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# Changes of Carbon Emission in Chinese Regional Economy: A Decomposition Analysis Using Nested Logarithmic Mean Divisia Approach

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## Abstract

This paper describes a nested logarithmic mean Divisia approach and analyzes the potential factors influencing the changes in carbon emission in Chinese northwest region for the period 1995-2010. The analysis is performed by decomposing annual carbon emission into components representing changes in economic activity, economic structure, energy mix, and energy intensity, population growth, population structure, as well as changes in per capita energy consumption and emission factor. This paper argues that the vast majority of changes in carbon emissions since 1995 are due to economic activity and energy intensity, where the former is found to be a predominant role in rising carbon emission and the later contributing dominantly to decreasing carbon emission. Moreover, the economic structure, population growth, and population structure effects are all found responsible for carbon emissions in the region, although their effects reverse in different time period. Besides, the decreases in carbon emission, however, are attributable mainly to per capita energy consumption and energy mix. There is no doubt that the current emission profile poses significant challenges to the local government's policies for emission reduction. It is of vital importance to take into account the regional and stage characteristics of influences on carbon emission for policy making.

**Keywords:** Regional carbon emission, Decomposition analysis, The Northwest model.



## 1. Introduction

Overtaking USA, China topped the list of emitter becoming the largest national carbon emitter in 2007 and also ranked first spot of energy consumption in total in 2010 (EIA, 2010), because of which the international denies the image of China being still a developing economy country. However, "China is not only subject to the constraints of domestic resource endowment and environmental carrying capacity, but also confronted with the challenges associated with climate change and CO2 emissions mitigation during her rapid industrialization and urbanization (Jian *et al.*, 2012)." At the same time, an agreement has been reached in the global scope that the practices of the reductions of carbon emission guarantee the environmental protection and the quality of development. Given these facts into consideration, we could declare with some confidence that the issues of energy and environment are still the big hindrance for economy growth in China. Despite the huge environmental challenges it faces, Chinese government approved a series of positive policies to address those issues associated with carbon emission. Chinese government promises that carbon emission intensity per GDP will decrease 40-45% in 2020 compared to the level of 2005. What's more, eco-civilization is a further set to be one of targets to achieve the people's livelihood for the period 2011-2015 (the 12th five-year plan of China), which represents the attitude and determination of Chinese government towards environmental issues.

The developments of China's industrialization and urbanization are now entering into a special stage, which necessitate the need for energy consumption at a deeper level. The strengthening of environmental constraints, however, makes it facing an unpalatable dilemma. There is a unidirectional Granger causality running from energy consumption to carbon dioxide in Chinese economy (Ang, 2009; Zhang and Chen, 2009). For an energy-dependent economy, it is with little possible for China to reduce energy consumption largely resulting in sacrificing its economic growth. Along with the energy-related issue comes the need for systemic and complete systemic analyzing framework to understand what involved into the influencing factors of carbon emission and their contributions to carbon emission in China. Therefore, particular attention has to be provided to the regional environment on the grounds that amelioration of regional environment plays an important role as a prerequisite of achieving the whole nation's environmental improvement. Based on above, both of scholars and researchers at home and abroad make discussions of Chinese environmental problems at different levels.

There are two categories of decomposition techniques to choose for the factor-analysis. One is structural decomposition analysis (SDA) which is based on input-output coefficients and final demands from inout-output tables, and the other is index decomposition analysis (IDA) which bases its framework on aggregate input and output data both typically at a higher level of aggregation than input-output tables. Both of these techniques are useful tools to analyze issues of energy consumption and greenhouse gas (GHG) emissions. Compared to SDA, IDA framework can readily deal with any data available at any level of aggregation. Also, the IDA framework can be applied to data with a time series form. Meanwhile, there are a variety of different indexing methods used in IDA. A whole picture of these methods can be achieved since Ang (2004) provides a useful summary of the index methods with their advantages and disadvantages displayed. Compared to other decomposition analysis frameworks, the logarithmic mean Divisia index method (LMDI) is used widely in exiting literature because of its advantage in complete decomposition with no residual terms. And two types of decomposition can be performed with LMDI: additive and multiplicative (Ang, 2005). Especially for dealing with successfully the zero and negative values (Ang and Liu, 2007a; 2007b) as well as its feature to be performed and understood easily (Cahill and Ó Gallachóir, 2010), this method has formed a complete analytical system which is widely applied to the research of energy consumption and carbon emission (Ang and Liu, 2007; Sheinbaum *et al.*, 2010; Wang *et al.*, 2011; Ali *et al.*, 2012; Ang and Xu, 2013).

In terms of influences on carbon emission, Lin Boqiang and Liu Xiying (2010) attribute the changes in per capita carbon emission in china between 1990 and 2007 to the growth in per capita GDP, energy consumption intensity, and energy structure. Can *et al.* (2005) decompose changes in energy-related carbon emission in China during 1957-2000 into potential factors completely, such as population growth, energy intensity, and energy structure etc. which are affirmed by previous literatures. By establishing a decomposition model to quantitatively analyze the per capita carbon emission, Xu *et al.* (2006) calculate how changes in economic growth, energy mix, energy intensity and emission factor influence carbon emission from coal, oil, natural gas, hydropower and nuclear power consumption in China between 1995 and 2004. Finally, Liu *et al.* (2007) identify the relative contribution of factors influencing carbon emission and point out that, with evidence from 36 industry departments of China, the changes in carbon emission are attributable mainly to economic activities of various industry sectors and energy intensity, although the influence of energy intensity is fluctuating in different time. From a regional characteristic of carbon emissions point of view, low-carbon economy gets its way in the west region of China (Yang and Chang, 2012). Furthermore, from the industry perspective, there also are many conclusions drawn with the use of the Divisia method. They basically study and discuss issues at three levels as nation, industry and region (Jin-Hua *et al.*, 2012). Nevertheless, in terms of the decomposed or chosen variables, those studies deal with data at the nation-macroscopic level neglecting the features of urban-rural dual economic development and lack of specific guidance to regional development. Therefore, the feasibility of the policy is debased. As for urbanization factor, although there are many literatures analyzing the effect of urbanization on carbon emission (Phetkeo and Shinji, 2010; Hui-Ming *et al.*, 2012; Zhang and Lin, 2012; Usama *et al.*, 2013), the methods used in these papers are mostly econometric analysis models. Few of the exiting studies have attempted to introduce the urbanization factor into the decomposition model to explain in a directly modeling way how it changes the carbon emission. These analyses at the macro level are necessary but weak of guiding the specific regional economic development plans and strategies. It is the very things for the substantial formulation of effective emission mitigation policies and strategies to identify the key factors driving carbon emission. The aim of this paper is to identify and decompose the potential factors that change the growth of carbon emission and to investigate the trends of variables and their explanatory power to carbon emission in the region with a modeling way. We are trying to provide precise model explanatory results for factors, such as urbanization, which serves as dominating role in the process of Chinese regional economic growth.

Based on the virtue of methodological superiority and data feature, we select the LMDI to carry out our analysis. With a modified version of this method, we decompose the total energy consumption into productive energy consumption and residential energy consumption. In the end, the general formulas of the additive LMDI for carbon emission decomposition are derived. What's more, what makes the northwest region of China as an interesting case study is that:

- Taking into account the resources endowment, developing state and technology of similarity, we find that the five provinces in this region possess huge potential new energy such as wind and solar energy indicating a big market prospect for wind power generation and photovoltaic power generation. Therefore, this region could be regarded as a prior role in energy policy reform.
- Compared with economy development between the provinces at the regional level, we find this region holds a similar technology similarity between the provinces hovering between 60% and 70% (Zhu *et al.*, 2009) as well as a similar industrial structure and Hoffman index levels (Hong, 2004).
- Due to setups of demonstration province, Shaaxi, toward low carbon economy development and the Guanzhong-Tianshui economic zone, this region becomes a special area when it comes to the national regional planning. So it is helpful for achieving emission reduction goal at a national level to carry out a regional research on the emission reduction and energy consumption.

The rest of the paper is organized as follows: section 2 describes the current situation about energy consumption in this region as well as carbon emission over the period 1995-2010. Section 3 introduces a general outline of the modified version of LMDI analytical framework used in this paper. Section 4 presents and discusses the decomposition results followed a policy implication to address the carbon emission issue in section 5. Finally, section 6 offers a brief conclusion remarks.

