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Regional Differences of the Driving Factors and Decoupling Effect of Carbon Emissions

Evidence from China's Pollution-Intensive Industry

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Abstract: The completed decomposition model combined with the decoupling index is used to analyze the contribution of each factor which influences energy-related CO_2 emission in 15 regions over the period 2000-2012. The results show that the major factors that influence CO_2 emission in areas are industrial output effect and energy intensity effect, followed by the industrial structure effect, while the energy structure and energy emission intensity have a smaller effect. Moreover, a reduction potential model is implemented in order to investigate the emission reduction potential of regions and sub-industrial sectors. It is found that although most governments showed great enthusiasm in promoting emission reduction, most regions present no decoupling effect. It indicates that emission reduction efforts have not always proven effective till now, therefore, most regions, including Beijing, have great energy saving and emission reduction potential.

1. INTRODUCTION

The Chinese Government has promised a CO_2 intensity target of 40%-45% reduction by year 2020 compared to 2005 levels, but the situation of its carbon emission ranking first in the world makes this task difficult to fulfil. How to implement the emission reduction policies at the industry level is key to realize this target. At present, China's economic growth is still in the pattern of growth led by manufacturing. So, although China has taken important measures to reduce its carbon emission, a sustainable high growth rate of manufacturing, especially of pollution-intensive ones, is still the main driving force of the rapid growth in CO_2 emissions.

Chinese natural resources are unevenly distributed and there have been big economic development differences in regions, which lead to an obvious regional difference in carbon emissions (Liu, Z. et al., 2010; Xiong et al., 2012). Many studies have focused on China’s energy-related CO_2 emissions and some important opinions have been gained from the existing literature regarding the driving factors of CO_2 emissions (Wang, C., Chen, & Zou, 2005; Xu, Xu, & Hu, 2011). Unfortunately, there are very few studies with respect to the driving factors of CO_2 emission from a regional perspective (Li, Song, & Liu, 2014; Wei, Ni, & Du, 2012; Yi et al., 2011). Hardly any comparison of CO_2 emissions at the regional level from the perspective of pollution-intensive industries has been done. Therefore, it is necessary to investigate the driving forces of CO_2 emissions in the pollution-intensive industries and realize a deeper understanding of how CO_2 emissions related to pollution-intensive industries have evolved in regions. To achieve this goal, the proper approach needs to decompose the CO_2 emissions into the possible factors that affect such emissions. In this way, we can get a deeper understanding of the strengths and weaknesses of each region regarding their emission performance.

There are a variety of methods that can be used to decompose the CO_2 emissions, such as Structural decomposition analysis (SDA), IPAT equation, Divisia index decomposition analysis (Divisia IDA), and Laspeyres index decomposition analysis (Laspeyres IDA). The SDA method has been used in many studies (Tukker & Dietzenbacher, 2013; Wiedmann, 2009). However, it is based on an environmentally extended input-output table which is published every five years. Although the interval of data for four years can be calculated, it is built on a series of assumptions, the reliability is not high, and the economic development situation changes very fast. Therefore, SDA cannot fit the needs of research. For the IPAT equation, it is mainly used to analyze the impact of human activities on the environment, which reflects the influence of population, output and technology on CO_2 emissions (Dietz & Rosa, 1994; Ehrlich & Holdren, 1971). The IPAT equation does not take other factors such as the energy use into account. Divisia IDA and Laspeyres IDA use the index concept in decomposition (Hoekstra & Van den Bergh, 2003), which has been used in many studies on CO_2 emissions' decomposition due to the abundant availability of data. Although it has been proved by Ang (2004) and Greening et al. (1997) that there is a stronger theoretical basis in Divisia IDA than that in Laspeyres IDA, because there is a large residual term after decomposition in the traditional Laspeyres IDA, the Laspeyres IDA does have some advantages compared with others (Diakoulaki & Mandaraka, 2007; Xu, Xu, & Hu, 2011). Sun (1998) improved the Laspeyres IDA, modifying it into a complete decomposition technique, which eliminates the un-decomposed residual term, and makes the results more accurate. According to these advantages and disadvantages of above decomposition methods, this research employs the complete decomposition technique to decompose the CO_2 emissions.

The decomposition of carbon emissions can reflect the impact of each factor on carbon emissions, and tell us which factors determine the change of CO_2 emissions in different regions of China's pollution-intensive industries over the examined time. However, the degree of decomposition analysis is not sufficient for full examination of changes that took place in each area and sub-sector separately, and cannot show: (1) what reduction efforts have been done contributing to the maximum decline of the CO_2 emissions in each region? (2) Is there a regional difference in the relationship between development and emission reduction? (3) What is the reduction potential of CO_2 emissions of the pollution-intensive industries and how high can this be?

To answer the question (1) and (2), the proper approach is to try to determine the decoupling process of industrial growth from the CO_2 emissions level and to realize the joint exploitation of the factors identified in the complete decomposition analysis. This decoupling was proposed by OECD in 2002 firstly (Organization for Economic Co-operation and Development, 2002). As an important concept for integrating economy and environment (Enevoldsen, Ryelund, & Andersen, 2007; Wang, W. et al., 2013), it breaks the relationship between environmental damage and economic wealth, or the relationship between environmental pressure and economic performance. The decoupling theory has been widely used in many studies. The main methods adopted were the comprehensive analysis of variation method, the decoupling index method, the elastic analysis, the decoupling analysis method which is based on a complete decomposition technique, the statistical analysis method, the econometric analysis method and the differential regression coefficient method (Zhong et al., 2010). Among them, the decoupling index method is more widely applied. The decoupling index method and the elastic analysis are mainly focused on studying the relationship between economic growth and CO_2 emissions and they do not take other influence factors into account; the econometric analysis method and the differential regression coefficient method have high demand in data. Considering the availability of data and the purpose of this paper, we will choose the decoupling analysis method which is based on complete decomposition technique as a tool.

The third question implies an assessment of the gap between the optimal value and the real value of emission reduction. Although sample areas are regions of China, they show big differences in their levels of industrial development and industrial structure. Moreover, other obvious distinctions such as the availability of natural resources and the historical attachment to particular industrial activities make assessment a rather important task.

The remainder of this paper is organized as follows: Section 2 introduces the definition of pollution-intensive industries. Section 3 presents the methodology and the data. Section 4 provides the result and discussion. Section 5 contains concluding remarks.

2. DEFINITION OF POLLUTON-INTENSIVE INDUSTRY

According to the existing literature, pollution-intensive industries are generally considered to be those who produce large amounts of pollutants in the process of production or sales, but there is no consistent definition in current academia for this kind of industry, and also no uniform standard to define it. The current way of definition can be roughly divided into the following categories:

a) Calculating the index of pollution emission uses multiple indicators, such as industrial wastewater, waste gas and solid waste. And then the industry can be divided into high, middle, low pollution industries and cleaning industry (Liu, Q., Wang, & Li, 2012). The advantage of this method is that it can distinguish whether the industry is polluting industry or not, but it cannot distinguish the industry pollution types.
b) Judging by the degree or scale of pollution or contamination uses a single indicator, such as emissions scale or emissions intensity. Generally, the emissions scale is the sum of different kinds of pollutants. However, this method does not take the different properties of each pollutant into account.

From what has been mentioned above, in this paper, we take those two aspects into account when we define the pollution-intensive industries.

Step 1: Classify the type of pollutant. To achieve this, two indicators, including the emission intensity and emission scale, are constructed. Their calculation formula can be expressed as follows:

$$EI_{ij} = \frac{XE_{ij}}{X_i} \tag{1}$$

$$ES_{ij} = \frac{XE_{ij}}{ET} \tag{2}$$

where EI_{ij} and ES_{ij} denote the emission intensity and the emission scale of *j* pollutant in industry *i*; XE_{ij} denotes the j^{th} pollutant emission quantities of the i^{th} industry; X_i is the industrial production of the i^{th} industry; while ET is the total industrial added value. Using the relevant data of 2010, EI_{ij} and ES_{ij} can be calculated.

Step 2: Calculate the pollutant index of each type. The pollutants are divided into three categories: water pollutant which is measured by wastewater emissions, gas pollutant which is measured by the emission of SO_2, dust and smoke dust, and solid waste which is measured by solid waste emissions. Based on Equation (1) and Equation (2), the normalization process is shown as follows:

$$\overline{EI_{ij}} = \frac{EI_{ij} - \min(EI_{ij})}{\max(EI_{ij}) - \min(EI_{ij})} \tag{3}$$

$$\overline{ES_{ij}} = \frac{ES_{ij} - \min(ES_{ij})}{\max(ES_{ij}) - \min(ES_{ij})} \tag{4}$$

Based on Equation (3) and (4), the pollution index I_{ij} (where *j* is waste air, waste water and solid waste, respectively) of industry *i* can be calculated as illustrated in Equation (5):

$$I_{ij} = (\overline{EI_{ij}} * \overline{ES_{ij}})^{1/2} \tag{5}$$

Table 1, below, summarizes the results of these three kinds of pollution indexes. Correspondingly, the pollution-intensity industry is sorted into three groups including high-water-pollution industry, high-gas-pollution industry and high-solid-waste pollution industry.

