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Original Article

The effects of urbanization and household-related factors on residential direct CO_2 emissions in Shanxi, China from 1995 to 2014: A decomposition analysis

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A B S T R A C T

Multiple household-related driving factors of residential direct carbon emissions (RDCE) in China at regional level have not yet been sufficiently addressed or quantified. In this paper, a logarithmic mean Divisia index (LMDI) decomposition analysis was employed to examine the factors (e.g., the number of households, per capita household income, household size, urbanization, energy intensity, energy structure and emission coefficient) impacting the changes in RDCE in Shanxi province of China from 1995 to 2014. The results showed that the increase in RDCE mainly attributed to the growing per capita household income and the increasing number of households. Additionally, the expansion of urbanization also contributed marginally to the increase in emissions. However, the shrinking household size was a main inhibitory factor and the decline in energy intensity was also responsible for the diminishing emissions. Based on the results, four emission reduction measures and strategies were identified: (i) using market economic mechanism to regulate household consumption behaviors towards environment protection and low carbon development, as well as encouraging the use of energy-efficiency domestic appliances and less energy-intensive lifestyles; (ii) setting strict divorce processes to lower divorce rates and encouraging people to live with their children and parents; (iii) realizing green transformation development of urbanization; (iv) promoting a shift to renewable and clean energy in people's daily life and power generation, e.g., wind, solar, hydro, nuclear and biogas.

1. Introduction

It is well-known that global warming, which seriously threatens the survival and development of mankind, mainly driven by the continual growth of CO_2 emissions. As the world's largest carbon emitter, China was responsible for 23.4% of global CO_2 emissions in 2014 (Wang et al., 2016). To mitigate the CO_2 emissions, the Chinese government promised to reach the peak of CO_2 emissions no later than 2030 and implement the carbon intensity reduction of 60–65% below 2005 levels by 2030 (China's State Council, 2015), which indicates that mitigating carbon emissions has become a strategic imperative of China. As the second-largest energy consuming and carbon emitting sector in China (Nie and Kemp, 2014), the residential sector consumed 396.66 Mt (million tons) standard coal equivalent of energy in 2012, rising by 131.13% compared to 2000 (Wang and Yang, 2016). Meanwhile, the residential CO_2 emissions showed an annual growth rate of 8.7% after the year 2000 (Fan et al., 2013). Consequently, it is vital for Chinese government to effectively control residential CO_2 emissions growth for achieving the national emissions reduction goal. Residential CO_2 emissions can be divided into residential direct and indirect CO_2 emissions (Weber and Perrels, 2000; Wei et al., 2007). The residential indirect CO_2 emissions is from the energy consumption indirectly consumed in different phases of the lifecycle of goods and services, such as in their production, transportation and marketing (Wang and Yang, 2016), while the residential direct CO_2 emissions (RDCE) refers to the CO_2 emissions from the consumption of energy carriers (such as fossil fuels, heat and electricity) purchased directly by households for space lighting, space heating, cooking, water heating, using household appliances and driving private vehicles (Wei et al., 2007; Yuan et al., 2015). Currently,

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residential direct energy consumption and RDCE have changed greatly and represented significant potentials of energy savings and emissions reduction around the world during the last two decades (Nejat et al., 2015).

As an inner province in central China, Shanxi province has entered the stage of accelerating urbanization process since 1995, and its urbanization level is expected to pass 60% by 2020 (Standing Committee of Shanxi Provincial Party Committee, 2015). Based on the information from Shanxi Statistical Yearbook, the number of households in Shanxi province increased from 7.70 million to 11.97 million during 1995–2014. Meanwhile, the annual growth rate of the number of households was 2.78%, which was much more than the annual growth rate of permanent population (0.94%). Moreover, the household size decreased from 4.00 members to 3.09 members during 1995–2014, and the per capita incomes of urban and rural households respectively rose from 395.88 USD to 1827.62 USD (1995 constant price) and from 144.69 USD to 624.18 USD, representing an annual average growth rate of 8.38% and 8.00%, respectively. Along with the rapid development of urbanization, the significant increase in the number of households and the continuous improvement of people's living standards in Shanxi province, the total residential direct energy consumption has also drastically increased from 6.92 Mtce (million tons coal equivalent) in 1995 to 16.08 Mtce in 2014, implying an annual average growth rate of 6.62%. Accordingly, RDCE has also increased from 23.62 Mt in 1995 to 68.05 Mt in 2014, with an annual growth rate of 6.42%. Furthermore, Shanxi province is one of the biggest coal-producing provinces in China, and coal is the major energy resource in both urban and rural households. Rapid urbanization, shrinking household-related factors and irrational energy structure are vital in driving RDCE in Shanxi. However, the influences of these factors on CO_2 emissions are complicated and various based on different research samples and methods, it is uncertain whether the previous findings are available for Shanxi. Thus, a detailed analysis about residential direct CO_2 emissions of Shanxi province is urgently required.

Under these circumstances, this study takes Shanxi province of China as an example to analyze the effects of three household-related factors (e.g., the number of households, the per capita household income and household size), urbanization, energy intensity, energy structure and emission coefficient on RDCE from 1995 to 2014 with the LMDI method. Furthermore, this paper aims to solve three major problems. First, systematically examining the impacts of three household-related factors on RDCE in Shanxi Province. Second, identifying the relationship between urbanization and RDCE. Third, finding effective and practical policies for Shanxi province to mitigate the RDCE.

The remainder of this paper is organized as follows. Section 2 presents a literature review. Section 3 details the decomposition method and the data source. Results and discussions are reported in Section 4. Section 5 concludes this study.

2. Literature review

In recent years, a great number of researchers have taken considerable interest in the underlying factors influencing the residential direct energy consumption and related CO_2 emissions. Among the existing literatures, population has been widely examined as one of the key contributing factors of residential energy consumption. The results indicated that growing population had an increasing effect on residential energy use (Liu and Zhao, 2015; Zhao et al., 2012; Holzmann et al., 2013). In fact, household is the basic unit of society, and family members usually share living space, domestic appliances, sanitary facilities, shower facilities, kitchen utensils and private vehicles with each other. Therefore, each household can be regarded as a unit regarding to the residential direct energy consumption. To date, several foreign researchers have already used it instead of population in their index decomposition analyses. Shorrock (2000) applied decomposition method to identify the carbon emissions changes of domestic sector in the United Kingdom between 1990 and 2000. The results displayed that the growing number of households increased carbon emissions by 3.6 Mt. Chung et al. (2011) decomposed the changes of residential energy consumption over the period of 1990–2007 into four contributing factors: number of households, household type, energy consumption per household, and climate effect. They discovered that the increasing number of households was the major contributor to the increase in energy consumption. Using household surveys from 1980 to 2005, Hojjati and Wade (2012) decomposed the changes in household energy consumption of the United States, founding that the number of households had the most significant increasing effect on national household energy consumption.

Apart from the number of households, previous studies have shown that per capita income of households and household size, which are other two considerable household-related factors, influenced residential energy consumption and related CO_2 emissions. Regarding per capita income of households, several researchers have used it as an income effect in the index decomposition analysis of China's residential issues. These studies revealed that the per capital income of households played an important role in increasing the residential energy consumption and carbon emissions at national level, regional level and urban-rural level (Liu and Zhao, 2015; Zha et al., 2010; Lin and Liu, 2015). When it comes to the impacts of household size on residential direct energy consumption or related carbon emissions, Tso and Guan (2014) introduced a multilevel regression model to calculate the effects of environment indicators and household features on residential energy consumption. They found that household size was one of the significant determinants in residential energy consumption. Wilson (2013) used a unique dataset to examine the relationship between residential electricity consumption and subdivision design characteristics. The results indicated that household size, number of bedrooms and reliance on electricity for space heating were all significant and exerted positive influences on annual electricity consumption. Meier and Rehdanz (2010) studied the determinants of residential space heating expenditures in Great Britain. The results showed that heating expenditure increased with the expansion of household size. Lin et al. (2013) presented a survey-based GHG (greenhouse gas) emissions accounting methodology for urban residential consumption, and held the view that housing area and household size were the two main factors determining GHG emissions from residential consumption at the household scale.