## 2. Energy Consumption and Carbon Emission of the Region

The regional economy experienced a phenomenal growth over more than one decade. Since the initial of the 9th five year of China (1996-2000), the regional growth has been about 15.20% per annum higher than that of the whole nation, approximate 9.70% per annum reported by World Bank in 2009. With rapid economic growth, the demand for energy consumption at regional level is surging, as is the regional carbon emission. Especially during post-2000, economic growth enters into a new high-speed growth stage with an average annual growth rate of 15.93%. At the same time, energy consumption shows a significant increasing trend. The year 2003, which indicates two obvious growth stages of energy consumption, tops the list of growth rate with 30.09% compared to others. Over the period 1995-2010, energy consumption supported the rapid economic growth.

The striking growth of Chinese economy is at the cost of substantial fossil energy, especially heavily reliant on the emission intensive fuels, mainly coal. However, this situation has not changed in the regional economy, even to a lesser extent. The huge energy consumption is still the approach to achieve economic and social development goals. On the other hand, some measures from the authority have been conducted to achieve the reductions in carbon emissions. One approach is to switch the energy consumption to clean energy consumption such as wind, natural gas etc. since the energy consumption structure is regarded as a potential factor affecting carbon emission. Fig.1 presents the energy structure trend of selected energy types over the time period from 1995 to 2010. A prominent change in energy structure can be seen. The dominant position of coal consumption mitigates a little bit as a result of other energy types' increment in the share. The per cents of oil consumption in the total energy depletion have a relative stable trend while those of natural gas grow increasingly. Natural gas recently regains some shares it losses previous years. More to this point, the regional energy consumption structure tends to be diversity.

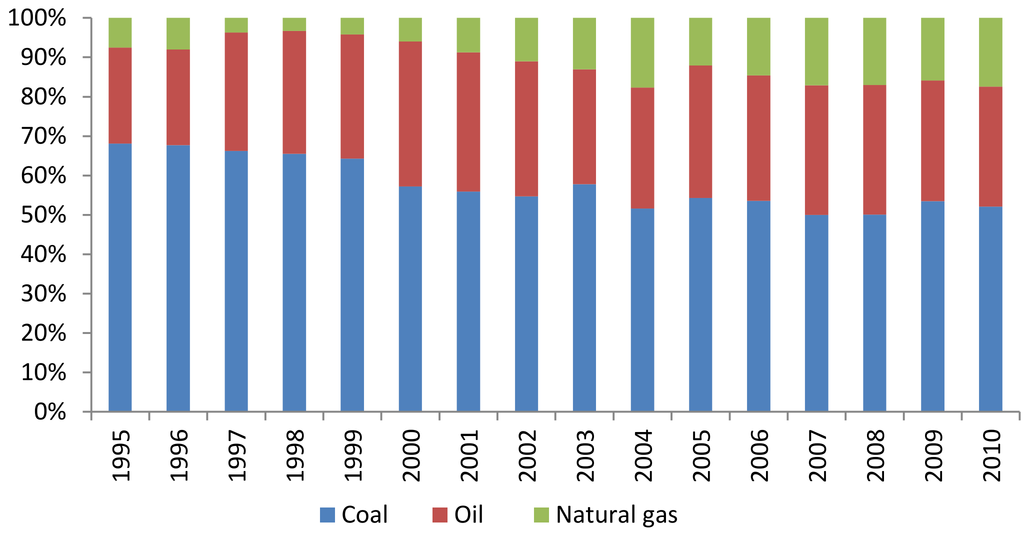


**Figure-1.**Energy mix for selected energy types in northwest region of china over the period 1995-2010.

Nevertheless, sectoral energy consumption provides us another picture. Industrial sector is the main driver responsible for the growth in energy consumption accounting for approximate 50 per cent of total amount during 1995-2010. Transportation sector experiences a sequential increment both in absolute term of sectoral energy use and in sectoral shares of energy consumption. The same situation has been happening in the wholesale & retail sector, but not significant. By contrast, a relatively drastic drop in residential energy consumption makes itself as an opposite side of sectoral shares of energy use, while "Others" sector (it will be described in more details in data set) maintains the same per cent levels of energy consumption over time. All these are displayed by Fig. 2.

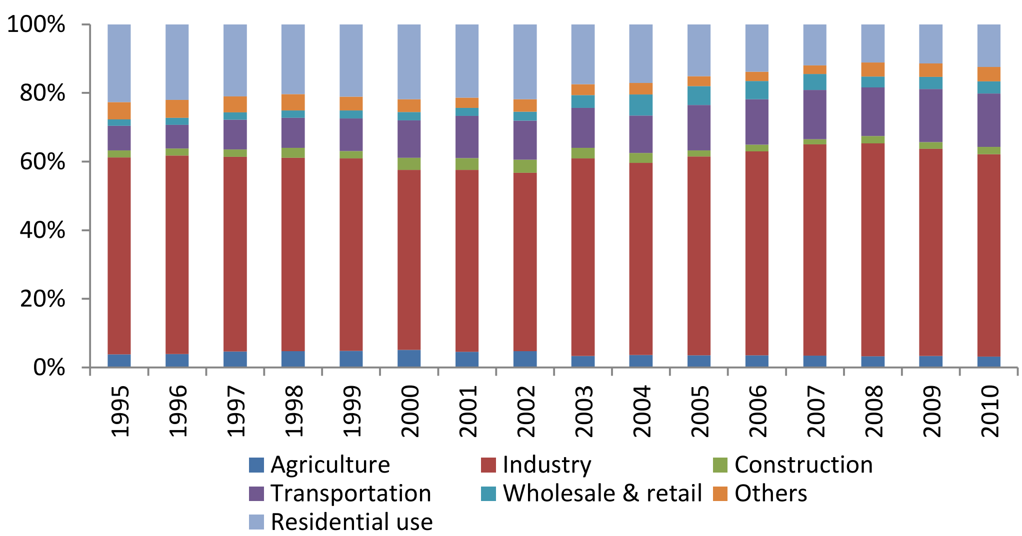


**Figure-2.**Sectoral shares of energy consumption in the northwest region of china in total amount over the period 1995-2010.

The regional growth in carbon emission is directly attributable to industrial and transport sectors because of almost 80 per cent of contribution to the total. In fact, transportation sector has been becoming one of the fastest growing sectors in carbon emission. Industrial sector, having long been a “troubled youth”, still dominants the regional direction of the growth in total emission whose contribution degree does not change due to the shifts taken place in sectoral energy consumption structure. In addition, this sector, together with “Others” sector, exhibits a noticeable growth trend in carbon emission, as seen in Fig.3.

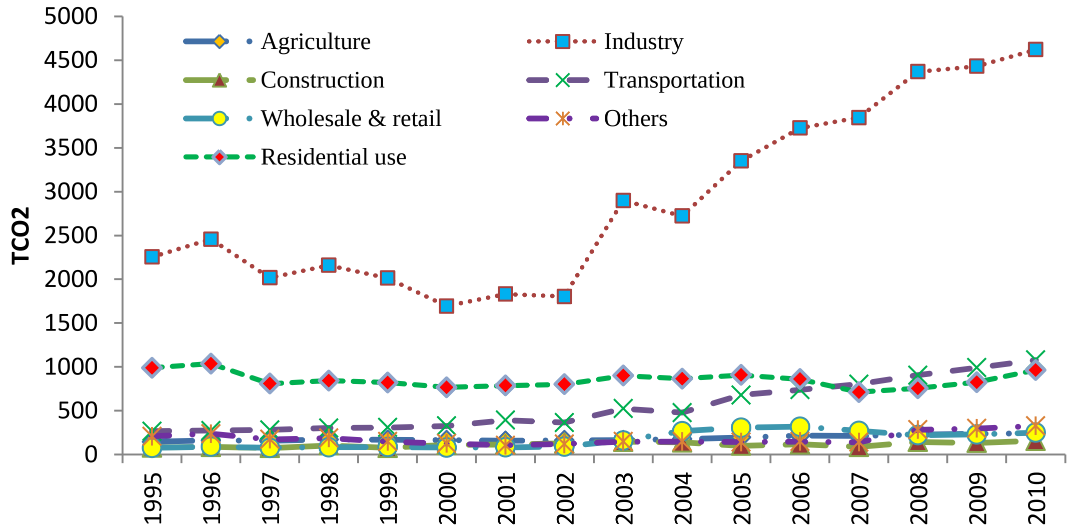


**Figure-3.**Sectoral carbon emission trends in the northwest region of china over the period 1995-2010.

On the other hand, energy intensity in economic output sectors differs from each other. For example, as tow dominant energy use sectors, industrial sector slows down sharply its energy intensity while transport sector is characterized by upward trend energy intensity, especially for recent years (Fig.4). To our best of knowledge, energy intensity is an aggregate concept of technology improvement indicating energy efficiency in energy use fields. In terms of per capita carbon emission, a drastic increase illustrated in Fig.5 can be seen since 2000. In the past decades, per capita carbon emission increased sharply with an average annual growth rate of 8.46%. With the facts in consideration, the Chinese government has been dealing with a huge challenge for coping with the pressure of emission reduction. To this regard, policy making would be suggested to encourage sectoral innovation in energy consumption and energy efficiency amelioration.