The scope of this paper is to analyse the decoupling process of industrial growth from the CO_2 emissions level in the pollution-intensive industries. As the high carbon emissions industry generally belongs to the high-gas-pollution industry, we chose the pollution-intensive industry according only to the result of high-gas-pollution industries. As shown in *Table 1*, there are seven typical high-gas-pollution industries, including electricity, heat production and supply, non-metallic mineral products industry, ferrous metal smelting and rolling industry, chemical materials and chemical products manufacturing, paper and paper products industry, non-ferrous metal smelting and rolling industry, and petroleum processing and coking and nuclear fuel processing.

All the data of high-pollution industries that Section 3 requires are calculated from these seven industries.

Table 1. The categories of pollution-intensive industry

Industry	Waste air	Waste water	Solid waste
Production and Supply of Electric Power and Heat Power	1.0000	0.1602	0.4144

Manufacture of Non-metallic Mineral Products	0.5195	0.0400	0.0445
Manufacture and Processing of Ferrous Metals	0.2622	0.1254	0.2587
Manufacture of Chemical Raw Material and Chemical Products	0.1349	0.3598	0.1015
Manufacture of Paper and Paper Products	0.1270	1.0000	0.0351
Manufacture and Processing of Non-ferrous Metals	0.1151	0.0418	0.0811
Processing of Petroleum, Coking, Processing of Nucleus Fuel	0.1129	0.1002	0.0317
Mining and Washing of Coal	0.0521	0.1779	0.2848
Manufacture of Textile	0.0396	0.3725	0.0067
Mining of Non-ferrous Metal Ores	0.0391	0.1612	0.7383
Manufacture of Beverage	0.0350	0.2018	0.0149
Manufacture of Chemical Fibre	0.0348	0.1536	0.0100
Mining and Processing of Non-metal Ores	0.0308	0.0331	0.0495
Manufacture of Foods	0.0297	0.1291	0.0096
Mining of Ferrous Metal Ores	0.0292	0.0482	0.6402
Processing of Food from Agricultural Products	0.0284	0.1926	0.0174
Processing of Timbers, Manufacture of Wood, Rattan, Palm and Straw Products	0.0211	0.0114	0.0037
Manufacture of Medicines	0.0206	0.1222	0.0057
Manufacture of Rubber	0.0132	0.0204	0.0027
Manufacture of General Purpose Machinery	0.0116	0.0094	0.0045
Mining of Other Ores N.E.C	0.0113	0.0000	0.0195
Production and Distribution of Gas	0.0112	0.0075	0.0022
Extraction of Petroleum and Natural Gas	0.0086	0.0261	0.0031
Manufacture of Special Purpose Machinery	0.0082	0.0107	0.0021
Manufacture of Metal Products	0.0075	0.0498	0.0038
Manufacture of Transport Equipment	0.0067	0.0189	0.0034
Manufacture of Plastic	0.0059	0.0053	0.0008
Manufacture of Leather, Fur, Feather and its Products	0.0043	0.0789	0.0012
Manufacture of Tobacco	0.0032	0.0054	0.0007
Manufacture of Textile Wearing Apparel, Footwear and Caps	0.0028	0.0237	0.0006
Manufacture of Artwork, Other Manufacture N.E.C	0.0026	0.0052	0.0006
Recycling and Disposal of Waste	0.0017	0.0034	0.0020
Manufacture of Electrical Machinery and Equipment	0.0013	0.0000	0.0003
Printing, Reproduction of Recording Media	0.0010	0.0038	0.0002
Manufacture of Furniture	0.0010	0.0051	0.0003
Production and Distribution of Water	0.0007	0.2383	0.0009
Manufacture of Measuring Instrument and Machinery for Cultural Activity and Office Work	0.0001	0.0126	0.0005
Manufacture of Communication, Computer and Other Electronic Equipment	0.0000	0.0305	0.0008
Manufacture of Articles for Culture, Education and Sport Activity	0.0000	0.0018	0.0000

3. METHODOLOGY

3.1 Complete decomposition technique

The residuals decomposition method of the complete decomposition technique is based on the principle of “jointly created and equally distributed” (Sun, 1998). For example, the target variable Z can be decomposed as Equation (6):

$$Z = \prod_{i=1}^{n} x_i \tag{6}$$

where X_i denotes the i^{th} factor of target variable Z, n denotes the number of factors. Z_t and Z_0 denote the target variable in year t and in base year, therefore, Z_t and Z_0 is the sum of X_{it} (i.e. $X_{it} = X_{i0} + \Delta X_i$) and X_{i0} , respectively. Then the change in target variable recorded in time t in comparison with their level in a base year t=0 can be expressed as follows:

$$\Delta Z = Z_t - Z_0 = \prod_{i=1}^{n} x_{it} - \prod_{i=1}^{n} x_{i0} = \prod_{i=1}^{n} (x_{i0} + \Delta x_i) - \prod_{i=1}^{n} x_{i0} \tag{7}$$

In this paper, n=5, thus ΔZ can be shown as Equation (8):

$$\Delta Z = Z_t - Z_0 = \prod_{i=1}^{5} x_{it} - \prod_{i=1}^{5} x_{i0} = \prod_{i=1}^{5} (x_{i0} + \Delta x_i) - \prod_{i=1}^{5} x_{i0} \tag{8}$$

From Equation (8), we can see that ΔZ can be divided into two parts. The first part is the first item, which reflects the change of ΔZ resulting from the individual factor change. This is also the only part of the traditional LMDI model. The second part is the rest and reflects the change caused by multiple factors.

According to the principle of the complete decomposition technique, the value in the second part should be assigned to each of the corresponding factors (Sun, 1998), and then we can obtain the contribution of each factor to the target variable, which is shown as Equation (9):

$$\begin{aligned} X_{i-effect} = & \sum_{i=1}^{5} \frac{Z_0}{x_{i0}} \cdot \Delta x_i + \frac{1}{2} \sum_{i \neq j} \frac{Z_0}{x_{i0} \cdot x_{j0}} \cdot \Delta x_i \cdot \Delta x_j \\ & + \frac{1}{3} \sum_{i \neq j \neq k} \frac{Z_0}{x_{i0} \cdot x_{j0} \cdot x_{k0}} \cdot \Delta x_i \cdot \Delta x_j \cdot \Delta x_k \\ & + \frac{1}{4} \sum_{i \neq j \neq k \neq m} \frac{Z_0}{x_{i0} \cdot x_{j0} \cdot x_{k0} \cdot x_{m0}} \cdot \Delta x_i \cdot \Delta x_j \cdot \Delta x_k \cdot \Delta x_m \\ & + \frac{1}{5} \sum_{i \neq j \neq k \neq m \neq r} \frac{Z_0}{x_{i0} \cdot x_{j0} \cdot x_{k0} \cdot x_{m0} \cdot x_{r0}} \cdot \Delta x_i \cdot \Delta x_j \cdot \Delta x_k \cdot \Delta x_m \cdot \Delta x_r \end{aligned} \tag{9}$$

In this paper, the target variable Z is CO_2 emission C_{kt}, thus, C_{kt} can be decomposed as follows:

$$C_{kt}=\sum_{j=1}^{5}C_{jkt}=\sum_{i=1}^{7}P_{kt}\frac{P_{ikt}}{P_{kt}}\cdot\frac{E_{ikt}}{P_{ikt}}\cdot\sum_{j=1}^{5}\frac{E_{jkt}}{E_{kt}}\cdot\frac{C_{jkt}}{E_{jkt}}=\sum_{i=1}^{7}P_{kt}\cdot PS_{ikt}\cdot EI_{ikt}\cdot\sum_{j=1}^{5}ES_{jkt}\cdot EF_{jkt} \tag{10}$$

where C_{kt} denotes the total CO_2 emission of *k* region in year *t*. It also can be expressed as the total CO_2 emission of *k* region resulting from the consumption of five types of energy. C_{jkt} is the total CO_2 emission of the j^{th} energy of *k* region in year *t*. PS_{ikt} reflects the output shares of sector *i* in *k* region (i.e. P_{ikt}) within the total industry output of *k* region (i.e. P_{kt}) in year *t*. EI_{ikt} reflects the change in the ratio of energy consumption of sector *i* in *k* region (i.e. E_{ikt}) to the total produced value of sector *i* in *k* region (i.e. P_{ikt}). ES_{jkt} reflects the change in the share of energy forms in the total energy consumption of the pollution-intensive industry in *k* region. EF_{jkt} is the CO_2 emission of industrial energy use in *k* region.