Urbanization is another crucial factor when examining residential energy consumption and CO_2 emissions in rapidly emerging economies (Komatsu et al., 2013). The urbanization level in China rose from 26.4% in 1990 to 51.3% in 2011, and it will increase to 60% by 2030 (Xu and Lin, 2015). Urbanization may make people's way of life shift from rural to urban lifestyle, and the changes of residents' consumption demands and behaviors will increase the residential CO_2 emissions (Wang et al., 2014). Wang et al. (2014) has investigated the effects of China's urbanization on residential energy consumption from 1980 to 2011 through a time-series analysis, and found that urbanization slowed per capita residential energy consumption growth but had greater promotional effects on the growth of residential energy consumption. Yuan et al. (2015) have investigated the impacts of urbanization on residential indirect CO_2 emissions in China during 2002–2007, and results suggested that the expansion of urbanization played an important role in the growth of residential indirect emissions. However, few quantitative studies have focused on the effects of urbanization on residential direct emissions. Among the few studies, Wang et al. (2015) explored the underlying influencing factors of direct household energy-related carbon emissions in Guangdong province of eastern China from 1995 to 2012 by using decomposition analysis. Their research indicated that the improvement of urbanization level overall promoted household carbon emissions growth in a certain extent. Xu and Lin (2016) analyzed the key driving forces of pollution emissions at the regional level based on the panel data and panel data models. The results showed that the impacts of urbanization on pollution emissions varied across regions in China and decreased continuously from the central region to the western and eastern regions. Therefore, in order to provide differentiated measures for carbon emissions, it is crucial and valuable to pay attention to the impacts of urbanization on RDCE in China's central or western provinces.

In addition, most of the researchers have studied the driving forces of residential energy consumption or related CO_2 emissions at national level for various countries, such as French (Charlier and Risch, 2012), Netherlands (Papachristos, 2015), UK (Williams et al., 2012), the United States (Bin and Dowlatabadi, 2005; Estiri, 2014), Austria (Holzmann et al., 2013), Brazil (Achão and Schaeffer, 2009), India (Ahmad et al., 2015; Yeo et al., 2015), South Korea (Oh et al., 2010), Malaysia (Sohag et al., 2014) and China (Zha et al., 2010; Fan et al., 2013; Xu et al., 2014; Yeo et al., 2015). China is a large country with a vast territory and exhibits significant diversities in regional development. Due to the regional differences in the number of households, living standard of residents and natural resources endowment, the carbon emissions exhibit marked variability among provinces. However, only a handful of previous literatures have paid attention to the residential CO_2 emissions from provincial perspective. For instance, Wei et al. (2014) identified the effects of household characteristics (income and expenditure, household size, vehicles, residence period, locations and housing types) on energy spending of Shanghai based on fractional logit regression approach and a data set of floating people. Wang and Yang (2016) studied the indirect CO_2 emissions of Beijing by SDA (structure decomposition analysis) method.

Acknowledging the contributions of previous research works, this study can fill some gaps. First, the above studies about Chinese issues mainly regarded people as the unit of residential energy consumption and they explored the influential effect of people. However, family members usually share living space, household appliances, as well as other household equipment. Therefore, this paper is concerned with the impact of the number of households instead of people. Second, even though the two factors such as per capital income of households and household size have been investigated, most studies just focused on one of the two variables. In this paper, comprehensive study concerning multiple household-related factors is conducted. Third, the quantitative studies discussing the impact of urbanization on RDCE using LMDI method are still limited. In fact, the urbanization is an important factor influencing the residential CO_2 emissions, because urbanization level could affect people's daily life by transferring from rural to urban area, which will increase the residential CO_2 emissions. In response, this study discusses the urbanization effect on RDCE. Fourth, Most studies are from national perspective, seldom from the viewpoint of a province. Even though Wei et al. (2014), Wang et al. (2015) and Wang and Yang (2016) have conducted their studies at provincial or city level, the impact factors explored are different with this study. Therefore, a deeper analysis of the multiple household-related factors and urbanization at provincial level is further required to determine more detailed and specific explanations for RDCE changes. As Shanxi is a typical province of traditional energy consumption, in order to provide differentiated measures to realize the targets of carbon reduction, this paper focuses on the impact of household-related factors and urbanization on RDCE in Shanxi province by LMDI model.

3. Research methodology and data

3.1. The decomposition analysis

To quantify the impacts of different factors on the changes in energy consumption and CO_2 emissions, various decomposition methods have been proposed. Among them, the most widely applied methods are SDA and index decomposition analysis (IDA) (Ang, 2004; Wachsmann et al., 2009). Compared with SDA which is based on the input–output table (issued in the special year), IDA has the advantages of using annually updated data, and is popular among both domestic and foreign scholars (Xu et al., 2014). Howarth et al. (1991) and Ang and Zhang (2000) respectively gave details on two kinds of IDA methodologies: the Laspeyres index decomposition analysis and the Divisia index decomposition analysis. However, in the application of the Laspeyres index method, a large residual term which is a significant part of the examined changes is left unexplained (Ang and Zhang, 2000; Ang et al., 1998). Based on the Divisia index, Ang and Liu (2001) proposed the LMDI method, and then Ang (2004) deduced that the LMDI method was better than other IDA methods due to its theoretical foundation, adaptability, ease of use and result interpretation, and other desirable properties. Therefore, this study employs the LMDI method.

The LMDI analysis of CO_2 emissions from residential direct energy consumption in year t can be conducted by the following Eq. (1):

$$C^t = \sum_{ij} C^t_{ij} = \sum_{ij} \frac{C^t_{ij}}{E^t_{ij}} \times \frac{E^t_{ij}}{E^t_i} \times \frac{E^t_i}{RI^t_i} \times \frac{RI^t_i}{P^t_i} \times \frac{P^t_i}{P^t} \times \frac{P^t}{H^t} \times H^t = \sum_{ij} CI^t_{ij} \times ES^t_{ij} \times EI^t_i \times HPI^t_i \times U^t_i \times HS^t \times H^t \quad (1)$$

where i represents resident type ($i = 1$ for urban or 2 for rural); j represents various energy type; C^t represents the total CO_2 emission from residential direct energy consumption in year t; C^t_{ij} represents the CO_2 emissions based on fuel j of resident type i in year t; E^t_{ij} represents the energy consumption based on fuel j of resident type i in year t; E^t_i represents the total residential direct energy consumption of resident type i in year t; RI^t_i represents the residential incomes of resident type i in year t; P^t_i represents the population of resident type i in year t; P^t represents the total population in year t; H^t represents the total number of households in year t; $CI^t_{ij} = C^t_{ij}/E^t_{ij}$ represents the emissions coefficient of fuel j of resident type i in year t; $ES^t_{ij} = E^t_{ij}/E^t_i$ represents the share of fuel type j in the total energy consumption of resident type i in year t; $EI^t_i = E^t_i/RI^t_i$ represents the energy intensity of resident type i in year t; $HPI^t_i = RI^t_i/P^t_i$ represents the per capita income of households of resident type i in year t; $U^t_i = P^t_i/P^t$ represents the population ratio of resident type i in year t and denotes urbanization. $HS^t = P^t/H^t$ represents the number of residents per household in year t and denotes household size.

Referring to Ang (2004), the variation in CO_2 emissions between year 0 and year t (ΔC^t_{tot}) can be expressed as the following formula:

$$\Delta C^t_{tot} = C^t - C^0 = \sum_{ij} CI^t_{ij} ES^t_{ij} EI^t_i HPI^t_i U^t_i HS^t H^t - \sum_{ij} CI^0_{ij} ES^0_{ij} EI^0_i HPI^0_i U^0_i HS^0 H^0 = CI_{effect} + ES_{effect} + EI_{effect} + HPI_{effect} + U_{effect} + HS_{effect} + H_{effect} \quad (2)$$

where CI_{effect} is the emission coefficient effect. It reflects the CO_2 emissions change caused by the variation in the ratio of carbon emissions to energy consumption. As the emission factors for conventional fuels remain constant, this effect is largely determined by the changes in the heat and electricity coefficients over the study period; ES_{effect} is the energy structure effect, referring to the CO_2 emissions change caused by the change in the relative shares of energy forms in total energy consumption; EI_{effect} is the energy intensity effect, which represents the CO_2 emissions change caused by the change in the ratio of energy consumption to residential incomes of households; HPI_{effect} is the per capita household income effect. It reflects the CO_2 emissions change caused by the change in the per capita income of households; U_{effect} is the urbanization effect and means the CO_2 emissions change caused by the change in the ratio of urban population to total population; HS_{effect} is the household size effect. This effect reflects the CO_2 emissions change caused by the shrinking household size. The household size was defined as the average number of permanent residents per household: household size = total population/total households; H_{effect} is the household effect. It reflects the CO_2 emissions change caused by the change in the total number of households.

