Research Article

Empirical Study of Decomposition of CO₂ Emission Factors in China

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China's CO₂ emissions increase has attracted world's attention. It is of great importance to analyze China's CO₂ emission factors to restrain the CO₂ rapid growing. The CO₂ emissions of industrial and residential consumption sectors in China during 1980–2010 were calculated in this paper. The expanded decomposition model of CO₂ emissions was set up by adopting factor-separating method based on the basic principle of the Kaya identities. The results showed that CO₂ emissions of industrial and residential consumption sectors increase year after year, and the scale effect of GDP is the most important factor affecting CO₂ emissions of industrial sector. Decreasing the specific gravity of secondary industry and energy intensity is more effective than decreasing the primary industry and tertiary industry. The emissions reduction effect of structure factor is better than the efficiency factor. For residential consumption sector, CO₂ emissions increase rapidly year after year, and the economy factor (the increase of wealthy degree or income) is the most important factor. In order to slow down the growth of CO₂ emissions, it is an important way to change the economic growth mode, and the structure factor will become a crucial factor.

1. Introduction

At Copenhagen Conference in December 2009, China's CO₂ emissions attracted the world's attention, not only the rapid increase of CO₂ emissions but also the leading position of China's CO₂ emissions in the world. This has exerted considerable pressure upon China in CO₂ emissions reduction. It is becoming more and more significant to acquire quantity and feature of CO₂ emissions by all sectors and regions in China. As the first major carbon emitters and the largest developing country in the world, China's CO₂ emissions will increase in a long period. The Chinese State Council or cabinet said that China would aim to cut carbon intensity—the amount of carbon dioxide emissions per unit of gross domestic product—by a range of 40% to 45% by 2020. However, the acceleration of China's urbanization process and the improvement of the living standard contribute to the rapid increase of CO₂ emissions. As a result, analysis should be made on the causes for CO₂ emissions in China.

CO₂ emissions are determined by the economic development, technical level, energy structure, economic structure,

population structure, and many other factors. However, their contributions to CO₂ emissions are not of the same significance, and many types of models have been used to acquire quantity and feature of CO₂ emissions. The economic development factor is generally acknowledged as the major factor of CO₂ emissions by some studies. The study conducted by Fan et al. [1] showed that the economic development is the biggest factor to CO₂ emissions on the global perspective. A survey had been done by Li and Wang [2], and the results showed that in the long term, a 1% increase in real GDP per capita increases the consumption of energy by approximately 0.48%–0.50% and accordingly increases the carbon dioxide emissions by about 0.41%–0.43% in China. Based on dynamic general equilibrium model, macroeconomic data, and CO₂ emissions, the paper made by Fu and Pei [3] indicated that, with further effective emission control measures, China's economic growth over the next thirty years (2010–2040) will not lead to significant CO₂ emissions increasing. Scale effect and technical effect of Divisia index decomposition results showed that CO₂ emissions can be realized by focused abatement activities, cleaner production, advances in cleaner

fuel products and their use of technologies. A logarithmic mean Divisia index (LMDI) model has been used by Wang et al. [4] to study the carbon emission of China during 1957 to 2000. The study showed that China has achieved a considerable decrease in its CO₂ emissions mainly due to the energy intensity improved. In addition, fuel switching and renewable energy penetration also exhibit positive effect on the CO₂ decrease. Lin and Jiang [5] verified the influence of industrial structure and energy structure change to the CO₂ emissions. The cointegration analysis indicated that the relationship between industrial structure and CO₂ emission is balanced and steady over a long period of time. Liou and Wu [6] employed data envelopment analysis approach to construct the metafrontier global technical efficiency of energy use index and global technical efficiency of CO₂ emissions control index to measure the energy use efficiency and CO₂ emissions control efficiency at country level. The results indicated that, for developed countries, the enhancement of the pure technical efficiency in the energy use and the scale efficiency of CO₂ emissions control are important tasks to pursue. On the contrary, developing countries have to seek the improvement of the pure technical efficiency of CO₂ emissions control and scale efficiency of energy use. Knapp and Mookerjee [7] made a study on the relationship between CO₂ emissions and population. The paper indicated that there is no cointegration relationship between them. Based on a data for 93 countries over the period 1975–1996, the study made by Shi [8] found that global population change over the last two decades is proportionally associated with growth in carbon dioxide emissions and that the impact of population change on emissions is more pronounced in developing countries than in developed countries. York et al. [9] discussed the relationship of these three formulations, their similar conceptual underpinnings, and their divergent uses. They refined the stochastic impacts by regression on population, affluence, and technology (STIRPAT) model by developing the concept of ecological elasticity. Their findings suggested that population has a proportional effect (unitary elasticity) on CO₂ emissions and the energy footprint. The research made by Lin et al. [10] showed that the family planning policy has a positive effect on CO₂ emissions. On the contrary, some scholars considered that population will lead to technical reform and ultimately has a negative effect. For example, Bin and Dowlatabadi [11] argued that population growth will slow down the CO₂ emissions to a certain extent. Besides, Liu [12], Poumanyvong and Kaneko [13], and Martínez-Zarzoso and Maruotti [14] et al. studied the relationship between city urbanization and CO₂ emissions to test and verify the Cruz Nez effect between them.

Since there are many factors which affect CO₂ emissions, the decomposition method is widely used to study the CO₂ emission. The relationship between these factors and CO₂ emissions, which is studied by many authors using various methodologies for different time periods including some pioneering work of Ehrlich and Holdren [15], becomes key and hot topic in environmental science, climatology, and other relative academic fields. The two scholars developed a model named IPAT equation which considered the environmental impact (I), population (P), per capita wealth (A), and

technical level (T); that is, $I = PAT$. Kaya [16] formulated the Kaya Identity in Intergovernmental Panel on Climate Change (IPCC) based on $I = PAT$; that is,

$$C = \frac{C}{E} \times \frac{E}{GDP} \times \frac{GDP}{P} \times P, \quad (1)$$

where C/E is the carbon intensity, E/GDP represents energy intensity of GDP, GDP/P is the per capita GDP or income, and P represents population. The identity contains population, GDP, carbon intensity, and energy intensity factors which affect the CO₂ emissions.

With the improvement of the Kaya identity, this decomposition method was widely used in the field of CO₂ emissions. A research based on the STIRPAT model was formulated by York et al. [9] to analyze the relationship of CO₂ emissions, population, rich degree, and urbanization. The results showed that the elasticity coefficients of population, the per capita GDP, and urbanization to CO₂ emissions are 1, 0.82–1.48, and 0.62–0.70. Using the STIRPAT model, Fan et al. [17] analyzed the impact of population, affluence, and technology on the total CO₂ emissions of countries at different income levels over the period of 1975–2000. The results showed at the global level that economic growth has the greatest impact on CO₂ emissions, and the proportion of the population between ages 15 and 64 has the least impact. The proportion of the population between 15 and 64 has a negative impact on the total CO₂ emissions of countries at the high income level, but the impact is positive at other income levels. Diakoulaki et al. [18] presented a decomposition analysis of CO₂ emissions in Greece for the period of 1990–2002 split into two equal time intervals. The proposed analytical procedure relies on the refined Laspeyres model and follows a bottom-up approach starting from the major energy consuming sectors and aggregating the obtained effects for estimating their relative impact at the country level. Xu et al. [19] and Li and Wang [2] studied the contribution of energy structure, energy efficiency, and economic growth to the CO₂ emissions. With the development of research on the characteristics of carbon emissions, the particularities of industrial sector and residential consumption sector are remarkable gradually. A survey on the characteristics of carbon emissions made by Wei et al. [20] indicated that the CO₂ emissions were mainly caused by secondary industry, and at the same time, the secondary industry made great contribution to economy growth. Based on the STIRPAT model, a research was made by Lin et al. [10]. The paper analyzed the contribution of population, urbanization, per capita GDP, and industrialization level. The results showed that the contribution degrees of per capita GDP and population are 38% and 32%. The decrease of energy intensity is the main reason. Using the LMDI decomposition technique, Pani and Mukhopadhyay [21] examined the contribution of the major factors in changing the level of emissions. The effect of GDP on emissions is found to be substantially more than that of population. However, the income effect shows high fluctuation over time, while the population effect has been roughly constant. Wang et al. [22] adopted LMDI method based on the basic principle of Kaya identities and set up the expand decomposition model of CO₂ emissions. The

results showed that CO₂ emissions increase year after year, and the changes in economic growth and energy intensity are important factors for affecting CO₂ emissions. Zha et al. [23] estimated and compared the energy related CO₂ emissions from urban and rural residential energy consumption from 1991 to 2004. It is found that energy intensity and the income effects, respectively, contributed most to the decline and the increase of residential CO₂ emissions for both urban and rural China. In urban China, the population effect was found to contribute to the increase of residential CO₂ emissions with arising tendency. However, in rural China, the population effect on residential CO₂ emissions is kept decreasing since 1998. The study made by Shi and Zhang [24] indicated that economy scale and energy efficiency are the main factors of the CO₂ emission. The effects of energy transform and population are small relatively. In addition, the paper predicted that energy efficiency will become the most important factors.

