	1992-1997	1997-2002	2002-2007	2007-2012
Petroleum processing, coking and nuclear fuel processing	-6.89	9.07	-1.40	-42.03
Chemistry	-58.77	11.76	24.98	32.26
Non-metallic mineral products industry	25.20	-86.59	-79.80	117.53
Metal smelting	-46.29	-33.33	321.84	-152.42
Paper, printing and stationery manufacturing	-8.54	-0.80	-22.48	-140.22

Impact of Energy Intensity. Energy intensity is the most important negative driving force to carbon emission change. Table 4 shows that except for 2002-2007, the reduction of carbon emissions is mainly caused by declination of energy intensity in high-energy consumption manufacturing. Contributions of energy intensity in high- and low-energy consumption manufacturing are always negative; however, during 2002-2007 and 2007-2012, the contribution of energy intensity in medium-energy consumption manufacturing is positive, indicating that its energy use efficiency is enhanced.

Table 4 The impacts of energy intensity change on CO_2 emissions [MtCO_2]

Classification	1992-1997	1997-2002	2002-2007	2007-2012
High-energy Consumption	-249.14	-111.49	-27.78	-179.17
Medium-energy Consumption	-131.33	-5.98	10.84	5.30
Low-energy Consumption	-139.97	-71.83	-49.50	-14.25
Sum	-520.44	-189.3	-66.44	-188.12

From 1992 to 2012, most industries' energy use efficiencies in manufacturing are being improved, thus promoting continued decline in their energy intensities and slowing down the growth of manufacturing carbon emissions. The improvement of energy efficiency may come from two aspects: technological progress and changes in ownership structure of enterprise. Technological progress improves the way of energy use, thus reduces the amount of energy per unit of value-added, leading to reduction of carbon emissions. Studies have shown that technical efficiency and resource use efficiency of non state-owned enterprises are higher than those of state-owned enterprise [11]. From

1992 to 2012, with the depth of state-owned enterprise reform and ownership structure adjustment, the proportion of state-owned enterprises in China has been declining, while the proportion of non state-owned enterprises has been increasing gradually, thereby, the carbon emissions are reduced.

Impact of aggregated carbon emission coefficient. The contribution of aggregated carbon emission coefficient to manufacturing carbon emission change is shown in table 5. From 1992 to 1997, aggregated carbon emission coefficients of high-, medium- and low-energy consumption manufacturing have slightly negative impacts on carbon emissions while these coefficients have slightly positive impacts from 1997 to 2002, indicating that energy structure in manufacturing does not change significantly from 1992 to 2002. From 2002 to 2007, aggregated carbon emission coefficient plays a positive role in carbon emissions, and high-energy consumption manufacturing contributes the most, reaching 23.32 $MtCO_2$. This is mainly because the development of Non-metallic mineral products, Chemistry and Metal smelting leads to proportion of high-emission energy consumption such as raw coal and coke to total manufacturing energy consumption increase by about 3%, thus promoting the growth of carbon emissions. From 2007 to 2012, aggregated carbon emission coefficient is an important negative driving force, and high-energy consumption manufacturing also makes the largest contribution, reaching -79.05 $MtCO_2$. This is mainly because the development of above three sectors leads to the proportion of high-emission energy consumption to total manufacturing energy consumption decrease by about 9%. The above results indicate that lowering the proportion of high-emission energy consumption can significantly slow down the growth of carbon emissions.

Table 5 The impacts of change of aggregated carbon emission factor on CO_2 emissions [$MtCO_2$]

Classification	1992-1997	1997-2002	2002-2007	2007-2012
High-energy Consumption	-0.26	2.33	23.32	-79.05
Medium-energy Consumption	-0.06	0.47	5.73	-17.55
Low-energy Consumption	-0.05	0.35	5.06	-19.74
Sum	-0.37	3.15	34.11	-116.34

Conclusions and outlooks

From the analysis of influencing factors on carbon emissions in China's manufacturing, we can conclude that:

The carbon emission increase slightly with the annual growth rate of 1.84% from 1996 to 2002, while the next period from 2002 to 2007 rise up dramatically with the annual rate of 17.45%. After 2007, the growth rate of carbon emissions is declining gradually, with an average annual growth rate of 5.72%.

As for influencing factors, manufacturing value-added is the primary positive driving force while energy intensity is the main negative driving force. Manufacturing structure is generally a negative driving factor. Aggregated carbon emission coefficient has little impact on carbon emission change during 1992-2007, while it becomes main negative driving force which is only second to energy intensity during 2007-2012.

Except for 2002-2007, manufacturing structure is a negative influencing factor. From 1992 to 2007, Chemistry, Non-metallic mineral products and Metal smelting make the largest contributions. After 2007, the dominant position of high-energy consumption manufacturing has changed, and the influence of medium- and low-energy consumption manufacturing to carbon reduction increases gradually, leading to a negative effect on carbon emissions.

We will improve the study in two aspects. Firstly, due to data limitation, the data used in this paper was combined into 21 sectors, in which manufacturing accounted for 14. The aggregation of data caused data loss, resulting in the declination of accuracy compared with the results of disaggregated sectors. Secondly, we divided whole manufacturing into three categories (high- medium- and low-energy consumption manufacturing) according to energy intensity, without considering classification according to production factors. Applying classification according to production factors can instruct government and enterprises to achieve the goal of energy-saving and emission reduction through the change of investment of production factors.

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