Each effect on the right hand side of Eq. (2) can be calculated as follows:

$$CI_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{CI_{ij}^t}{CI_{ij}^0}\right) \quad (3)$$

$$ES_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{ES_{ij}^t}{ES_{ij}^0}\right) \quad (4)$$

$$EI_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{EI_i^t}{EI_i^0}\right) \quad (5)$$

$$HPI_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{HPI_i^t}{HPI_i^0}\right) \quad (6)$$

$$U_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{U_i^t}{U_i^0}\right) \quad (7)$$

$$HS_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{HS^t}{HS^0}\right) \quad (8)$$

$$H_{effect} = \sum_{ij} L\left(C_{ij}^t - C_{ij}^0\right) \ln\left(\frac{H^t}{H^0}\right) \quad (9)$$

where

$$L\left(C_{ij}^t - C_{ij}^0\right) = \begin{cases} \dfrac{C_{ij}^t - C_{ij}^0}{\ln C_{ij}^t - lnC_{ij}^0}, & C_{ij}^t \neq C_{ij}^0 \\ C_{ij}^t, & C_{ij}^t = C_{ij}^0 \end{cases} \quad (10)$$

3.2. Data sources

The study period spans from 1995 to 2014. Urban and rural annual data for the per capita income of households, household size and population are all from the Shanxi Statistical Yearbook (Shanxi Bureau of statistics, 1996–2015). Urban and rural annual data on residential direct energy consumption are from China Energy Statistical Yearbook (National Bureau of Statistics of China, 1996–2015). The per capita income of households is converted to 1995 constant price (USD). To organize data for easily undertaking the decomposition analysis, all kinds of the residential direct energy consumption are classified into seven types, i.e. coal, coke, coke gas, oil, natural gas, heat and electricity.

The detailed computational formulas of RDCE and emission coefficients of heat and electricity are presented in Appendix A.

3.3. Data description

Fig. 1 depicts the changes of RDCE in Shanxi from 1995 to 2014. The total RDCE increased to 66.40 Mt (million tons) in 2014 from 22.69 Mt in 1995, with an annual growth rate of 5.81%. The change of total RDCE showed a curve of three-stage growth pattern: a slow waved stage between 1995 and 2000, a moderate speed growth stage from 2001 to 2007, and then a high speed growth stage from 2008 to 2014. The total RDCE was not more than 25.02 Mt during the period 1995–2000, whereas increased by more than 10 Mt from 2001 to 2007. The annual growth rate in the third stage significantly increased to 11.39%, compared with 5.87% in the

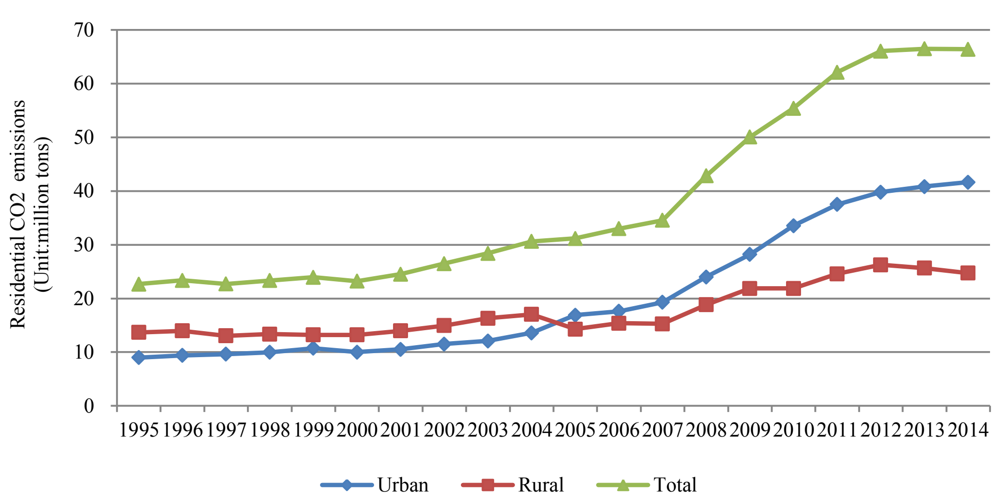

Fig. 1. Residential direct CO_2 emissions in the urban and rural areas of Shanxi province from 1995 to 2014.

second stage. In a word, the rapid increase of RDCE in Shanxi since 2001 has become a severe and urgent problem.

4. Results and discussions

Table 1 and Fig. 2 present aggregate and annual results of decomposition analysis. Increasing and decreasing effects on RDCE of Shanxi province have been showed from 1995 to 2014. The results indicated that only three out of seven analyzed influence factors had a decreasing effect on RDCE of Shanxi: changes in household size, energy intensity and emission coefficient. Changes in per capital income of households, the number of households, urbanization and energy structure were responsible for the increasing emissions.

4.1. The per capita household income effect

The per capita household income effect (HPI_{effect}) was the strongest and most stable promoting factor over the 1995–2014 period, which contributed 57.46 Mt to the aggregate increase of RDCE with a contribution ratio of 131.46% (Table 1). This effect increased the RDCE during the whole study period. It could be explained by the remarkable growth of per capita income in both urban and rural households, as shown in Fig. 3. From 1995 to 2014, the per capita incomes of urban and rural households respectively rose from 395.88 USD to 1827.63 USD and from 144.69 USD to 624.18 USD, representing an annual average growth rate of 8.38% and 8.00%, respectively.

Since the Reform and Opening up, the income and living standard of both urban residents and rural households in Shanxi province have obtained a great achievement. First, the per capita floor space of rural and urban residents respectively increased from 17.13 m^2 (square meter) in 1995 to 32.90 m^2 in 2014 and from 17.22 m^2 in 2002 to 29.35 m^2 in 2014 (Shanxi Bureau of statistics, 1996–2015). Second, with the expansion of living space and the improvement of living conditions, the energy consumption for household light and heating were growing continuously. Third, the ownership of all kinds of appliances (washing machine, refrigerator, micro-wave oven, color television, air conditioner, telephone, mobile telephone and computer) increased both in urban and rural households (Table B1 and Table B2). Besides, both urban and rural household vehicles experienced explosive growth over the study period. Ownership of household cars per 100 urban households rose rapidly from 3.13 set in 2005 to 24.24 set in 2014 (Table B1). Consistently, ownership of motorcycles per 100 rural households at the end of 2014 was 55.94 set, comparing 3.33 set in 1995 (Table B2). These were followed by a sharp increase in the consumption of gasoline and diesel oil.

In terms of annual data, the 1998 and 2008 financial crises dramatically slowed the growth rate of the income in urban and rural areas, which explained why the per capita household income effect was not the most important effect in increasing RDCE during 1998–1999 and 2008–2009. It was obvious that since China acceded to WTO (World Trade Organization) in 2001, the per capita household income has significantly increased, which resulted in a certain growth of RDCE. In addition, the Chinese government issued the “Central First Document” about improving peasants' income in 2004 and abolished the agricultural taxation in 2006. These two policies ensured that the per capita income of rural residents increased rapidly and played an important role in promoting the RDCE. In 2009, the Standing Committee of the State Council of China implemented the “Central China's Rising Strategy”, which stated that central China (including six provinces: Shanxi, Henan, Anhui, Jiangxi, Hubei and Hunan) should achieve the 9% annual growth rate of per capita urban and rural income during 2009–2015 (NDRC, 2009). This strategy explained the significant increase of RDCE after the period of 2008–2009 (Table 1).