However, there are still some aspects that need to improve when calculating the CO₂ emissions and discussing the factors affecting the CO₂ emissions. Firstly, some scholars use the primary energy consumption when calculating the CO₂ emissions. However, some energy is used as raw material and dose not release CO₂. Some papers divide the energy into coal, oil, and natural gas which may make the results do not reflect the CO₂ emissions accurately. Secondary, the CO₂ emission is divided into direct emission and indirect emission of terminal energy consumption. The former means the CO₂ caused by energy combustion directly, while the latter one means the CO₂ emissions when the primary energy is transformed into secondary energy, like electric and heat. Some research works take the CO₂ emissions made from electric and heat energies as the CO₂ emissions of secondary industry. As a result, the CO₂ emissions of secondary industry are larger than the real amount, while the CO₂ emissions of residential consumption sector are too small. This makes the decomposition results not accurate. Finally, the energy consumption of China is divided into industrial sector (material production department and service department) and residential consumption sector. The latter does not make a contribution to the GDP, and its position in the energy consumption system is relatively independent. Residential consumption sector should be analyzed individually, while most papers did not separate it from the industrial sector.

To solve the issues mentioned above, this paper calculates the CO₂ emissions of industrial sector and residential consumption sector. Based on the Kaya identity, decomposition of CO₂ emissions factors in China in the period of 1980–2010 is discussed in the paper. The remainder of the paper is organized as follows. Section 2 describes an overview of decomposition analysis. Sources of data of this study are included in Section 3. Section 4 reports the results. Section 5 provides the conclusions.

2. Method

2.1. CO₂ Emissions Calculation. In this paper, we assumed complete combustion of energy sources to generate carbon

emissions. The calculation equation of CO₂ emissions is shown as

$$C = \sum_i^n \sum_j^n (E_{ij} \times a_j) \quad i = 1, 2, \dots, n; \quad j = 1, 2, \dots, n, \quad (2)$$

where C is the CO₂ emissions, E_{ij} means the energy j consumptions of sector or trade i , and a_j refers to CO₂ emission factor of energy j .

2.2. Completed Decomposition Model of Industrial Sector. The factors affecting CO₂ emissions can be divided into 4 kinds as follows: (1) economy factor, which represents the effect caused by scale of economy, (2) structure factor, which represents the effect caused by industrial structure, (3) efficiency factor, which represents the effect caused by the change of energy intensity, and (4) emission factor, which represents the CO₂ emission per unit of energy consumption. The model is shown in

$$C = \sum_{i=1}^3 \left(G \times \frac{G_i}{G} \times \frac{E_i}{G_i} \times \frac{C_i}{E_i} \right), \quad i = 1, 2, 3, \quad (3)$$

where C is the CO₂ emissions of industrial sector, G represents gross domestic product (GDP), G_i is the product of the industry sector i , E_i means the energy consumption of industrial sector i , and C_i is the CO₂ emissions of the industry sector i . G , G_i/G , E_i/G_i , and C_i/E_i are the economy factor, structure factor, efficiency factor, and emission factor, respectively.

As is shown in (3), the change of CO₂ emissions can be attributed to the four factors:

$$\begin{aligned} \Delta C = & \sum_{i=1}^3 \left(\Delta G \times \frac{G_i}{G} \times \frac{E_i}{G_i} \times \frac{C_i}{E_i} \right) \\ & + \sum_{i=1}^3 \left(G \times \Delta \frac{G_i}{G} \times \frac{E_i}{G_i} \times \frac{C_i}{E_i} \right) \\ & + \sum_{i=1}^3 \left(G \times \frac{G_i}{G} \times \Delta \frac{E_i}{G_i} \times \frac{C_i}{E_i} \right) \\ & + \sum_{i=1}^3 \left(G \times \frac{G_i}{G} \times \frac{E_i}{G_i} \times \Delta \frac{C_i}{E_i} \right) + \Delta r, \end{aligned} \quad (4)$$

where Δ is the difference between the current year and the reference which is the last year in this paper. On account of the annual GDP change of China being very large, the residual term Δr would lead the results of the formula to large errors. In order to improve the precision of the model analysis, in this study, the residual is decomposed according to the principle of “jointly created and equally distributed.” In the time interval $(0, t)$, let

$$\begin{aligned} \frac{G_i}{G} &= S_i, & \frac{E_i}{G_i} &= I_i, & \frac{C_i}{E_i} &= D_i, \\ G^t - G^0 &= \Delta G, & S_i^t - S_i^0 &= \Delta S_i, \\ I_i^t - I_i^0 &= \Delta I_i, & D_i^t - D_i^0 &= \Delta D_i, \end{aligned} \quad (5)$$

where $i = 1, 2, 3$ means three industry sectors and the complete decomposition model can be written as follows.

Economy factor (GF):

$$\begin{aligned}\Delta GF_i &= \Delta GS_i^0 I_i^0 D_i^0 + \frac{1}{2} \Delta G \left(S_i^0 \Delta I_i D_i^0 + \Delta S_i I_i^0 D_i^0 + S_i^0 I_i^0 \Delta D_i \right) \\ &+ \frac{1}{3} \Delta G \left(\Delta S_i \Delta I_i D_i^0 + S_i^0 \Delta I_i \Delta D_i + \Delta S_i I_i^0 \Delta D_i \right) \\ &+ \frac{1}{4} \Delta G \Delta S_i \Delta I_i \Delta D_i.\end{aligned}\quad (6)$$

Structure factor (SF):

$$\begin{aligned}\Delta SF_i &= G^0 \Delta S_i I_i^0 D_i^0 + \frac{1}{2} \Delta S_i \left(\Delta G I_i^0 D_i^0 + G^0 \Delta I_i D_i^0 + G^0 I_i^0 \Delta D_i \right) \\ &+ \frac{1}{3} \Delta S_i \left(\Delta G \Delta I_i D_i^0 + \Delta G I_i^0 \Delta D_i + G^0 \Delta I_i \Delta D_i \right) \\ &+ \frac{1}{4} \Delta G \Delta S_i \Delta I_i \Delta D_i.\end{aligned}\quad (7)$$

Efficiency factor (IF):

$$\begin{aligned}\Delta IF_i &= G^0 S_i^0 \Delta I_i D_i^0 + \frac{1}{2} \Delta I_i \left(\Delta G S_i^0 D_i^0 + G^0 \Delta S_i D_i^0 + G^0 S_i^0 \Delta D_i \right) \\ &+ \frac{1}{3} \Delta I_i \left(\Delta G \Delta S_i D_i^0 + \Delta G S_i^0 \Delta D_i + G^0 \Delta S_i \Delta D_i \right) \\ &+ \frac{1}{4} \Delta G \Delta S_i \Delta I_i \Delta D_i.\end{aligned}\quad (8)$$