The change in CO_2 emission ΔC_{kt} during the period of [0, *t*] can be shown in Equation (11):

$$\begin{aligned}\Delta C_{kt}&=C_{kt}-C_{k0}\\&=\sum_i P_{kt}\cdot PS_{ikt}\cdot EI_{ikt}\cdot\sum_j ES_{jkt}\cdot EF_{jkt}-\sum_i P_{k0}\cdot PS_{ik0}\cdot EI_{ik0}\cdot\sum_j ES_{jk0}\cdot F_{jk0}\end{aligned} \tag{11}$$

Combing Equation (9), the changes in CO_2 emission ΔC_{kt} during the period of [0, *t*] can be decomposed into five parts as shown in Equation (12):

$$\Delta C_{kt}=P_{kt}^{eff}+PS_{kt}^{eff}+EI_{kt}^{eff}+ES_{kt}^{eff}+EF_{kt}^{eff} \tag{12}$$

where P_{kt}^{eff} is the industrial output effect, reflecting CO_2 emission changes of *k* region resulting from output changes in pollution-intensive industries; PS_{kt}^{eff} is the industrial structural effect, reflecting CO_2 emission changes of *k* region resulting from structural changes in pollution-intensive industries; EI_{kt}^{eff} is energy intensity effect, reflecting CO_2 emission changes of *k* region resulting from energy intensity; ES_{kt}^{eff} is energy structural effect, reflecting CO_2 emission changes of *k* region resulting from the changes of the energy structure in pollution-intensive industries; EF_{kt}^{eff} is energy source emission intensity effect, reflecting CO_2 emission changes of *k* region resulting from the changes of energy emission intensity in pollution-intensive industries.

The value of ΔC_{kt} in equation (12) is an absolute value (*kt* CO_2). In order to better reflect the change in carbon emissions, the absolute value can be converted into the relative value (%) which is shown as a percentage:

$$dM_{kt}=\frac{M_{kt}^{eff}\cdot dC_{k}}{C_{k0}} \tag{13}$$

Here $dC_{kt}=\frac{\Delta C_{kt}}{C_{k0}}$, $M_{kt}^{eff}=P_{kt}^{eff},PS_{kt}^{eff},EI_{kt}^{eff},ES_{kt}^{eff},EF_{kt}^{eff}$, respectively.

3.2 Decoupling analysis method

In reference to the definition given by Diakoulaki and Mandaraka (2007), the emission reduction is actually the result of all actions inducing a decline in the CO_2 emission of industrial production, such as optimizing the industrial structure, improving energy efficiency, and increasing the usage ratio of clean energy. These efforts correspond to the industrial structural effect PS_{kt}^{eff} , energy intensity effect EI_{kt}^{eff} , energy structure effect ES_{kt}^{eff} and energy source emission intensity effect EF_{kt}^{eff} . Therefore, for the government of region *k*, all the effort they made in year *t* (ΔF_{kt}) can be expressed as the sum of these four effect factors, that is:

$$\Delta F_{kt} = PS_{kt}^{eff} + EI_{kt}^{eff} + ES_{kt}^{eff} + EF_{kt}^{eff} \tag{14}$$

Generally, when talking about low-carbon economies, this refers to an economy which is in the decoupling process between economic growth and greenhouse gas emissions, that is, the growth speed of the economy is faster than that of the CO_2 emission intensity (Guo, 2010). According to the decoupling theory, the decoupling index is measured by the ratio of environmental pressures to economic driving forces such as economic activities (Diakoulaki & Mandaraka, 2007). The value of ΔF_{kt} may take a negative sign if the sum of these four factors resulting in emission reduction. Therefore, the decoupling index (D_{kt}) can be expressed as Equation (15):

$$\begin{aligned} D_{kt} &= \begin{cases} -\Delta F_{kt} / P_{kt}^{eff}, & P_{kt}^{eff} > 0 \\ (\Delta F_{kt} - P_{kt}^{eff}) / P_{kt}^{eff}, & P_{kt}^{eff} < 0 \end{cases} \\ &= D_{PS} + D_{EI} + D_{ES} + D_{EF} \end{aligned} \tag{15}$$

where D_{PS} indicates the industrial-structure decoupling index, D_{EI} indicates the energy-intensity decoupling index, D_{ES} is the energy-structure decoupling index, and D_{EF} reflects the energy-emissions-intensity decoupling index.

According to the above analysis, there are three values in this decoupling index D_{kt} :

a) If $D_{kt} \leq 0$, it reflects no decoupling efforts. That is to say, emission reduction policies miss the mark or the policies have no effect. So the CO_2 emission still increases fast alongside the development of the economy.

b) If $0 < D_{kt} < 1$, it means there is a weak decoupling efforts. This case suggests that the emission reduction policies have a certain effect, CO_2 emission is now slowing, but the reduction volume is less than the increase of emission caused by the development of the economy. Therefore, the total CO_2 emission is still increasing.

c) If $D_{kt} \geq 1$, it means there are strong decoupling efforts. It reflects that the emission reduction policies have an obvious effect in the reduction of CO_2 emission and lead to a larger volume reduction of CO_2 emission than the new growth resulting from the development of the economy.

3.3 Reduction potential

The above reflects the government's carbon emissions reduction efforts, but it cannot reflect the reduction potential of the CO_2 emissions of pollution-intensive industries.

The reduction potential is the likelihood that emissions can be reduced. Emission reduction potential of each region can be represented as follows:

$$I_k = (1 - \frac{CE_{\min}}{CE_k})*100 \tag{16}$$

where $CE_{\min}$ reflects the minimum of the carbon emission intensity among all samples; CE_k is the carbon emission intensity of the region k. Equation (16) implies that the carbon intensity of all areas will be close to the minimum value. The emission reduction potential of the lowest carbon emissions intensity of the region is zero, and the rest of the region varies from 0 to 100. The bigger the I, the bigger the emission reduction potential.

3.4 Data description

In this paper, the data comes from various issues of the statistical yearbook of provinces and cities. The industrial output was calculated at constant 2000 prices. Carbon emissions are the total emission of five energies used by seven high-pollution industries. Because the original data of energy consumption is in physical quantities, we convert the physical quantities to standard statistics firstly, and then use the standard coal consumption coefficient to calculate the total emission of each type of energy (*Table 2*). This method is more reasonable and accurate compared with the emission of end-use energy consumption. It needs every kind of energy consumption data of the seven pollution-intensive industries in regions, but the data in the statistical yearbook of some provinces is not complete. Therefore, this paper picks up fifteen typical provinces and cities as the subjects of study, including Beijing, Tianjin, Shanxi, Inner Mongolia, Liaoning, Jilin, Anhui, Fujian, Jiangxi, Henan, Hubei, Chongqing, Gansu, Ningxia and Xinjiang. The energy is composed of coal, coke, gasoline, diesel and electricity.

Table 2. The standard coal coefficient and carbon emissions coefficient of four energies

Energy	Standard coal coefficient (kgce/kg)	Carbon emission coefficient (tCO2/toe)	Energy	Standard coal Coefficient (kgce/kg)	Carbon emission coefficient (tCO2/toe)
Raw coal	0.7143	2.769	Gasoline	1.4714	2.029
Coke	0.971	3.314	Diesel	1.4571	2.168

The standard coal coefficient is referenced from "General principles for calculation of total production energy consumption" (GB/T2589-2008), and the carbon emission coefficient of energy, except electricity, is calculated in reference to the IPCC Carbon Emission Calculation Formula (2006 edition). The carbon emissions coefficient of electricity is not fixed because the power generation technology in cities and provinces is different. Therefore, we calculate the carbon emissions coefficient of electricity in reference to the method of Fu (2011). The standard coal coefficient and carbon emission coefficient of five energies are shown in *Table 2* and *Table 3*.