According to the report at the Eighteenth National Congress of the Communist Party of China in 2012, the government sets a goal of doubling the per capita income for both urban and rural residents by the year 2020 compared with 2010 (Hu, 2012). With the income of urban and rural residents growing continuously and the remarkable improvement of living standard, it is possible to consume more energy to obtain a quality life characterized by comfortable living and convenient traveling, which will pose more pressure on the mitigation of RDCE. Therefore, a feasible method is using market economic mechanism and legal ways to adjust household consumption behaviors. For example, setting up differential electricity price to encourage households to conserve energy and purchase energy-efficiency electric appliances instead of outdated and energy-intensive ones. Furthermore, promoting the utilization of new-energy cars by extending subsidies is essential.

Table 1
Decomposition results of residential direct CO_2 emissions in Shanxi province (Unit: Mt).

Time period	CI_{effect}	ES_{effect}	EI_{effect}	HPI_{effect}	U_{effect}	HS_{effect}	H_{effect}	Total
1995–1996	0.20 (29.41)	0.38 (55.88)	−3.00 (−441.18)	2.84 (417.65)	0.03 (4.41)	0.00 (0.00)	0.24 (35.29)	0.68 (100)
1996–1997	−0.58 (86.57)	0.38 (−56.72)	−2.24 (334.33)	1.51 (−225.37)	0.04 (−5.97)	−0.28 (41.79)	0.52 (−77.61)	−0.67 (100)
1997–1998	−0.03 (−4.62)	−0.09 (−13.85)	−0.98 (−150.77)	1.48 (227.69)	0.04 (6.15)	−0.29 (−44.62)	0.52 (80.00)	0.65 (100)
1998–1999	−0.21 (−35.00)	0.21 (35.00)	0.20 (33.33)	0.13 (21.67)	0.04 (6.67)	−0.33 (−55.00)	0.57 (95.00)	0.60 (100)
1999–2000	−0.41 (57.75)	0.53 (−74.65)	−2.61 (367.61)	0.96 (−135.21)	0.49 (−69.01)	−0.49 (69.01)	0.81 (−114.08)	−0.71 (100)
2000–2001	0.04 (3.10)	0.31 (24.03)	−0.87 (−67.44)	1.71 (132.56)	−0.06 (−4.65)	−0.40 (−31.01)	0.57 (44.19)	1.29 (100)
2001–2002	−0.19 (−9.60)	0.14 (7.07)	−1.68 (−84.85)	3.31 (167.17)	0.22 (11.11)	−0.33 (−16.67)	0.50 (25.25)	1.98 (100)
2002–2003	0.08 (4.21)	−0.21 (−11.05)	−0.03 (−1.58)	1.85 (97.37)	0.04 (2.11)	−0.42 (−22.11)	0.59 (31.05)	1.90 (100)
2003–2004	0.55 (24.55)	0.49 (21.88)	−1.21 (−54.02)	2.19 (97.77)	0.04 (1.79)	−0.33 (−14.73)	0.51 (22.77)	2.24 (100)
2004–2005	0.36 (65.45)	0.89 (161.82)	−3.82 (−694.55)	2.68 (487.27)	0.25 (45.45)	−0.35 (−63.64)	0.53 (96.36)	0.55 (100)
2005–2006	−1.05 (−58.33)	1.07 (59.44)	−1.24 (−68.89)	2.71 (150.56)	0.13 (7.22)	−0.55 (−30.56)	0.73 (40.56)	1.80 (100)
2006–2007	−0.64 (−40.76)	1.69 (107.64)	−3.01 (−191.72)	3.19 (203.18)	0.16 (10.19)	−0.37 (−23.57)	0.55 (35.03)	1.57 (100)
2007–2008	0.55 (6.66)	0.17 (2.06)	5.28 (63.92)	1.87 (22.64)	0.19 (2.30)	−0.54 (−6.54)	0.75 (9.08)	8.26 (100)
2008–2009	−0.68 (−9.39)	0.27 (3.73)	4.76 (65.75)	2.48 (34.25)	0.17 (2.35)	−0.26 (−3.59)	0.48 (6.63)	7.24 (100)
2009–2010	2.45 (45.79)	1.45 (27.1)	−5.53 (−103.36)	4.28 (80.00)	0.50 (9.35)	−1.17 (−21.87)	3.37 (62.99)	5.35 (100)
2010–2011	−0.20 (−2.99)	0.85 (12.69)	−0.83 (−12.39)	6.12 (91.34)	0.44 (6.57)	−3.07 (−45.82)	3.38 (50.45)	6.70 (100)
2011–2012	−1.71 (−43.51)	1.03 (26.21)	−2.33 (−59.29)	6.24 (158.78)	0.40 (10.18)	−0.56 (−14.25)	0.88 (22.39)	3.93 (100)
2012–2013	−0.71 (−161.36)	0.91 (206.82)	−5.30 (−1204.55)	4.89 (1111.36)	0.30 (68.18)	0.35 (79.55)	0.00 (0.00)	0.44 (100)
2013–2014	−2.58 (2866.67)	1.78 (−1977.78)	−6.94 (7711.11)	7.03 (−7811.11)	0.29 (−322.22)	−1.17 (1300.00)	1.51 (−1677.78)	−0.09 (100)
1995–2014	−4.76 (−10.89)	12.23 (27.98)	−31.38 (−71.79)	57.46 (131.46)	3.72 (8.51)	−10.57 (−24.18)	17.00 (38.89)	43.71 (100)

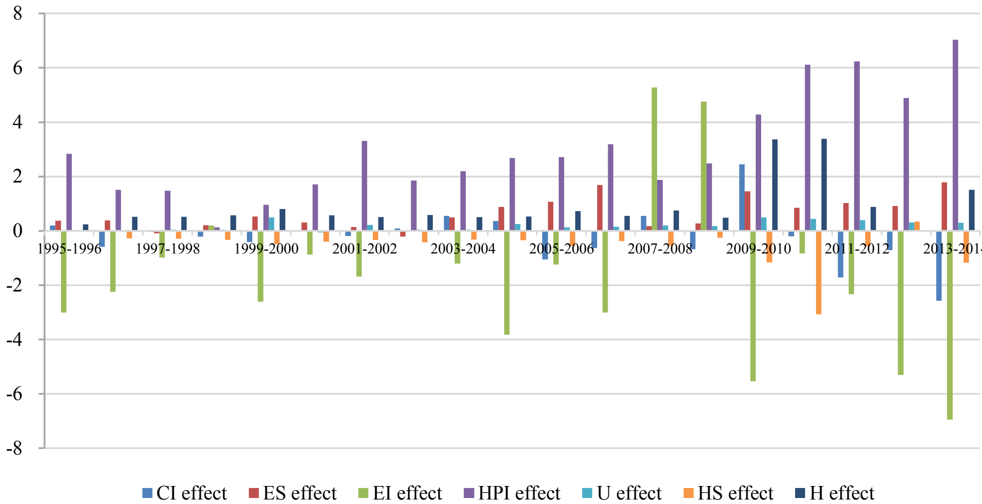

Fig. 2. Decomposition results of residential direct CO_2 emissions in Shanxi province for the period of 1995–2014.

