Comparative analysis of driving forces behind carbon emissions among regions in China during 2002-2014

Siqin Xiong1,2, Yushen Tian1,2, Xiaoming Ma1,2,3
1School of Environment and Energy, Peking University Shenzhen Graduate School, Shenzhen 518055, China;
2Key Laboratory of Urban Environment, School of Environment and Energy, Shenzhen Graduate School, Peking University, Shenzhen 518055, China;
3College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China.

Abstract. By using the logarithmic mean Divisia index (LMDI) method, this paper decomposed the factors that affect carbon emissions both at a national and multi-regional level, and comparatively analysed the difference of driving factors between 2002-2008 and 2008-2014. It is found that economic growth and the energy intensity are two major factors that drive up carbon emissions in the two periods. The economic structure effect and the energy structure effect had little influence on national carbon emissions, and the inhibitory impact was more obvious in 2008-2014 than the first period in most regions. Both the change of economic structure and energy structure can result in the change of national carbon emissions. Also, the variety of different regions can be attributed to the effect of economic growth and the energy intensity.

1. Introduction
Since China has become the largest carbon emitter, the pressure to reduce emissions is greater than ever. Therefore, China has issued a series of emission reduction policies and promised to peak its carbon emissions by 2030. China is a vast territory with big differences in economic scale and resource endowment among different regions. Thus, it is necessary to elucidate the characteristics of regional carbon emission and provide guideline for governments to formulate corresponding policies.

Some studies have examined the driving factors related to carbon emissions. Fan et al. (2007) studied the factors that influence carbon emissions in China, and concluded that the economic output effect is a key factor that promotes carbon emissions, whereas the energy intensity has an adverse effect. Lei (2011) adopted the LMDI method to analyse the increase of China’s carbon emissions and suggested that the decrease of energy intensity is the main factor to restrain the growth of carbon emissions, while the changes of industrial structure and energy structure promote the increase of carbon emissions. Meng et al. (2011) used panel model to analyse the characteristics of China's regional carbon emissions. Deng et al. (2014) decomposed the carbon emission into population scale, economic development level, energy intensity and energy structure to elucidate the carbon emission characteristics of eight regions in China from 1995 to 2010, and explored the causes and patterns of regional differences.

In general, most researchers suggest that the amount of carbon emission is influenced by economic development, economic structure, energy structure and technological progress. But more researches are still needed in this field. These studies mentioned have investigated the driving forces in a long-time period, but a few conducted comparative analysis of the difference in driving forces during different periods and take the economic status into account. And due to the access of data, the analysis of the driving factors at a regional level is still rare and worth of in-depth research.
Decomposition model, input-output model and metric methods are the main methods to study what may drive the carbon emissions up. LMDI, one of the decomposition model, is wildly used for the lack of an unexplainable residual and its availability even though the data is incomplete.

In this study, from the multi-regional perspective, we adopted the LMDI multiple method to decompose the factors that influence carbon emissions with respect to seven regions of China from 2002-2008 and 2008-2014, and analysed the distinctions between different periods and different regions. The paper is organized as follows: Section Two describes the methodology and data. Section 3 presents the empirical analysis. Section 4 gives our conclusions and policy implications.

2. Methodology and data

2.1. Methodology

From Ang (2005), the LMDI decomposition model is as follows:

\[
C = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} \frac{\Delta GDP}{GDP} \times \frac{\Delta E_i}{\Delta GDP} \times \frac{C_i}{GDP} = \sum_{i=1}^{n} Q \times V_i \times I_i \times F_i
\]

where C represents the total carbon emissions in China; i represents each region; Q represents the regional gross domestic product; Vi represents the proportion of the gross domestic product of industry i accounted for GDP; Ii represents the energy intensity of industry i; Fi represents carbon emissions caused by energy consumption in industry i.

