Regional Variation of Energy-related Industrial CO_2 Emissions Mitigation in China

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Abstract: This paper aims to analyze the reasons for regional variations in industrial CO_2 emissions mitigation. Using a two-level LMDI perfect decomposition technique, the total energy-related industrial CO_2 emissions of nine economic regions in China are decomposed into energy structure, energy intensity, industrial structure and economic output effects during the period of "11th Five-Year Plan". As the results suggest, the rapid growth of industry is the most important factor responsible for increase in CO_2 emissions. The adjustment of industrial structure and energy structure both contribute to the increase of CO_2 emissions slightly. Decline in energy consumption per unit GDP is the most important actuation factor of CO_2 emissions mitigation and the energy emission factor also makes a weeny contribution to the CO_2 reduction as a result of electricity generation efficiency enhancement.

Keywords: CO_2 emissions; mitigation; industrial development; factor decomposition

1. Introduction

The next 15-20 years are expected to be an important period for China's social and economic development, as controlling greenhouse gases (GHG), especially CO_2, emissions will be the key to sustained development. In recent years, the high rate of economic growth has been accompanied by an equally high growth in fossil energy consumption, particularly because of the coal-dominated structure of the economy; Chinese CO_2 emissions are now the highest in the world. According to IEA (2009), China was the world's largest emitter of CO_2 in 2007. Not surprisingly, it faces increasing pressure from the international community to curb CO_2 emissions. In the total CO_2 emissions, industrial energy-related CO_2 emissions account for over 90% of the total. Therefore, study of the driving forces governing industrial CO_2 emissions has been of considerable interest to researchers and policymakers.

On the basis of regional revitalization program guidance in China, this paper divides China into nine economic regions (Table 1). The regional revitalization program comprises "The regional planning of Yangtze River Delta Region" (2010), "The reformation and development planning outline of Pearl River Delta Region" (2008), "The integrated development planning of Bohai Rim Economic Region(underway)" (2011), "Some comments of the Central Committee of the CCP and the State Council on the rise of Midland Region" (2006), "The revitalizing planning of Northeast Region" (2007), "Some comments of the State Council on supporting Fujian to build Economic Zone on the Western Coast of the Taiwan Straits" (2009), "The regional planning of Chengyu Economic Region" (2011), "The 11th planning of West Development Strategy" (2006) and "Some comments of the State Council on promoting to build Hainan International Travel Island" (2009).

After constructing a comprehensive model that considers both direct and indirect CO_2 emissions, we decompose the total industrial CO_2 emissions in the above nine economic regions during the period of "11th Five-Year Plan", analyze the underlying reasons and compare differences between regions. This provides important information about change in carbon emissions in China's various regions and their reasons during the period of "12th Five-Year Plan"(2011-2015).

Table 1. Economic regions in China

Region	Provinces covered
Yangtze River Delta Region	Shanghai, Jiangsu, Zhejiang
Pearl River Delta Region	Guangdong

Bohai Rim Economic Region	Beijing, Tianjin, Hebei, Shandong
Midland Region	Hunan, Hubei, Anhui, Shanxi, Jiangxi, Henan
Northeast Region	Liaoning, Heilongjiang, Jilin
Economic Zone on the Western Coast of the Taiwan Straits	Fujian
Chengyu Economic Region	Chongqing, Sichuan
Western Region	Guizhou, Yunnan, Guangxi, Qinghai, Ningxia, Gansu, Shanxi, Inner Mongolia, Xinjiang
Hainan International Travel Island	Hainan

Notes: "Chinese Energy Statistics Yearbook" does not provide Tibet's energy data for the relevant years, so the Western Region has not included Tibet; Hong Kong, Macao and Taiwan's energy data are in formats very different from other provinces and, therefore, Hong Kong, Macao and Taiwan have not been included in the above.