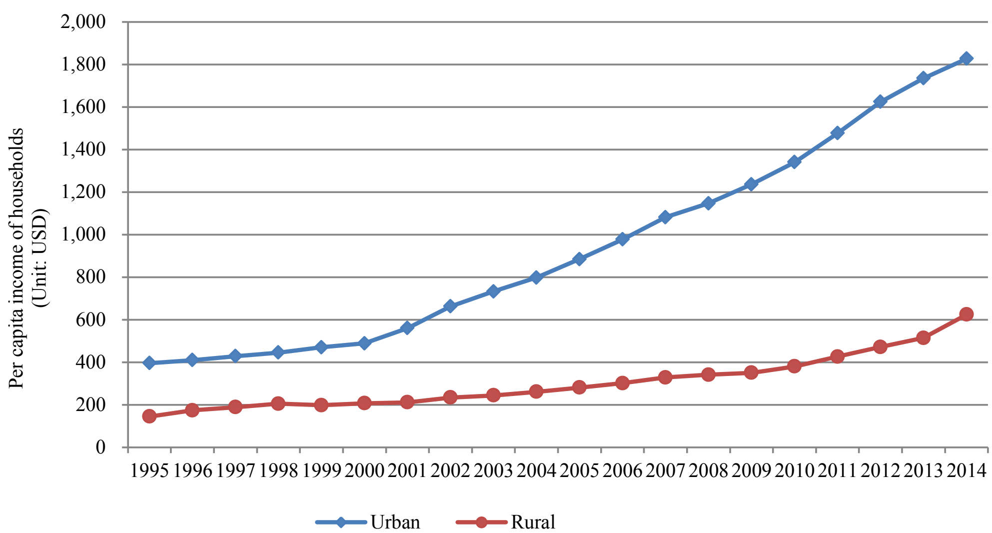

Fig. 3. Per capita income of households in the urban and rural areas of Shanxi province from 1995 to 2014.

4.2. The household effect

The household effect (H_{effect}) was another factor that led to the increase in RDCE over the 1995–2014 period, which contributed 17.00 Mt to the aggregate change of RDCE and accounted for 38.89%. In this case, the household effect refers to the RDCE change caused by the change in the total number of households in Shanxi. As shown in Fig. 4, the number of households in Shanxi province increased to 11.96 million in 2014 from 7.70 million in 1995, with an annual growth rate of 2.50%. The number of urban households showed a linear growth trend and increased from 2.77 million to 6.51 million. However, the number of rural households fluctuated around a generally stable level of about 5 million households. The above data revealed that the increase in the number of urban households was mainly responsible for the increase in the number of total households and the RDCE. This can be attributed to a series of measures and social phenomenon since 1999. First, along with the development of urban economy, large-scale rural surplus labor force migrated into urban areas and a large number of college graduates flocked into cities (Zhang et al., 2016). At the same time, urban economic development stimulated the expansion of urban areas. As a result, more local rural households became urban households (Health and Family Planning Commission of China, 2014). Second, Chinese view of marriage has been changing with the development of society. More elderly unmarried youth in urban areas lived alone, which led to the steady growth in number of one-person households. The divorce rate has been rising as well, which increased single parent households in urban areas (Health and Family Planning Commission of China, 2014). In addition, with the implementation of the “Central China's Rising Strategy” in 2009 (NDRC, 2009), the number of urban households grew by 17.32% from 2009 to 2011, which is the fastest pace since 1995.

Under this circumstance, policies aiming to slow down the growth rate of the number of households should be encouraged, e.g., setting strict divorce processes to result in lower divorce rates, encouraging middle-aged people in urban area to live together with their children or seniors to a higher extent. Furthermore, through effective publicity and education, the authorities should advocate low-carbon life concept and promote less energy-intensive lifestyles, e.g., promoting walks, bicycles and public

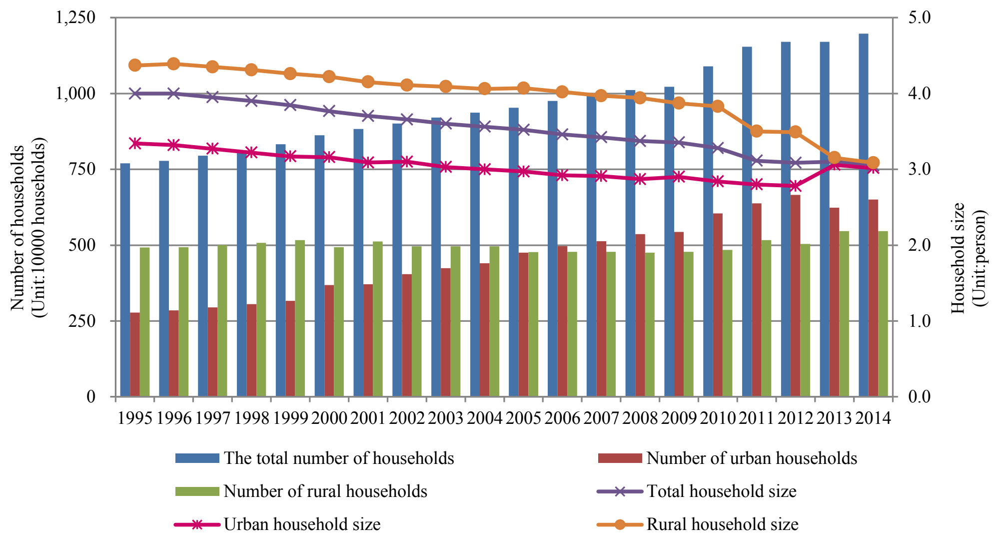

Fig. 4. The number of households and household size in the urban and rural areas of Shanxi province from 1995 to 2014.

transportation instead of private cars and encouraging residents to cultivate a habit of readily switch off the appliances to avoid the waste of electricity.

4.3. The household size effect

The household size effect (HS_{effect}) was the only household-related factor that stayed negative over the whole study period, which was the second largest negative effect and contributed 10.57 Mt to the aggregate decrease of RDCE, constituting 24.18% (Table 1). Fig. 4 showed that the total household size kept falling since 1995. In 2014, the total household size was 3.05 people compared to 4.00 people in 1995, meaning that the major type of Shanxi households has transformed from “four person households” to “three person households”. The household size effect kept negative can be explained from two aspects. On one hand, with the acceleration of population ageing process, the proportion of “Elders Living Alone” households (consist of one or two elders) in the total households has been growing. The vast majority of “Elders Living Alone” households have no computers, motorcycles or household Cars, which saves enormous electricity and oil products. On the other hand, China's one-child policy which encourages late marriages and late childbearing increases the number of Single-young households and DINK households (Double Income No Kids). People from these households often have their meals in restaurants rather than at home, which results in lots of oven gas, natural gas, LPG and electricity in residential sector being conserved. At the same time, comparing with large households, one-person and two-person households are liable to replace their old and energy-intensive household appliances with energy-efficient but expensive appliances, because most of them have little economic burden and pursuit the quality of life. In addition, it should be noted that the economics of scale on household energy consumption has weakened with household size shrinking. So the decreased RDCE caused by the household size effect is partly offset by the weakness of economics of scale. In order to deal with aging problem, Chinese government has already released the two-child policy in 2015 (The Standing Committee of the National People's Congress, 2015). Additional members in a household require more energy use, even though two or more household members can share a number of energy services such as cooking, heating, lighting, and transport. Therefore, in the case of the inevitable increase in the household size, the government can set different energy consumption quotas for different household size of households, and reward households with less energy consumption.

4.4. The urbanization effect

During 1995–2014, the urbanization effect (U_{effect}) increased the RDCE by 3.72 Mt, accounting for 8.51% (Table 1). However, this contribution was comparatively small. Since the urban-rural dual economy structures continued to be buffeted, the process of urbanization in China has been accelerated gradually since reform and opening-up (Sha et al., 2006), and changed the lifestyles of rural households who moved to urban areas (Li and Lin, 2015). Energy is one of the key resources required to sustain the city's metabolic processes for the benefit of humans. After living in urban areas, these rural households used fossil fuels instead of bioenergy for cooking and boiling water (Parikh and Shukla, 1995), and consumed more electricity for the increased domestic appliances (Holtedahl and Joutz, 2004). Meanwhile, with the constant extension of urban areas, the private transportation developed rapidly, which required additional gasoline and diesel (Jones, 2004). On the contrary, urbanization could also reduce residential direct energy demand by promoting the utilization of efficient appliances, central heating systems, and fuel-efficient transportation (Ma, 2015). Therefore, although Shanxi experienced the stage of quickened urbanization process over the study period (Fig. 5), the urbanization effect did not play an obvious role in emissions increase.