Table 3. Carbon emission coefficient of electricity in ten provinces and cities: 2000-2012 (tCO_2/toe)

	BJ	TJ	LN	JL	FJ	SX	NMG	HN
2000	7.04	7.54	7.85	6.67	3.97	8.3	8.06	8.33
2001	7.03	7.39	7.7	6.35	3.65	8.14	8.03	8.09
2002	7.00	7.39	7.72	6.79	4.42	8.11	7.99	7.99

2003	6.87	7.37	7.6	7.18	5.16	8.08	7.83	8.01
2004	7.01	7.28	7.49	6.87	5.76	7.98	7.47	8.71
2005	6.9	7.23	7.4	6.56	4.61	7.91	7.08	7.72
2006	6.66	7.19	7.42	6.99	4.55	7.63	7.51	7.44
2007	6.49	7.12	7.18	6.74	4.91	7.48	7.38	7.16
2008	6.21	7.16	6.98	6.4	4.78	7.14	7.24	6.89
2009	5.96	7.05	6.92	6.02	5.11	7.21	6.97	6.75
2010	5.79	6.83	6.5	5.52	4.43	7.02	6.63	6.66
2011	5.77	6.82	6.52	5.85	5.43	7.02	6.6	6.65
2012	5.35	6.75	6.17	5.59	4.5	6.85	6.43	6.37
	HB	AH	JX	CQ	GS	NX	XJ	
2000	4.07	7.71	6.35	6.77	4.72	7.45	8.28	
2001	4.44	7.62	6.26	6.91	5.04	7.57	7.73	
2002	4.54	7.48	6.1	6.54	5.44	7.56	7.64	
2003	4.13	7.93	6.98	6.42	5.93	7.34	7.91	
2004	2.97	7.53	7.04	6.27	5.48	7.27	8.00	
2005	2.85	7.44	6.8	6.31	5.03	7.3	8.27	
2006	3.29	7.41	6.28	6.67	5.17	7.26	8.12	
2007	2.87	7.2	6.49	5.99	5.07	7.16	7.63	
2008	2.3	6.98	6.11	5.4	4.93	6.98	7.53	
2009	2.51	6.8	6.16	5.42	4.5	6.84	7.34	
2010	2.68	6.72	5.93	5.31	4.81	6.7	6.81	
2011	3.11	6.77	6.32	5.52	4.76	6.8	6.96	
2012	2.62	6.56	5.44	2.44	4.73	6.52	6.47	

Data resource: China Electric Power Yearbook from 2001 to 2012

Abbreviation note: BJ: Beijing City, TJ: Tianjin City, SX: Shanxi Province, NMG: Inner Mongolia Autonomous Region, LN: Liaoning Province, JL: Jilin Province, AH: Anhui Province, FJ: Fujian Province, JX: Jiangxi Province, HN: Henan Province, HB: Hubei Province, QC: Chongqing City, GS: Gansu Province, NX: The Ningxia Hui Autonomous Region, and XJ: Xinjiang Uygur Autonomous Region.

The other data used in this paper are presented in *Table 4*-*Table 6*, below. Specifically, *Table 4* shows total energy consumption in high-pollution industries and the consumption ratio of five energies. It can be seen that during the period 2000-2012, coal, accounting for 76% of total energy consumption, is the principal energy in all regions. The total energy consumption in each region is rising, and the average growth rate is 310%. Among them, the highest growth rate of energy consumption is Xinjiang (729%), while the smallest one is Beijing (35%).

Table 4. Total energy consumption in high-pollution industries and the five energy consumption ratios for the years 2000-2012

Regions	Year	Raw coal	Coke	Gasoline	Diesel	Electricity	Total (10^7ktoe)
BJ	2000	36%	46%	1%	1%	16%	929
	2012	83%	0%	0%	1%	15%	1258
TJ	2000	48%	30%	1%	2%	19%	429
	2012	32%	46%	0%	1%	21%	1815
SX	2000	85%	11%	0%	0%	4%	8224
	2012	82%	12%	0%	0%	6%	22567
NMG	2000	86%	7%	0%	1%	6%	3165
	2012	86%	6%	0%	0%	8%	23295
LN	2000	79%	13%	0%	0%	7%	6223
	2012	69%	21%	0%	1%	9%	14573

JL	2000	84%	7%	0%	0%	8%	2141
	2012	83%	10%	0%	0%	7%	6192
AH	2000	82%	11%	0%	0%	6%	2069
	2012	82%	10%	0%	0%	8%	9461
FJ	2000	82%	6%	0%	2%	10%	1338
	2012	77%	9%	0%	1%	13%	5879
JX	2000	71%	16%	0%	1%	13%	1268
	2012	69%	20%	0%	0%	11%	4281
HN	2000	85%	7%	0%	0%	8%	5166
	2012	89%	0%	0%	0%	11%	16483
HB	2000	83%	0%	0%	1%	16%	2048
	2012	83%	0%	0%	0%	17%	5936
CQ	2000	75%	14%	0%	0%	10%	955
	2012	71%	11%	0%	1%	17%	2503
GS	2000	73%	12%	0%	0%	14%	1426
	2012	72%	12%	0%	0%	16%	5401
NX	2000	80%	5%	0%	0%	15%	719
	2012	84%	2%	0%	0%	14%	5317
XJ	2000	87%	5%	1%	1%	6%	1103
	2012	79%	10%	0%	0%	11%	9148

Table 5 denotes total output in high-pollution industries and the share of sub-sectors. The growth rate of output in high-pollution industries presents significant differences in both their reference values in 2000, as well as in their development with time. The maximum growth rate is Shanxi with a rate of 2300%, while the minimum one is Beijing with a rate of 214%. For most regions, Chemical, ferrous metals and electric and heat power are the main sectors which account for more than 50% in output, but the new increasing areas of the economy in some regions have transformed chemical to non-metals and non-ferrous metals during the period 2000-2012.

Table 6 presents the energy intensities of the high-pollution industries and of seven sub-sectors calculated based on the data of *Table 4* and *Table 5*. With the exception of Xinjiang and Ningxia having increased energy intensity, all other regions present a decreasing trend. The maximum energy intensity is Shanxi, although it has decreased 88.9% from 2000 to 2012. The minimum one is Tianjin. At a sector level, the maximum sector is electric and heat power, which is larger than other sub-sectors, followed by petroleum, non-metals, ferrous metals, chemical and paper, and the minimum is non-ferrous metals, but the gap between sectors is small.

Table 5. Total output in high pollution industries and the share of sub-sectors for the years 2000-2012

Region	Year	Paper	Petroleum	Chemical	Non-metallic	Ferrous	Non-ferrous	Electric	Total
BJ	2000	2%	34%	17%	12%	23%	1%	10%	768
	2012	1%	18%	7%	9%	3%	2%	60%	2416
TJ	2000	4%	19%	28%	6%	29%	6%	9%	705
	2012	3%	3%	17%	4%	53%	10%	10%	4935
SX	2000	1%	12%	15%	8%	32%	13%	20%	129
	2012	0%	20%	9%	5%	37%	7%	22%	3096
NMG	2000	2%	7%	11%	6%	37%	9%	27%	377
	2012	1%	6%	17%	9%	22%	21%	23%	3909
LN	2000	1%	33%	15%	9%	24%	6%	12%	2073
	2012	2%	23%	15%	18%	28%	6%	9%	9896
JL	2000	3%	7%	48%	9%	13%	3%	16%	555
	2012	3%	4%	31%	27%	17%	3%	16%	3245
AH	2000	4%	15%	20%	14%	19%	13%	17%	578
	2012	3%	4%	17%	17%	21%	16%	23%	3613
FJ	2000	12%	13%	15%	20%	11%	6%	24%	701
	2012	9%	9%	13%	23%	19%	9%	19%	3739
JX	2000	3%	19%	13%	12%	18%	17%	17%	401

	2012	2%	3%	9%	9%	6%	21%	48%	2932
HN	2000	7%	10%	16%	22%	10%	12%	23%	1381
	2012	5%	6%	14%	27%	15%	19%	14%	7370
HB	2000	5%	16%	19%	16%	23%	6%	16%	1034
	2012	4%	6%	24%	17%	26%	8%	15%	5418
CQ	2000	3%	1%	27%	19%	20%	11%	18%	273
	2012	5%	2%	21%	20%	20%	14%	17%	1936
GS	2000	1%	22%	15%	8%	10%	25%	19%	519
	2012	0%	26%	8%	7%	18%	25%	16%	2349
NX	2000	6%	4%	31%	6%	8%	23%	21%	133
	2012	2%	22%	13%	6%	11%	18%	29%	727
XJ	2000	2%	53%	6%	10%	11%	4%	13%	292
	2012	1%	41%	12%	8%	15%	11%	16%	1242

Abbreviation notes: Paper: Manufacture of Paper and Paper Products; Petroleum: Processing of Petroleum, Coking, Processing of Nucleus Fuel; Chemical: Manufacture of Chemical Raw Material and Chemical Products; Non-metallic: Manufacture of Non-metallic Mineral Products; Ferrous: Manufacture and Processing of Ferrous Metals; Non-ferrous: Manufacture and Processing of Non-ferrous Metals; Electric: Production and Supply of Electric Power and Heat Power. Total: the total of all high pollution industries.

