Changes in carbon dioxide emissions and LMDI-based impact factor decomposition: the Xinjiang Uygur autonomous region as a case

Li ZHANG^{1,2}, Jun LEI^{1*}, Xuan ZHOU³, XiaoLei ZHANG¹, Wen DONG¹, Yu YANG^{2,4}

¹ Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China;

² University of Chinese Academy of Sciences, Beijing 100049, China;

³ Department of Mathematics, Jinan University, Guangzhou 510632, China;

⁴ Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

Abstract: Studies on carbon dioxide (CO₂) emissions at provincial level can provide a scientific basis for the optimal use of energy and the formulation of CO₂ reduction policies. We studied the variation of CO₂ emissions of primary energy consumption and its influencing factors based on data in Xinjiang Uygur autonomous region from 1952 to 2008, which were calculated according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Xinjiang's CO₂ emission process from 1952 to 2008 could be divided into five stages according to the growth rates of total amount of CO₂ emissions and CO₂ emission intensity. The impact factors were quantitatively analyzed using Logarithmic Mean Divisia Index (LMDI) method in each stage. Various factors, including government policies and technological progress related to the role of CO₂ emissions, were comprehensively analyzed, and the internal relationships among various factors were clarified. The results show that the contribution rates of various impact factors are different in each stage. Overall, economic growth and energy consumption intensity were the main driving factors for CO₂ emissions. Since the implementation of the birth control policy, the driving force of population growth on the increase in CO₂ emissions has slowly weakened. The energy consumption intensity was further affected by the industrial structure and energy consumption intensity of primary, secondary and tertiary industries, with the energy consumption intensity of the secondary industries and the proportion of secondary industries being the most important factors affecting the energy consumption intensity. Governmental policies and technological progress were also important factors that affected CO₂ emissions.

Keywords: CO₂ emissions; Logarithmic Mean Divisia Index; economic growth; energy consumption intensity

Citation: Li ZHANG, Jun LEI, Xuan ZHOU, XiaoLei ZHANG, Wen DONG, Yu YANG. 2014. Changes in carbon dioxide emissions and LMDI-based impact factor decomposition: the Xinjiang Uygur autonomous region as a case. *Journal of Arid Land*, 6(2): 145–155. doi: 10.1007/s40333-013-0242-3

Global warming is one of the most important environmental problems of the time. Strategies and technologies for reducing greenhouse gases, such as CH₄ (Zhang and Chen, 2010), SO₂ (Carmichael et al., 2002) and NO_x (Kadian et al., 2007), have been studied. However, carbon dioxide (CO₂) is considered to be the major greenhouse gas that contributes to global warming (Ma et al., 2011). CO₂ emissions produced from the consumption of fossil fuel-based energy

sources are the largest source of anthropogenic emissions and the primary source of atmospheric greenhouse gases. The annual CO₂ emissions from the consumption of fossil fuels account for approximately 70% of total atmospheric CO₂ emissions (Itousek et al., 1997; Scholes and Noble, 2001). China is the largest producer of CO₂ emissions in the world. At the Copenhagen climate conference, the government of China pledged that China would reduce the intensity

*Corresponding author: Jun LEI (Email address: leijun@ms.xjb.ac.cn)

Received 2012-06-01; revised 2013-04-15; accepted 2013-05-20

© Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Science Press and Springer-Verlag Berlin Heidelberg 2014

of its CO₂ emissions by 40%–45% from 2005 to 2020. Therefore, China is facing major pressure regarding the reduction of CO₂ emissions. Searching for ways to reduce emissions and accelerating the development of a low-carbon economy are important for China to follow the world developmental trend. Reducing CO₂ emissions is also an internal requirement for China to achieve sustainable development.

There have been studies on large-scale areas, such as the Asia-wide emissions of greenhouse gases (Siddiqi, 1995) and global strategy for the reduction of CO₂ emissions (Sinyak, 1995). Researches on Chinese CO₂ emissions mainly addressed the calculation of total CO₂ emissions and spatial patterns of changes in emissions (Zhang et al., 2010; Wang et al., 2011a), CO₂ emission driving forces and influencing factors (Fan et al., 2006; Zha et al., 2010), efficient use of energy and CO₂ reduction policy (Liu et al., 2010), cross-border transfer of CO₂ emissions (Lin and Sun, 2010), and CO₂ emissions prediction based on various econometric models (Fan et al., 2007). Some studies have also been performed at the regional level, such as within Taiwan (Chang et al., 2008), Hong Kong (Leung and Lee, 2000), Shanghai (Li et al., 2010), Anhui and Fujian (Wang et al., 2011b), Tianjin (Ma et al., 2011), Shaanxi (Lu et al., 2010), Hebei (Niu et al., 2011) and Shandong (Hong, 2011).