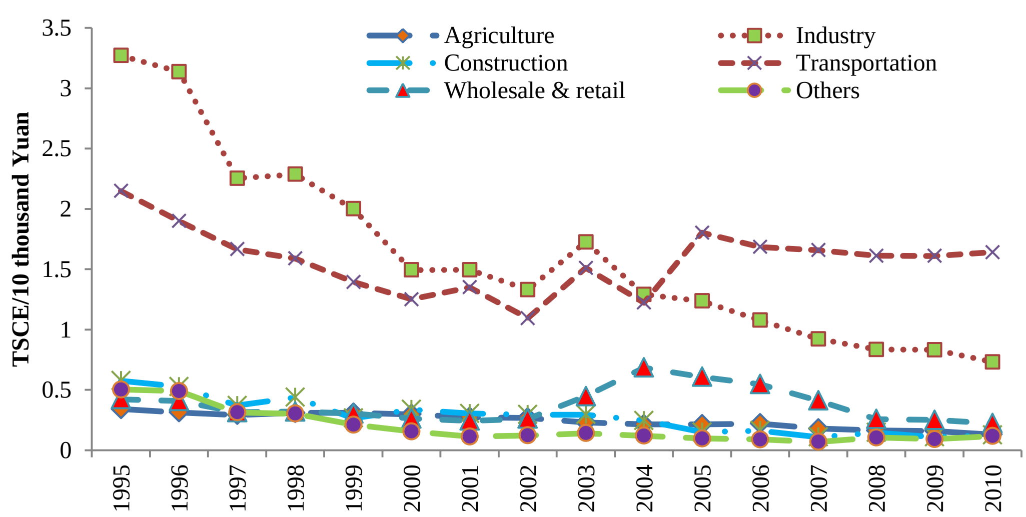


**Figure-4.**Energy intensity in productive sectors in northwest region of china over the period 1995-2010.

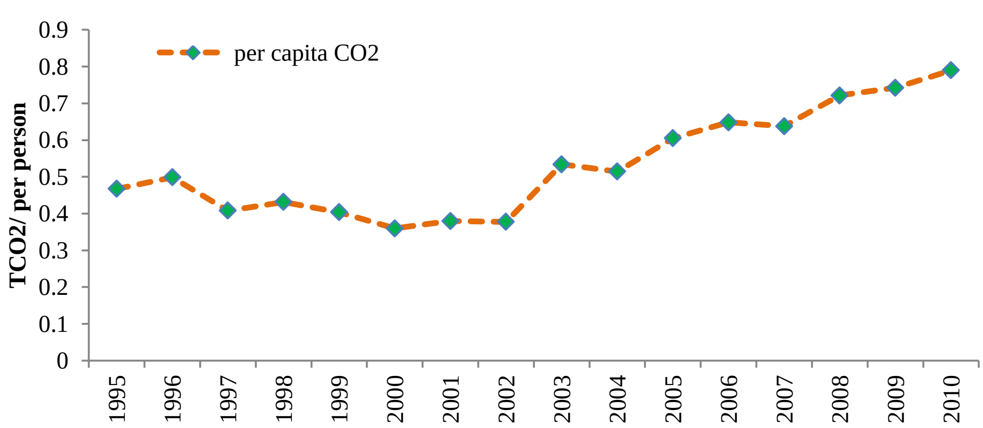


**Figure-5.**Per capita carbon emission in the northwest region of China over the period 1995-2010.

## 3. Methodology to Determine Factors Affecting Changes in Carbon Emission

In this section, we derive a methodology for decomposing the regional carbon emission growth to the contributing factors and the data used to implement the method are also discussed.

### 3.1. A General Decomposition of Carbon Emission Factors

Let us start from a general decomposition model of energy-related carbon emission. Consider the following carbon emission decomposition model.

$$C = \sum_i E \frac{E_i}{E} \frac{C_i}{E_i} = \sum_i e_i E F_i \tag{1}$$

Where $C$ denotes the total carbon emission related to energy consumption. $E$ indicates the total energy consumption. $E_i$ represents the total energy consumption of energy $i$. $e_i$ ($=E_i/E$) means the consuming proportion of energy$i$ in the total amount of energy consumption. And $F_i$ ($=C_i/E$) is the quantity of carbon emission of energy $i$.*Eq.*(1) suggests that total carbon emission is influenced by the energy consumption activity (energy activity), and energy consumption structure (energy mix), and carbon emission intensity (carbon emission factor). Corresponding to an analysis of energy use, decomposition analysis separates the effects of key components on carbon dioxide emission trends over time. Three main most vitally important components that are usually considered in decomposition analysis are activity effect (the level of aggregate activity), structure effect (the composition of various activities), and intensity effect (referring to carbon dioxide emission per unit of activity).

Using additive decomposition, the change in total carbon emission can be decomposed into changes in energy activity ($\Delta C_{eact}$), energy mix ($\Delta C_{estr}$), and carbon emission factor ($\Delta C_{eemf}$). Therefore, the change in carbon emission can be expressed as:

$$\Delta C_{tot} = C^t - C^{t-1} = \Delta C_{eact} + \Delta C_{estr} + \Delta C_{eemf} \tag{2}$$

Where, $t$ is time period (year) and $\Delta C_{tot}$ denotes the change of carbon emission in total from year *t-1* to year $t$. Under the logarithmic mean Divisia index, the values of decomposed terms on the right hand side of *Eq.* (2) can be calculated according to:

$$\Delta C_{eact} = \sum_i \psi(C_i^t, C_i^{t-1}) \ln\left(\frac{E^t}{E^{t-1}}\right) \tag{3}$$

$$\Delta C_{estr} = \sum_i \psi(C_i^t, C_i^{t-1}) \ln\left(\frac{e_i^t}{e_i^{t-1}}\right) \tag{4}$$

$$\Delta C_{eemf} = \sum_i \psi(C_i^t, C_i^{t-1}) \ln\left(\frac{F_i^t}{F_i^{t-1}}\right) \tag{5}$$

Where $\psi(C_i^t, C_i^{t-1})$ is logarithmic mean and $\psi(C_i^t, C_i^{t-1}) = \dfrac{C_i^t - C_i^{t-1}}{\ln C_i^t - \ln C_i^{t-1}}$, if $C_i^t \neq C_i^{t-1}$; $\psi(C_i^t, C_i^{t-1}) = C_i^t$, if $C_i^t = C_i^{t-1}$. Based on the same definition, equations $\zeta(E_{yj}^t, E_{yj}^{t-1})$ and $\omega(E_{hk}^t, E_{hk}^{t-1})$ in the coming analysis are also defined in the same way.

### 3.2. Decomposition of Total Energy Consumption

In order to shed light on how the energy consumption systems of production- and resident-energy consumption change regional carbon emission, we decompose further the energy depletion $E$ as expressed in *Eq.* (1) into productive energy consumption and residential energy consumption, it can be written as:

$$E = E_y + E_h = \sum_j E_{yj} + \sum_k E_{hk} \tag{6}$$

Where $E_y$ is productive energy consumption and $E_h$ is residential energy consumption. In the productive energy consumption, $j$ (=1,2,3,4,5,6) represents six productive industries making up of agriculture, industry, construction, transportation, wholesale & retail and “Others” sectors. For the residential energy consumption, $k$ (=1,2) represents urban and rural energy consumptions respectively. *Eq.* (6) suggests that changes in total energy consumption associate with two ways referring to productive energy consumption and residential energy consumption.