2. Methodology approach

2.1. Industrial CO_2 emissions calculation model

Based on IPCC (2006) carbon emissions computation guide, energy-related industrial CO_2 emissions can be expressed as follows:

$$E = \sum_{j=1}^{19} C_j \varepsilon_j (j = 1, 2 \cdots 19) \qquad (1)$$

where E indexes total industry-related CO_2 emissions; C_j indexes consumption of each fuel type after conversion into standard coal equivalent; ε_j indexes CO_2 emissions factor of each fuel type.

2.2. Two-level perfect decomposition model

We refer to Wu et al. (2005) "three-level perfect decomposition" method to decompose total industrial CO_2 emissions into nineteen types of energy and three broad categories of industries, i.e. primary, secondary and tertiary. We have considered regions rather than provinces for studying emissions patterns. The concrete decomposition model can be expressed as follows:

$$C = \sum_{i=1}^{3}\sum_{j=1}^{19} C_{ij} = \sum_{i=1}^{3}\sum_{j=1}^{19} \frac{C_{ij}}{F_{ij}} \cdot \frac{F_{ij}}{F_i} \cdot \frac{F_i}{P_i} \cdot \frac{P_i}{P} \cdot P \qquad (2)$$

Function 2 can be transformed as:

$$C = \sum_{i=1}^{3}\sum_{j=1}^{19} C_{ij} = \sum_{i=1}^{3}\sum_{j=1}^{19} CI_{ij} \cdot FS_{ij} \cdot FIP_i \cdot ES_i \cdot P \qquad (3)$$

In the above two equations, i denotes industry sector, i=1, 2, 3 represent primary, secondary and tertiary industries; j denotes fuel type, j=1, 2,…, 19, i.e. raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, other gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, refinery gas, natural gas, other petroleum products, other coking products, heat and electricity.

We define the following terms C, total industrial CO_2 emissions; C_{ij}, CO_2 emissions by fuel type j in sector i; F_{ij}, consumption of fuel type j in sector i; F_i, energy consumption in sector i; P_i, economic output of sector i; $CI_{ij} = C_{ij} / F_{ij}$, CO_2 intensity of fuel type j in sector i; $FS_{ij} = F_{ij} / F_i$, energy mix ratio for fuel type j in sector i; $FIP_i = F_i / P_i$, energy intensity for fuel type j in sector i; $ES_i = P_i / P$, share of economic output in sector i; P, total economic output. The meaning of each factor in the function is described in Table 2.

Take logarithm about time on both sides of Function 3, the instantaneous increasing rate of CO_2 emissions then be resulted as follows:

$$\begin{aligned} \frac{dC}{dt} = & \sum_{i=1}^{3}\sum_{j=1}^{19} \frac{dCI_{ij}}{dt} \cdot FS_{ij} \cdot FIP_i \cdot ES_i \cdot P + \\ & \sum_{i=1}^{3}\sum_{j=1}^{19} CI_{ij} \cdot \frac{dFS_{ij}}{dt} \cdot FIP_i \cdot ES_i \cdot P + \\ & \sum_{i=1}^{3}\sum_{j=1}^{19} CI_{ij} \cdot FS_{ij} \cdot \frac{dFIP_i}{dt} \cdot ES_i \cdot P + \\ & \sum_{i=1}^{3}\sum_{j=1}^{19} CI_{ij} \cdot FS_{ij} \cdot FIP_i \cdot \frac{dES_i}{dt} \cdot P + \\ & \sum_{i=1}^{3}\sum_{j=1}^{19} CI_{ij} \cdot FS_{ij} \cdot FIP_i \cdot ES_i \cdot \frac{dP}{dt} \end{aligned} \qquad (4)$$