The economy and society of Xinjiang had great progress after the implementation of the strategy of developing western China and the energy consumption in Xinjiang has increased rapidly. Since 2001, Xinjiang's energy consumption has been accelerating. The proportion of Xinjiang's energy consumption to the country's total has been increasing in terms of energy consumption per RMB 10,000 of GDP and Xinjiang's CO₂ emissions are much higher than the national average (Yao and Gao, 2011). Xinjiang's CO₂ emission status in the country has been highlighted. However, researches about energy consumption and CO₂ emissions are not enough. Therefore, this paper is of great theoretical and practical significance. It can enrich studies of CO₂ emissions at provincial level and provide a scientific basis for the optimal use of energy and the formulation of CO₂ reduction policies in Xinjiang.

1 Study area

The Xinjiang Uygur autonomous region, located in Northwest China of Central Eurasia, has a total area of 1,664,900 km², accounting for 1/6 of China's total land area, and borders eight countries: Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Pakistan, Mongolia, India and Afghanistan (Fig.1). The land border of the region is over 5,600 km long, representing one quarter of China's land border. Xinjiang has rich coal, oil and natural gas resources. As China's leading energy production and reserve base, Xinjiang holds 1/3 of the oil resources, 34% of the land natural gas resources and 40% of the estimated coal reserves in the country. At the end of 2009, the population of the Xinjiang Uygur autonomous region was 21.59 million and Xinjiang's gross domestic product (GDP) was 628.93 billion USD (4,277.05 billion RMB) in 2009.

Fig. 1 Location of Xinjiang Uygur autonomous region

2 Methods and data

2.1 CO₂ emission calculation

The CO₂ emission of primary energy consumption was calculated according to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) as follows:

$$C = \sum_{i=1}^n ef_i \times E_i \quad (1)$$

Where C is the amount of CO₂ emissions, E_i is the i^{th} type of primary energy consumption according to the standard coal calculation in tons of coal equivalent

(tce) and ef_i is the i^{th} energy CO₂ emission coefficient. The raw data use J as the unit, and the unit of energy is converted into standard coal and the specific conversion factor is one ton standard coal, which is equivalent to 29.3 GJ. The calculated coal, oil and natural gas CO₂ emission coefficients were 0.7559, 0.5857 and 0.4483 t/tce, respectively. Finally, i is the type of energy (coal, oil, natural gas), for which the value is 3 here.

2.2 Decomposition of CO₂ emission impact factors

For the quantitative analysis of CO₂ emission impact factors and further investigation of the role of various impact factors, we used the Logarithmic Mean Divisia Index (LMDI) to decompose the CO₂ emissions:

$$\Delta C = \Delta C_p + \Delta C_{inc} + \Delta C_{int} + \Delta C_s, \quad (2)$$

$$\Delta C = C_t - C_0. \quad (3)$$

Where ΔC is the total effect of the difference of CO₂ emissions between year 0 and year t , and consists of four parts: population effect caused by the change of population (ΔC_p), the income effect caused by change of income (ΔC_{inc}), the energy intensity effect caused by the change of the aggregate energy intensity (ΔC_{int}), and the fuel share effect caused by the change of the consumption share of fuel type (ΔC_s).

The expressions for the additive LMDI technique are:

$$\Delta C_p = \sum_{i=1}^3 \frac{C_{i,t} - C_{i,0}}{\ln C_{i,t} - \ln C_{i,0}} \ln\left(\frac{P_t}{P_0}\right), \quad (4)$$

$$\Delta C_{inc} = \sum_{i=1}^3 \frac{C_{i,t} - C_{i,0}}{\ln C_{i,t} - \ln C_{i,0}} \ln\left(\frac{inc_t}{inc_0}\right), \quad (5)$$

$$\Delta C_{int} = \sum_{i=1}^3 \frac{C_{i,t} - C_{i,0}}{\ln C_{i,t} - \ln C_{i,0}} \ln\left(\frac{I_t}{I_0}\right), \quad (6)$$

$$\Delta C_s = \sum_{i=1}^3 \frac{C_{i,t} - C_{i,0}}{\ln C_{i,t} - \ln C_{i,0}} \ln\left(\frac{S_{i,t}}{S_{i,0}}\right), \quad (7)$$

where

$$S_i = \frac{C_i}{C}, \quad (8)$$

$$I = \frac{E}{GDP} \text{ is the energy intensity,} \quad (9)$$

$$inc = \frac{GDP}{P} \text{ is the income.} \quad (10)$$

C is the total CO₂ emissions, C_i is the CO₂ emissions from fuel type i , P is the total population, inc is the per

capita income, I is the energy consumption intensity.