Emission factor (DF):

$$\begin{aligned}\Delta DF_i &= G^0 S_i^0 I_i^0 \Delta D_i + \frac{1}{2} \Delta D_i \left(\Delta G S_i^0 I_i^0 + G^0 S_i^0 \Delta I_i + G^0 \Delta S_i I_i^0 \right) \\ &+ \frac{1}{3} \Delta D_i \left(\Delta G S_i^0 \Delta I_i + \Delta G \Delta S_i I_i^0 + G^0 \Delta S_i \Delta I_i \right) \\ &+ \frac{1}{4} \Delta G \Delta S_i \Delta I_i \Delta D_i.\end{aligned}\quad (9)$$

The change of CO₂ emissions of industrial sector between the current year and the reference can be written as

$$\Delta C = \sum_{i=1}^3 (\Delta GF_i + \Delta SF_i + \Delta IF_i + \Delta DF_i). \quad (10)$$

2.3. Completed Decomposition Model of Residential Consumption Sectors. There is difference between urban and rural in the life style and living standard, so separating them into urban and rural parts can make the results more accurate. The factors affected CO₂ emissions can be described as follows: (1) population factor, the effect caused by change of population, (2) economy factor, which represents the effect caused by per capita income, (3) efficiency factor, and (4) emission factor. The model is shown in

$$C = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{C}{E}, \quad (11)$$

where P is the population, G means the residents income (disposable income is used in urban model, while rural model uses pure income according to the initial data of yearbook), E represents energy consumption, and C is CO₂ emissions of residential consumption sector. P , G/P , E/G , and C/E are the population factor, economy factor, efficiency factor, and emission factor, respectively. The decomposition equations of CO₂ emission of residential consumption sector are obtained in (12)–(15).

Population factor (PF):

$$\begin{aligned}\Delta PF &= \Delta P \times \frac{G}{P} \times \frac{E}{G} \times \frac{C}{E} \\ &+ \frac{1}{2} \Delta P \left(\Delta \frac{G}{P} \times \frac{E}{G} \times \frac{C}{E} + \frac{G}{P} \times \Delta \frac{E}{G} \times \frac{C}{E} \right. \\ &\quad \left. + \frac{G}{P} \times \frac{E}{G} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{3} \Delta P \left(\Delta \frac{G}{P} \times \Delta \frac{E}{G} \times \frac{C}{E} + \Delta \frac{G}{P} \times \frac{E}{G} \times \Delta \frac{C}{E} \right. \\ &\quad \left. + \frac{G}{P} \times \Delta \frac{E}{G} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{4} \Delta P \times \Delta \frac{G}{P} \times \Delta \frac{E}{G} \times \Delta \frac{C}{E}.\end{aligned}\quad (12)$$

Economy factor (EF):

$$\begin{aligned}\Delta EF &= P \times \Delta \frac{G}{P} \times \frac{E}{G} \times \frac{C}{E} \\ &+ \frac{1}{2} \Delta \frac{G}{P} \left(\Delta P \times \frac{E}{G} \times \frac{C}{E} + P \times \Delta \frac{E}{G} \times \frac{C}{E} \right. \\ &\quad \left. + P \times \frac{E}{G} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{3} \Delta \frac{G}{P} \left(\Delta P \times \Delta \frac{E}{G} \times \frac{C}{E} + \Delta P \times \frac{E}{G} \times \Delta \frac{C}{E} \right. \\ &\quad \left. + P \times \Delta \frac{E}{G} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{4} \Delta P \times \Delta \frac{G}{P} \times \Delta \frac{E}{G} \times \Delta \frac{C}{E}.\end{aligned}\quad (13)$$

Efficiency factor (IF):

$$\begin{aligned}\Delta IF &= P \times \frac{G}{P} \times \Delta \frac{E}{G} \times \frac{C}{E} \\ &+ \frac{1}{2} \Delta \frac{E}{G} \left(\Delta P \times \frac{G}{P} \times \frac{C}{E} + P \times \Delta \frac{G}{P} \times \frac{C}{E} \right. \\ &\quad \left. + P \times \frac{G}{P} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{3} \Delta \frac{E}{G} \left(\Delta P \times \Delta \frac{G}{P} \times \frac{C}{E} + \Delta P \times \frac{G}{P} \times \Delta \frac{C}{E} \right. \\ &\quad \left. + P \times \Delta \frac{G}{P} \times \Delta \frac{C}{E} \right) \\ &+ \frac{1}{4} \Delta P \times \Delta \frac{G}{P} \times \Delta \frac{E}{G} \times \Delta \frac{C}{E}.\end{aligned}\quad (14)$$

TABLE 1: China's GDP and energy consumption by industrial sector.

Year	GDP (billion yuan)				Energy consumption (Mtce)			
	Total	Primary	Secondary	Tertiary	Total	Primary	Secondary	Tertiary
1980	1756.0	671.5	571.5	513.1	506.9	34.7	419.7	52.6
1981	1848.1	711.1	576.2	560.8	477.4	47.7	382.6	47.0
1982	2015.5	785.5	602.5	627.5	493.4	48.9	401.1	43.5
1983	2234.2	849.3	663.6	721.3	525.9	50.4	427.9	47.7
1984	2573.3	956.4	757.9	858.9	560.9	54.7	450.2	56.0
1985	2919.8	984.9	908.7	1026.2	633.6	40.5	523.7	69.5
1986	3178.1	1020.5	1004.5	1153.1	672.7	42.4	556.6	73.7
1987	3546.3	1073.7	1147.5	1325.0	723.1	44.7	600.5	77.9
1988	3946.3	1110.0	1324.8	1511.6	774.6	47.1	642.0	85.6
1989	4106.6	1142.8	1373.1	1590.8	813.5	47.4	674.2	91.9
1990	4264.3	1224.6	1414.4	1625.3	829.0	48.5	687.9	92.6
1991	4655.7	1259.9	1618.0	1777.9	877.9	51.0	727.5	99.4
1992	5318.7	1329.2	1975.2	2014.4	935.3	50.2	777.4	107.7
1993	6061.4	1401.5	2384.2	2275.7	1007.6	47.3	835.9	124.3
1994	6854.3	1467.5	2841.3	2545.5	1073.2	51.0	895.8	126.4
1995	7603.1	1547.2	3248.7	2807.3	1154.3	55.1	977.3	122.0
1996	8364.1	1630.8	3652.5	3080.8	1205.2	36.9	991.4	176.9
1997	9141.7	1689.3	4038.6	3413.8	1212.3	36.9	997.5	177.9
1998	9857.8	1750.4	4403.6	3703.9	1214.0	36.9	997.7	179.5
1999	10609.0	1799.1	4761.1	4048.8	1253.1	37.8	1027.1	188.2
2000	11503.5	1843.5	5213.5	4446.5	1299.2	39.1	1063.0	197.0
2001	12458.3	1896.2	5656.7	4905.3	1342.2	41.2	1097.4	203.7
2002	13589.7	1952.4	6216.5	5420.9	1422.7	43.3	1163.5	215.9
2003	14952.2	2002.6	7009.3	5940.3	1640.3	49.5	1342.0	248.7
2004	16460.1	2129.5	7790.8	6539.8	1906.9	57.0	1559.4	290.5
2005	18321.7	2242.0	8736.5	7343.3	2106.9	60.7	1724.8	321.4
2006	20644.3	2354.4	9907.5	8382.4	2309.1	63.3	1891.4	354.4
2007	23568.0	2442.9	11401.5	9723.7	2496.9	62.3	2050.6	384.1
2008	25838.7	2574.4	12528.4	10735.9	2595.5	60.1	2135.5	399.9
2009	28193.4	2682.2	13774.2	11737.1	2728.0	62.5	2242.3	423.2
2010	31458.0	2795.8	15519.2	13143.0	2903.8	64.8	2377.8	461.2

Note. tce refers to ton of standard coal equivalent, similarly hereinafter.