### 3.3. Decomposition of Productive Energy Consumption

There are three traditional factors decomposed as reported in previous literatures that influence energy consumption. Generally, in the application of index decomposition analysis, changes in energy consumption sectors are usually decomposed into three parts: Activity, Structure and Intensity effects. Specifically the issue in question, the activity effect indicates how to measure the impact on energy consumption due to the changes in the overall activity level. Structure effect denotes the impact on energy consumption arising from the changes in activity mix. And intensity effect reflects some changes in energy efficiency coming from the subsector energy intensity as a integrate factor. In our analysis, the three components are also expected as the main driving forces to affect the changes in productive energy consumption.

$$E_y = \sum_j E_{yj} = \sum_j GDP \frac{GDP_j}{GDP} \frac{E_{yj}}{GDP_j} = \sum_j g_j GI_j \tag{7}$$

Where $g_i$ ($=GDP_j/GDP$) represents the industrial sectoral output structure that is the ratio of the total production of industrial sector $j$ to total regional GDP. $I_j$ ($=E_{yj}/GDP_j$) means energy consumption intensity of industrial sector $j$.

Hence, the change in the productive energy consumption can be influenced by aggregate economic activity effect ($\Delta E_{yact}$), activity share of sectors (economic structure) ($\Delta E_{ystr}$), and energy intensity of sectors ($\Delta E_{yint}$) , so this can be describe as:

$$\Delta E_y = E_y^t - E_y^{t-1} = \Delta E_{yact} + \Delta E_{ystr} + \Delta E_{yint} \tag{8}$$

Where these components are calculated in the following ways,

$$\Delta E_{yact} = \sum_j \zeta(E_{yj}^t, E_{yj}^{t-1}) \ln\left(\frac{G^t}{G^{t-1}}\right) \tag{9}$$

$$\Delta E_{ystr} = \sum_j \zeta(E_{yj}^t, E_{yj}^{t-1}) \ln\left(\frac{g_j^t}{g_j^{t-1}}\right) \tag{10}$$

$$\Delta E_{yint} = \sum_j \zeta(E_{yj}^t, E_{yj}^{t-1}) \ln\left(\frac{I_j^t}{I_j^{t-1}}\right) \tag{11}$$

### 3.4. Decomposition of Residential Energy Consumption

To the best of our knowledge, urbanization is a crucial factor in Chinese economy. Urbanization process necessitates the changes in consuming and lifestyle pattern, especially the change in the pattern of energy consumption pattern over time. Therefore, urbanization factor is expressed in the following decomposition model:

$$E_h = \sum_k E_{hk} = \sum_k P \frac{P_k}{P} \frac{E_{hk}}{P_k} = \sum_k p_k P Q_k \tag{12}$$

Where $P$ denotes the regional population growth effect.$P_k$($=P_k/P$) represents the rate of urban and rural population (population structure) ($K=1,2$ represents urban and rural regions). $Q_k$($=E_{hk}/P_k$) shows the per capita energy consumption in the urban and rural areas respectively. Thereby, factors influencing residential energy consumption can be decomposed into population growth, population structure and per capita energy consumption, so the changes in residential energy consumption can be written as:

$$\Delta E_h = E_h^t - E_h^{t-1} = \Delta E_{pact} + \Delta E_{pstr} + \Delta E_{pqua} \tag{13}$$

Where the values of different items on the right hand side of Eq. (13) can be gotten through the following methods:

$$\Delta E_{pact} = \sum_k \omega(E_{hk}^t, E_{hk}^{t-1}) \ln\left(\frac{P_k^t}{P_k^{t-1}}\right) \tag{14}$$

$$\Delta E_{pstr} = \sum_k \omega(E_{hk}^t, E_{hk}^{t-1}) \ln\left(\frac{p_k^t}{p_k^{t-1}}\right) \tag{15}$$

$$\Delta E_{pqua} = \sum_k \omega(E_{hk}^t, E_{hk}^{t-1}) \ln\left(\frac{Q_k^t}{Q_k^{t-1}}\right) \tag{16}$$

### 3.5. Factors Decomposition Associated with Carbon Emission

We are interested in deriving the carbon emission decomposition formula by putting *Eq*. (7) and *Eq*. (12) into *Eq*. (1), we obtain the general formula of carbon emission decomposition. The standard additive forms of decomposition of the changes in carbon emission from year *t-1* to *t* can be expressed as:

$$\Delta C_{tot} = C^t - C^{t-1} = \Delta C_{yact} + \Delta C_{ystr} + \Delta C_{yint} + \Delta C_{pact} + \Delta C_{pstr} + \Delta C_{pqua} + \Delta C_{estr} + \Delta C_{eemf} \tag{17}$$

Thereby, the growth in carbon emission is changed by economic activity, economic structure, energy structure, and energy intensity, population growth, population structure effect as well as per capita energy consumption and emission factor effect. All the components on the right hand side of *Eq*. (17) correspond to the forms of followings with $\Delta C_{eemf} = 0$.

$$\Delta C_{yact} = \left(\frac{\Delta E_{yact}}{\Delta E}\right) \Delta C_{eact} \tag{18}$$

$$\Delta C_{ystr} = \left(\frac{\Delta E_{ystr}}{\Delta E}\right) \Delta C_{eact} \tag{19}$$

$$\Delta C_{yint} = \left(\frac{\Delta E_{yint}}{\Delta E}\right) \Delta C_{eact} \tag{20}$$

$$\Delta C_{pact} = \left(\frac{\Delta E_{pact}}{\Delta E}\right) \Delta C_{eact} \tag{21}$$

$$\Delta C_{pstr} = \left(\frac{\Delta E_{pstr}}{\Delta E}\right) \Delta C_{eact} \tag{22}$$

$$\Delta C_{pqua} = \left( \frac{\Delta E_{pqua}}{\Delta E} \right) \Delta C_{eact} \tag{23}$$

*Eq*. (17)’s key advantage is that it yields an relative complete decomposition model regarding carbon emission on the ground that all the traditional factors that have been identified and confirmed in the previous literature are included and the urbanization factor has been introduced into the decomposition model framework with partly a modeling explanatory power. Urbanization has been long a key factor that affects regional economic operation system. In terms of energy-related carbon emission, urbanization can also been regarded as a dominant setting factor discussed in existing studies. In this paper, we intend to give some visual illustration and explanation in a direct modeling way which yields more insights into the forces that affect the change of carbon emission.

### 3.6. Data Set

The samples of this paper range from 1995 to 2010 produced by the five provinces in northwest area of China, namely, Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang province. The data set of energy consumption comes from *China energy statistical yearbook*, taking forms of terminal real energy consumption (coal, oil and natural gas). Here, the original data is divided into six productive industries and residential energy consumption. Population and regional GDP data comes from the five provinces statistical yearbook in 2011. Productive industry consists of agriculture, industry, architecture, transport, wholesale & retail and “Others” sector. Of which, Agriculture sector contains farming, forestry, husbandry, fishing and water conservancy. Transportation sector includes transportation, storage and communications. Wholesale & retail sector refers to wholesale and retail trade as well as food and beverage. “Others” sector represents financial service.

Carbon dioxide emission in this paper is calculated by:

$$C_t = \sum_i f_i \varepsilon_i m_i \tag{24}$$

Where $C_i$ is the sum of carbon emission of time $T$. $f_i$ is carbon emission factor for different energy type. $\varepsilon_i$ is the conversion factor of standard coal equivalent for different energy type with them both obtained from *National Development and Reform Commission of China* (Table1), and $m_i$ is the amount of final energy use of energy $i$.

**Table-1.**Carbon emission factor and conversion factor of standard coal equivalent.

| | conversion factor of TCE | carbon emission factor |
|---|---|---|
| Coal | 0.7143 | 0.7476 |
| Oil | 1.4286 | 0.5825 |
| Natural gas | 1.3300 | 0.4435 |

## 4. Results and Discussions

### 4.1. An Analysis of Factor Influencing Energy Consumption

Using *Eqs*. (6) (7) and (12), we execute decomposition of energy consumption in two sub-levels to the regional date: productive energy consumption and residential energy consumption for the period 1995-2010. In terms of influencing factors of energy consumption, productive energy consumption directs the changes in the total energy consumption, while residential energy use has small effect on total energy consumption. But the both, for the time horizon considered in the study, promote the growth of energy consumption (Fig.6). The contribution degree of productive energy consumption to carbon emission maintains 70% approximately whilst that of residential energy consumption is lower than 30%. Although it asserts itself as a negative influence of carbon emission in some years, such as 2006 and 2007, residential energy consumption has hardly stopped the growth trend of energy consumption in total. (Table 2).

Fig.7 shows the trend of factors influencing productive energy consumption. Energy activity is found a main positive factor that affects the sum of productive energy consumption. The influence of energy intensity, however, is negative and becomes even stronger over the period of time 2005-2010. From 1996 to 2001, energy mix stops the increasing of productive energy consumption. Although energy mix does not significantly decelerate the growth of productive energy consumption from a perspective of contribution degree, the role of energy structure, in the whole studied period, mainly assert itself as an inhibition of increasing in productive energy consumption (Table 2).