2.3 Decomposition of energy consumption intensity factors

To further explore the factors affecting the intensity of energy consumption, we conducted LMDI decomposition on the energy consumption intensity using the following decomposition formula:

$$I = \frac{E}{GDP} = \frac{\sum_j E_j}{\sum_j GDP_j} = \sum_j \frac{E_j}{GDP_j} \times \frac{GDP_j}{\sum_j GDP_j} = \sum_j e_j \times s_j, \quad (11)$$

where e_j is the energy consumption intensity, indicating the intensity effect; s_j is proportion of the output value as part of the total value of the GDP, indicating the structural effect; and j uses 1, 2 and 3 to represent the primary, secondary and tertiary industries. The total change of energy consumption intensity can be expressed as follows:

$$\Delta I = \Delta I_{e1} + \Delta I_{e2} + \Delta I_{e3} + \Delta I_{s1} + \Delta I_{s2} + \Delta I_{s3}, \quad (12)$$

$$\Delta I_{ej} = \frac{W_{jt} - W_{j0}}{\ln W_{jt} - \ln W_{j0}} \ln\left(\frac{e_{jt}}{e_{j0}}\right), \quad (13)$$

$$\Delta I_{sj} = \frac{W_{jt} - W_{j0}}{\ln W_{jt} - \ln W_{j0}} \ln\left(\frac{s_{jt}}{s_{j0}}\right), \quad (14)$$

$$W_j = e_j \times s_j. \quad (15)$$

Where, ΔI , total change of energy consumption intensity between year 0 and year t ; ΔI_{e1} , energy consumption intensity change of primary industries (ECIC PI); ΔI_{e2} , energy consumption intensity change of secondary industries (ECIC SI); ΔI_{e3} , energy consumption intensity change of tertiary industries (ECIC TI); ΔI_{s1} , proportion change of primary industries (PC PI); ΔI_{s2} , proportion change of secondary industries (PC SI); ΔI_{s3} , proportion change of tertiary industries (PC TI).

2.4 Data source

The data for parameters, such as energy consumption related to coal, oil, natural gas, gross regional product and the total population during 1952–2004, were obtained from “Xinjiang: 50 Years” (Statistical Bureau of Xinjiang Uygur Autonomous Region, 2005); the corresponding data for other years from 2006–2010 came from the “Xinjiang Statistical Yearbook” (Statistical Bureau of Xinjiang Uygur Autonomous Region,

2006–2010). Data on the energy consumption of primary, secondary and tertiary industries from 1985–2008 were taken from the Energy Consumption Balance Table in the “Xinjiang Statistical Yearbook of 1989–2010” (Statistical Bureau of Xinjiang Uygur Autonomous Region, 1989–2010) (because there are no data about energy consumption of primary, secondary and tertiary industries before 1985, the calculation of CO₂ emissions of all three industries and the energy consumption intensity decomposition were performed for 1985–2008).

3 Results

Equation 1 was applied to calculate the CO₂ emissions in Xinjiang over the study years and to calculate parameters such as per capita CO₂ emissions and the amount of CO₂ emissions per RMB 10,000 of GDP.

3.1 Change in the total amount of CO₂ emission

From 1952–2008, Xinjiang’s CO₂ emissions from primary energy consumption exhibited an overall increasing trend from 1.23×10^5 to 4.36×10^7 t, which represented a 353-fold increase over the 56 years. From 1952–1957, Xinjiang’s CO₂ emissions increased rapidly, with the average annual growth rate reaching 19.08%. From 1958–1961 (during the “Great Leap Forward” period), a small peak appeared in the amount of Xinjiang’s CO₂ emissions, and energy consumption exhibited a sharp increase. Following that time, CO₂ emissions slowed down until 2001, when Xinjiang’s CO₂ emissions initiated a new round of rapid growth (Fig. 2).