Using the LMDI method, this paper decomposed carbon emissions into four driving factors, including economic growth, energy intensity effect, economic structure effect and energy structure effect. The decomposition model is as follows and X represents Q, V, I, F, respectively.

\[
\Delta C = \sum_{i=1}^{n} \frac{C_i^T - C_i^0}{\ln C_i^T - \ln C_i^0} \ln \left(\frac{X^T}{X^0}\right)
\]

2.2. Data

The paper regrouped China's 30 provinces and municipalities into seven regions, taking the geographic position into account combined with the economic development level (Table 1). Due to the access to the data, Hong Kong, Macao, Tibet, and Chinese Taiwan were not included in our analysis.

| Region          | Provinces or Municipalities                                      |
|-----------------|-----------------------------------------------------------------|
| East China      | Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Shandong, Fujian  |
| North China     | Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia                 |
| Central China   | Henan, Hubei, Hunan                                            |
| South China     | Guangdong, Guangxi, Hainan                                      |
| Southwest       | Chongqing, Sichuan, Guizhou, Yunnan                            |
| Northwest       | Shanxi, Gansu, Qinghai, Ningxia, Xinjiang                      |
| Northeast       | Heilongjiang, Jilin, Liaoning                                  |

The time series data was from 2002 to 2014 and divided into 2002-2008 and 2008-2014. The energy data used was from The Energy Statistical Yearbook and different energy types were converted into standard coal. GDP data was obtained from the China Statistical Yearbook and was converted into standard prices using a price index (2002,100). Since we could not obtain the energy-balance table for Hainan and Hunan provinces in 2002, we used the table in 2003 to represent the table in 2002. Carbon emissions were calculated based on the carbon-emission coefficients provided by IPCC (2006).
3. Empirical results

3.1. Driving factors of China’s carbon emissions

3.1.1. The total carbon emissions in China between 2002-2014. From 2002 to 2014, the national total carbon emissions increased from 3580.83Mt to 8933.06Mt. Due to the long-term birth control policy, China's population growth rate was relatively stable, and the growth of per capita carbon emissions had the same trend as the growth of total carbon emissions. In 2002, the energy intensity was 2.81 tce/10^4RMB and continuously increased to 4.10 tce/10^4RMB until 2007. But from 2008 to 2012, the energy intensity showed a downward trend in 2014.

![Figure 1. The carbon emissions in China between 2002-2014](image)

3.1.2. Impact of driving factors on China's carbon emissions during 2002-2014. The effect of GDP and energy intensity played a stimulating role in promoting China's carbon emissions whereas the effect of economic structure and energy structure reduced carbon emissions during 2002-2014. Before 2008, China’s economy grew rapidly, which was mainly attributed to the secondary industry growth, and led to the year by year increase of carbon emissions. But in 2008 due to the financial crisis, the accumulated carbon emission was 49.70Mt. After that, China shift the economic growth mode, and subsequently entered a new normal stage. Therefore, the contribution rate of the GDP effect dropped since 2012. The carbon emission was 49.70Mt. After that, China shift the economic growth mode, and sub

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3.1.3. Impact of driving factors on China's carbon emissions during 2002-2008 and 2008-2014. In 2008, the economy slowdown due to the financial crisis, after that, the government began to optimize economic structure and develop innovation-oriented industries. Therefore, comparative analysis of the

| Economic growth effect | 2002-2003 | 2003-2004 | 2004-2005 | 2005-2006 | 2006-2007 | 2007-2008 | 2008-2009 | 2009-2010 | 2010-2011 | 2011-2012 | 2012-2013 | 2013-2014 |
|------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Economic structure effect | 103.6     | 292.9     | 192.3     | 224.1     | 516.1     | 502.7     | 49.7      | 574.3     | 715.0     | 248.1     | 251.9     | 67.8      |
| Energy intensity effect | 6.2       | 3.4       | 64.7      | 18.2      | -121.7    | -47.2     | -241.3    | -54.6     | -104.2    | -271.1    | -267.4    | -211.2    |
| Energy intensity effect | 277.1     | 336.0     | 537.5     | 435.8     | 202.3     | 9.8       | 546.3     | 219.5     | 262.5     | 362.5     | 43.0      | -184.1    |

Table 2. Impact of driving factors on China's carbon emissions during 2002-2014
driving factors between the period of 2002-2008 and 2008-2014 is useful for the country to implement corresponding emission reduction policies in accordance with different economic status.

From 2002 to 2008, the energy intensity effect played a major role in stimulating the growth of carbon emissions in China. From 2008-2014, the stimulus effect of the energy intensity effect slightly weakened, and the cumulative increase in carbon emissions was 1235.86 MTe. Following the energy intensity effect, the GDP effect also played a stimulating effect from 2002-2008, and the contribution in 2008-2014 increased slightly, up to 1773.08 MTe. Adjustment of industrial structure played an inhibitory role in China's carbon emissions. During 2008-2014, the inhibitory effect of this factor was more obvious, with the emission reductions of 1045.55 MTe. Before 2008, the effect of energy structure had inhibition of carbon emissions, with carbon emissions decreased 12.65 Mte. During 2008-2014, the contribution rate increased to -6.9%, with the cumulative reductions increased by nearly 10 times, up to 126.46 MTe.