To elucidate the determinants of energy consumption at national level, Liu *et al*. (2007) argue that urbanization is one of driving factors, but there is no evidence given to support the role attributed. In this paper, we propose an alternative explanation from a perspective of residential-wise energy consumption. Fig.8 presents the trends of factors involving residential energy consumption. The impact of per capita energy consumption is remarkable. On the other hand, what motivate the impact of per capita energy consumption might be some induced factors caused by urbanization development. The process of urbanization has a direct impact on patterns of consumption and ways of production and living. These results, as regulatory factors, further impact energy consumption. Population structure, which indicates the characteristic of urban-rural dual economic of China in one way, has a moderate effect on residential energy consumption. This influence decreases the growth of residential energy consumption before 2000, but spurs the growth after 2000 due to a speed-up development of urbanization. What’s more, the contribution degree of population structure to residential energy consumption is less than 10% in most years. But it indicates a powerful potential impact path to the growth of residential energy consumption (Table 2). On the contrast, the effect of population growth on residential energy consumption is eclipsed by population structure and per capita energy consumption effect. Yet, it is still a crucial factor of changing energy consumption at a sub-level.

**Table- 2.**Complete decomposition of energy consumption in percentage (of ∆E, ∆Ey and ∆Eh) (1995-2010).

| | ∆E | | | ∆Ey | | | | ∆Eh | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ∆Ep | ∆Eh | | ∆Eyact | ∆Eystr | ∆Eyint | | ∆Epact | ∆Epstr | ∆Epint |
| 1996-95 | 0.86 | 0.14 | | 1.79 | -0.21 | -0.59 | | 0.24 | 0.01 | 0.75 |
| 1997-96 | 0.73 | 0.27 | | -0.66 | -0.02 | 1.67 | | -0.05 | 0.01 | 1.04 |
| 1998-97 | 0.88 | 0.12 | | 1.02 | -0.18 | 0.15 | | 0.26 | -0.13 | 1.04 |
| 1999-98 | 0.92 | 0.08 | | -1.06 | -0.06 | 2.12 | | -0.45 | 0.10 | 1.05 |
| 2000-99 | 0.87 | 0.13 | | -1.41 | -0.13 | 2.54 | | -0.21 | 0.91 | 0.60 |
| 2001-00 | 0.84 | 0.16 | | 1.30 | -0.12 | -0.18 | | 0.13 | 0.15 | 0.72 |
| 2002-01 | 0.15 | 0.85 | | 70.64 | 2.51 | -72.16 | | 0.21 | 0.30 | 0.49 |
| 2003-02 | 0.93 | 0.07 | | 0.36 | 0.04 | 0.60 | | 0.05 | 0.08 | 0.87 |
| 2004-03 | 0.21 | 0.79 | | -137.93 | -26.35 | 165.28 | | -0.25 | -0.39 | 1.64 |
| 2005-04 | 0.97 | 0.03 | | 1.00 | 0.01 | -0.01 | | 0.27 | 0.36 | 0.39 |
| 2006-05 | 1.01 | -0.01 | | 1.73 | 0.41 | -1.14 | | -0.79 | -1.38 | 3.21 |
| 2007-06 | 4.30 | -3.30 | | 6.55 | -0.13 | -5.41 | | -0.05 | -0.07 | 1.12 |
| 2008-07 | 0.95 | 0.05 | | 1.52 | 0.03 | -0.55 | | 0.11 | 0.12 | 0.78 |
| 2009-08 | 0.77 | 0.23 | | 3.81 | -1.89 | -0.92 | | 0.12 | 0.10 | 0.79 |
| 2010-09 | 0.73 | 0.27 | | 1.59 | 0.74 | -1.33 | | 0.03 | 0.04 | 0.93 |