Table 6. Energy intensities in high pollution industries and in seven sub-sectors for the years 2000-2012

Region	Year	Paper	Petroleum	Chemical	Non-metallic	Ferrous	Non-ferrous	Electric	Total
BJ	2000	0.5	0.1	0.4	2.1	3.2	0.2	0.7	1.2
	2012	0.2	0.0	0.2	0.1	0.1	0.0	0.3	0.5
TJ	2000	0.6	0.1	0.6	1.2	1.1	0.4	0.1	0.6
	2012	0.2	0.0	0.2	0.2	0.4	0.0	0.1	0.3
SX	2000	10.3	43.2	7.8	8.9	5.7	1.6	17.2	63.8
	2012	0.9	5.8	2.0	1.6	1.7	1.6	5.2	7.1
NMG	2000	2.1	7.4	6.0	5.6	3.7	1.5	19.8	8.4
	2012	0.2	4.8	1.7	2.1	1.4	0.3	8.3	5.7
LN	2000	2.8	0.3	1.0	2.3	4.6	1.1	11.0	3.0
	2012	0.2	0.1	0.2	0.4	1.1	0.2	3.3	1.5
JL	2000	3.2	0.1	0.4	3.0	2.3	1.5	17.6	3.9
	2012	0.5	0.1	0.2	0.6	1.0	0.4	5.0	1.7
AH	2000	1.3	0.9	2.1	3.5	3.3	0.4	11.1	3.6
	2012	0.3	0.1	0.5	0.9	0.7	0.0	2.6	2.4
FJ	2000	0.8	0.0	2.0	1.7	1.6	0.3	4.1	1.9
	2012	0.2	0.0	0.3	0.5	0.6	0.1	2.0	1.6
JX	2000	2.7	0.4	2.3	5.1	3.5	0.6	7.9	3.2
	2012	0.2	0.0	0.1	4.1	1.0	0.0	0.2	1.6
HN	2000	1.4	1.3	3.2	2.4	3.0	1.6	8.5	3.7
	2012	0.3	2.0	0.5	0.2	0.2	0.2	3.3	2.2
HB	2000	0.8	0.0	1.9	2.2	1.0	0.7	6.2	2.0
	2012	0.2	0.0	0.5	0.5	0.2	0.1	1.5	1.2
CQ	2000	1.0	0.8	1.4	4.4	2.6	0.4	9.1	3.5
	2012	0.5	1.0	0.5	0.7	0.6	0.2	1.7	1.4
GS	2000	1.5	0.2	1.9	3.6	5.6	1.6	6.1	2.7
	2012	0.7	0.1	1.0	1.5	1.5	0.6	3.5	2.2
NX	2000	2.8	3.6	3.3	6.4	5.1	1.3	13.8	5.4
	2012	2.1	1.1	2.1	1.7	1.2	0.9	6.0	7.4
XJ	2000	3.4	1.0	2.1	5.9	2.7	1.2	16.1	3.8
	2012	1.2	1.1	2.4	1.9	1.8	0.9	6.2	6.0

4. RESULTS AND DISCUSSION

4.1 Analysis of energy-related CO_2 emissions from high-pollution industrial sectors

The direct (due to fuel consumption) and indirect (because of industrial electricity consumption) contribution of CO_2 emissions of the high-pollution industrial sectors in China's industrial sectors rose between 2000 and 2012 from 82.86% to 87.53% (*Figure 1*). In 2000, the amount of carbon emissions of polluting industries exceeded 100 million tons in Liaoning and Shanxi, Tianjin is the smallest with only 8.72 million tons. But in 2012, there are nine provinces, the two largest regions are Inner Mongolia and Shanxi, reaching up to 455 million tons and 444 million tons, respectively, followed by Liaoning, 307 million tons, and Beijing, the smallest with only 22.16 million tons. CO_2 emissions of the 15 regions increased, the fastest growth rate is in Xinjiang (713%), while the growth rate of Beijing is only 6.5%. The reasons explaining these changes in energy-related CO_2 emissions will be investigated through the complete decomposition analysis presented in the following section.

Figure 1. Energy-related CO_2 emissions from high-pollution industrial sectors (ten thousand ton)

4.2 Decomposition of changes in CO_2 emissions in high-pollution industrial sectors

As can be seen from *Table 7*, each driving factor has a different impact on CO_2 emissions in these fifteen regions. The main factors are the industrial output effect (P_{kt}^{eff}) and energy intensity effect (EI_{kt}^{eff}), followed by the industry structural effect (PS_{kt}^{eff}), while the energy structural effect (ES_{kt}^{eff}) and energy emission intensity effect (EF_{kt}^{eff}) make a small contribution to CO_2 emission. Furthermore, industrial output effect is a constant positive, which not only means that the industrial output effect results in the continual increase of energy-related CO_2 emissions over the period 2000-2012, but also indicates that energy saving and emission reduction in high-pollution industries may pay a price by enacting output growth deceleration. The energy intensity effect in most regions is negative in most years over the period 2000-2012, indicating that energy intensity effect plays a key role in decreasing the regional CO_2 emissions. With the exception of a few regions having positive effects, the industry structural effect mainly plays a negative role, indicating that the optimization of the industrial structure has a negative impact on the increase of emissions. The energy structure effect is unbalanced, which is related to endowment elements that vary in regions.

Although the whole energy consumption relative to GDP drops obviously, China's coal-dominated energy structure have not changed drastically. In addition, we can also see that energy emission intensity mainly contributes negatively to CO_2 emission, but in some areas shows positive effects. It is worth mentioning that although the energy structure effect makes a small contribution to CO_2 emission, if China cannot gradually reduce the proportion of coal consumption, the negative effect brought on by the energy intensity effect would be offset by the positive effect brought on by the energy structure effect.

Table 7. The components of the complete decomposition analysis

Region	Year	P_{kt}^{eff}	PS_{kt}^{eff}	EI_{kt}^{eff}	ES_{kt}^{eff}	EF_{kt}^{eff}	ΔC_{kt}
BJ	2000-2006	1155.8	169.0	-716.5	-378.8	-56.7	172.8
	2006-2012	725.4	175.2	-877.9	215.0	-196.7	41.0
TJ	2000-2006	994.1	146.3	-228.7	43.8	-47.9	907.6
	2006-2012	1678.7	194.2	-1077.6	133.8	-86.9	842.2
SX	2000-2006	5406.0	1134.7	-6329.3	85.3	-190.3	106.4
	2006-2012	12357.2	225.9	-5531.8	1810.3	-602.9	8258.6
NMG	2000-2006	6321.8	-97.6	-2321.7	1027.5	-244.7	4685.3
	2006-2012	9849.3	-1547.3	-2551.7	230.3	-856.1	5124.4
LN	2000-2006	4204.7	654.9	-924.2	65.5	-200.0	3801.0
	2006-2012	5139.2	-1509.2	-1098.2	350.5	-657.5	2224.9
JL	2000-2006	1956.8	625.4	-886.2	-390.2	60.2	1366.1
	2006-2012	2769.8	-835.2	-1967.3	92.5	-279.7	-219.8
AH	2000-2006	1042.7	59.8	529.2	-1051.7	4.1	584.1
	2006-2012	2832.7	542.3	-3593.3	1643.2	-242.9	1182.1
	2000-2012	3689.3	1462.2	-2853.9	581.5	-718.5	2160.4
FJ	2000-2006	1256.4	177.1	-431.9	168.5	124.8	1294.9
	2006-2012	1858.8	-572.5	-201.7	78.8	-13.2	1150.2
JX	2000-2006	1131.4	-126.9	-302.0	-205.1	-260.12	491.3
	2006-2012	2970.3	3520.94	-1207.51	175.23	3.3	-4612.5
HN	2000-2006	5026.9	-652.8	-995.1	503.6	-453.4	3429.2
	2006-2012	4473.8	-2249.3	-805.7	495.7	-598.2	1316.3
HB	2000-2006	1788.6	188.4	-573.2	-414.4	-279.3	710.1
	2006-2012	1767.0	-412.6	-2209.6	316.1	-213.5	-752.7
CQ	2000-2006	959.8	-60.0	-435.2	147.4	-12.1	599.9
	2006-2012	1356.4	-31.7	-681.9	250.4	-366.9	526.2
GS	2000-2006	1339.7	-555.3	-192.8	-24.0	115.1	682.7
	2006-2012	2117.8	516.4	-980.2	227.1	-192.4	1688.6
NX	2000-2006	1309.8	13.9	-587.5	99.3	-35.3	800.2
	2006-2012	1739.6	-4.2	-24.9	-191.9	-192.9	1325.8
XJ	2000-2006	997.6	-155.9	150.5	-88.5	-21.2	882.5
	2006-2012	1639.3	336.6	-236.3	100.6	-418.0	1422.1

The impact of each single factor is illustrated in the following remarks.