Currently, Shanxi province is constructing a people-oriented, urban-rural integration, efficient, green and low-carbon urbanization (Shanxi Development and Reform Commission, 2015), and its urbanization level is expected to pass 60% by 2020, which will make the province suffer an increasing pressure to reduce CO_2 emissions. Therefore, more attention should be given to the promotion of green urbanization. Shanxi province needs to unswervingly take the way of “intensive, smart, green and low-carbon” urbanization development. First, the government should strengthen the urban land intensive use and improve land use capability, which will affect the locations of employment and labor forces to reduce journey-to-work energy use. Second, green construction should be developed, especially improving the living conditions of the shanty

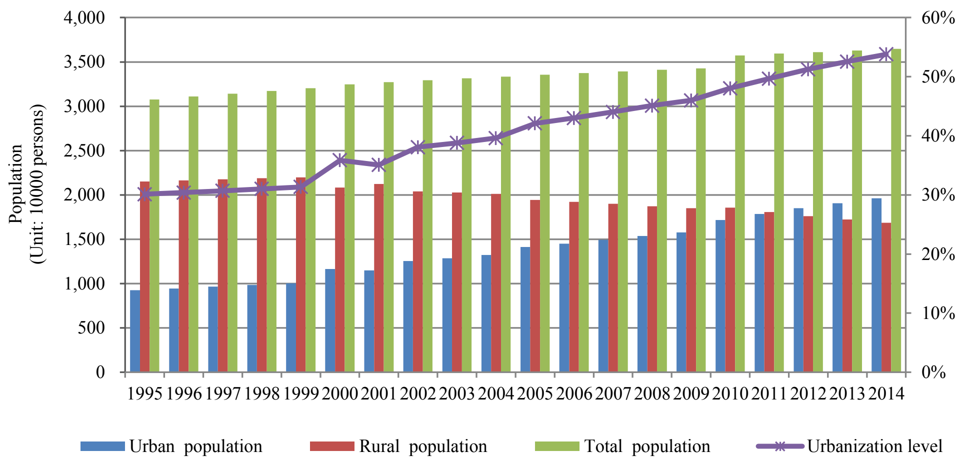

Fig. 5. The level of urbanization and population distribution in Shanxi province from 1995 to 2014.

town and consummating urban infrastructure such as power supply, heat supply and gas supply. Thirdly, more efforts should be given to the construction of public transportation systems and the structure of way to travel in urban areas should be optimized.

4.5. The other effects

The energy intensity effect (EI_{effect}) was the strongest promoting factor in the reduction of RDCE. The energy intensity effect contributed 31.38 Mt (71.79%) to the decrease of RDCE from 1995 to 2014, as shown in Table 1. In this paper, energy intensity refers to residential energy consumption per household income. The residential direct energy consumption will inevitably increase with the process of urbanization. Meanwhile, continuous urbanization can serve as a powerful vehicle for promoting income growth of residents with its massive domestic demand. As shown in Fig. 6, the energy intensity has been experiencing a steady decline, indicating that the income growth is more remarkable than the increase in energy consumption with urbanization process. The energy intensity can be evaluated by energy efficiency, the decreasing energy intensity largely attributed to a great many measures implemented for the improvement of energy efficiency in both urban and rural areas. For example, in 1990, the Chinese government formally implemented energy efficiency standards for household appliances (Lu, 2005). Over the years, management method of energy efficiency labels was promulgated in 2004, which enhanced the energy efficiency of household appliances (NDRC and AQSIQ, 2004). Besides, the government has implemented the vehicle fuel consumption limits since 2005, which greatly improved the energy efficiency of household cars (Li, 2005). The Development Planning for Energy Saving and New Energy Vehicle Industry (2012–2020) (State Council of the People's Republic of China, 2012) was issued in 2012, which clearly put forward that the average fuel consumption of passenger vehicles should drop below 6.9 L/100 km after 2020. Although energy intensity will continue to play a crucial role in reducing the RDCE, it is essential to further encourage the use of energy-efficient and low-emission appliances, vehicles and buildings.

The results showed that the energy structure effect (ES_{effect}) contributed to an increase in RDCE by 12.23 Mt, which made up 27.98% of the total RDCE change (Table 1). This can be explained by the dramatic increase in the ratio of electricity and oil in both rural and urban areas and the increase in the ratio of heat in urban area (Fig. 7). Proverbially, oil is a type of emission-intensive energy,

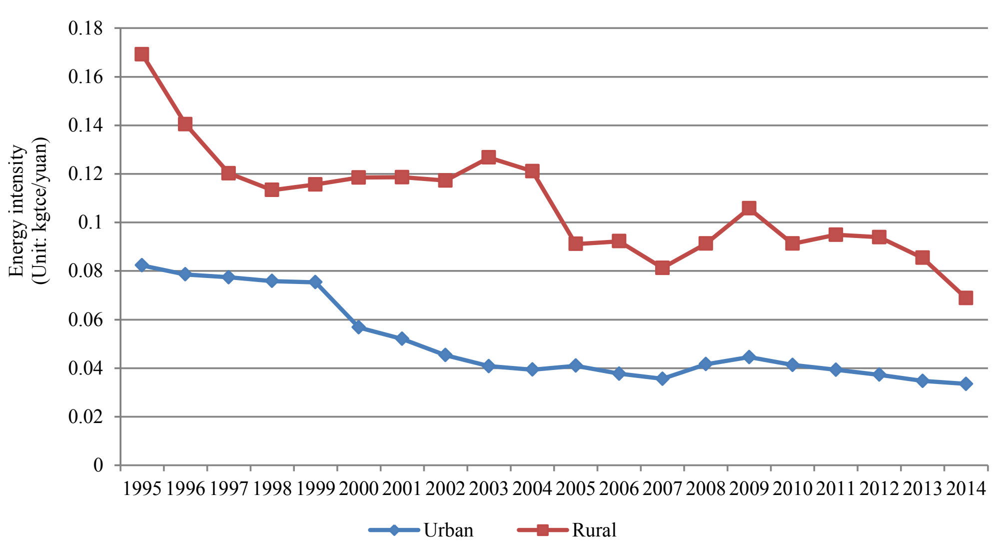

Fig. 6. Energy intensity in the urban and rural areas of Shanxi province from 1995 to 2014.

hence, the increase in oil consumption inevitably lead to the growth of carbon emissions. Additionally, almost 95% of electricity capacity depends on thermal power in Shanxi, explaining that the energy consumption of Shanxi province was mainly based on the emission-intensive energy. Therefore, the energy structure should be optimized by promoting the use of clean and renewable energy in residents' daily life and power generation, e.g., wind, solar, hydro and biogas.

The emission coefficient effect (CI_{effect}) contributed slightly to the reduction in RDCE, which resulted in an accumulated decrease in RDCE by 4.76 Mt and accounted for 10.89%. As the emission factors for conventional fuels remain constant, this effect is largely determined by the changes in the heat and electricity coefficients over the study period. As seen in Fig. 8, the coefficient for electricity generation showed a certain degree of decrease from 1.07 kg/KWh in 1995 to 0.82 kg/KWh in 2014, which largely caused by the improvement of fuel quality used in the electricity generation. However, the coefficient for heat generation fluctuated approximately 0.115 kg/MJ, with a slight increase over the study period. This indicated that it was essential to improve heat generation efficiency for further emissions mitigation in the long run. Therefore, power plants and heating plants should improve the utilization rate of the electrical equipment, increase the utilization rate of the high-efficient equipment during the production process and encourage the deployment of distributed generation technologies. Furthermore, the government should optimize the types and quality of fuels used in electricity and heat production.