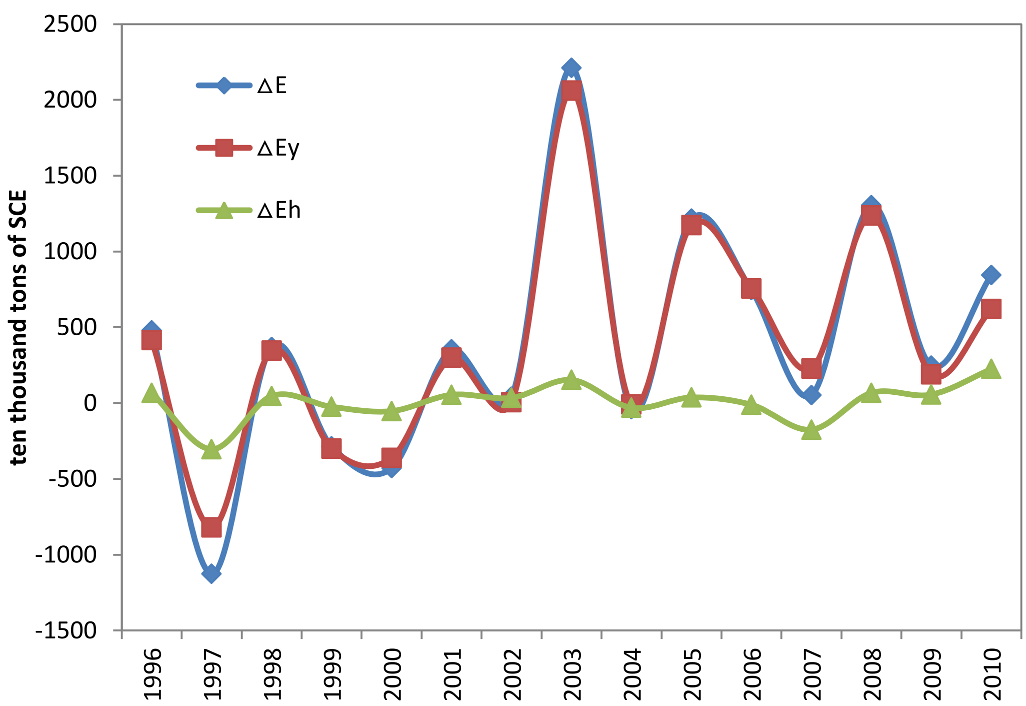


**Figure-6.**Trends of the influencing factors of total energy consumption over the period 1995-2010.

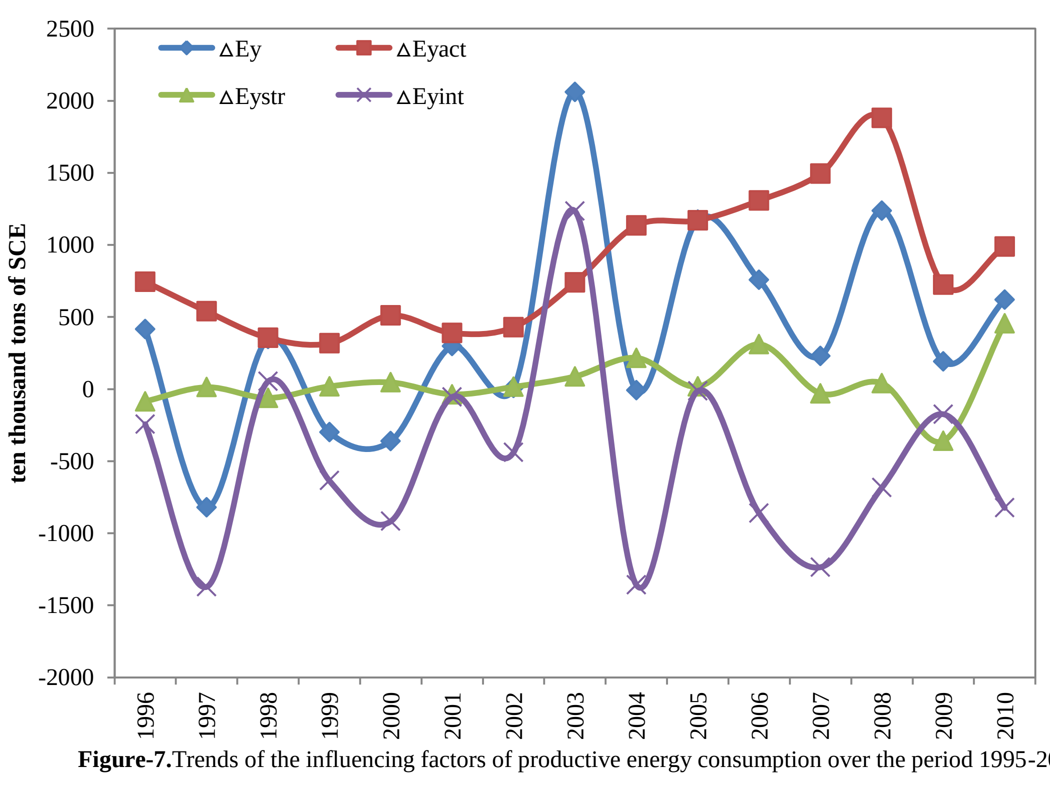


**Figure-7.**Trends of the influencing factors of productive energy consumption over the period 1995-2010.

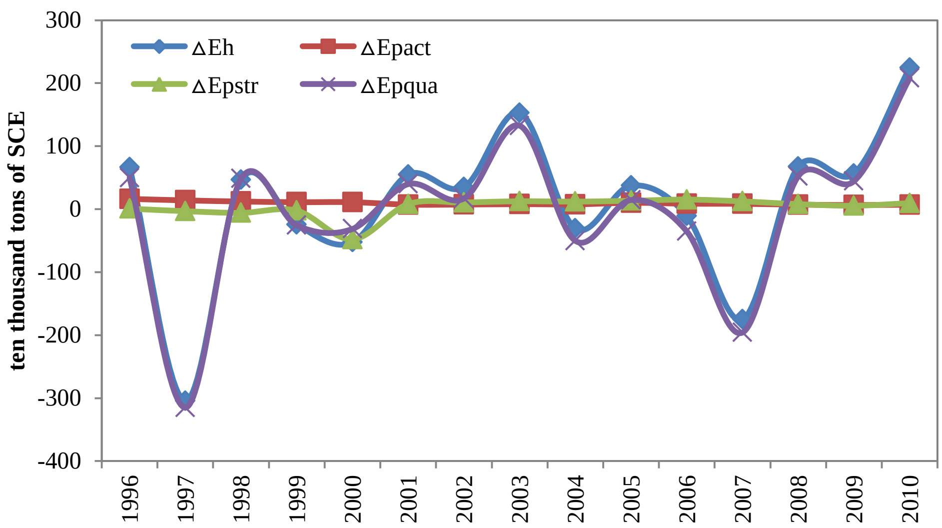


**Figure-8.** Trends of the influencing factors of residential energy consumption over the period 1995-2010.

## 4.2. An Analysis of Factors Influencing Carbon Emission

In this subsection, we firstly apply the proposed model (*Eq*. (1)) to the data set and explore the contributions of influences to the changes in Chinese regional carbon emission. We conduct the decomposition of carbon emission in general sense over the period from1995 to 2010. Three clear trends could be implied in the results. First, the change in total carbon emission fluctuates a lot in the period of time. Second, energy activity mainly dominants changing trend of carbon emission and the both similarly have the same changing trajectory. Third, the effect of energy mix on carbon emission is not significant but has a positive promotion power in most years. Simply put, the changes in carbon emission of this region are mainly triggered by energy activity effect, while energy mix plays an un-significant role in this change at the regional-data level. They evolve concurrently, to some extent independently, and affect carbon emission of the region in both reinforcing and offsetting ways.

The result in Table 3 illuminates to what degree the influences drive the changes in carbon emission. To this respect, we find (1) during the period of time, energy activity distinguishes itself as a crucial factor driving carbon emission. In the 9$^{th}$ five-year plan of China (1996-2000), energy activity begins and continues to dominate the changes in carbon emission. This effect, however, mitigates gradually in the coming years with a reversed power in some year. (2) Energy mix inhibits the growth of carbon emission in the 9$^{th}$ five-year plan mostly. While entering into the 10$^{th}$ five-year plan (2001-2005), this influence reverses with most of the contributions occurring in this time to play an upward role in carbon emission. And (3) a relative extremum of the effects of energy activity and energy mix on carbon emission happened between 2001and 2002. The success in becoming a membership of World Trade Organization (WTO) might be a potential reason. Afterwards, there happens an intense new cycle of growth in Chinese economy followed by some newly innovations policies towards almost every respect. Besides, the tremendous changes occur in energy consumption as China needs a deeper economic development to support her new role in the international world. At the same time, the urbanization in China gains a historical opportunity once in a blue moon to deepen its developing. These are key factors behind the regional carbon emission. Of course, we need to further analyze the specific and underlying reasons as to how the carbon emission is driven by urbanization.

Fig.9 indicates that economic activity and energy intensity are mainly responsible for the changes of carbon emission of the region. Economic activity increases the sum of carbon emission in the process of regional economy development, while the influence of energy intensity is negative. This result is accordance with that of the previous researches (Min *et al*., 2010). From a perspective of micro-quantity, both population size and economic structure promotes the growth of carbon emission. Population size is one of the most active factors that affect carbon emission. The impact of production structure on carbon emission illustrates the unique pattern and characteristic of economic development of the northwest region. The development of this region is still driven by industrial development, which does not change because concerns have been raised regarding the issues and technologies relating to low carbon development in this region.

As is known, urban-rural population structure serves as one of the most important measures of urbanization process in China and is affirmed as a significant factor that affects the carbon emission. There are two stages of the historical impact of population structure upon carbon emission. Over the period of the 9$^{th}$ five-year plan, population structure effectively reduces carbon emission. Although the contribution degree is not significant, the local effect of population structure, between 2001 and 2002, is of much maximization (Table 3). Entering into the 10$^{th}$ five-year plan, population structure gradually turns to be positive to increase the carbon emission. With the development of urbanization, the balance of population structure break up provisionally because of the Chinese rural-urban population mobility. Especially, urbanization triggers the factors which increase energy consumption. At the same time, per capita energy consumption and energy structure reduce carbon emission largely. However, china has been long continuing to maintain a steady energy consumption structure with coal accounting for a large part. The current situation of energy structure cannot achieve a great breakthrough change in a short-run term, which results in lower degree of contribution of energy structure to carbon emission in the long run (Table 3). It will suffer a long time before this situation improves. But that would be a way deserving to be considered and stressed to reduce emission.

Fig.10 indicates that, from 1995 to 2000, energy activity and energy intensity effect are the dominant and opposite influences. The energy activity effect increases the carbon emission by 1338.153 thousand tons of carbon dioxide (ttc), but energy intensity effect reduces it by1502.81 ttc during the same period. Once the population size is taken into account, overall carbon emission increases by 36.46 ttc, while population structure, per capita energy consumption, energy structure and economic structure decline the carbon emission by 165.76 ttc, 78.89 ttc and 0.71 ttc respectively. However, during the next period of 2000-2005, economic structure effect and per capita energy consumption reverse impact direction with their increasing carbon emission by 215.44 ttc and 7.082 ttc respectively. Other influences are remaining the same direction. The last period, 2005-2010, has a powerful positive economic activity effect and a negative energy intensity effect, but the population structure and energy structure start to contribute to rising carbon emission by 35.06 ttc and 52.61 ttc respectively. In this period, economic structure effect and per capita energy consumption return to the role of increasing carbon emission as in the first period of 1995-2000.

Over the whole period, 1995-2010, both economic activity and economic structure push upward the carbon dioxide emission while energy intensity is negative, decreasing the carbon emission. Otherwise, the increasing of carbon emission in this region is mainly due to population size and population structure although their effects are eclipsed by that of economic activity and economic structure. Besides, the effect arising from population structure is slightly larger than that of population size. Overall, the reduction in carbon emission is due to energy intensity overwhelmingly. At the same time, Fig.10 shows that per capita energy consumption and energy structure effect are slightly obvious and their effects take place mostly during the period 1995-2010.

As is well known, the industrialization and urbanization of China continue developing with a speed faster than you'd ever believe. It is a prerequisite to reduce carbon emission for improving of development environment. From 1980 to 2003, carbon intensity related to energy consumption declined year by year, which was mainly due to real energy intensity. So the measures of policy orientation are preferred by the government with a hope benefited from decline of energy intensity (Ying *et al.*, 2007). In the coming years, carbon reduction policies are gradually stressed when considering the issues in question (Xia *et al.*, 2011).

However, is there any necessary practical significance for China to implement emission reduction policy? Evidence from a shock decomposition analysis of GHG growth rate indicates that there is no choice but sacrifice economic growth for realizing the carbon reduction in the short run, even do some harm for the development of the national urbanization (Dong and Yuan, 2011). It is also an interesting topic, but it is beyond the scope of this paper to suggest whether to consider the decomposed influences or not. These findings in the paper just indicate what involved into carbon emission in the region and there is little to suggest that these factors will solely play a key role as an effective approach in the move to a low carbon but a potential to cope with environmental pressure.