Industrial output effect (see Figure 2): the output effect is the critical driving factor in the growth of energy-related CO_2 emissions influencing carbon emissions changes, reflecting the corresponding growth of industrial output in 15 regions. In most regions, the contribution amounts to 60%-70%. Tianjin shows the highest impact (180.8%), followed by Inner Mongolia and Ningxia. Among the leading industries contributing to the rise in the industrial output, chemical, ferrous metals, and the electric industry are predominant in these regions (see *Table 5*). The output of these three sub-sectors averagely amount to about 60% of the high pollution industries. Among them, ferrous metals and the electric industry are the largest energy consumers of the seven sub-sectors. Conversely, Liaoning and Anhui present the lowest influence in accordance with the declining role of high pollution industries in their economies.

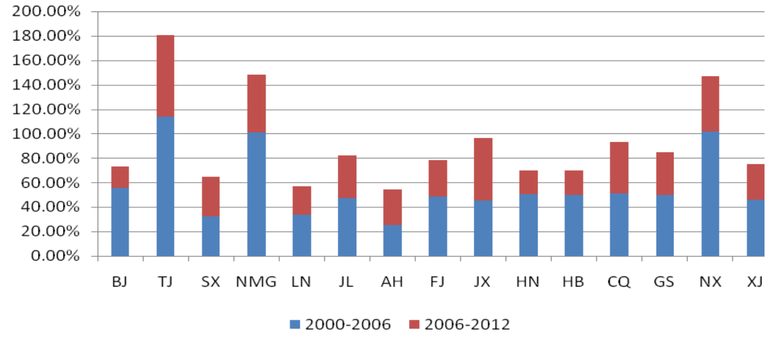

Figure 2. Percent change in pollution-intensive industrial CO_2 emissions due to the output effect

Industrial structure effect (*Figure 3*): From the perspective of absolute amount, in the period 2000-2012, the industrial structure effect mainly has a positive effect in Jiangxi and Tianjin, in that the share of high CO_2 emission industries such as ferrous metal, electric and other industries are growing rapidly, leading to the rapid growth of CO_2 emissions. Unfortunately, no dramatic changes take place in typical regions toward the reduction in number of the energy intensive sectors. Although Inner Mongolia, Henan and Chongqing present a negative industrial structure effect, it does not show great shifts in regional industrial activities, but a slight decline of energy intensive sectors. Simultaneously, the proportion of low CO_2 emissions industries in these regions is increasing. Industrial structure, therefore, helps to reduce CO_2 emissions and plays a negative effect. Tianjin, Beijing, Anhui and Shanxi show an opposite trend with the rapid growth of its heavy industries, thus acquiring its overall industrial development.

Energy intensity effect (*Figure 4*): the energy intensity effect also plays a key role in inhibiting carbon emissions increase. Results show that in 15 regions, energy efficiency improvements are higher in the seven energy intensive industries than other industries, especially in the ferrous metals and chemical industries. Tianjin, Beijing, Shanxi and Inner Mongolia have great absolute amounts of this effect, and the energy intensities of these regions show a sharp drop of about 70%, 52%, 51% and 49%, respectively. The only exception toward improving energy efficiency is recorded in Xinjiang, exhibiting energy intensity increase, especially in the ferrous metals, electric and chemical industries.

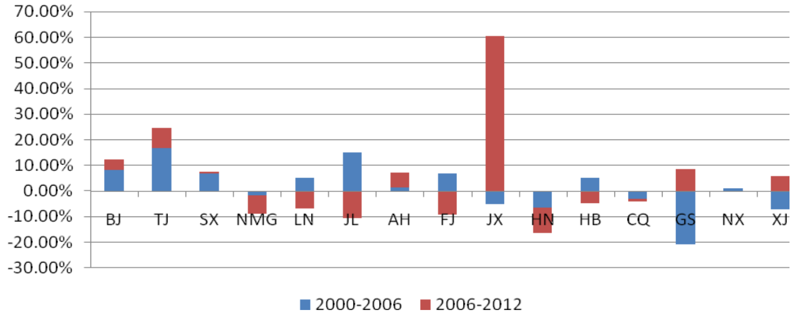

Figure 3. Percent change in pollution-intensive industrial CO_2 emissions due to the industrial structure effect

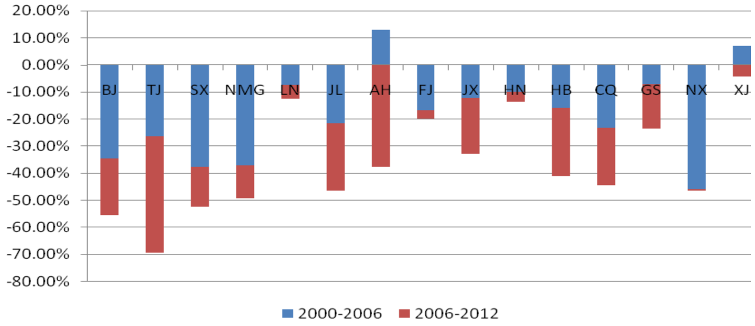

Figure 4. Percent change in pollution-intensive industrial CO_2 emissions due to the energy intensity effect

Energy structural effects (*Figure 5*): this effect is generally less than 10%. It is dominated by the energy consumption structure of China, and it reflects that China’s fuel switching from coal and oil to natural gas is not obvious, the primary energy type of consumption is still coal. The energy structure in Tianjin, Inner Mongolia and Chongqing, plays a significant positive role, indicating that the adjustment of energy in these areas promotes the carbon emissions increase. The energy structure in Beijing, Anhui, Jilin and Hubei, shows a negative effect. In addition to a positive shift from coal and oil towards natural gas, they further increase the use of biomass and of combined electricity in energy intensive industries.

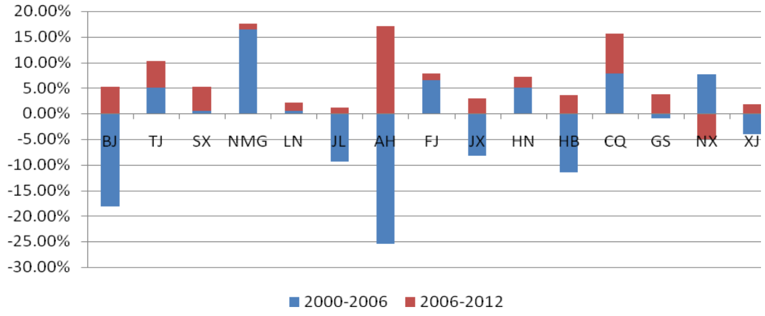

Figure 5. Percent change in pollution-intensive industrial CO_2 emissions due to the energy structure effect

Energy emission intensity effect (*Figure 6*): the effect of energy emissions intensity on carbon emissions is relatively small and negative as a whole, showing that the effect of energy emission intensity on carbon emissions plays a slightly inhibitory role in most regions. It reflects that the gradual implementations of energy-saving policies improve the energy efficiency and decrease the energy intensity in most regions with growing shares of natural gas or renewable energies. Fujian province is the only area showing a rising effect.

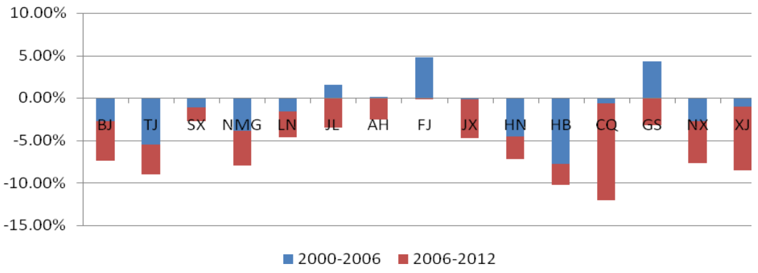

Figure 6. Percent change in pollution-intensive industrial CO_2 emissions due to the energy emission intensity effect

4.3 Analysis of reduction efforts

Figure 7 presents the emission reduction efforts made during the period 2000-2006 and 2006-2012. It can be observed that the emission reduction measures of 15 regions are basically effective in two periods. The top three are Beijing, Tianjin and Fujian. In the period 2006-2012, their efforts lead to a total emission reduction of about 17%-39%. In the other twelve areas the respective percentage is below 10%. Among them, Shanxi's reduction effort lead to an accumulated decrease of 17093.6×10^4 ton (i.e. -3.8%) CO_2 emissions during the period 2000-2012.

