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Study on China's regional carbon emission factors: The case of Chongqing city

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Abstract

Low-carbon development has become a hot issue concerned by the whole world. Governments respectively introduced the country's low-carbon strategy and action. China has put forward a series of obligatory targets and has issued a provincial area "twelfth five-year" carbon intensity reduction target. How to coordinate the contradiction between economic growth and environmental constraints, and formulating corresponding low-carbon development path and the supporting measures, has become one of the problems to be solved. Considering the regional resource endowment, stage of economic development, energy structure, industrial structure, technical development level and other factors, this article constructs the model of regional carbon emission factors, the paper takes Chongqing of China as an example. The research results show that: The major contribution of elements, in turn, is the improvement of technology energy efficiency, the optimization of energy structure, and the adjustment of industrial structure. Based on this, this paper puts forward the corresponding low-carbon development policies according to the results of analysis, from the aspects such as energy structure, industrial structure, and technological progress and so on.

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*Keywords:*low-carbon development; carbon emission; LMDI factor analysis model;

1. Introduction

Over the past century, CO_2 concentration in the air has risen in parallel with global climate, and climate changes associated with greenhouse gases have resulted in huge losses to the world economy. As climate changes become an increasing concern, major developed economies such as the UK, the US and Japan have set their respective low-carbon economic targets based on their advantages in technology and management experience, with a view to getting the upper hand in the new round of industrial and technical competition[1][2][3]. In the meantime, other nations across the globe, including emerging economies like Russia, Brazil, India and Korea, are also turning their eyes to low-carbon policies [4][5] .

The Chinese central government has also set its 2020 target to bring down CO2 emission per unit of GDP by 40%~50% from the 2005 level, with 31 provincial and municipal governments setting forth their respective carbon intensity reduction targets for the 12th Five-Year Plan period. Thus, how to define regional low-carbon targets, principal tasks and supporting policies to secure a leap forward in low-carbon development has become an important subject and hot area of research both at home and abroad.

For status-based key factor analysis, IPCC[6] and PAS 2050[7][8] respectively provided a top-down and a bottom-up (product-based) carbon accounting system. Furthermore, existing key factor analysis may be subdivided into structural decomposition analysis (SDA) that uses input-output tables and index decomposition analysis (IDA) that uses sector-level data[9][10][11]. The research object of SDA is the structure of national economy while that of IDA is the individual sectors in a specific geographic region. So the latter is more suitable for our present region-specific low carbon research. Among the many IDA models, the LMDI decomposition model[12] is believed to be one of the most widely applicable. By

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establishing and using the LMDI decomposition model, many studies examine the key factors of carbon emissions, energy consumption and pollutions[13][14][15].

The objective of this study is to establish an analysis model that integrates present situation and key influencing factors analysis. The paper analysis the carbon emission factors according to LMDI model that influence China's carbon emission to suit it to China's realities and provide a basis for setting reasonable low-carbon targets.

2. Methodology

2.1 Status accounting algorithm

Greenhouse gas accounting algorithms[6] recommended by IPCC (Inter-governmental Panel on Climate Change) and emission factors recommended by the Guidelines for provincial greenhouse gas inventories were used.

Accounting formula for CO2 emission:

$$CO_2(t) = \sum_j \sum_i E_{ij}(t) \times EF_i \tag{1}$$

Where: $CO_2(t)$: CO_2 emission, tons;

$E_{ij}(t)$: use of energy i by sector j, tons, (i=1,2,3,4, representing coal, petroleum, natural gas and electric power, respectively; j=1,2,3,4,5, representing 5 accounting objects.

EF_i : carbon emission factor of energy i, tons of CO_2/t of standard coal).

2.2 Factor analysis method

To identify the key factors influencing regional carbon emission, after literature review, a frequently used LMDI factor decomposition method was used for our study. This method turns energy consumption or environmental index variations into the contributions of various driving factors and effectively addresses surplus from decomposition and zeros in processing data[16]. Processes of this method include:

Carbon emission factor decomposition modeling:

$$C = \sum_{i=1}^{5} \sum_{j=1}^{4} Cij = \sum_{i=1}^{3} \sum_{j=1}^{4} \frac{Cij}{Eij} \frac{Eij}{Ei} \frac{Ei}{Yi} \frac{Yi}{Y} \frac{Y}{P} P + \sum_{i=4} \sum_{j=1}^{4} \frac{Cij}{Eij} \frac{Eij}{Ei} \frac{Ei}{Yi} \frac{Yi}{VN} VN + \sum_{i=5} \sum_{j=1}^{4} \frac{Cij}{Eij} \frac{Eij}{Ei} \frac{Ei}{TFI} AFI \times FN \tag{2}$$

The above formula can be further expressed as:

$$C = \sum_{i=1}^{3} \sum_{j=1}^{4} CIij \times FSij \times EIPi \times ESi \times PCG \times P + \sum_{i=4} \sum_{j=1}^{4} CIij \times FSij \times EIT \times PVG \times VN + \sum_{i=5} \sum_{j=1}^{4} CIij \times FSij \times EIR \times AFI \times FN \tag{3}$$

Meanings of symbols in the formula are given in the table below.