**Table-3.** Complete decomposition of carbon emission in percentage (of △Ctot) (1995-2010).

| | △Cyact | △Cystr | △Cyint | △Cpact | △Cpstr | △Cpqua | △Cestr |
|---|---|---|---|---|---|---|---|
| 1996-95 | 1.59 | -0.18 | -0.52 | 0.03 | 0.00 | 0.11 | -0.03 |
| 1997-96 | -0.49 | -0.01 | 1.25 | -0.01 | 0.00 | 0.29 | -0.02 |
| 1998-97 | 0.92 | -0.16 | 0.14 | 0.03 | -0.02 | 0.12 | -0.03 |
| 1999-98 | -1.00 | -0.06 | 2.00 | -0.03 | 0.01 | 0.08 | 0.00 |
| 2000-99 | -0.92 | -0.08 | 1.66 | -0.02 | 0.09 | 0.06 | 0.22 |
| 2001-00 | 1.26 | -0.12 | -0.18 | 0.02 | 0.03 | 0.13 | -0.15 |
| 2002-01 | -126.58 | -4.50 | 129.28 | -2.17 | -3.12 | -4.97 | 12.13 |
| 2003-02 | 0.33 | 0.04 | 0.55 | 0.00 | 0.01 | 0.06 | 0.01 |
| 2004-03 | -4.88 | -0.93 | 5.85 | -0.03 | -0.05 | 0.22 | 0.83 |
| 2005-04 | 0.85 | 0.01 | -0.01 | 0.01 | 0.01 | 0.01 | 0.12 |
| 2006-05 | 1.92 | 0.46 | -1.27 | 0.01 | 0.02 | -0.05 | -0.10 |
| 2007-06 | -17.51 | 0.35 | 14.48 | -0.10 | -0.14 | 2.30 | 1.62 |
| 2008-07 | 1.44 | 0.03 | -0.52 | 0.01 | 0.01 | 0.04 | 0.00 |
| 2009-08 | 1.96 | -0.97 | -0.47 | 0.02 | 0.01 | 0.12 | 0.33 |
| 2010-09 | 1.29 | 0.60 | -1.08 | 0.01 | 0.01 | 0.27 | -0.10 |

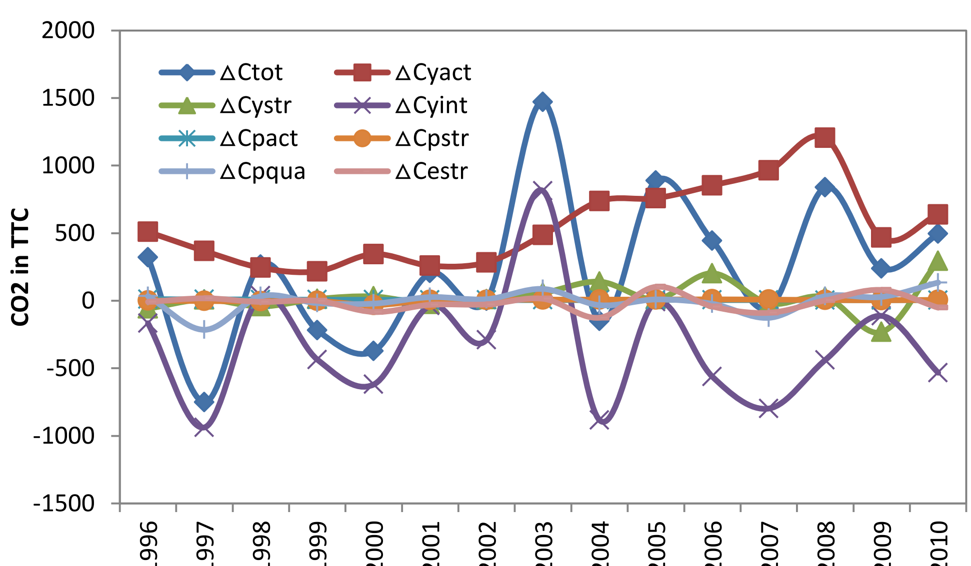


**Figure-9.**Trends of variables associated to carbon emission in the northwest region of China over the period 1995-2010.

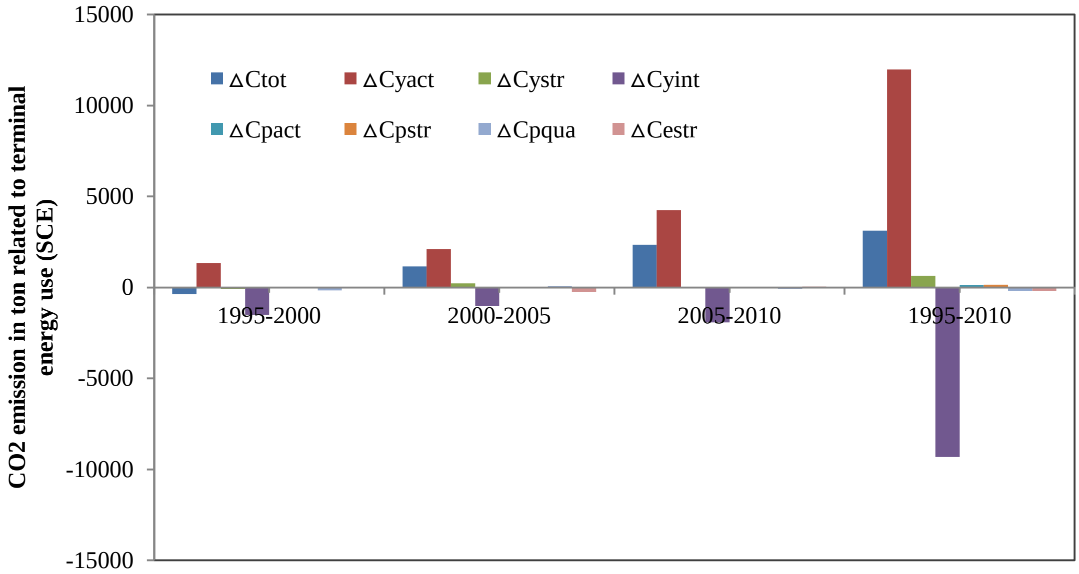


**Figure-10.**Results of additive decomposition (changing analysis) of regional carbon emission related to energy use in different periods: 1995-2010.

## 5. Policy Implications to Address Carbon Emission Growth

A series of policies and strategies aimed at reducing the carbon emission in China are already underway. Especially for the regional economy, the low carbon policies and technologies are needed to support the regional sustainable development. In addition, a number of areas remain to be taken into account for China to transform its economy to a low carbon one because there is a range of uncertainties in projecting future socio-economic variables in China as well as their possible effect on emission (Ajay *et al.*, 2013). However, this verdict general at the aggregated level becomes much more explicit at the regional economy.

There are abundant clean energy types, such as wind, solar energy etc. in the northwest region of China. Therefore, it is advisable for the local government's policy makers to take such regional environment-advantage into account when proposing any long term emission reduction strategies and targets. In addition, what development strategies to be made are likely to have huge impact on china's responsibility for the global emission reduction and is pivotal for consolidating and promoting the Chinese voice in the Durban Platform on Enhanced Cooperation. Thereby, a primary step to achieve this lies in the regional level which in line with the principle of the Chinese eighteenth national congress of the communist party.

Energy mix in China has been long characterized by the dominant role of coal use in the overall economic level, and this situation remains in regional economy. For now, the dominant position of coal consumption in the regional economy is unlikely to change albeit its share in total energy consumption declines yearly. Energy structure provides us an anticipating pathway to decarbonize the regional economy. As the analysis mentioned above, a diversity and optimization of energy consumption in the region are easier to be achieved because of the resource-endowment advantage in this region. Obviously, the question is how to do so.

Infrastructure construction for green energy can be considered as another pathway to accomplish the emission reduction targets. In our analysis, population growth and population structure effect are found as the crucial factors influencing the carbon emission in the region although their effects are eclipsed by other effects. Therefore, future policies for public service need not only more encouragement of low carbon life concept but also substantial practice for supporting low carbon life.

In developing countries, the development of urbanization and industrialization is much reliant on economy growth and this is the truth in China as the largest developing country. Hence, it is very difficult for china to pursue greenhouse gas abatement policy trough reducing productive activity. It seems to be a great challenge to both meet the growth target and keep the carbon emission under control. In fact, it is not possible for China to mitigate emission pressure via sacrificing her economic growth. Switching to greener energy sources or improving energy mix diversifications might be a possible alternative in a long term consideration.