Fig. 2 Changes in total CO₂ emissions in Xinjiang from 1952–2008

3.2 Structural changes in CO₂ emission

The CO₂ emission of energy consumption depends on the total energy consumption and energy consumption structure, while the structure of energy consumption mainly depends on a country’s (region’s) natural resources, energy strategy, economic and technological development level. Coal-rich countries (regions) often use a large proportion of coal in their total energy consumption. It is generally believed that in industrialized societies, the energy consumption structure is changing gradually from a coal-dominated pattern towards the use of oil, natural gas, hydroelectricity, wind and solar energy. The overall energy consumption structure of Xinjiang from 1952–2008 has been developed in accordance with the above route. In 1952, Xinjiang’s primary energy consumption was based only on coal and oil in proportions of 82.1% and 17.9%, respectively. The proportion of coal gradually declined thereafter until 2008, when the proportions of coal, oil, natural gas and water/wind power involved in primary energy consumption were 61.7%, 20.3%, 13.1% and 4.9%, respectively. The energy consumption structure has been continuously optimized, but the coal-dominated energy consumption pattern has not changed. With respect to CO₂ emissions from primary energy consumption, the CO₂ emissions from coal, oil and natural gas consumption in 2008 were 3.17×10^7 , 0.8×10^7 and 0.39×10^7 t, respectively (Fig. 3), accounting for 72.6%, 18.4% and 9.0% of total emissions, respectively. Coal consumption remained to be the major source of CO₂ emissions.

3.3 CO₂ emission changes in primary, secondary and tertiary industries

Because there are no detailed data on coal, oil and natural gas energy consumption in primary, secondary and tertiary industries for calculating the CO₂ emissions from all three industries and consumption related to daily life, the energy consumption of all three industries and daily life consumption (calculated in standard coal) were multiplied by the CO₂ emission coefficient for Xinjiang’s energy consumption in that particular year (the total CO₂ emissions in that year divided by the amount of energy consumption), which provided the CO₂ emissions of all three industries and daily life consumption over the years.

Fig. 3 Changes in CO₂ emissions from coal, oil, natural gas consumption in Xinjiang from 1952–2008

Since 1985, CO₂ emissions from secondary industries have been in a dominant position in the total CO₂ emissions of primary energy consumption in Xinjiang. The proportion showed an increasing trend (Fig. 4), from 51.1% in 1985 to 67.6% in 2008, similar to the trend of the proportions of production value in secondary industries (increasing from 36% to 49% over the same period). This trend indicates that in the rapid industrialization and developmental stage under Xinjiang's economical level, the secondary industries are still associated with the majority of industrial energy consumption and CO₂ emissions.

Fig. 4 Proportion changes in CO₂ emissions of Xinjiang's primary, secondary and tertiary industries during 1985–2008

3.4 CO₂ emission intensity

Per capita CO₂ emissions increased from 0.06 t/person in 1952 to 2.05 t/person in 2008, which is equivalent to a 35-fold increase over 56 years. The CO₂ emission levels per RMB 10,000 of GDP exhibited an inverted V-shaped curve, first increasing, then decreasing (ex-

cluding the abnormal values of the 4 years from 1958–1961), with the inflection point appearing before and after 1978 (Fig. 5). The increase of per capita CO₂ emissions was mainly because of the improvement of people's living standards that caused the increase of per capital energy consumption. With the development of science and technology and the optimization of industrial structure, the energy utilization efficiency improved continuously, so that the CO₂ emission level per RMB 10,000 of GDP was reduced.

Fig. 5 Changes in Xinjiang's CO₂ emissions per RMB 10,000 of GDP and per capita CO₂ emissions during 1952–2008

Based on a comparison of the CO₂ emission intensities of the different classes of industries (CO₂ emission amount per RMB 10,000 of GDP), we found that the CO₂ emission intensity of secondary industries was significantly higher than those of tertiary industries and primary industries. From 1985–2008, the CO₂ emission intensity of secondary industries declined greatly, but it remained much higher than those of other industries (Fig. 6).

Fig. 6 Changes in CO₂ emission intensity of primary, secondary and tertiary industries during 1985–2008

Table 1 Index values of the evaluation phase of the different CO₂ emission stages

Evaluation index	Stage 1 (1950–1957)	Stage 2 (1958–1961)	Stage 3 (1962–1978)	Stage 4 (1979–2000)	Stage 5 (2001–2008)
	National economy recovery period	Great Leap Forward	Cultural Revolution	Reform and opening-up	Western China development
Average annual GDP growth rate (%)	13.15	8.29	5.07	17.56	15.94
Average annual growth rate of CO ₂ emissions (%)	19.08	43.6	8.03	5.74	10.63
Average annual growth rate of CO ₂ emissions per RMB 10,000 GDP (%)	5.24	20.57	2.83	–10.05	–4.58
Average annual growth rate of CO ₂ emissions per capita (%)	14.83	35.2	4.56	3.81	8.63

3.5 Stages of CO₂ emissions

According to characteristics such as socio-economic developmental status, the growth rate of CO₂ emissions and the CO₂ emission intensity in Xinjiang since 1952, Xinjiang's CO₂ emission process was divided into five stages (Table 1):

Stage 1 (1952–1957): the rapid growth of CO₂ emissions during the national economic recovery. In this stage, Xinjiang's economy grew rapidly, with GDP exhibiting an average annual growth rate of 13%. The total CO₂ emissions, per capita CO₂ emissions and CO₂ emissions per RMB 10,000 of GDP were low, but the CO₂ emissions increased rapidly, with the average annual growth rate reaching 19.5%.

