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Performance and decomposition analyses of carbon emissions from industrial energy consumption in Tianjin, China

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ABSTRACT

Rapid economic development of industrial cities has led to a significant increase in energy consumption and carbon emissions in China. Through the log-mean Divisia index decomposition method and the cluster analysis method, this paper provides a systematic method to (1) analyze the time series of carbon emissions from the energy consumption of the industrial sector in a city; (2) explore the main factors affecting carbon emissions; and (3) divide industries in a city into different types and analyze combination features of "emissions–efficiency". Finally, this paper takes Tianjin as an example, and studies the emissions characteristics of Tianjin. Results show that high-emission and low-efficiency industries play important roles in the development and economic growth of industries in Tianjin, improvements in energy utilization efficiency are the most important contributors to effective industrial energy conservation and emission reductions in Tianjin, and that the method developed in this paper is practical in the analysis of carbon emissions characteristics of an industrial city or region.

1. Introduction

Climate change has caused widespread concern in the international community, and responding to climate change has become a major element in the functions of all levels of government in China (He, 2011; Li et al., 2011). According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), increase in carbon dioxide (CO_2) emissions due to energy consumption is a key factor that affects climate change.

Scholars have performed research on methods to control increasing amounts of CO_2 emissions (Pauli, 1997; Reijnders and Huijbregts, 2008). Research studies on factors that influence CO_2 emission decomposition have become popular (Casler and Rose, 1998; Vinuya et al., 2010). Decomposition methods commonly used to determine factors that influence CO_2 emissions can be divided into two categories: index decomposition analysis of summary data at the sectoral level (Hatzigeorgiou et al., 2008; Ma and Stern, 2008) and structure decomposition analysis using input–output tables (Achão and Schaeffer, 2009; Zhang and Qi, 2011). Based on an improved version of the decomposition method presented by Bourdonnaye et al. (1997), Ebohon (2006) decomposed CO_2 emission factors into carbon energy intensity, CO_2 emission factors, and structural variables. Using an extended Kaya equation, Kawase (2006) divided CO_2 emission factors in Japan into CO_2 sources and sinks, CO_2 emission intensity, energy efficiency, energy intensity, economic impact factors, and other residual items. Timilsina and Shrestha (2009) determined factors responsible for the increase of CO_2 emissions from the transportation sector in twenty Latin American and Caribbean countries from 1980 to 2005. Among numerous index decomposition methods, the log-mean Divisia index (LMDI) method (Sunil, 2009; Ang, 2004) appears to be the most advantageous. Local scholars have performed CO_2 emission research using the LMDI method. Zhao et al. (2010) identified and quantitatively analyzed main factors responsible for industrial CO_2 emissions in Shanghai using the LMDI method. Guo et al. (2009) analyzed the impact of CO_2 emissions in Shanghai using the LMDI method. Song and Lu (2009) used a "two-stage" LMDI method to decompose CO_2 emissions in China into four factors. Zhao and Long (2010) analyzed the effects of CO_2 emission increases in Jiangsu Province.

Although informative, these studies have neither specifically investigated the industrial sector nor analyzed the effect of changes in the proportion of light and heavy industries. None of these studies have verified the degree of progress and implementation results of industry structure adjustment, energy conservation, and energy structure adjustment measures in the industrial system. Experience in other countries shows that energy consumption and

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corresponding CO_2 emissions of people living in rapidly developing areas will increase as economic income level increases. Energy-conservation and emission-reduction tasks will be implemented by the industrial sector (Zhang et al., 2010). In an effort to address these factors, the Chinese government has implemented several measures to adjust the economic structure of China and to reduce its greenhouse gas emissions (Hicks and Dietmar, 2007; Shao et al., 2008).

In industrial cities with fast growing economies, and especially those in developing countries, rapid development of the industrial sector has led to continuous growth in energy consumption. The energy structure exhibits high CO_2 emissions of fossil energy, thereby making industrial CO_2 emissions the main source of CO_2 emissions in such cities. Achieving low-carbon development is the core of our development project, and low-carbon industrial results will determine the benefit of low-carbon urban construction in cities. To provide a scientific basis for industrial CO_2 emissions in industrial cities and further understand their CO_2 emissions characteristics, this paper develops a systematic method. Additionally, this paper takes Tianjin, a heavily industrialized city in China as an example and analyzes the time series of carbon emissions caused by the energy consumption of the industrial sector to verify our proposed method. Section 2 introduces the research method and data for Tianjin. Section 3 analyzes the main factors affecting carbon emissions using the LMDI method. Section 4 identifies the energy carbon types of 35 industries in Tianjin using clustering analysis, and determines the industries that should be focused on to reduce carbon emissions and provide major economic benefits. Section 5 presents the conclusion.

2. Methodology

2.1. Carbon emission calculation method

The types of industrial energy consumption in Tianjin include primary sources of energy such as coal, coke, coal gas, coking products, crude oil, gasoline, kerosene, diesel, fuel oil, natural gas, and other petroleum products, and secondary sources of energy such as heat and electricity.