On the other hand, energy intensity is found predominant to reduce carbon emission and a break through to meet the reduction targets. The improvement in energy efficiency toward low carbon emission confirms the benefits of relative clean of economic sectors. It is reported that transportation sector consume now one third of the petroleum products yearly, and based on current growth trends, energy consumption of petroleum products in transportation could overtake half part in percentage reaching 57% by 2020, and 70% by 2035 (Zhu *et al.*, 2009) Transport sector has been becoming one of the main sources of carbon emission in China (Govinda *et al.*, 2009; Jian *et al.*, 2012). Therefore, special attention must be paid to the issues arising in economic sectors, such as transportation. To understand the features of energy consumption and carbon emission in transport sector are critical because of its increasing prominence as a source of carbon emission.

## 6. Conclusions

This study investigates the growth of carbon emission and potential factors that influence the carbon emission growth in northwest region of China over the period 1995-2010. To identify the driving factors, we decompose the carbon emission growth into eight potential factors, namely, economic activity, economic structure, energy mix, and energy intensity, population growth, population structure as well as per capita energy consumption and emission factor.

A decomposition analysis framework with a modified version of LMDI is performed in this paper. By undertaking a quantitative analysis of development trajectories for the carbon emission in the northwest region of china, we illustrate every decomposed factor in a modeling manner. Compared to the previous literatures, this paper makes some advanced work to introduce urbanization factor into model analysis framework. Thereby, we gained the complete and comprehensive factor-analysis associating with carbon emission.

Our study shows that the growth in carbon emission is attributable to economic activity as well as population growth, although its effect is eclipsed by that of economic activity at aggregate level. Energy intensity effect, however, contributes significantly to decreasing carbon emission with a pivotal role to decarbonize the regional economy. Energy mix and per capita effect are found the main causes of decreasing the regional carbon emission, along with economic structure. Finally, population structure effect is identified a key factor responsible for increment in carbon emission in the region. Whereas the degree of influence of these factors affecting the changes in carbon emission varies from time to time.

Based on the analysis, some policy recommendations are proposed toward emission reduction targets. More to the point, urbanization is a key and crucial factor in policy making because of its huge potential effect on carbon emission. With the development of urbanization, there are many changes happened to the pattern of public consumption, way of producing and living which have great impact on the energy consumption and carbon emission. It is of vital importance to take into account the regional and stage characteristics of influences on carbon emission for policy making.

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## References

Ajay, G., S. Niels, N. Tamaryn, T. Danlu, M. Luis, F. Mark and R. Keywan, 2013. A hybrid modeling approach to develop scenarios for China's carbon dioxide emissions to 2050. Energy Policy, 59(August): 614-632.

Ali, H., D.L.R.D.C. Stephane and S. Jayant, 2012. Analysis and decomposition of the energy intensity of California industries. Energy Policy, 46(July): 234-245.

Ang, B.W., 2004. Decomposition analysis for policy making in energy: Which is the preferred method? Energy Policy, 32(9): 1131–1139.

Ang, B.W., 2005. The LMDI approach to decomposition analysis: A practical guide. Energy Policy, 33: 867-871.

Ang, B.W. and N. Liu, 2007. Energy decomposition analysis: IEA model versus other methods. Energy Policy, 35(3): 1426–1432.

Ang, B.W. and N. Liu, 2007a. Handling zero values in the logarithmic mean divisia index decomposition approach. Energy Policy, 35(1): 238-246.

Ang, B.W. and N. Liu, 2007b. Negative-value problems of the logarithmic mean divisia index decomposition approach. Energy Policy, 35(1): 739-742.

Ang, B.W. and X.Y. Xu, 2013. Tracking industrial energy efficiency trends using index decomposition analysis. Energy Economics, 40(November): 1014-1021.

Ang, J.B., 2009. CO2 emissions, research and technology transfer in China. Ecological Economics, 68(10): 2658-2665.

Cahill, C.J. and B.P. Ó Gallachóir, 2010. Monitoring energy efficiency trends in European industry: Which top-down method should be used? Energy Policy, 38(11): 6910–6918.

Can, W., C. Jining and Z. Ji, 2005. Decompostion of energy-related CO2 emission in China: 1957-2000. Energy, 30(1): 73-83.

Dong, X. and G. Yuan, 2011. China's greenhouse gas emissions' dynamic effects in the process of its urbanization: A perspective from shocks decomposition under long-term constraints. Energy Procedia, 5(2011): 1660-1665.

EIA, 2010. China country analysis briefs (November 2010 Update).

Govinda, R., Timilsina and S. Ashish, 2009. Transportsector CO2 emissions growth in Asia: Underlying factors and policy options. Energy Policy, 37(11): 4523-4539.

Hong, S.-j., 2004. An empirical analysis on the similarization of regional industrial structure in China. Joural of Fiem & Fsa, 1: 57-65.

Hui-Ming, Z., Y. Wan-Hai and Z.-F. Zeng, 2012. Urbanization and CO2 emissions: A semi-parametric panel data analysis. Economics Letters, 117(3): 848-850.

Jian, C., W. Shubin, W. Shouyang and G. Ju'e, 2012. Demand forecast of petroleum product consumption in the Chinese transportation industry. Energies, 5(3): 577-598.

Jin-Hua, X., F. Tobias, E. Wolfgang and F. Ying, 2012. Energy consumption and CO2 emissions in China's cement industry: A perspective from LMDI decomposition analysis. Energy Policy, 50(11): 831-832.

Lin Boqiang and Liu Xiying, 2010. China's carbon dioxide emissions under the urbanization process: Influence factors and abatement policies. Economic Research Jurnal, (In Chinese), 8: 66-78.

Liu, L.-C., F. Ying, W. Gang and W. Yi-Ming, 2007. Using LMDI method to analyze the change of China's industrial CO2 emissions from final fuel use: An empirical analysis. Energy Policy, 35(11): 5892-5900.

Min, Z., T. Lirong, Z. Weiguo, J. Minhe, L. Yuan and Y. Lizhong, 2010. Decomposition the influencing factors of industrial carbon emissions in Shanghai using the LMDI method. Energy, 35(6): 2505-2510.

Phetkeo, P. and K. Shinji, 2010. Does urbanization lead to less energy use and lower CO2 emissions? A cross-country analysis. Ecological Economics, 70(2): 434-444.

Sheinbaum, C., L. Ozawa and D. Castillo, 2010. Using logarithmic mean divisia index to analyze changes in energy use and carbon dioxide emissions in Mexico's iron and steel industry. Energy Economics, 32(6): 1337–1344.

Usama, A.-M., G.F. Hassan, Y.M.L. Janice and B.C.S. Che Normee, 2013. Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries. Renewable and Sustainable Energy Reviews, 23(July): 107-112.

Wang, W.W., M. Zhang and M. Zhou, 2011. Using LMDI method to analyze transport sector CO2 emission in China. Energy, 36(10): 5909-5915.

Xia, X.H., G.T. Huang, G.Q. Chen, B. Zhang, Z.M. Chen and Q. Yang, 2011. Energy security, efficiency and carbon emission of Chinese industry. Energy Policy, 39(6): 3520-3528.

Xu, G.-q., Z.-y. LIU and Z.-h. JIANG, 2006. Decomposition model and empirical study of carbon emissions for China,1995-2004. China Population Resources and Environment, (In Chinese), 6(July): 158-161.

Yang, R. and X. Chang, 2012. Characteristics of carbon emission and the way of developing low-carbon economy in the Western region. Journal of Southwest Petroleum University (Social Sciences Edition), 1(Januay): 17-22.

Ying, F., L. Lan-Cui, W. Gang, T. Hsien-Tang and W. Yi-Ming, 2007. Changes in carbon intensity in China: Empirical findings from 1980-2003. Ecological Economics, 62(3-4): 683-691.

Zhang, C. and Y. Lin, 2012. Panel estimation for urbanization, energy consumption and CO2 emissions: A regional analysis in China. Energy Policy, 49(October): 488-498l.

Zhang, X.-p. and X.-m. Chen, 2009. Energy consumption, carbon emissions, and economic growth in China. Ecological Economics, 68(10): 2706-2712.

Zhu, Z., L. Sun, Z. He and S. Sun, 2009. Similarity measuring and difference analyzing of technology in the East and the West of China. Science & Technology Progress and Policy, 26(16): 44-47.