Stage 2 (1958–1961): inefficient energy utilization and abnormal growth of CO₂ emission. This stage corresponded to China's "Great Leap Forward" period. In 1958, after the Beidaihe meeting, a nationwide steel production movement was initiated. However, due to the failure to meet technical specifications, the movement consumed a large amount of energy associated with very low economic benefits, resulting in tremendous waste. CO₂ emissions in Xinjiang increased rapidly during this stage, from 6.56×10^5 t in 1957 to 2.1×10^6 t in 1958. In 1959 and 1960, CO₂ emissions continued to increase rapidly. However, in 1961, the emissions began to decrease at the end of the "Great Leap Forward". A brief peak occurred in CO₂ emissions per RMB 10,000 of GDP and CO₂ emissions per capita during this stage (Fig. 5).

Stage 3 (1962–1978): the slow growth of CO₂ emissions with the slow economic growth. This stage

corresponded to China's "Cultural Revolution" period, when China's economic development was seriously affected. There was slow economic growth, with an average annual GDP growth rate of only 5.06% in Xinjiang, and the increase in the rate of total CO₂ emissions was 8.03%. The growth rate of per capita CO₂ emissions and the average annual growth rate of CO₂ emissions per RMB 10,000 of GDP were 4.56% and 2.83%, respectively.

Stage 4 (1979–2000): the slow growth of CO₂ emissions with the rapid economic growth. This stage corresponded to the rapid economic development occurring during China's reform and opening-up period. Since its reform and opening-up, China has undergone a great historical transformation from a closed economy to an open one. China's economy experienced rapid development and Xinjiang's economy also developed rapidly in this good environment. The GDP of Xinjiang increased 25 fold over the 21 years, and the average annual growth rate reached 17.56%. The industrial structure was optimized at the same time. Compared to the rapid growth of GDP, CO₂ emissions showed no corresponding growth, with an average annual growth rate of only 5.7%, which was closely related to the adjustment and optimization of the industrial structure in Xinjiang.

Stage 5 (2001–2008): the rapid increase of the economy and CO₂ emissions. Since 2001, Xinjiang began to rely on its own mineral resources. Under a series of preferential policies to promote the development of western China, economic progress was achieved in Xinjiang. GDP increased rapidly, with an average annual growth rate of 15.9%. Meanwhile,

the exploration and development of mineral resources, especially coal, oil and natural gas, further accelerated. The coal chemical industry and petrochemical industry developed rapidly. The economic development associated with the industrialization trend was obvious. The proportion of secondary industrial output value gradually increased from 42.4% in 2001 to 49.5% in 2008, with a corresponding decrease for tertiary industries from 38.2% to 34%. The growth rate of Xinjiang's CO₂ emissions in this stage was relatively fast, with the average annual growth rate reaching 10.6%.

3.6 Decomposition of CO₂ emission impact factors

To explore the impact factors for CO₂ emissions and to study various factors associated with CO₂ emissions from Xinjiang in the five stages, we applied Eqs. 2–10 to analyze the amount of CO₂ emissions. The effective values and contribution rates of the impact factors for CO₂ emissions at different stages were obtained (Fig. 7).

Stage 1 (1952–1957): rapid economic growth was the main reason for the increase in CO₂ emissions during this period (the contribution rate reached 50.94%). The increases in the energy consumption intensity and the total population also had large impacts on CO₂ emissions (the contribution rates were 30.31% and 20.84%, respectively).

Stage 2 (1958–1961): energy consumption intensity was the most important contribution factor for the increase in the CO₂ emission intensity at this time (the contribution rate was 74.09%). The economic development exhibited a lower contribution rate to CO₂ emissions (the contribution rate was 9.68%). At this stage, the main reason for the rapid growth of CO₂ emissions could be due to the inefficient use of energy.

Stage 3 (1962–1978): rapid population growth was the main driving force for the increase in CO₂ emissions during this period (the contribution rate was 46.99%). Due to the liberal population policy during this time, following the second baby boom in the 1960s and the third baby boom in the 1970s in Xinjiang, the average annual population growth rate increased by 36%. The rapid population growth contributed to the growth in energy consumption, resulting in

a rapid increase in CO₂ emissions. Following the energy consumption intensity (the contribution rate was 36.71%), the effect of economic growth was weak (the contribution rate was 19.13%) due to slow economic growth in this stage.