It should be noted that this does not mean the efforts in the 15 areas are sufficient. In Beijing, the efforts made in the period 2006-2012 have compensated for a small part of the negative changes of the others. On the one hand, that might be the reason that the marginal cost of further reducing energy intensity or of increasing the share of cleaner energy forms for Beijing's fuel mix is high. On the other hand, in this period, not all the energy intensity of pollution-intensive industries declined in Beijing. The growth rate of the oil industry and electricity industry reached 127% and 63%, respectively, which makes the overall energy intensity fail to curb the increase of carbon emissions.

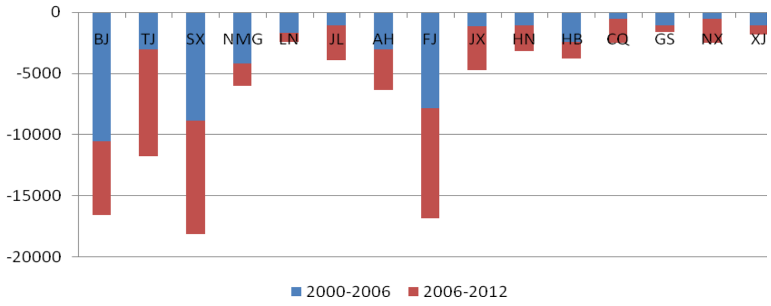

Figure 7. Absolute change in pollution-intensive industrial CO_2 emissions associated with emission reduction effort

Figures 1 to *7* reveal significant points. For example, Beijing, despite its impressive efforts, failed to decrease carbon emissions below the 2000 level, conversely emissions exhibited an increase of 13%. Similarly, with a total increase of 140%, Tianjin showed great initiatives in promoting CO_2 emission reduction measures. This indicates that we cannot assess the effort of government's performance only based on the change of the amount of CO_2 emissions.

4.4 Analysis of decoupling index

Figures 8 and *9* show the decoupling index calculated for the 15 regions under consideration, together with the distribution of four efforts. It indicates that among the four decoupling indexes, the biggest contributor to the total decoupling index is energy intensity, followed by industry structure and energy structure, while energy emission intensity is the smallest contributor.

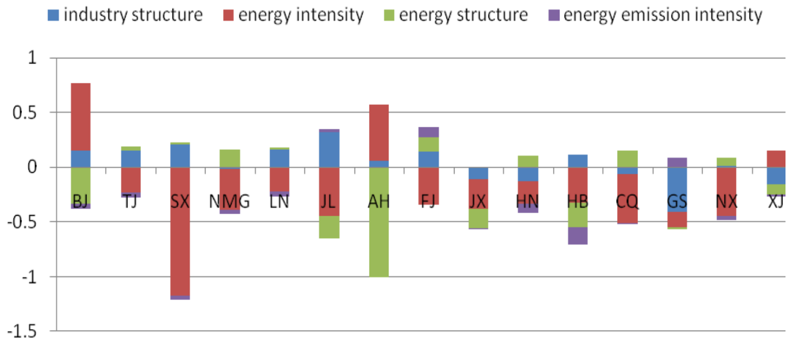

Figure 8. The decoupling index of high pollution industries of 15 regions in the period 2000-2006

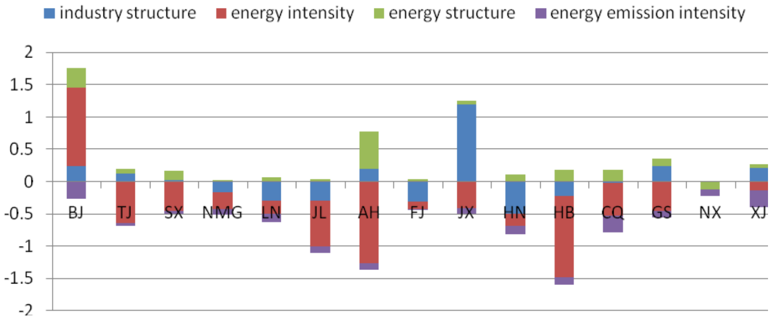

Figure 9. The decoupling index of high pollution industries of 15 regions in the period 2006-2012

According to the decoupling index, in the period 2006-2012, the 15 regions can be divided into three categories:

Regions with a strong decoupling index ($D>1$), including Beijing: The decoupling index of Beijing's pollution-intensive industries has changed from 0.39 in the period 2000-2006 to 1.48 in the period 2006-2012. From *Figures 1* and *7*, we find that the regions with a strong decoupling index is mainly due to the larger decoupling index of energy intensity, indicating that carbon emission reductions due to energy intensity reduction are greater than the increase resulting from industrial growth. At the same time, among the

15 regions, Beijing presents a low and positive industrial output effect, which indicates that its decoupling procession goes along with the stabilization of energy-intensive industries' production and with shifts toward other sectors. Of course, the fuel switches in utilities in Beijing is also a very important cause.

Regions with a weak decoupling effect ($0<D<1$), including Jiangxi, indicate that carbon emission reductions owing to government efforts in their pollution-intensive industries have compensated for a large part of the increases caused by industrial growth. Energy intensity is still the decisive factor to make Jiangxi weak in decoupling, while other factors play a minor role. The industrial structure of Jiangxi plays a negative role in the total decoupling index because the ratio of high pollution industry output to regional output increased during 2000-2012, thus making carbon emissions increased.

Regions with no decoupling effect ($D<0$) included all regions except Beijing and Jiangxi. Results show that in most regions the carbon emissions reduction measures failed to inhibit the increase of carbon emissions and the industrial output effect on carbon emissions played a positive and dominant role. In fact, the emission reduction measures of these regions are basically effective, but it does not suffice.

4.5 Analysis of reduction potential

The above reflects the government's carbon emissions reduction efforts. The results can be used to determine policy priorities for improving the decoupling effectiveness in 15 regions. For example, for regions with no decoupling effect, the possibilities to further reduce energy intensities should be reconsidered. Although most of the 15 regions present no decoupling effect, most governments show great enthusiasm in promoting CO_2 emission reduction. So, what can the reduction potential of CO_2 emissions for the pollution-intensive industries be?

Table 8 shows the carbon emission intensity of 15 regions. In the period 2000-2012, the carbon emissions intensity of Tianjin is the minimum, namely, Tianjin will serve as a target region, and the carbon emissions intensity of other regions will gradually converge to Tianjin. The results in descending order are listed in *Table 9*.

Table 8. The carbon emissions intensity of pollution-intensive industries in the period 2000-2012

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
BJ	2.7	2.5	3.5	3.3	3.3	3.3	2.8	2.5	2.1	1.9	1.1	1	0.9	2.4
TJ	1.2	1.4	1.2	1.7	0.8	1.2	1.4	1.4	1.2	1.2	0.9	0.8	0.8	1.2
SX	25.4	28.0	31.4	30.9	26.8	25.4	24.3	22.7	19.7	19	17.2	16	14.7	23.2
NMG	16.6	15.8	17.3	17.1	17.9	17.7	16.1	14.9	14.3	12.5	11.2	12.5	11.4	15
LN	6.1	5.6	5.5	5.9	5.7	5.5	5.1	4.7	4	3.5	3.7	3.4	3.1	4.8
JL	7.4	6.9	6.9	6.7	5.8	7.1	6.7	5.5	5.5	4.8	4.5	3.9	3.8	5.8
AH	7.2	8.2	7.2	8.6	8.9	7.8	7.5	7.2	7.1	6.7	6	5.5	5.1	7.2
FJ	3.7	3.5	3.8	3.3	4.6	4.1	4	4.2	3.9	3.7	3.2	3.4	2.9	3.7
JX	6.2	5.7	5.4	6.1	6.6	5.7	5.5	5.1	4.4	4	3.7	3.6	2.9	5
HN	7.2	7.1	6.6	6.4	7.6	7	6.9	6.5	5.8	5.1	4.7	4.4	4	6.1
HB	3.5	3.3	3.5	3.5	3.8	4.6	4.2	3.4	2.8	2.6	2.4	2.2	1.9	3.2
CQ	6.9	6.3	5.8	5.8	5.1	4.9	5	4.8	4	3.6	3.1	3.1	2.4	4.7
GS	5.2	2.2	5.0	5.2	6.2	6	5.6	5.5	5.3	4.5	4.6	4.6	4.2	4.9

NX	9.7	9.0	9.8	9.5	12.8	12.1	12.1	12.3	10.8	10.9	12.3	14.9	12.9	11.5
XJ	7.4	7.0	7.6	7.7	8.6	8.7	10	10.6	11	12.6	13.4	14.8	15.9	10.4
Total	6.3	5.9	6.0	6.4	7	7.2	7.2	6.9	6.6	6.4	6	6.1	5.8	6.4

Results show that in addition to Tianjin, emission reduction potentials of other areas are greater than 50, indicating that the energy efficiency of pollution-intensive industries in most areas is low. In general, the carbon emissions intensity has a close relationship with energy efficiency, namely, high energy efficiency means low carbon emissions intensity. Therefore, excepting Tianjin, the 14 regions with low energy efficiency have great energy-saving potential in future.