Emission factor (DF):

$$\begin{aligned}
 \Delta DF = & P \times \frac{G}{P} \times \frac{E}{G} \times \Delta \frac{C}{E} \\
 & + \frac{1}{2} \Delta \frac{C}{E} \left(\Delta P \times \frac{G}{P} \times \frac{E}{G} + P \times \Delta \frac{G}{P} \times \frac{E}{G} \right. \\
 & \quad \left. + P \times \frac{G}{P} \times \Delta \frac{E}{G} \right) \\
 & + \frac{1}{3} \Delta \frac{C}{E} \left(\Delta P \times \Delta \frac{G}{P} \times \frac{E}{G} + \Delta P \times \frac{G}{P} \times \Delta \frac{E}{G} \right. \\
 & \quad \left. + P \times \Delta \frac{G}{P} \times \Delta \frac{E}{G} \right) \\
 & + \frac{1}{4} \Delta P \times \Delta \frac{G}{P} \times \Delta \frac{E}{G} \times \Delta \frac{C}{E}.
 \end{aligned} \tag{15}$$

The CO₂ emissions of current and base year can be calculated and written as follows:

$$\Delta C = \Delta PF + \Delta EF + \Delta IF + \Delta DF. \tag{16}$$

3. Data Management

The GDP, population by residence, annual per capita income, and energy consumption in this study are statistical data from 1981 to 2010 from China Statistical Yearbook [25], and China Energy Statistical Yearbook [26] respectively. Taking into account the comparability between variables, GDP of industrial sector is calculated at 2005 constant price by the GDP indices to eliminate the price impact before the data analysis. Annual per capita income is different because it is disposable income in urban residential consumption but net income in rural residential consumption. And annual per capita income has been calculated at the base year 2005 according to Engel's coefficient. Table 1 shows China's GDP

TABLE 2: China's population, annual per capita income, and energy consumption by residence.

Year	Population (million persons)		Per capita income (yuan)		Energy consumption (Mtce)	
	Urban	Rural	Urban	Rural	Urban	Rural
1980	191.4	795.7	2194.0	724.5	54.3	41.5
1981	201.7	799.0	2243.5	836.0	66.4	50.7
1982	214.8	801.7	2354.1	1002.3	72.1	55.1
1983	222.7	807.3	2444.8	1144.6	76.3	58.3
1984	240.2	803.4	2741.9	1300.4	84.0	64.2
1985	250.9	807.6	2771.0	1401.5	75.5	57.7
1986	263.7	811.4	3152.7	1622.0	78.6	57.3
1987	276.7	816.3	3228.7	1521.9	81.2	62.1
1988	286.6	823.7	3152.7	1619.4	86.5	68.9
1989	295.4	831.6	3157.9	1593.3	86.4	69.5
1990	302.0	841.4	3422.2	1622.0	89.0	69.0
1991	312.0	846.2	3669.3	1654.3	89.6	70.3
1992	321.8	850.0	4023.4	1752.3	84.5	71.9
1993	331.7	853.4	4406.9	1808.0	81.6	70.7
1994	341.7	856.8	4781.8	1898.7	80.2	73.9
1995	351.7	859.5	5015.0	1999.3	84.1	73.4
1996	373.0	850.9	5210.2	2179.1	86.4	60.4
1997	394.5	841.8	5388.2	2279.2	86.8	60.0
1998	416.1	831.5	5699.1	2377.2	88.2	59.6
1999	437.5	820.4	6229.5	2467.9	91.0	61.6
2000	459.1	808.4	6628.5	2519.5	93.9	62.2
2001	480.6	795.6	7191.7	2625.3	97.4	64.4
2002	502.1	782.4	8156.2	2751.4	103.2	68.5
2003	523.8	768.5	8889.9	2869.7	118.9	78.8
2004	542.8	757.1	9574.0	3064.7	136.8	90.9
2005	562.1	745.4	10493.0	3254.9	153.9	99.1
2006	582.9	731.6	11586.5	3495.7	170.3	107.3
2007	606.3	715.0	12999.6	3827.7	190.2	117.9
2008	624.0	704.0	14091.4	4133.9	196.2	122.8
2009	645.1	689.4	15468.3	4485.3	206.3	132.1
2010	669.8	671.1	16674.1	4974.2	207.1	138.5

and energy consumption by industrial sector, while Table 2 indicates China's population, annual per capita income, and energy consumption by residence.

CO₂ emissions have been divided into three distinct sectors consistent with GDP according to the data. The primary sector includes agriculture, forestry, animal husbandry, fishery, and water conservancy; the secondary sector includes industry and construction; the tertiary sector includes transport, storage and post, wholesale and retail trades, hotels and catering services, and other sectors. This paper adopts the final energy consumption from the energy balance tables of China. To improve the resolution of the energy analysis, we define 17 kinds of energy: raw coal, washed coal, other washed coal, coal briquettes, coke, crude oil, gasoline, kerosene, diesel

TABLE 3: CO₂ emission factors by kinds of energy.

Energy	CO ₂ emission factor (kg/TJ)
Raw coal	97500
Washed coal	94600
Other washed coal	94600
Coal briquette	97500
Coke	107000
Crude oil	73300
Gasoline	74100
Kerosene	71500
Diesel oil	74100
Fuel oil	77400
LPG	63100
Other petroleum products	73300
Other coking products	63100
Natural gas	56100
Coke oven gas	44400
Refinery dry gas	57600
Other gas	44400

TABLE 4: CO₂ emissions of per unit power and heat.

Year	Electric (kg/kWh) energy	Heat (kg/MJ) energy
1986	0.899	0.106
1987	0.910	0.107
1988	0.939	0.114
1989	0.944	0.114
1990	0.952	0.118
1991	0.958	0.118
1992	0.959	0.118
1993	0.957	0.119
1994	0.920	0.118
1995	0.966	0.122
1996	1.011	0.125
1997	0.927	0.119
1998	0.901	0.115
1999	0.896	0.132
2000	0.869	0.135
2001	0.851	0.131
2002	0.872	0.122
2003	0.901	0.135
2004	0.880	0.133
2005	0.865	0.130
2006	0.863	0.129
2007	0.840	0.128
2008	0.811	0.125
2009	0.810	0.124
2010	0.793	0.127

oil, fuel oil, LPG, other petroleum products, other coking products, natural gas, coke oven gas, refinery dry gas, and other gas. The carbon-emission coefficients for the 17 kinds of

TABLE 5: Decomposition results of industrial sector CO₂ emissions change (1981–2010).

Year	Economy factor GF (Mt)	Structure factor SF (Mt)	Efficiency factor IF (Mt)	Emission factor DF (Mt)	Calculated ΔC (Mt)	Actual ΔC (Mt)	Inaccuracy (%)
1981	53.9	-30.5	-75.9	25.5	-27.0	-27.0	$-4.1E-05$
1982	92.4	-30.7	-28.7	21.8	54.8	54.8	$3.3E-05$
1983	115.2	-4.1	-39.7	-21.0	50.4	50.4	$-1.9E-04$
1984	171.9	-6.6	-85.3	68.7	148.7	148.7	$6.4E-05$
1985	176.5	58.9	-66.3	49.4	218.5	218.5	$-3.4E-06$
1986	133.2	20.6	-60.0	30.1	123.9	123.9	$6.8E-05$
1987	186.3	32.4	-95.9	8.4	131.2	131.2	$-4.5E-06$
1988	195.9	52.7	-122.6	7.7	133.7	133.7	$-9.7E-05$
1989	77.5	-5.3	23.0	-0.4	94.8	94.8	$-9.7E-05$
1990	75.6	-13.3	-24.2	-13.1	24.9	24.9	$2.7E-04$
1991	175.7	70.3	-131.3	-157.6	-42.9	-42.9	$-2.5E-04$
1992	271.8	99.3	-242.6	-5.4	123.1	123.1	$-8.4E-05$
1993	289.0	93.0	-218.3	58.0	221.7	221.7	$-1.2E-05$
1994	293.0	90.9	-234.0	-31.7	118.2	118.2	$7.1E-05$
1995	266.0	56.7	-136.9	70.1	255.9	255.9	$-1.2E-05$
1996	264.7	44.6	-191.9	40.6	158.1	158.1	$5.6E-05$
1997	252.1	27.8	-263.2	-59.0	-42.2	-42.2	$-3.6E-04$
1998	214.7	25.0	-235.8	63.8	67.8	67.8	$-2.5E-04$
1999	212.9	13.5	-134.8	-53.8	37.8	37.8	$-4.0E-05$
2000	239.3	24.3	-157.0	-30.4	76.1	76.1	$-2.5E-04$
2001	242.3	8.2	-151.4	-8.7	90.4	90.4	$5.8E-05$
2002	276.3	19.8	-111.1	7.6	192.6	192.6	$6.3E-05$
2003	338.1	61.1	104.5	39.3	543.0	543.0	$-1.9E-05$
2004	395.1	28.1	196.2	-14.0	605.4	605.4	$-8.7E-06$
2005	501.9	26.7	-61.6	64.1	531.2	531.2	$1.1E-05$
2006	620.5	27.1	-171.6	16.1	492.1	492.1	$3.8E-05$
2007	747.0	36.2	-342.8	-61.3	379.1	379.1	$2.0E-05$
2008	543.9	11.5	-327.0	-61.3	167.1	167.1	$-2.0E-05$
2009	535.4	33.4	-263.4	-15.9	289.6	289.6	$-2.0E-05$
2010	714.0	45.2	-353.3	59.3	412.0	412.0	$-2.0E-05$