4.6. Discussions

Since several studies have studied the factors influencing the residential direct carbon emissions of China, it is meaningful to carry out a comparison between this study and previous ones. First, we focused on household-related factors, while many existing decomposition analysis studies used population as one of the contributing factors. In order to better compare the

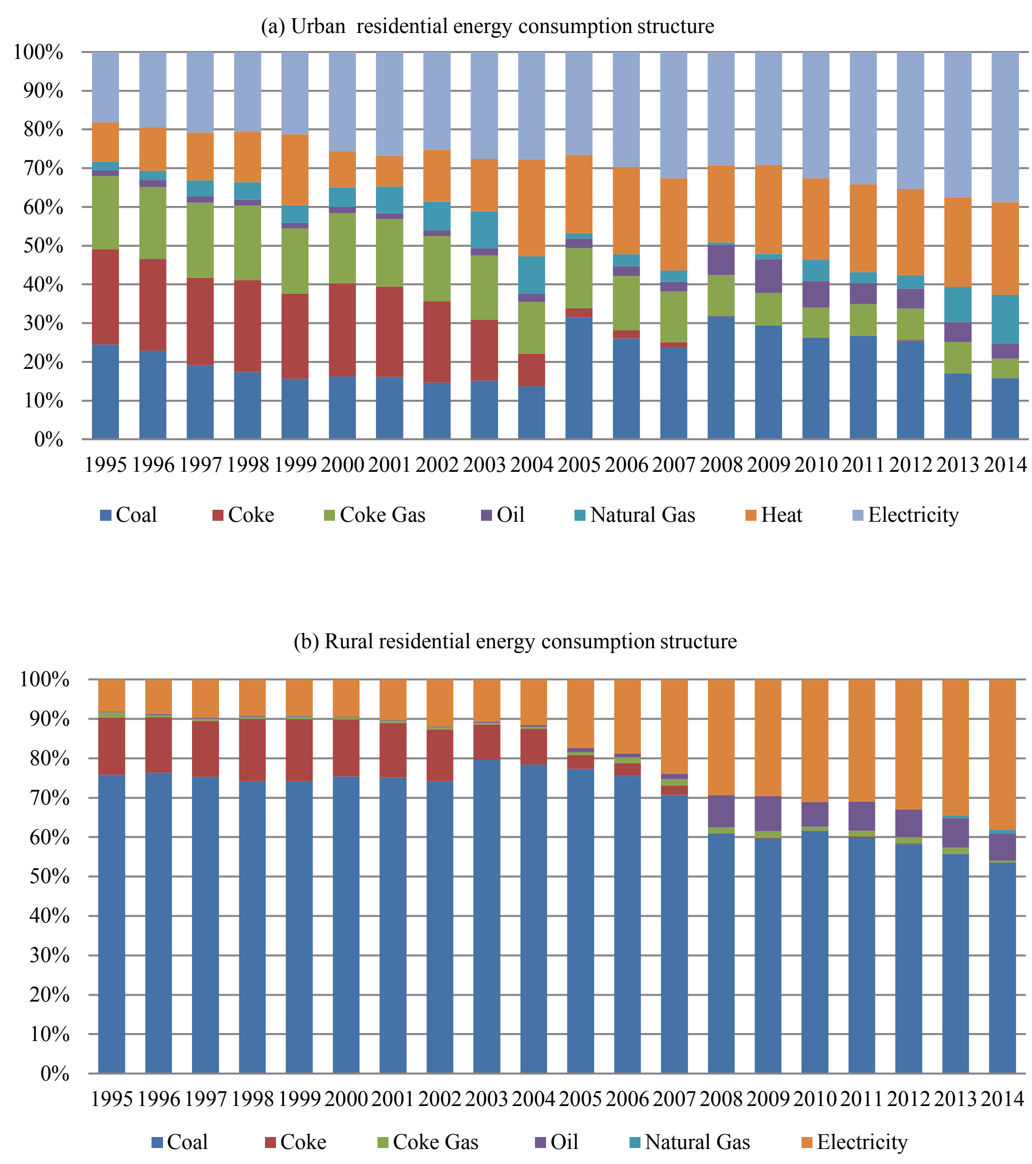

Fig. 7. Energy structure of Urban and rural areas in Shanxi province from 1995 to 2014.

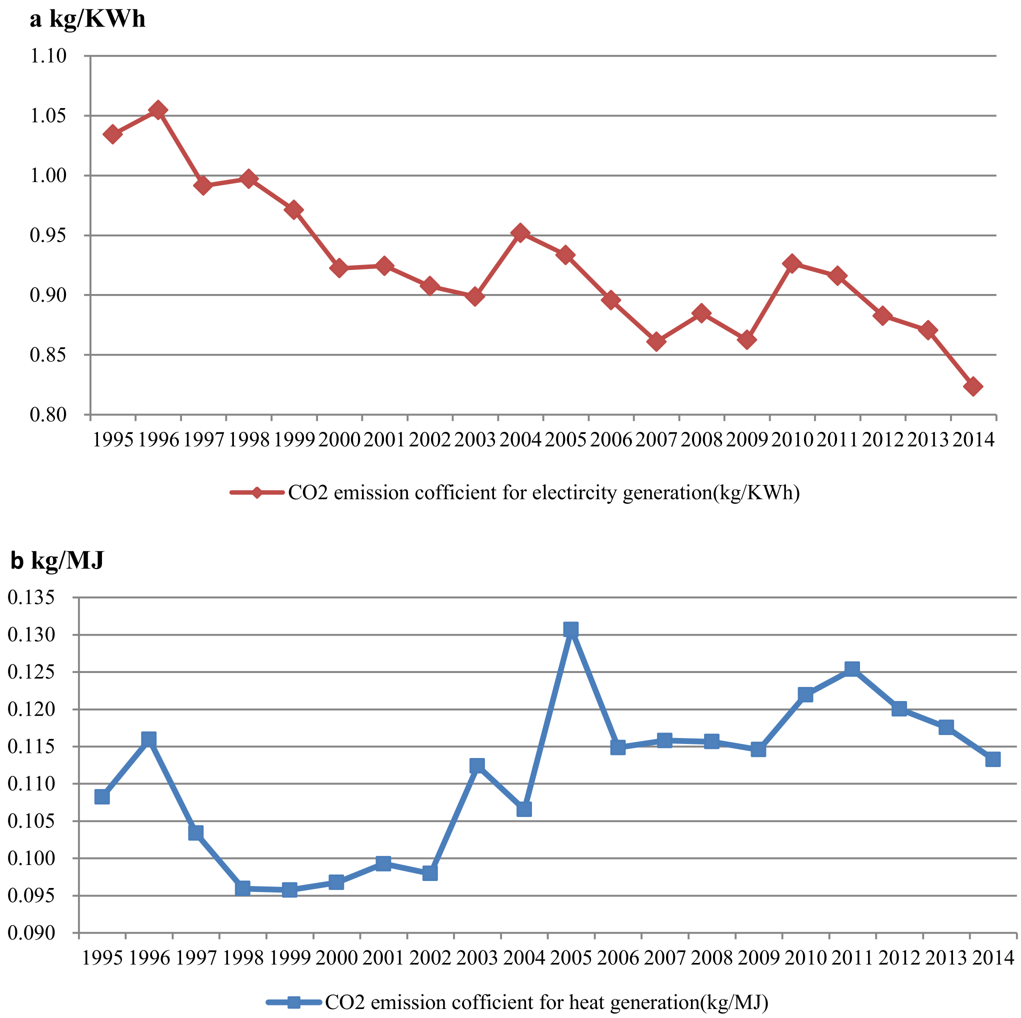

Fig. 8. CO_2 emission coefficients in Shanxi province from 1995 to 2014 for (a) electricity generation and (b) heat generation.

decomposition results of households-related factors and population, we decomposed the changes of RDCE in Shanxi province during 1995–2014 based on the total population. The detailed decomposition formulas and results were presented in Appendix C. Comparing Table C1 and Table 1, we found that the sum of the household effect and the household size effect was equal to the population effect. This demonstrated that considering population as an impact factor will conceal the influences of both household size and the number of household on the resource consumption and environmental pollution. Therefore, household-related factors are more appropriate than population to be used in this decomposition analysis study. In addition, the household effect was far greater than the population effect in increasing the RDCE in previous studies (Liu and Zhao, 2015; Xu et al., 2014). The reason was that the household size effect played a negative role. Second, by comparing other factor effects with the previous works, we found the following similarities and differences. The per capital household income played a dominant role in increasing RDCE, which was consist with the results of Zha et al. (2010). The household size effect of our results was in accordance with Wei et al. (2014), however, it was inconsistent with that of Zhu and Peng (2012) who maintained that shrinking household size increased residential consumption and carbon emissions. The reason lay in that they considered the impact of household size on the total residential CO_2 emission (including residential direct and indirect CO_2 emission), but we only considered the impact of household size on residential direct CO_2 emission. Energy intensity effect was the main driver to the reductions in residential CO_2 emissions, and this was also proved by Zha et al. (2010) and Fan et al. (2013). The energy structure and emission coefficient respectively had positive and negative effect on residential CO_2 emissions, which were supported by Zha et al. (2010) and Fan et al. (2013).