Table 1 Meanings of symbols

Variable	Implication	Variable	Implication
C	Total CO2 emission	FN	Number of household
Cij	CO2 emission from fuel j consumed by industry i;	CIij	CO2 emission factor of fuel j consumed by industry i;
Eij	Volume of fuel j consumed by industry i	FSij	Proportion of fuel j consumed by industry i of the region in the total fuel consumption of the sector
Ei	Total fuel consumed by industry i	EIPi	Energy intensity of industry i
Yi	Output value of industry i	EIT	Energy intensity of transportation sector
Y	Total output value	EIR	Energy intensity of residents
P	Population	ESi	Share of the output value of industry i in the provincial output value
VN	Number of transport vehicles	PCG	Per-capita GDP
TFI	Total household income	PVG	Average output value per transport vehicle
AFI	Average household income		

Take the time derivative t from both ends of Equation (3), and multiply them with the ends of $1=\sum_{i=1}^{5}\sum_{j=1}^{4}Cij/C$; define $\omega ij = Cij/C$; integrate the result from t through to 0 and, using the mean value theorem of integrals and according to the function of logarithmic mean, the $\omega ij(t^*)$ herein is expressed as: $\bar{\omega} ij(t^*) = \frac{L(Cij_0, Cij_T)}{L(C_0, C_T)}$, from which we get:

$$\frac{C_T}{C_0} \equiv \exp[\sum_{i=1}^{5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{CIij_T}{CIij_0}]\times\exp[\sum_{i=1}^{5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{FSij_T}{FSij_0}]\times\exp[\sum_{i=1}^{3}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{EIPi_T}{EIPi_0}]\times\exp[\sum_{i=1}^{3}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{ESi_T}{ESi_0}]\times$$
$$\exp[\sum_{i=1}^{3}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{PCG_T}{PCG_0}]\times\exp[\sum_{i=1}^{3}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{P_T}{P_0}]\times\exp[\sum_{i=4}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{EIT_T}{EIT_0}]\times\exp[\sum_{i=4}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{PVG_T}{PVG_0}]\times \quad (4)$$
$$\exp[\sum_{i=5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{VN_T}{VN_0}]\times\exp[\sum_{i=5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{EIR_T}{EIR_0}]\times$$
$$\exp[\sum_{i=5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{AFI_T}{AFI_0}]\times\exp[\sum_{i=5}\sum_{j=1}^{4}\bar{\omega}ij(t^*)\ln\frac{FN_T}{FN_0}]$$

Logarithms are taken from the two ends of both equations and simplified as:

$$G(CO_2)=[C(CI)+C(FS)+C(EIP)+C(ES)+C(PCG)+C(P)]+[C(EIT)+C(PVG)+C(VN)]+[C(EIR)+C(AFI)+C(FN)] \quad (5)$$

If the variation of CT relative to C0 was minor, the lnCT/C0 in this equation could be an indication for the growth of CO_2 emission. This, however, is not true. The variation of CT relative to C0 is significant. Nevertheless, to make things easy, we still used InCT/C0 as the growth of CO_2 emission since while absolutely the growth here is some way off from the true one, the relative trend is the same. The $G(CO_2)$ in this equation implies that the current-period CO_2 emission and base-period growth can be decomposed into contributions from 3 industries plus transportation, household consumption and the 12 factors CI, FS...FN, where: CO_2 emission growth (Growth) is expressed as $G(CO_2)$ and the contributions from factors (Contributions) are expressed as C (.).

3. Case study

Analysis is made using Chongqing as an example. This is the only municipality in the west part of China and one of the country's first low-carbon pilot cities. The energy consumption structure of the city is broken up into end energy consumers including the first industry, second industry, third industry, transportation and household consumption.

3.1 Data sources

Data of the case are cited from China Energy Statistical Yearbook 2000-2009 and Chongqing Statistical Yearbook 2000-2009. And carbon emission factors of fuels are cited from the guidelines on provincial greenhouse gas inventories of China.

Both the output values of different sectors and the total output value of the city are adjusted to the fixed price of year 2005 as the base year. The total household income of the city is the per-capita disposable household income of the urban citizens multiplied by the urban population, plus the per-capita net income of the rural residents multiplied by the rural population. This variable is also adjusted to the fixed price as mentioned above. All the other variables are derived from these variables.

3.3 Results analysis

3.3.1 Status of carbon emission

The accounting results for the case of Chongqing indicate a 2-stage profile for the city's carbon emission during 2000-2009 (Figure 1): a fall during 2000-2003 and a continued rise during 2004-2009. Carbon emission in 2003 was up 16.7% over 2000 while that in 2009 was up 103.2% over 2003.During 2000-2009, the city's annual CO2 emission growth rate was 5.5%. The carbon emission intensity in 2009 dropped 40.8% from 2000.