Both sides of Function 3 are divided by C, where $W_{ij} = C_{ij} / C$ in Function 4, and then:

$$\frac{1}{C}\frac{dC}{dt} = \sum_{i=1}^{3}\sum_{j=1}^{19} W_{ij} \cdot \frac{1}{CI_{ij}} \cdot \frac{dCI_{ij}}{dt} + \sum_{i=1}^{3}\sum_{j=1}^{19} W_{ij} \cdot \frac{1}{FS_{ij}} \cdot \frac{dFS_{ij}}{dt} + \cdots + \sum_{i=1}^{3}\sum_{j=1}^{19} W_{ij} \cdot \frac{dP}{dt} \cdot \frac{1}{P} \qquad (5)$$

Take definite integral from time zero to T on Function 5, and then:

$$\int_0^T \frac{d\ln C}{dt}dt = \sum_{i=1}^{3}\sum_{j=1}^{19}\int_0^T W_{ij}(\frac{d\ln CI_{ij}}{dt} + \frac{d\ln FS_{ij}}{dt} + \frac{d\ln FIP_i}{dt} + \frac{d\ln ES_i}{dt} + \frac{d\ln P}{dt})dt \quad (6)$$

One way to obtain the approximate value of $W_{ij}(t^*)$ is to use the Logarithmic Mean Divisia Index Method (LMDI), which is able to deal with zero value in the data set and also leaves no residual term (Ang B. W. and Ki-Hong Choi 1997). The logarithmic mean of two positive numbers is defined as:

$$L(x,y) = \begin{cases} (x-y)/(\ln x - \ln y), x \neq y \\ x, x = y \\ 0, x = y = 0 \end{cases} \quad (7)$$

The weight function is then given by:

$$\overline{W}_{ij}(t^*) = \frac{L(C_{ij,T}, C_{ij,0})}{L(C_T, C_0)} \quad (8)$$

Function 8 can then be changed to:

$$\frac{C_T}{C_0} \equiv \exp\left[\sum_{i=1}^{3}\sum_{j=1}^{19}\overline{W}_{ij}(t^*)\ln\frac{CI_{ij,T}}{CI_{ij,0}}\right]\cdot \exp\left[\sum_{i=1}^{3}\sum_{j=1}^{19}\overline{W}_{ij}(t^*)\ln\frac{FS_{ij,T}}{FS_{ij,0}}\right]\cdot \exp\left[\sum_{i=1}^{3}\sum_{j=1}^{19}\overline{W}_{ij}(t^*)\ln\frac{FIP_{ij,T}}{FIP_{ij,0}}\right]\cdot \exp\left[\sum_{i=1}^{3}\sum_{j=1}^{19}\overline{W}_{ij}(t^*)\ln\frac{ES_{ij,T}}{ES_{ij,0}}\right]\cdot \exp\left[\sum_{i=1}^{3}\sum_{j=1}^{19}\overline{W}_{ij}(t^*)\ln\frac{P_{ij,T}}{P_{ij,0}}\right] \quad (9)$$

Function 9 can be written as:

$$\Delta C = \Delta CI + \Delta FS + \Delta FIP + \Delta ES + \Delta P \quad (10)$$

The meaning of Function 10 is that industrial CO_2 emissions can be decomposed into CI, FS, FIP, ES and P factors' contribution. △C indexes the total CO_2 emissions' variance (or the rate of variance), △CI indexes the CO_2 emissions' variance caused by energy emission factor effect (or the rate of variance), △FS indexes the CO_2 emissions' variance caused by energy structure effect (or the rate of variance), △FIP indexes the CO_2 emissions' variance caused by energy intensity effect (or the rate of variance), △ES indexes the CO_2 emissions' variance caused by industrial structure effect (or the rate of variance), and △P indexes the CO_2 emissions' variance caused by economic output effect (or the rate of variance).

3. Data management

In this study, industry energy consumption data of various regions are directly collected from "Chinese Energy Statistics Yearbook (2006-2010)", and the consumption of each fuel type has been converted into standard coal equivalent. Industry output value data of various regions are directly collected from "Chinese Statistics Yearbook (2006-2010)", and has been adjusted by fixed price computation, taking 1995 as the base period.