According to the method introduced by the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), calculating CO_2 emissions generated by consuming primary sources of energy (except electricity and heat energy) may be conducted as follows:

$$\mathrm{EC}_i = \mathrm{ec}_i - \mathrm{ec}_{\mathrm{is}}, \tag{1}$$

$$C = \sum_i \mathrm{EC}_i \times \mathrm{EF}_i, \tag{2}$$

$$\mathrm{EF}_i = \mathrm{NCV}_i \times \mathrm{ef}_i \times o_i \times 12/44, \tag{3}$$

where i is the type of energy consumed, such as coal, oil, or natural gas; EC_i is the terminal-type consumption of energy i; ec_i is the total fuel consumption; $\mathrm{ec}_{\mathrm{is}}$ is the fuel consumption deducted by the energy used by the industrial sector for raw materials; C is the total CO_2 emission resulting from all types of energy consumption; EF_i is the CO_2 emission factor of energy i; NCV_i is the average net calorific value of energy i; ef_i is the CO_2 emission factor of energy i provided by the IPCC; o_i is the carbon oxidation rate of energy i, and 12/44 is the proportion by weight of carbon in CO_2.

According to the China Energy Statistical Yearbook (National Bureau of Statistics, 2000–2010), net calorific value of energy, standard coal equivalent coefficient of energy, and coefficient of carbon emissions of fossil energy from all types of fuel may be determined as shown in Table 1.

Given the actual consumption of electricity, the heating process produces no direct carbon emissions when such emissions are generated from the carbon content of coal, natural gas, and other energy sources used as raw materials during production. Electrical energy in Tianjin is provided by local thermal power and external power. In local thermal power, the carbon emission factor μ_{in} is calculated using the following equation:

$$\mu_{\mathrm{in}} = \frac{\sum_i \mathrm{EC}_i \times \mathrm{NCV}_i \times \mathrm{ef}_i \times o_i \times 12/44}{Q_e}, \tag{4}$$

where Q_e is the total amount of thermal power.

Carbon emissions of local thermal power consumption C_{in} are obtained by multiplying the carbon emission factor μ_{in} by the local electricity consumption q_{in}, that is:

$$C_{\mathrm{in}} = \mu_{\mathrm{in}} \times q_{\mathrm{in}}. \tag{5}$$

Given that external electricity comes primarily from the North China Power Grid, the carbon emission factor is the operating margin emission factor of the North China Regional Grid for calendar year $\mathrm{EF}_{\mathrm{grid,OM,y}}$ (National Development and Reform Commission and Department of Climate Change, 2006). Carbon emissions of external electricity consumption C_{ex} are obtained by multiplying the carbon emission factor μ_{ex} by the external electricity consumption q_{ex}, that is:

$$C_{\mathrm{ex}} = \mu_{\mathrm{ex}} \times q_{\mathrm{ex}}. \tag{6}$$

Among all factors studied, only the data from 2006 to 2010 are considered as operating margin emission factors ($\mathrm{EF}_{\mathrm{grid,OM,y}}$) of the North China Regional Power Grid in this paper, (obtained from the Tianjin Bureau of Statistics (2000–2011)). According to the statistics, external electricity accounted for less than 10% of total electricity consumption from 1999 to 2005. Therefore, μ_{ex} can be approximated by the local electricity carbon emission factor data μ_{in}:

$$\mu_{\mathrm{ex}} = \mathrm{EF}_{\mathrm{grid,OM,y}},\ y \in [2006, 2010], \tag{7}$$

$$\mu_{\mathrm{ex}} = \mu_{\mathrm{in}},\ y \in [1999, 2005]. \tag{8}$$

Indirect carbon emissions from electrical energy in Tianjin are calculated from the proportion of local power and external power.

Table 1
Carbon emission factors of all types of fuel energy.

Item	Average net calorific	CO_2 emission factor	Carbon oxidation rate	Standard coal coefficient	Carbon emission factor
	(kJ/kg)/(kJ/m^3)	(kg/TJ)	(%)	(kgce/kg) (kgce/m^3)	(t/tce)
Coal	20,908	94,600	98.0	0.7143	0.7401
Coke	28,435	107,000	98.0	0.9714	0.8371
Coal gas	17,254	44,400	99.5	5.9285	0.3507
Coking products	50,179	63,100	99.5	1.1429	0.6378
Crude oil	41,816	73,300	99.0	1.4286	0.5793
Gasoline	43,070	70,000	99.0	1.4714	0.5532
Kerosene	43,070	71,900	99.0	1.4714	0.5682
Diesel	42,652	74,100	99.0	1.4571	0.5856
Fuel oil	41,816	77,400	99.0	1.4286	0.6117
Other gasoline products	41,816	73,300	99.0	1.4286	0.5793
Natural gas	38,931	56,100	99.5	13.3000	0.4456