Table 9. The carbon emissions potential of pollution-intensive industries in the period 2000-2012

Region	Potential	Ranking	Region	Potential	Ranking	Region	Potential	Ranking
SX	94.98	1	Total	81.91	6	LN	75.53	11
NMG	92.25	2	HN	80.96	7	CQ	75.09	12
NX	89.84	3	JL	79.94	8	FJ	68.65	13
XJ	88.83	4	JX	76.65	9	HB	63.71	14
AH	83.74	5	GS	76.41	10	BJ	50.88	15

Although all regions have a large emissions reduction potential, the potentials are varied and there exist large gaps. Shanxi, with the greatest reduction potential, reaches up to 94.98, and the larger five main areas are Inner Mongolia, Ningxia, Xinjiang, Anhui and Henan, all above 80. The emission reduction potential of Beijing is relatively low. Due to the limitation of marginal cost and technical factors, further emission reduction in Beijing is more difficult than areas with high carbon emission intensity.

In general, the reduction potentials of the eastern area rank relatively far down the list, are small and are below the national average, such as Beijing, Tianjin and Fujian, while the central and eastern areas show great reduction potential, such as Shanxi, Inner Mongolia, Ningxia, Xinjiang and other regions. Moreover, in the eastern area, the emission reduction potentials of Jilin and Liaoning are relatively higher than other regions of this area. It is because these two regions are the representatives of the old industrial bases and the heavy industry output makes up a large proportion of total output. The emission reduction potentials of the western areas of Chongqing rank down the list probably in that the energy intensity is low and continues to decline, thus gradually improving the energy efficiency.

The regional reduction potentials of seven industries are shown in *Table 10*, including the rankings in the brackets. From *Table 10*, we know that the minimum of industrial carbon intensity concentrates on Beijing, Tianjin and Hubei, indicating that the energy use efficiency and output efficiency of these areas are relatively high. However, the reduction potentials of seven industries in Shanxi, Inner Mongolia, Henan, Ningxia, Xinjiang and other areas are relatively large. These areas are abundant in natural resources, lack energy savings and emission reduction motivation and have low energy efficiency. In addition, there are significant regional differences between the chemical and non-ferrous industries in reduction potential. Xinjiang (96.4) has the largest emission reduction potential in the chemical industry, the lowest, Tianjin, only 8.6. Shanxi (95.4) has the largest emission reduction potential in the non-ferrous industry, the lowest, Tianjin, only 13. However, the regional differences between the ferrous industry and electric industry is minor, especially in the electric industry where the emission reduction potentials of all regions are more than 97, indicating low energy efficiency in this industry. The reason is that more than 70% of power production is supplied by coal power generation with poor power generation technology and a small proportion of the use of clean energy generation, leading to low energy use efficiency and large emission reduction potential.

Comparing the industrial emission reduction potential with the national level, we found that the emission reduction potentials of the petroleum, ferrous and electric industries are basically higher than the national level.

Table 10. The regional emissions reduction potential of pollution-intensive industries and ranking in the period 2000-2012

Region	Paper	Petroleum	Chemical	Non-metallic	Ferrous	Non-ferrous	Electric
BJ	1.7(15)	71.4(13)	0	31.7(15)	73.6(14)	0	97.3(14)
TJ	0	38.4(14)	8.6(15)	0	62.2(15)	13.0(15)	0
SX	89.9(1)	99.9(1)	95.3(2)	83.44(1)	93.4(1)	95.4(1)	99.1(4)
NMG	79.2(6)	99.7(3)	95.2(3)	83.38(3)	84.8(8)	93.9(2)	99.2(3)
LN	81.2(4)	89.5(10)	65.5(13)	55.4(11)	87.5(5)	81.3(6)	98.3(8)
JL	79.5(5)	78.3(12)	27.9(14)	74.7(6)	81.9(11)	85.1(8)	98.9(5)
AH	69.5(9)	84.0(11)	85.8(7)	79.16(5)	86.1(7)	40.2(12)	98.8(6)
FJ	42.0(14)	10.2(15)	79.6(8)	49.5(13)	77.0(12)	33.6(14)	96.9(15)
JX	68.2(10)	92.3(9)	75.9(10)	73.9(7)	86.2(6)	62.8(11)	98.0(10)
HN	70.6(8)	99.1(5)	87.7(5)	41.8(14)	84.6(9)	93.5(3)	98.1(9)
HB	48.3(13)	0	86.1(6)	50.4(12)	0	76.2(10)	97.5(13)
CQ	74.5(7)	99.2(4)	70.7(12)	67.1(9)	74.6(13)	43.4(13)	97.9(11)
GS	68.1(11)	93.6(8)	74.8(11)	72.9(8)	91.9(3)	86.1(5)	97.8(12)
NX	88.7(2)	99.8(2)	89.4(4)	83.39(2)	84.5(10)	83.1(9)	99.3(2)
XJ	86.1(3)	98.9(6)	96.4(1)	82.5(4)	93.3(2)	91.7(4)	99.4(1)
Total	59.2(12)	98.8(7)	77.6(9)	57.0(10)	88.3(4)	85.2(7)	98.5(7)

5. CONCLUSIONS

This paper focuses on the pollution-intensive industries and examines energy related to CO_2 emissions in 15 regions in China. The sample time period starts in 2000, just before China entered the World Trade Organization (WTO), and ends in 2012, so, all necessary data are available. The year 2006 is a turning point to assess whether the emission reduction measures affect emission trends and their key factors.

In fact, the CO_2 emissions in most areas of China continue their upward trend. The complete decomposition analysis tries to explain this trend. At the same time, in order to comparatively assess the effectiveness of areas in reducing CO_2 emissions in terms of various measures, this paper also focuses on their ability and degree in decoupling industrial growth from their upward trend in CO_2 emissions. Finally, this paper assesses the reduction potential of CO_2 emissions in pollution-intensive industries to end the analysis.

According to the analysis of driving factors and the decoupling index above, we know that the largest driving factors of carbon emissions are the industrial output effect and energy intensity effect, thus the emission reduction efforts should focus on these two aspects. Energy intensity decreases can be effective in reducing carbon emissions through improving energy efficiency, strengthening technological innovation, increasing investment on advanced energy saving technology R&D and learning from other regions with lower energy intensity to improve their energy efficiency.

The industrial output effect shows that industry development will inevitably lead to carbon emissions increase, and finding a balance between industrial development and carbon emissions becomes a key point in energy saving in the case of industry development. Although the governments in each region have taken efforts to reduce carbon emission, the effectiveness of emission reduction has regional differences, and not all efforts are effective.

The energy structure and energy emission intensity basically play a negative role in the total decoupling index, which goes along with carbon reduction measures, thus it is necessary to optimize energy structure and energy emission intensity. Energy structural optimization can be done by reducing fossil energy consumption and increasing clean energy consumption; China has abundant hydropower, wind energy, solar energy in clean energy endowment, while the technology of use and development is not mature, thus the premise of completing emission reduction targets is to improve technology. Moreover, in this paper we only consider five types of energy which are of high carbon emission intensity and cannot reflect regional energy structure optimization. All the energy emission intensities are fixed, except electricity, and optimizing the energy emission intensity can lower the energy emission intensity of electricity, which can be done by improving power generation technology and increasing clean power generation.

The output of high pollution industries occupies a certain proportion in regional total output. Therefore, changing development mode, adjusting industrial structure and upgrading industry may be helpful to carbon emission reductions. The output ratio and energy intensity are large in electric, ferrous metals and chemical industries, thus the focal point of industry development transition and industrial structure adjustment should be put on these three sub-sectors.

Most of the regions, including Beijing, have great energy-saving and emission-reduction potential. Therefore, the optimization and adjustment of high energy consuming and high polluting industries is the key to energy conservation and emission reduction.

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