CO_2 emissions factor of each fuel type (except electricity) is fixed, so we can use the CO_2 emissions factor using the parameters of average net calorific value, carbon emissions coefficient, CO_2 conversion coefficient, carbon oxygenation efficiency and the coefficient to convert energy consumption into standard coal equivalent (refer to IPCC 2006 computational method). The result is shown in Table 2.

The CO_2 emissions factor of electricity is special, for the electricity consumption does not bring CO_2 directly, but during the electricity generation process a lot of fundamental energy is consumed, therefore the electricity consumption may cause CO_2 emissions indirectly, whereas the quantity of emissions is quite huge. The CO_2 emissions from electricity consumption are influenced by some factors such as energy structure for electricity generation, standard rate of coal consumption of thermoelectricity and so on. As the data of energy structure for electricity generation of Chinese Electric power Department are deficient, and above 90% of Chinese thermoelectricity comes from the raw coal generation, we estimate the CO_2 emissions factor of electricity approximately through the CO_2 emissions factor of raw coal. The result is shown in Table 3.

Table 2. CO_2 emissions factor of each energy type except electricity

Energy type	CO_2 emissions factor (tCO_2/toe)	Energy type	CO_2 emissions factor (tCO_2/toe)
Raw coal	2.769	Kerosene	2.104
Cleaned coal	2.769	Diesel oil	2.168
Other washed coal	2.776	Fuel oil	2.265
Briquettes	2.862	Liquefied	1.846

		petroleum gas	
Coke	3.134	Refinery gas	1.687
Coke oven gas	1.299	Natural gas	1.642
Other gases	1.299	Other petroleum products	2.148
Crude oil	2.147	Other coking products	2.365
Gasoline	2.029	Heat	3.249

Data source: Average net calorific power and the coefficient to convert into standard coal equivalent are collected from "Chinese Energy Statistics Yearbook 2010"，carbon emissions coefficient and carbon oxygenation efficiency are collected from IPCC(2006).

Notes: CO_2 emissions factor of each energy type except electricity=（average net calorific power * carbon emissions coefficient * (44/12) * carbon oxygenation efficiency）/ the coefficient to transform standard coal.

Table 3. CO_2 emissions factor of electricity

Year	Standard coal equivalent (Kg/kWh)	Emissions factor of electricity (tCO_2/toe)
2005	0.343	6.307
2006	0.342	6.425
2007	0.332	6.240
2008	0.322	5.898
2009	0.322	5.898

Data source: Chinese Electric Power Yearbook 2006-2009. As "Chinese Electric Power Yearbook 2010" is not available now, all data for the year 2009 have been assumed to be the same as 2008.

Notes: CO_2 emissions factor of electricity=（proportion of thermoelectricity * standard rate of coal consumption of thermoelectricity * CO_2 emissions factor of raw coal）/ the coefficient of electricity to transform standard coal.

4. Results and discussion

Table 5 summarizes the results of decomposition analysis by determining the positive or negative effects explaining the changes in the amount of energy-related CO_2 emissions released from all industries in each region during the period under consideration.

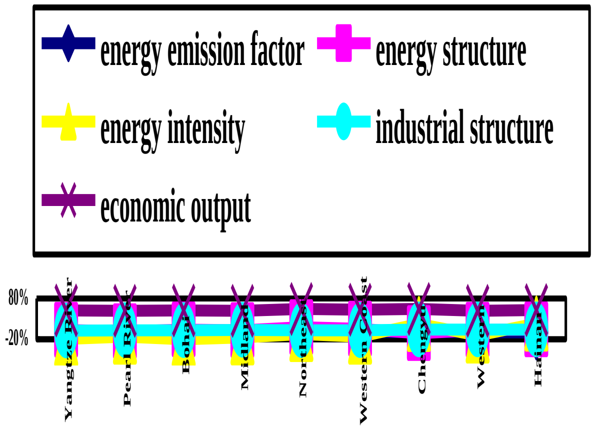

Figure 1. The contribution of five effects to various regions' industry CO_2 emissions change