FIGURE 1: CO₂ emissions of industrial and residential consumption sectors (1980–2010).

energy are obtained from 2006 Inventories Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories [27]. Based on the data from energy balance tables and the carbon-emission coefficients shown in Table 3, this paper calculates the CO₂ emissions of industrial sector and residence. It should be noted that the direct and indirect CO₂ emissions are calculated in this paper. That is to say, CO₂ emissions of power and heat are considered. The indirect CO₂ emissions of per unit power and heat are calculated based on the data from energy balance tables in China Energy Statistical Yearbook [26]. Table 4 indicates CO₂ emissions of per unit power and heat.

4. Results

4.1. Calculated CO₂ Emissions. According to (2), CO₂ emissions of industrial and residential consumption sectors are shown in Figure 1. From the figure, several conclusions can be summarized as follows.

FIGURE 2: Decomposition results of industrial sector CO₂ emissions change (1981–2010).

- (1) The stage of CO₂ emission: the CO₂ emissions have an obvious stage from 1980 to 2010. It is a rapid growth phase from 1980 to 1996 during which CO₂ emissions grew from 1.36 Gt to 3.23 Gt. After the rapid growth phase, the CO₂ emissions came into a stable stage that they grew only 0.08 Gt. Another rapid growth phase is from 2000 to 2010, the net increased amount of CO₂ emissions is 4.29 Gt, and in 2010, CO₂ emissions reached 7.58 Gt.
- (2) There is an obvious difference for CO₂ emission among the sectors. The CO₂ emissions of primary, secondary, and tertiary industry are from 0.11 Gt (1980) to 0.16 Gt (2010), 0.84 Gt (1980) to 5.54 Gt (2010), and 0.11 Gt (1980) to 1.05 Gt (2010), respectively. At the same time, the proportion of primary industry is from 8.20% to 2.07%, while it increases from 8.05% to 13.80% for tertiary industry. The secondary industry has a heavy proportion which is between 59.59% and 73.34%. On the other hand, CO₂ emissions of urban consumption increase from 0.17 Gt in 1980 to 0.50 Gt in 2010, while the CO₂ emissions of rural consumption increase from 0.13 Gt in 1980 to 0.34 Gt in 2010. The growth rate is lower than that in industry sector. Besides, the proportions of urban and rural CO₂ emissions decrease from 12.29% to 6.50% and from 9.39% to 4.52%, respectively. As is shown in Figure 1, the difference between industrial sector and residential consumption sector is becoming large. It is 0.77 Gt in 1980, while it turns to 5.91 Gt in 2010. The proportion of industrial sector is nearly 90% which is as 8.08 times as residential consumption sector. The CO₂ emissions caused by secondary industry make great contribution.

4.2. Industrial Sector. Based on (9)–(12), CO₂ emissions of industrial sector in China are decomposed from 1980 to 2010. The results are shown in Table 5 and Figure 2. It should be noted that the positive means increase of CO₂ emissions, while the negative indicates decrease. The actual CO₂ emissions change is calculated with annual energy

FIGURE 3: Accumulated CO₂ emissions change of industrial sector (1981–2010).

consumption in the energy balance sheets. The differences between the calculated CO₂ emissions change in (13) and the actual change are, respectively, small, about 0.01%, which means that the model is accurate.

Table 5 and Figure 2 indicate that CO₂ emissions of industrial sector are mainly caused by economy factor. Efficiency factor slows down the speed of CO₂ emissions increase. Efficiency factor is always negative except 2003 and 2004. The effect of the industry structure is positive to the change of CO₂ emissions. The accumulated values of decomposition factors as the reference year of 1980 are shown in Figure 3. During the 30 years, CO₂ emissions increase caused by economy factor was 8.68 Gt, while the amount caused by structure was 0.93 Gt. The main factor to decrease the CO₂ emission was efficiency factor, and it was about 4.00 Gt. The effect of emission factor was not obvious.

Decomposition results of economy and structure factor are shown in Table 6. Column $GF/\Delta G$ represents the change of CO₂ emission when the GDP changes one percent. Similarly, columns $SF_1/\Delta S_1$, $SF_2/\Delta S_2$, and $SF_3/\Delta S_3$ represent the change of CO₂ emission when the structure of three industries changes one percent. For example, when the GDP increased 1% in 2010, the CO₂ emissions increased 61.7 Mt. The corresponding values for primary industry, secondary industry, and tertiary industry are 16.8 Mt, 109.2 Mt, and 24.0 Mt. The secondary sector value is much higher than the others. Table 6 indicates that the CO₂ emission of secondary sector is mainly caused by economy factor. If the mode of economic growth and economy structure does not change, the rapid growth trend will not change in a long period of time.

Table 7 is the decomposition results of efficiency factor. Columns $IF_1/\Delta I_1$, $IF_2/\Delta I_2$, and $IF_3/\Delta I_3$ represent the change of CO₂ emissions when the energy intensity of primary industry, secondary industry, and tertiary industry changes one percent. Just the same as structure factor, the secondary sector value is much higher than the others. Columns $IF_1/\Delta I_1$, $IF_2/\Delta I_2$, and $IF_3/\Delta I_3$ are 1.5 Mt, 55.3 Mt, and 10.2 Mt in 2010. That is to say, it is very effective to reduce the ratio of secondary sector and energy intensity for CO₂

TABLE 6: Decomposition results of economy and structure factor (1981–2010).