Stage 4 (1979–2000): this was the period of fastest economic growth in Xinjiang. Economic development was the main driving force for the growth in CO₂ emissions and showed a strong positive effect (the contribution rate was 258.75%). The impact of the energy consumption intensity on the growth in CO₂ emissions shifted from positive before 1978 to negative in this period (the contribution rate was –188.58%). The sharp decline in the energy consumption intensity significantly reduced the growth rate of CO₂ emissions.

Stage 5 (2001–2008): economic development was still the main driving force for the growth in CO₂ emissions (the contribution rate was 127.02%). When compared to the strong negative effect during Stage 4, the negative effect of the energy consumption intensity at this stage started to diminish (the contribution rate was –45.44%), which was closely related to the increase in the proportion of secondary industries output during this period (further analysis below). The impact of the energy structure on CO₂ emissions was different from the four preceding stages, with a positive effect being observed for the first time (the contribution rate was 1.44%). This result was mainly because of the increase in the proportion of coal consumption in the energy consumption structure, indicating that the structure of energy consumption during this period did not develop in a direction conducive to CO₂ emission reduction.

Overall, economic development exerted a positive effect on CO₂ emissions. Economic growth was the main driving factor for the increase in CO₂ emissions. The impact of the energy consumption intensity on CO₂ emissions showed a positive effect before 1978 and a negative effect after 1978. The absolute values of the contribution rates at various stages were more than 30%, indicating that the main factor of energy consumption intensity reduction (increase) contributed to CO₂ emission reduction (increase). The energy consumption structure showed a negative effect from

Stage 1 to Stage 4, but the contribution rate was small, indicating that the micro-optimization of the energy consumption structure did not change the pattern dominated by coal and had little effect on CO₂ emissions. Population growth exerted a positive effect on the increase of CO₂ emissions. It had the most intense impact on CO₂ emissions in Stage 3. Because of the implementation of the family planning policy, population growth gradually declined, and the driving force of population growth on the growth of CO₂ emissions gradually weakened.

Fig. 7 Contribution rates of CO₂ emission decomposition factors. ECIC PI, energy consumption intensity change of primary industries; ECIC SI, energy consumption intensity change of secondary industries; ECIC TI, energy consumption intensity change of tertiary industries; PC PI, proportion change of primary industries; PC SI, proportion change of secondary industries; PC TI, proportion change of tertiary industries.

3.7 Decomposition of the impact factors of energy consumption intensity

The energy consumption intensity was one of the most important impact factors related to CO₂ emissions, indicating that further exploration of this factor should be undertaken. Similarly, Eqs. 11–15 were applied to energy consumption intensity to perform residual-free decomposition.

Since 1985, Xinjiang's energy consumption intensity (energy consumption per RMB 10,000 of GDP) has continued to decrease, with the reduced energy intensity in secondary industries contributing the most to this decrease (Fig. 8). The rapid decline in the energy consumption intensity of secondary industries was the most important reason for the reduction in the overall energy consumption intensity; the proportion

of the secondary industries output increased (decreased), having a large impact on the increase (decrease) in the energy consumption intensity. From 2001–2008, the contribution rate of the proportion of the secondary industries output to the energy consumption intensity was negative, indicating that since the implementation of the national policy to develop western China in 2001 and because the proportion of

Fig. 8 Contribution rates of various decomposition factors related to the energy intensity

secondary industries output gradually increased, the overall energy consumption intensity was reduced. This was an important reason for the decrease in the negative effect of CO₂ emissions related to the Stage 5 overall energy consumption intensity on the amount of CO₂ emissions. In summary, the energy consumption intensity of secondary industries and the proportion of the secondary industries output were the major factors that affected the energy consumption intensity. Therefore, improved energy efficiency of secondary industries, continuous optimization of the industrial structure and gradually increased proportion of the total output of tertiary industries increased the overall energy efficiency of the region and, thus, controlled the important parameters related to excessive growth.

3.8 Comprehensive analysis of impact factors

Although the application of an LMDI decomposition model was able to quantitatively analyze the effects of various impact factors on CO₂ emissions, it ignored the impact of governmental policies and technological advances on CO₂ emissions and could not show the relationships between impact factors. Therefore, based on quantitative analysis, we comprehensively ana-

lyzed the role of various factors on CO₂ emissions, including governmental policies and technological progress, as well as clarified the internal relationships between various factors.