5. Conclusions

During the period of "11th Five-Year Plan", various regions' industrial CO_2 emissions have had the tendency of remarkable growth in China. The economic output is the most important factor causing a sharp increase in industrial CO_2 emissions. The proportion of secondary industry has been increasing all along and the adjustment of energy structure caused by the increased proportion of electricity consumption contribute to the increase of CO_2 emissions slightly. On the other hand, the unit GDP energy consumption's decline is the most important actuation factor of CO_2 emissions mitigation. While electricity generation efficiency is improving, energy emission factor also makes a weeny contribution to CO_2 reduction.

From the analysis above, it is obvious that energy intensity is the uppermost positive factor driving industrial CO_2 emissions mitigation. Since each region's promotion of energy efficiency is relatively small, in future industrial development more investment should be made to impel advanced energy conservation technological development in energy exploitation, transformation and utilization and enhance energy efficiency in each sector, specially sectors with high energy consumption. Only in these ways can we fully exploit the industries' emission mitigation potential.

In addition, economic output is the uppermost negative driving factor of industrial CO_2 emissions mitigation. Considering the history of US, England, Germany and so on, we can see that CO_2 emissions increase caused by industrial development is inevitable. China is in the industrialization stage and emphasizing low-carbon transformation of the economic growth mode and developing strategic emerging industries is the way to accomplish a new style of industrialization.

For China, enhancement of electricity generation efficiency and reduction of unit standard coal consumption can reduce industry's CO_2 emissions to a certain degree but the most fundamental solution is to speed up the electric power structure adjustment. Our government should enhance exploration of clean electricity generation such as hydropower, wind power, nuclear power and so on, and reduce the proportion of thermoelectricity in the overall electricity output, and pay more attention to technological upgradation of the thermoelectricity electricity generation process, and diligently realize the transformation to "green electricity generation" from "black electricity generation".

In regionwise differences, Midland Region, Yangtze River Delta, Bohai Rim Economic Region and Pearl River Delta have obviously made efforts to mitigate industrial CO_2 emissions because they have done well in reducing energy intensity. The effort of Economic Zone on the Western Coast of the Taiwan Straits and Western Region in CO_2 mitigation needs enhancement. Hainan International Travel Island, Northeast Region and Chengyu Economic Region are inferior to other regions and need to improve their performance urgently. In these three regions, Hainan International Travel Island and Chengyu Economic Region both have done badly in energy efficiency promotion, while Northeast Region's effort has been insufficient mainly due to the adjustment of energy structure caused by the increased proportion of coke-based energy consumption.

Contraposing the characteristics of reduction of industrial CO_2 emissions in each region in China, we can make some suggestions in the following respects. Yangtze River Delta, Pearl River Delta and Bohai Rim Economic Region should make some efforts to adjust the inter-industry and intra-industry structure and focus on the reconstruction of traditional industries by using emerging technology and developing high-tech industries. In other words, they should actively develop modern service industries and greatly increase the proportion of high-tech industry in secondary and tertiary industry sectors in order to step into the "post-industrialization" era as soon as possible. Midland Region, Chengyu Economic Region and Northeast Region should emphasize acceleration of the aggregation level of industrial development, improve the energy transfer efficiency and reduce the energy intensity. At the same time, they should focus on energy structure adjustment and vigorously develop and promote clean coal technology. Western Region, Economic Zone on the Western Coast of the Taiwan Straits and Hainan International Travel Island should increase technology spending, especially technological innovation, and strive to introduce advanced technology from the developed areas and abroad. Moreover, they should accelerate the development of energy-saving technology and promote industrial production factors to convert from labor intensive into knowledge-intensive output. And the output results should be transformed from low value-added to high value-added.

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