Year	GF (Mt)	SF ₁ (Mt)	SF ₂ (Mt)	SF ₃ (Mt)	ΔG (%)	ΔS_1 (%)	ΔS_2 (%)	ΔS_3 (%)	GF/ ΔG	SF ₁ / ΔS_1	SF ₂ / ΔS_2	SF ₃ / ΔS_3
1981	53.9	0.7	-35.5	4.2	5.2	0.2	-1.4	1.1	10.3	3.0	26.0	3.7
1982	92.4	1.5	-35.2	3.0	9.1	0.5	-1.3	0.8	10.2	3.0	27.3	3.8
1983	115.2	-3.0	-5.6	4.4	10.9	-1.0	-0.2	1.2	10.6	3.1	29.4	3.9
1984	171.9	-2.9	-8.1	4.3	15.2	-0.8	-0.2	1.1	11.3	3.4	32.5	4.0
1985	176.5	-11.2	62.3	7.8	13.5	-3.4	1.7	1.8	13.1	3.2	37.4	4.4
1986	133.2	-4.9	20.0	5.5	8.8	-1.6	0.5	1.1	15.1	3.0	41.4	4.8
1987	186.3	-6.2	33.3	5.4	11.6	-1.8	0.8	1.1	16.1	3.4	44.1	5.0
1988	195.9	-8.2	56.1	4.9	11.3	-2.2	1.2	0.9	17.4	3.8	46.3	5.2
1989	77.5	-1.2	-6.5	2.4	4.1	-0.3	-0.1	0.4	19.1	4.1	48.4	5.5
1990	75.6	3.7	-13.5	-3.5	3.8	0.9	-0.3	-0.6	19.7	4.1	50.2	5.7
1991	175.7	-7.2	77.0	0.4	9.2	-1.7	1.6	0.1	19.1	4.3	48.6	6.0
1992	271.8	-9.8	111.1	-2.0	14.2	-2.1	2.4	-0.3	19.1	4.7	46.6	6.4
1993	289.0	-9.3	104.7	-2.4	14.0	-1.9	2.2	-0.3	20.7	4.9	47.6	7.2
1994	293.0	-9.2	103.3	-3.2	13.1	-1.7	2.1	-0.4	22.4	5.4	48.8	7.9
1995	266.0	-6.6	65.0	-1.7	10.9	-1.1	1.3	-0.2	24.3	6.2	51.0	7.9
1996	264.7	-4.9	50.3	-0.8	10.0	-0.9	0.9	-0.1	26.5	5.7	53.5	9.5
1997	252.1	-4.9	27.0	5.7	9.3	-1.0	0.5	0.5	27.1	4.8	53.1	11.1
1998	214.7	-3.6	26.0	2.5	7.8	-0.7	0.5	0.2	27.4	4.9	52.8	11.0
1999	212.9	-4.1	11.0	6.6	7.6	-0.8	0.2	0.6	27.9	5.2	53.3	11.1
2000	239.3	-5.2	23.9	5.6	8.4	-0.9	0.4	0.5	28.4	5.5	53.8	11.4
2001	242.3	-4.9	4.7	8.4	8.3	-0.8	0.1	0.7	29.2	6.0	54.9	11.6
2002	276.3	-5.8	19.4	6.2	9.1	-0.9	0.3	0.5	30.4	6.7	57.2	12.0
2003	338.1	-7.8	71.0	-2.1	10.0	-1.0	1.1	-0.2	33.7	8.0	62.6	13.3
2004	395.1	-4.5	32.5	0.0	10.1	-0.5	0.5	0.0	39.2	9.8	71.6	15.5
2005	501.9	-7.9	28.6	6.1	11.3	-0.7	0.4	0.3	44.4	11.3	81.1	17.4
2006	620.5	-10.5	27.6	10.0	12.7	-0.8	0.3	0.5	48.9	12.6	89.6	19.0
2007	747.0	-14.5	37.2	13.4	14.2	-1.0	0.4	0.7	52.7	13.9	96.5	20.6
2008	543.9	-5.8	11.1	6.3	9.6	-0.4	0.1	0.3	56.5	14.5	100.7	21.5
2009	535.4	-6.8	38.4	1.8	9.1	-0.4	0.4	0.1	58.8	15.2	104.0	22.4
2010	714.0	-10.5	52.1	3.6	11.6	-0.6	0.5	0.1	61.7	16.8	109.2	24.0

emissions reduction. Efficiency factor value is always negative in most years which means that efficiency factor mitigates the pressure of CO₂ emissions reduction. Tables 6 and 7 indicate that the contribution made by structure factor is larger than efficiency factor when they change 1%. However, the CO₂ emissions reduction in the 30 years is mainly caused by efficiency factor. Structure factor increases the CO₂ emissions, which is due to the enhancement of secondary sector proportion. That is to say, the CO₂ emissions reduction of structure adjustment is obvious but hard to achieve.

Through the same manner, the decomposition results of emission factor can be obtained. As shown in Table 8, the values of columns $DF_1/\Delta D_1$, $DF_2/\Delta D_2$, and $DF_3/\Delta D_3$ represent the change of CO₂ emissions when the CO₂ emissions intensity of primary industry, secondary industry, and tertiary industry changes 1%. Just as the same as the former two factors, the secondary sector value is much higher than the others. The CO₂ emissions reduction contribution made from structure adjustment is outstanding. As a result, changing the energy structure can make great contribution to

CO₂ emission reduction. However, the situation that coal is as the main energy will not change in a short period of time in China.

4.3. Urban Residential Consumption. Based on (15)–(16), CO₂ emissions of urban residential consumption in China are decomposed from 1980 to 2010. The results are shown in Table 9 and Figure 4. Columns $PF/\Delta P$, $EF/\Delta E$, $IF/\Delta I$, and $DF/\Delta D$ represent the change of CO₂ emissions when population, per capita income, energy intensity, and CO₂ emission intensity change 1%, respectively. Obviously, the contributions are nearly the same.

The accumulated decomposition values of urban residential consumption CO₂ emissions as the reference year of 1980 are shown in Figure 5. The accumulated changes of population, economy, efficiency, and emission factors were 313.2 Mt, 557.9 Mt, -500.6 Mt, and -45.0 Mt from 1981 to 2010. The CO₂ emissions reduction of urban residential consumption is mainly caused by efficiency factor, while population and economy factors have a positive function to increase the CO₂

TABLE 7: Decomposition results of efficiency factor (1981–2010).

Year	IF ₁ (Mt)	IF ₂ (Mt)	IF ₃ (Mt)	ΔI_1 (%)	ΔI_2 (%)	ΔI_3 (%)	IF ₁ / ΔI_1	IF ₂ / ΔI_2	IF ₃ / ΔI_3
1981	29.9	-83.3	-22.4	29.9	-9.6	-18.2	1.0	8.7	1.2
1982	-8.8	2.1	-22.1	-7.3	0.3	-17.3	1.2	8.3	1.3
1983	-5.8	-28.1	-5.8	-4.7	-3.2	-4.7	1.2	8.9	1.3
1984	-4.7	-78.8	-1.8	-3.6	-7.9	-1.4	1.3	10.0	1.3
1985	-37.8	-34.3	5.8	-28.2	-3.0	3.9	1.3	11.5	1.5
1986	1.1	-50.9	-10.1	1.1	-3.8	-5.7	1.0	13.3	1.8
1987	0.3	-80.9	-15.3	0.3	-5.6	-8.0	1.1	14.5	1.9
1988	2.1	-117.3	-7.4	1.9	-7.4	-3.7	1.1	15.9	2.0
1989	-2.6	21.3	4.2	-2.2	1.3	2.0	1.2	16.1	2.1
1990	-5.4	-16.0	-2.9	-4.5	-1.0	-1.3	1.2	16.8	2.2
1991	2.6	-129.5	-4.4	2.2	-7.5	-1.9	1.2	17.2	2.3
1992	-8.5	-223.2	-10.9	-6.7	-12.5	-4.3	1.3	17.9	2.5
1993	-13.3	-210.9	5.9	-10.6	-10.9	2.2	1.3	19.3	2.7
1994	3.5	-209.3	-28.2	3.0	-10.1	-9.1	1.2	20.8	3.1
1995	2.9	-100.7	-39.2	2.3	-4.6	-12.5	1.3	22.0	3.1
1996	-51.0	-237.9	97.0	-36.4	-9.8	32.2	1.4	24.3	3.0
1997	-3.2	-219.9	-40.1	-3.5	-9.0	-9.3	0.9	24.4	4.3
1998	-3.4	-202.4	-30.0	-3.7	-8.3	-7.0	0.9	24.5	4.3
1999	-0.2	-117.1	-17.5	-0.2	-4.8	-4.1	0.9	24.5	4.3
2000	1.0	-137.0	-20.9	1.0	-5.5	-4.7	0.9	25.0	4.5
2001	2.1	-124.1	-29.4	2.2	-4.9	-6.3	0.9	25.6	4.7
2002	2.2	-93.3	-20.0	2.2	-3.5	-4.1	1.0	26.5	4.8
2003	12.1	65.8	26.6	11.5	2.3	5.2	1.1	28.7	5.2
2004	10.1	149.9	36.2	8.1	4.5	6.1	1.2	33.0	6.0
2005	1.7	-53.1	-10.2	1.2	-1.4	-1.5	1.4	38.8	7.0
2006	-1.0	-143.9	-26.7	-0.7	-3.3	-3.4	1.5	43.6	7.8
2007	-8.1	-277.5	-57.2	-5.2	-5.8	-6.6	1.6	47.9	8.7
2008	-12.9	-262.0	-52.1	-8.4	-5.2	-5.7	1.5	50.1	9.1
2009	-0.3	-232.8	-30.2	-0.2	-4.5	-3.2	1.5	51.8	9.5
2010	-0.9	-325.2	-27.2	-0.6	-5.9	-2.7	1.5	55.3	10.2

emissions. Emission factor has a weak function of CO₂ emissions reduction which means that the energy structure of urban residential consumption is more reasonable. With the enhancement of live level and the transformation of consumption structure, the CO₂ emission will expand further.