Based on our review of Xinjiang's CO₂ emission situation since 1952, we observed that the impact of governmental policies on CO₂ emissions was very significant. However, the policies did not act directly on CO₂ emissions but rather influenced social and economic development, the energy consumption structure, population growth and the industrial structure, which indirectly affect CO₂ emissions. This phenomenon is mainly reflected in the following policies. 1) Socio-economic policies: these include policies with major, far-reaching impacts, such as the "Great Leap Forward", the reform and opening-up and the development of western China, which resulted in a historic turning point in the economic development of Xinjiang and caused the CO₂ emission situation to change accordingly. Socio-economic development further promoted regional technological progress and the optimization and upgrading of the industrial structure, leading to further declines in the energy consumption intensity and ultimately reducing the increases in the amounts of CO₂ emissions. 2) Energy policies: in certain economic and technological conditions, the energy consumption structure at national and large regional scales depends on natural resources, while energy policies had an effect on the energy consumption structure. Although energy policies could not change Xinjiang's fundamental coal-dominated

energy consumption patterns in a short-term, through policy guidance, the energy consumption structure has gradually been optimized, and the proportion of low-carbon energy resources in the total energy consumption has continuously increased, thus resulting in the slow growth in CO₂ emissions. 3) Population policies: human demand for energy was the direct driving force for the growth of energy consumption. Population growth and improved living standards resulting in increased energy demand per capita could lead to increases in the total energy consumption, and population policies had a direct impact on population growth. 4) Industrial policies: the government affected CO₂ emissions through market and administrative mechanisms to guide the industrial structure by optimization and upgrading, decreasing the energy consumption intensity (Fig. 9).

Overall, governmental policies, economic growth and energy consumption intensity were the main driving factors for CO₂ emissions. The policies act indirectly on CO₂ emissions. However, economic development and energy consumption intensity act directly on CO₂ emissions. The rapid growth of China's economy depends on the rapid growth of resource and energy consumption. This is an extensive pattern of economic growth. Therefore, economic growth is the main driving factor for CO₂ emissions. The government has noticed this problem and improved energy utilization efficiency by setting out a series of related policies and measures, which decelerated the increase of CO₂ emissions.

Fig. 9 Diagram of the interaction between CO₂ emission impact factors

4 Conclusions and suggestions

Xinjiang's CO₂ emissions have gone through five stages, and the contribution rates of various impact factors are different in the five stages. Overall, governmental policies, economic growth and energy consumption intensity were the main driving factors for CO₂ emissions. Therefore, making proper policies and decreasing the energy consumption intensity are important measures to achieve the targets of CO₂ emission reduction. Xinjiang's coal-dominated energy consumption patterns have not changed considerably, so the energy consumption structure had little impact on CO₂ emissions. Since the implementation of the family planning policy, the driving force of population growth on the increase in CO₂ emissions has slowly weakened. The energy consumption intensity was further affected by the industrial structure, with the energy consumption intensity and the proportion of the secondary industries being the most important factors.

Governmental policies and technological progress were important factors that affected CO₂ emissions. In China, the impacts of policies on energy consumption and CO₂ emissions have been very significant. Policies have indirect impacts on CO₂ emission generation through affecting social and economic development, the energy consumption structure, population growth and industrial structure; technological progress was promoted by social and economic development and influenced the energy consumption intensity to produce an effect on CO₂ emissions.

For the above, we conclude that Xinjiang can reduce CO₂ emissions from several respects: Firstly, to integrate the resources of heavy chemical industries and speed up product upgrading, and in addition, energetically develop high and new technology industries and modern service industries, constantly improving the proportion of tertiary industries in the national economy and changing the way of economic development from extensive to intensive as soon as possible. Secondly, to support the development of wind power, solar and biomass energy projects in order to keep sustained growth in the proportion of non-fossil energy resources. Moreover, to make full use of

the advantage of abundant natural gas resources in Xinjiang and increase the proportion of natural gas in energy consumption. Thirdly, to increase investments in the advanced energy-saving technologies and to apply innovative technologies to energy exploitation and utilization, vigorously advocating the concept of low-carbon consumption and green consumption and guiding consumption patterns to a sustainable direction.

Acknowledgements

This project was funded by the National Natural Science Foundation of China (41101159) and the Western Doctor Project of West Light Foundation of the Chinese Academy of Sciences (XBBS201009).