By sector as indicated in Figure 2, carbon emission from the industry sector is the dominant contributor to carbon emission of Chongqing. From 2005 to 2009 the industry sector was the largest contributor to CO2 emission by burning fossil fuels. In the year 2005, the sector's CO2 emission by burning fossil fuels accounted for 71.1% of the city's total CO2 emission from burning fossil fuels, and in 2009 this percentage rose to 73.9%. Second to it was the household consumption sector, which accounted for more than 11% of the city's total emission. Carbon emission from transport and household consumption sectors increased rapidly. From 2005 to 2009, the annual rate of increase in carbon emission from the city's transportation sector was 10.24% and that from household consumption was 6.46%, both higher than the city's average increase in CO2 emission.

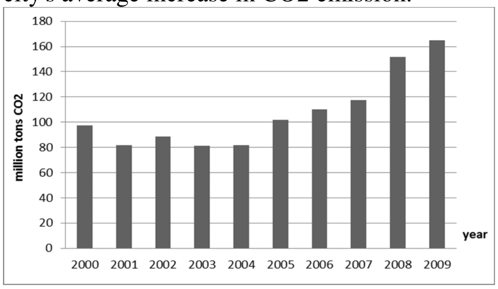

Figure 1 CO_2 emission in Chongqing

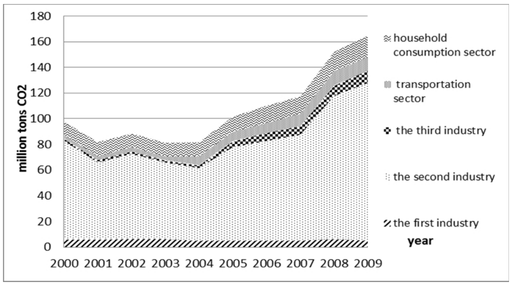

Figure 2 CO_2 emission in Chongqing by sectors

3.3.2 Factor analysis results

The factor analysis results of carbon emission in Chongqing during 2000-2009 with LMDI method is listed in Table 2. The results show that:

Table 2 Factor analysis on carbon emission of Chongqing

Contribution by factors		2000~2004	2004~2009
FS	Percentage of industry-specific energy consumption in the total fuel consumption of the sector	0.009	0.001
EIP	Energy intensity by industry of the region	-0.619	-0.179
EIP1	Energy intensity of the 1st industry	-0.023	-0.005
EIP2	Energy intensity of the 2nd industry	-0.588	-0.046
EIP3	Energy intensity of the 3rd industry	-0.008	0.041
ES	Share of the output value by industry in the total output value of the province	0.026	0.073
PCG	Per-capita GDP of the region	0.383	0.411
P	Population of the region	-0.018	0.019
EIT	Energy intensity of transportation sector in the region	-0.038	-0.021
PVG	Average output value per transport vehicle of the region	-0.025	-0.035
VN	Number of transport vehicles of the region	0.044	0.034
EIR	Energy intensity of residents of the region	0.009	0.027
AFI	Average household income of the region	-0.006	-0.007
FN	Number of households in the region	0.006	0.008

The regional energy structure, energy intensity of the third industry, industrial structure, per-capita GDP, population, number of transport vehicles, energy consumption intensity of residents and number of households are all stimulators to CO_2 emission growth, while the energy intensity of first industry, second industry and transportation, the output value of transport vehicles and regional household income are inhibitors to CO_2 emission growth. It is by adopting advanced energy-efficient technologies that the first industry, second industry and transportation industry have been able to inhibit CO_2 emission growth.

Of all the stimulators to CO_2 emission growth, per-capita GDP was the greatest. During 2000-2009, the per-capita GDP growth resulted in a 9.7% increase in annual average CO_2 emission. Changes in industrial structure also contributed to the city's carbon emission growth. During 2000-2009, industrial structure adjustment resulted in a 2.7% increase in the city's annual average CO_2 emission. Energy structure was a stimulator to the city's total carbon emission. During 2000-2009, energy structure adjustment resulted in a 1.6% increase in the city's annual average CO_2 emission.

Of all the inhibitors to CO_2 increase, the energy intensity of the second industry was the greatest, with a total contribution of 63.4% in the period of 2000-2009.

4. Conclusions

An integrated analysis combining status-key factor-potential analysis is built based on the regional status and the key factors influencing carbon emission to examine the status, key factors of carbon emission as well as low-carbon potential of the region. The status analysis subdivides the end energy consumption sectors to five objects. The factor analysis identified key factors that influence carbon emission using the LMDI decomposition method. The case of Chongqing, the only municipality in the western part of China and one of the country's first low-carbon pilot cities, is also analyzed as an example. The results show that the key factors are industrial structure, energy structure, per-capita GDP and technology advancement, and on this basis we recommend three policies to reduction carbon emissions.

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