4.4. Rural Residential Consumption. Through the same manner, the decomposition results of rural residential consumption CO₂ emission can be gotten. Table 10 and Figure 6 show the decomposition results of rural residential consumption CO₂ emission. Columns PF/ ΔP , EF/ ΔE , IF/ ΔI , and DF/ ΔD represent the change of CO₂ emissions when population, economy, efficiency, and emission factors change one percent, respectively. Obviously, the contributions are nearly the same. Figure 7 indicates the accumulated values of CO₂ emissions change in rural residential consumption. The efficiency factor is the main reason for the decrease of rural residential consumption CO₂ emissions. Since China begins to increase the speed of urbanization, the positive effect of population is becoming more and more obvious. Above all, the main reason for the increase of rural residential consumption CO₂

emission is economy factor. With the commercial energy being popularized step by step and residential consumption appliances becoming universal, the rural residential consumption CO₂ emission will increase in the future.

5. Conclusions

- (1) The CO₂ emissions of industry sector are mainly caused by economy factor. Efficiency factor slowed down the speed of CO₂ emission increase. The effect of the industry structure is positive to the change of total CO₂ emission, while the effect of emission factor is not obvious.
- (2) The CO₂ emissions of secondary sector are mainly caused by economy factor. It is very effective to reduce the ratio of secondary sector and energy intensity for CO₂ emissions reduction. Efficiency factor value is always negative in most years which means that efficiency factor mitigates the pressure of CO₂

TABLE 8: Decomposition results of emission factor (1981–2010).

Year	DF ₁ (Mt)	DF ₂ (Mt)	DF ₃ (Mt)	ΔD_1 (%)	ΔD_2 (%)	ΔD_3 (%)	DF ₁ / ΔD_1	DF ₂ / ΔD_2	DF ₃ / ΔD_3
1981	-33.4	43.3	15.5	-25.3	5.4	15.0	1.3	8.1	1.0
1982	0.5	6.5	14.8	0.4	0.8	13.7	1.2	8.3	1.1
1983	0.3	-17.5	-3.8	0.3	-2.0	-3.1	1.2	8.9	1.2
1984	1.2	79.7	-12.3	1.0	8.7	-9.0	1.3	9.2	1.4
1985	-2.1	50.9	0.6	-1.8	4.6	0.4	1.2	11.1	1.5
1986	1.3	28.0	0.7	1.3	2.2	0.4	1.0	12.9	1.7
1987	0.0	9.1	-0.7	0.0	0.6	-0.4	1.1	14.1	1.8
1988	0.6	7.6	-0.5	0.5	0.5	-0.2	1.1	15.2	2.0
1989	-0.5	4.7	-4.6	-0.4	0.3	-2.2	1.2	16.2	2.1
1990	-0.3	-15.2	2.4	-0.3	-0.9	1.1	1.2	16.8	2.2
1991	0.2	-158.2	0.4	0.2	-9.1	0.2	1.2	17.3	2.3
1992	-0.5	-1.5	-3.4	-0.4	-0.1	-1.4	1.2	16.8	2.5
1993	1.9	54.7	1.4	1.6	3.1	0.5	1.2	17.9	2.7
1994	-2.5	-27.0	-2.2	-2.0	-1.4	-0.8	1.2	19.8	3.0
1995	3.2	63.8	3.2	2.5	3.0	1.1	1.3	21.1	2.9
1996	1.6	42.7	-3.7	1.4	1.9	-1.0	1.1	22.9	3.5
1997	-2.9	-49.5	-6.5	-3.1	-2.1	-1.6	0.9	23.6	4.2
1998	0.5	62.8	0.6	0.5	2.7	0.1	0.9	23.1	4.1
1999	-1.7	-46.0	-6.1	-1.8	-1.9	-1.4	0.9	24.1	4.3
2000	-1.2	-26.1	-3.2	-1.3	-1.1	-0.7	0.9	24.4	4.4
2001	-0.7	-6.5	-1.6	-0.7	-0.3	-0.3	0.9	25.0	4.5
2002	1.8	2.6	3.3	1.8	0.1	0.7	1.0	26.0	4.7
2003	1.8	32.4	5.1	1.6	1.1	1.0	1.1	28.9	5.3
2004	-0.4	-8.5	-5.2	-0.3	-0.3	-0.8	1.3	33.8	6.2
2005	-0.9	65.7	-0.6	-0.7	1.7	-0.1	1.4	38.2	7.0
2006	0.3	14.0	1.8	0.2	0.3	0.2	1.5	42.8	7.7
2007	1.0	-63.2	1.0	0.6	-1.3	0.1	1.5	46.8	8.4
2008	-1.1	-49.8	-10.4	-0.7	-1.0	-1.2	1.5	49.0	8.9
2009	0.7	-22.0	5.3	0.5	-0.4	0.6	1.5	50.8	9.3
2010	1.0	56.5	1.9	0.6	1.1	0.2	1.5	53.4	10.0

FIGURE 4: Decomposition results of urban residential consumption CO₂ emissions (1981–2010). FIGURE 5: Accumulated CO₂ emissions change of urban residential consumption (1981–2010).

emissions reduction. Changing the structure of energy can make great contribution to CO₂ emissions

reduction. However, the situation that coal is the main energy will not change in a short period of time.

TABLE 9: Decomposition results of urban residential consumption CO₂ emissions (1981–2010).

Year	PF (Mt)	EF (Mt)	IF (Mt)	DF (Mt)	ΔP (%)	ΔE (%)	ΔI (%)	ΔD (%)	PF/ ΔP	EF/ ΔE	IF/ ΔI	DF/ ΔD	Inaccuracy (%)
1981	9.06	3.86	21.71	-24.25	5.39	2.26	13.40	-13.08	1.68	1.71	1.62	1.85	-3.6E-04
1982	11.66	8.92	-5.21	0.73	6.49	4.93	-2.77	0.39	1.80	1.81	1.88	1.85	4.2E-04
1983	7.21	7.51	-3.64	-0.65	3.70	3.85	-1.81	-0.33	1.95	1.95	2.01	1.99	-3.5E-04
1984	16.17	24.60	-20.08	0.02	7.83	12.15	-8.92	0.01	2.07	2.02	2.25	2.14	1.2E-05
1985	9.33	2.24	-34.17	-2.21	4.48	1.06	-14.87	-1.03	2.08	2.11	2.30	2.14	-6.5E-05
1986	10.12	26.40	-28.38	0.05	5.07	13.78	-12.95	0.02	2.00	1.92	2.19	2.05	3.0E-05
1987	10.23	5.04	-8.37	-0.42	4.96	2.41	-3.88	-0.20	2.06	2.09	2.16	2.12	-8.6E-04
1988	7.73	-5.25	11.50	-2.17	3.57	-2.35	5.35	-0.98	2.17	2.23	2.15	2.22	-8.0E-06
1989	6.79	0.37	-7.45	-2.79	3.07	0.16	-3.26	-1.23	2.21	2.25	2.29	2.26	8.8E-04
1990	4.95	18.15	-16.45	-2.02	2.22	8.37	-7.02	-0.89	2.23	2.17	2.34	2.27	5.9E-04
1991	7.51	15.93	-21.68	-0.96	3.34	7.22	-9.05	-0.42	2.25	2.21	2.40	2.29	1.3E-04
1992	6.76	20.32	-40.01	-5.12	3.12	9.65	-16.62	-2.30	2.17	2.10	2.41	2.23	4.8E-05
1993	6.43	19.17	-32.97	6.01	3.10	9.53	-14.49	2.90	2.07	2.01	2.27	2.08	2.3E-03
1994	6.03	16.66	-26.08	-8.11	3.00	8.51	-12.01	-3.90	2.01	1.96	2.17	2.08	-8.5E-04
1995	5.98	9.82	-6.23	7.45	2.94	4.88	-2.97	3.68	2.03	2.01	2.09	2.03	-3.0E-04
1996	12.57	8.17	-14.95	-8.15	6.06	3.89	-6.75	-3.74	2.08	2.10	2.21	2.18	1.0E-03
1997	11.70	7.03	-17.75	-7.76	5.75	3.42	-8.14	-3.64	2.04	2.06	2.18	2.13	-1.9E-04
1998	11.08	11.67	-19.45	0.82	5.47	5.77	-8.92	0.40	2.02	2.02	2.18	2.08	1.1E-03
1999	10.63	18.86	-22.74	-3.22	5.14	9.31	-10.17	-1.51	2.07	2.03	2.24	2.14	-6.9E-04
2000	10.39	13.40	-16.94	-2.15	4.93	6.41	-7.54	-0.99	2.11	2.09	2.25	2.17	-1.1E-03
2001	10.17	18.05	-20.22	-1.87	4.70	8.50	-8.73	-0.84	2.16	2.12	2.32	2.22	-5.1E-04
2002	10.16	29.22	-26.05	1.99	4.47	13.41	-10.60	0.86	2.27	2.18	2.46	2.31	6.7E-04
2003	10.97	22.39	3.49	5.30	4.31	9.00	1.35	2.06	2.55	2.49	2.58	2.57	7.3E-07
2004	10.77	22.31	9.15	-2.68	3.64	7.70	3.09	-0.89	2.96	2.90	2.96	3.03	-1.6E-04
2005	11.92	31.28	-2.92	0.82	3.55	9.60	-0.85	0.24	3.36	3.26	3.43	3.41	-7.1E-05
2006	13.84	37.82	-12.99	0.38	3.69	10.42	-3.34	0.10	3.75	3.63	3.88	3.82	9.5E-05
2007	16.66	48.58	-18.69	-4.57	4.02	12.20	-4.32	-1.08	4.14	3.98	4.32	4.25	1.2E-04
2008	12.84	35.99	-35.12	-8.72	2.92	8.40	-7.57	-1.93	4.40	4.29	4.64	4.51	-8.4E-06
2009	15.36	43.06	-35.15	3.34	3.38	9.77	-7.32	0.73	4.54	4.41	4.80	4.60	-2.8E-04
2010	18.17	36.36	-52.75	15.91	3.82	7.80	-10.31	3.34	4.75	4.66	5.12	4.77	1.7E-04