References

- Carmichael G R, Streets D G, Calori G, et al. 2002. Changing trends in sulfur emissions in Asia: implications for acid deposition, air pollution, and climate. *Environmental Science & Technology*, 36(22): 4707–4713.
- Chang Y F, Lewis C, Lin S J. 2008. Comprehensive evaluation of industrial CO₂ emission (1989–2004) in Taiwan by input-output structural decomposition. *Energy Policy*, 36(7): 2471–2480.
- Eggleston H S, Buendia L, Miwa K, et al. 2006. The 2006 IPCC guidelines for national greenhouse gas inventories. Japan: Institute for Global Environmental Strategies, 11–29[2012-05-01]. <http://down.pinggu.org/html/20100611/14645.html>.
- Fan Y, Liu L C, Wu G, et al. 2006. Analyzing impact factors of CO₂ emissions using the STIRPAT model. *Environmental Impact Assessment Review*, 26(4): 377–395.
- Fan Y, Liang Q M, Wei Y M, et al. 2007. A model for China's energy requirements and CO₂ emissions analysis. *Environmental Modelling & Software*, 22(3): 378–393.
- Hong X. 2011. The calculation of carbon emissions of Shandong province and the comparison with the national average. *Energy Procedia*, 5: 1514–1518.
- Itousek P M, Mooney H A, Jane L, et al. 1997. Human domination of earth's ecosystems. *Science*, 277(25): 494–499.
- Kadian R, Dahiya R P, Garg H P. 2007. Energy-related emissions and mitigation opportunities from the household sector in Delhi. *Energy Policy*, 35(12): 6195–6211.
- Leung D Y C, Lee Y T. 2000. Greenhouse gas emissions in Hong Kong. *Atmospheric Environment*, 34(26): 4487–4498.
- Li L, Chen C, Xie S, et al. 2010. Energy demand and carbon emissions under different development scenarios for Shanghai, China. *Energy Policy*, 38(9): 4797–4807.
- Lin B Q, Sun C W. 2010. Evaluating carbon dioxide emissions in

- international trade of China. *Energy Policy*, 38(1): 613–621.
- Liu W D, Zhang L, Wang L M, et al. 2010. A sketch map of low-carbon economic development in China. *Geographical Research*, 5: 778–788.
- Lu C Y, Zhang X L, He J K. 2010. A CGE analysis to study the impacts of energy investment on economic growth and carbon dioxide emission: a case of Shaanxi province in western China. *Energy*, 35(11): 4319–4327.
- Ma C, Ju M T, Zhang X C, et al. 2011. Energy consumption and carbon emissions in a coastal city in China. *Procedia Environmental Sciences*, 4: 1–9.
- Niu X G, Niu J G, Men D. 2011. Energy consumption and carbon emissions: analysis and prediction—the case of Hebei province in China. *Energy Procedia*, 5: 2271–92277.
- Scholes R J, Noble I R. 2001. Storing Carbon on Land. *Science*, 29(2): 1012–1013.
- Siddiqi T A. 1995. Asia-wide emissions of greenhouse gases. *Annual Review of Energy and the Environment*, 20(1): 213–232.
- Sinyak Y. 1995. Economics of a global strategy for reduction of carbon emissions. *International Journal of Environment and Pollution*, 5(1): 30–51.
- Statistical Bureau of Xinjiang Uygur Autonomous Region. 1989–2010. *Statistical Yearbooks of Xinjiang Uygur Autonomous Region*. Beijing: China Statistics Press.
- Statistical Bureau of Xinjiang Uygur Autonomous Region. 2005. *Statistical Yearbooks of Xinjiang Uygur Autonomous Region from 1955 to 2005*. Beijing: China Statistics Press.
- Wang S S, Zhou D Q, Zhou P, et al. 2011a. CO₂ emissions, energy consumption and economic growth in China: a panel data analysis. *Energy Policy*, 39(9): 4870–4875.
- Wang R, Liu W J, Xiao L S, et al. 2011b. Path towards achieving of China's 2020 carbon emission reduction target—A discussion of low-carbon energy policies at province level. *Energy Policy*, 39(5): 2740–2747.
- Yao L L, Gao Z G. 2011. The role of Xinjiang in low carbon China: challenges and strategy. *Finance & Economics of Xinjiang*, 2: 41–44.
- Zha D L, Zhou D Q, Zhou P. 2010. Driving forces of residential CO₂ emissions in urban and rural China: an index decomposition analysis. *Energy Policy*, 38(7): 3377–3383.
- Zhang B, Chen G Q. 2010. Methane emissions by Chinese economy: inventory and embodiment analysis. *Energy Policy*, 38(8): 4304–4316.
- Zhang L, Huang Y X, Li Y M, et al. 2010. An investigation on spatial changing pattern of CO₂ emissions in China. *Resources Science*, 2: 211–217.