3.2. Driving factors of carbon emissions in seven regions

We decomposed China’s regional carbon emissions over the period 2002-2008 and 2008-2014 based on the LMDI method for a better understanding of the changes in driving forces between different periods.

3.2.1. Impact of driving factors on seven regions during 2002-2008. From 2002 to 2008, the results demonstrate that the growth of GDP had stimulating effects on carbon emissions in all regions, with the contribution rate ranged from 33.5%-54.1%. The energy intensity effect was also the key factor that increased emissions. The energy intensity in East China and North China had relatively greater impacts on national carbon emissions than the remaining regions. The economic structure effect in North China, Northwest and Central China increased the emissions whereas decreased the emissions in remaining regions. The change of energy structure had a positive pulling effect on the carbon emissions of East China, Southwest China and Northwest China, on the contrary, exerted a negative effect for the North China, South China, Central China and Northeast regions.

3.2.2. Impact of driving factors on seven regions during 2008-2014. The results in 2008-2014 show that economic growth effect and energy intensity effect still had a great impact on the growth of carbon emissions in each region. Compared to 2002-2008, the adjustment of economic structure had a negative effect on the carbon emissions in all regions, and the contribution rate was about -6.2% - 22.6%. In addition to South China and Central China, the remaining five regions by the energy structure adjustment led to their carbon emission reduction.

| Table 3. Impact of driving factors in different regions between 2002-2008 and 2008-2014 |
|--------------------------------------------------|
| Economic growth effect | Economic structure effect | Energy intensity effect | Energy structure effect |
|------------------------|--------------------------|------------------------|------------------------|
| China                  | 1675.60                  | -38.12                 | 1890.46                | -1.65                  |
|                        | 1773.08                  | -1045.55               | 1235.86                | -12.65                 |
| Northeast              | 102.30                   | -19.83                 | 198.59                 | -11.76                 |
|                        | 104.85                   | -126.94                | 298.07                 | -6.03                  |
| North China            | 334.73                   | -22.69                 | 435.78                 | -10.95                 |
|                        | 176.28                   | -276.87                | 650.32                 | -5.59                  |
| East China             | 399.83                   | -38.68                 | 829.34                 | -1.66                  |
|                        | 284.53                   | -338.08                | 214.71                 | -71.44                 |
| South China            | 97.99                    | -31.09                 | 230.51                 | -17.27                 |
|                        | 71.40                    | -71.21                 | 163.39                 | 3.30                   |
| Central China          | 208.62                   | -2.42                  | 274.06                 | -10.15                 |
|                        | 157.62                   | -135.05                | 136.57                 | 12.82                  |
| Northwest              | 134.82                   | -29.59                 | 71.19                  | 13.50                  |
|                        | 140.37                   | -114.27                | 394.41                 | -4.22                  |
| Southeast              | 135.44                   | -3.68                  | 191.51                 | 21.55                  |
|                        | 137.50                   | -145.23                | 241.00                 | -67.36                 |

4. Conclusions and Policy implications

This paper identified the driving factors in carbon emissions at a national and multi-regional level and comparatively analysed the differences between 2002-2008 and 2008-2014. Here are main conclusions and policy implications:
China's economy expanded fast during 2002-2014, resulting in the increase of carbon emissions. But the growth rate declined during 2008-2014, indicating that the economic structure became less carbon-intensive and the efforts to optimize the energy structure achieved success to some degree.

(2) Differences in national carbon emissions between different periods mainly came from the economic structure and energy structure. During 2008-2014, the government implemented economic optimization and energy restructuring policies, which significantly inhibited carbon emission growth.

(3) Differences in carbon emissions between different regions mainly came from the economic effect and energy intensity. Economic growth effect on the East, North and Central China are more obvious than that in other regions. These regions are the major regions for booming China’s economic growth, therefore, the government should pay more attention to decouple the economic growth and energy consumption. Energy intensity effect had relatively small difference between regions, indicating that some actions to improve energy efficiency should be made in all regions. The economic structure played an inhibitory effect in all regions during 2008-2014, which shows the optimization of economic structure has achieved an initial success. Compared with other factors, the energy structure effect was small, but it still shows that the adjustment of energy structure is conducive to reducing China's carbon emissions. Thus, China should still support the development of renewable energies in the future.

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