FIGURE 6: Decomposition results of rural residential consumption CO₂ emissions (1981–2010). FIGURE 7: Accumulated CO₂ emissions change of rural residential consumption (1981–2010).

(3) The CO₂ emission of residential consumption sector is in a rapid growth phase. Economy factor is the main aspect of increase of CO₂ emissions not only in urban

area but also in rural village. With the commercial energy being popularized step by step and residential consumption appliances becoming universal, the

TABLE 10: Decomposition results of rural residential consumption CO₂ emissions (1981–2010).

Year	PF (Mt)	EF (Mt)	IF (Mt)	DF (Mt)	ΔP (%)	ΔE (%)	ΔI (%)	ΔD (%)	PF/ ΔP	EF/ ΔE	IF/ ΔI	DF/ ΔD	Inaccuracy (%)
1981	0.56	18.90	7.02	-18.54	0.42	15.40	5.46	-13.08	1.32	1.23	1.29	1.42	2.3E - 06
1982	0.49	25.76	-14.50	0.56	0.34	19.89	-9.69	0.39	1.42	1.30	1.50	1.42	-4.5E - 04
1983	1.06	20.19	-12.78	-0.50	0.70	14.20	-8.05	-0.33	1.52	1.42	1.59	1.52	5.5E - 04
1984	-0.80	20.91	-4.29	0.02	-0.49	13.62	-2.58	0.01	1.64	1.54	1.66	1.64	9.6E - 06
1985	0.85	12.24	-30.45	-0.13	0.52	7.78	-17.03	-0.08	1.63	1.57	1.79	1.63	2.5E - 04
1986	0.73	22.55	-24.41	0.10	0.48	15.73	-14.63	0.07	1.54	1.43	1.67	1.54	-5.2E - 04
1987	0.95	-10.19	22.04	0.05	0.60	-6.17	14.79	0.03	1.59	1.65	1.49	1.60	-5.3E - 04
1988	1.57	10.83	5.74	-1.03	0.91	6.40	3.34	-0.59	1.74	1.69	1.72	1.75	4.7E - 04
1989	1.77	-2.97	2.82	-1.58	0.97	-1.61	1.55	-0.86	1.82	1.85	1.82	1.84	-1.1E - 01
1990	2.12	3.25	-6.48	-1.31	1.17	1.80	-3.50	-0.72	1.81	1.80	1.85	1.83	-1.7E - 03
1991	1.04	3.60	-1.39	-0.17	0.57	1.99	-0.76	-0.10	1.82	1.81	1.83	1.82	1.4E - 03
1992	0.82	10.61	-7.34	-3.39	0.44	5.92	-3.90	-1.82	1.84	1.79	1.88	1.86	-7.2E - 03
1993	0.76	5.85	-9.54	7.41	0.41	3.18	-4.98	4.04	1.87	1.84	1.92	1.83	-6.1E - 04
1994	0.75	9.30	-1.78	-6.41	0.39	5.02	-0.93	-3.32	1.90	1.85	1.91	1.93	3.0E - 03
1995	0.61	10.11	-12.05	11.06	0.31	5.30	-5.97	5.81	1.96	1.91	2.02	1.90	-2.4E - 04
1996	-1.83	15.62	-48.93	-4.83	-1.00	8.99	-23.78	-2.63	1.82	1.74	2.06	1.83	3.5E - 05
1997	-1.74	7.27	-6.48	3.26	-1.07	4.59	-3.92	2.03	1.63	1.58	1.65	1.60	-1.5E - 04
1998	-2.00	6.87	-5.86	1.15	-1.22	4.30	-3.53	0.71	1.64	1.60	1.66	1.63	-2.0E - 02
1999	-2.21	6.13	1.29	-4.28	-1.34	3.81	0.79	-2.58	1.65	1.61	1.63	1.66	9.2E - 03
2000	-2.43	3.40	0.67	-0.82	-1.46	2.09	0.41	-0.49	1.66	1.63	1.64	1.65	-2.8E - 03
2001	-2.66	6.90	1.67	-0.24	-1.58	4.20	1.00	-0.15	1.69	1.64	1.67	1.68	-3.3E - 04
2002	-2.93	8.21	5.33	-1.81	-1.66	4.80	3.10	-1.03	1.76	1.71	1.72	1.76	2.3E - 05
2003	-3.41	8.01	22.10	-4.63	-1.78	4.30	12.32	-2.40	1.92	1.86	1.79	1.93	8.1E - 05
2004	-3.23	14.13	19.90	-3.09	-1.49	6.79	9.70	-1.42	2.17	2.08	2.05	2.17	-6.4E - 05
2005	-3.71	14.43	10.06	0.56	-1.53	6.21	4.28	0.23	2.42	2.33	2.35	2.40	-2.0E - 04
2006	-4.90	18.65	6.94	1.16	-1.86	7.40	2.69	0.45	2.64	2.52	2.58	2.61	-1.1E - 04
2007	-6.58	25.93	7.62	0.29	-2.27	9.50	2.70	0.10	2.89	2.73	2.82	2.86	7.3E - 05
2008	-4.68	23.30	-6.27	-6.26	-1.53	8.00	-2.05	-2.05	3.05	2.91	3.06	3.06	7.2E - 04
2009	-6.66	25.87	3.93	0.07	-2.08	8.50	1.25	0.02	3.21	3.04	3.15	3.17	-1.3E - 04
2010	-9.01	34.75	-9.91	-2.29	-2.65	10.90	-2.91	-0.68	3.41	3.19	3.41	3.37	-5.2E - 04

CO₂ emissions of residential consumption sector will increase in the future. It is very important to lead the consumers to choose sustainable live style.

- (4) It is of great importance to transform the economic growth mode to control the CO₂ emissions. Structure factor and efficiency factor can make great contribution to the CO₂ emissions reduction. The former has a more obvious effect and will be the key point of CO₂ emission reduction in the future.

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