5. Conclusion

In this paper, we applied the LMDI method to identify the key impact factors for residential direct carbon emissions in Shanxi over the period of 1995–2014, and focused on the effects of household-related factors (e.g., per capita household income, the number of households and household size) and urbanization. We found that the per capita household income effect was the most important contributor to the increase in the RDCE, and followed by the household effect which enhanced RDCE by 17.00 Mt. However, the household size effect was the second largest negative effect and contributed 10.57 Mt to the decrease of the RDCE, which largely depended on the decline in household size. Therefore, in view of the fact that the constant improvement of people's living standard and the implementation of two-child policy, the government should use market economic mechanism and legal ways to regulate household consumption behaviors towards environment protection, advocate low-carbon life concept, as well as promote the use of energy-efficiency electric appliances and less energy-intensive lifestyles. Meanwhile, policies aiming to slow down the growth rate of the number of households should be encouraged, e.g., setting strict divorce processes to result in lower divorce rates, encouraging middle-aged people in urban area to live together with their children or seniors to a higher extent.

Furthermore, the urbanization effect caused a marginal increase in RDCE. Shanxi has experienced the stage of accelerating urbanization process, and this will increase the pressure on its carbon mitigation. Therefore, the government should promote the green urbanization by developing green construction and improving the public transportation systems.

In addition, the decreasing energy intensity was the major contributing effect on decline in RDCE. The emission coefficient effect also contributed to a slight decrease in RDCE due to the diminishing emission coefficient of electricity. However, the energy structure effect increased the RDCE. To further mitigate the RDCE of Shanxi, the energy efficiency of residents should be improved. Meanwhile, the clean and renewable energy should be widely popularized and used in people's daily life, heating and power generation, e.g., wind, solar, hydro and biogas.

Acknowledgments

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Appendix A

The residential direct CO_2 emissions can be calculated by the following formula:

$$C^t = \sum_i C_i^t = \sum_i E_i^t \times EF_i \times \frac{44}{12} \tag{11}$$

where C_i^t denotes the CO_2 emissions of fuel type i in year t; C^t denotes the total CO_2 emissions in year t; E_i^t denotes the energy consumption of fuel i in year t; EF_i denotes the carbon emission coefficient of the fuel i; the factor 44/12 is the ratio of molecular weights of CO_2 and carbon.

The carbon emission coefficient of coal, oil and natural gas is from Liu et al. (2015), and the carbon emission factor of coke and coke gas is from Lanza et al. (2006).

The carbon emission coefficients (ef) of heat and electricity are changing significantly because the technology and fuel composition used for the generation of electricity and heat are continuously improved. According to the energy endowments of Shanxi province and the characteristics of heat and power generation, the average emission coefficients of heat and electricity can be calculated as follows:

$$ef^t = \frac{\sum_j {CO_2}_j^t}{E_{fossil}^t + E_{nuclear}^t + E_{hydro}^t} \tag{12}$$

where ef^t refers to the average emission factor of heat or electricity in year t; ${CO_2}_j^t$ refers to the CO_2 emissions of fossil fuel type j for heat or electricity generation in year t; the CO_2 emissions of nuclear and hydro energy for heat or electricity generation were assumed to be zero (Ang and Choi, 2002). E_{fossil}^t, $E_{nuclear}^t$ and E_{hydro}^t respectively refers to the heat or electricity generated by fossil fuel combustion, nuclear energy and hydropower in year t.

Appendix B

Table B1
Ownership of major durable consumer goods per 100 urban households at year-end.

Item	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Washing Machines (unit)	91.20	93.44	99.77	102.06	102.35	98.87	99.21	100.73	101.60	103.44	95.99	97.87
Refrigerators (unit)	46.90	75.95	87.08	88.62	89.86	85.56	86.97	90.19	91.07	91.81	85.15	87.68
Microwave Ovens (unit)	–	–	–	26.92	29.32	30.50	31.14	32.66	37.47	38.82	33.30	32.98
Color Television Sets (unit)	86.20	107.17	113.69	114.99	113.07	110.53	111.03	111.75	109.98	111.17	105.63	107.25
Air Conditioners (unit)	–	4.34	25.59	28.79	28.90	33.33	33.78	34.90	45.29	48.17	27.87	29.64
Computers (unit)	–	6.23	30.16	35.24	39.10	47.21	49.47	54.08	69.45	74.07	63.84	68.62
Mobile Telephones (set)	–	8.09	109.70	122.52	127.39	136.39	137.52	146.61	178.10	188.39	203.95	216.72
Motorcycles (unit)	8.40	21.34	26.23	26.69	30.87	22.09	26.02	27.54	21.06	21.08	21.52	23.48
Household Cars (unit)	–	–	3.13	4.01	4.66	8.40	10.03	11.53	18.60	20.81	20.72	24.24

Table B2
Ownership of major durable consumer goods per 100 rural households at year-end.

Item	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Washing Machines (unit)	19.76	51.71	69.29	69.52	76.28	77.14	78.62	81.05	84.24	86.62	78.87	80.74
Refrigerators (unit)	1.33	10.33	14.43	17.57	22.71	23.05	25.52	29.19	48.43	52.90	51.37	54.41
Microwave Ovens (unit)	–	–	0.29	1.86	1.81	2.57	2.67	3.38	4.05	4.81	6.88	7.00
Color TV Sets (unit)	20.57	63.48	82.33	98.38	102.05	104.09	107.14	109.00	106.86	109.24	103.74	105.20
Air conditioners(unit)	–	0.29	1.00	1.86	4.43	3.43	3.90	4.62	6.67	7.57	8.37	9.13
Telephones (unit)	–	16.10	50.29	72.14	76.33	77.19	76.05	75.62	47.62	46.86	30.25	31.28
Mobile Telephones (set)	–	–	27.52	51.76	66.76	78.81	94.29	107.71	172.81	186.76	174.20	190.89
Computers (unit)	–	–	0.57	1.38	3.43	3.52	6.24	8.71	24.05	27.67	23.50	26.03
Motorcycles (unit)	3.33	25.00	39.29	53.90	55.70	57.05	57.10	56.57	56.24	56.71	51.93	55.94
Household Cars (unit)	–	–	0.33	0.67	0.86	1.10	1.48	1.86	6.00	6.48	9.64	10.63

Appendix C

$$C^t = \sum_{ij} C^t_{ij} = \sum_{ij} \frac{C^t_{ij}}{E^t_{ij}} \times \frac{E^t_{ij}}{E^t_i} \times \frac{E^t_i}{RI^t_i} \times \frac{RI^t_i}{P^t_i} \times \frac{P^t_i}{P^t} \times P^t = \sum_{ij} CI^t_{ij} \times ES^t_{ij} \times EI^t_i \times HPI^t_i \times U^t_i \times P^t \quad (13)$$

$$\Delta C^t_{tot} = C^t - C^0 = \sum_{ij} CI^t_{ij} ES^t_{ij} EI^t_i HPI^t_i U^t_i P^t - \sum_{ij} CI^0_{ij} ES^0_{ij} EI^0_i HPI^0_i U^0_i P^0 = CI_{effect} + ES_{effect} + EI_{effect} + HPI_{effect} + U_{effect} + P_{effect} \quad (14)$$

Table C1
Decomposition results of residential direct CO_2 emissions in Shanxi based on the total population (Unit: Mt).

Time period	CI_{effect}	ES_{effect}	EI_{effect}	HPI_{effect}	U_{effect}	P_{effect}	Total
1995–1996	0.20 (29.41)	0.38 (55.88)	−3.00 (−441.18)	2.84 (417.65)	0.03 (4.41)	0.24 (35.29)	0.68 (100)
1996–1997	−0.58 (86.57)	0.38 (−56.72)	−2.24 (334.33)	1.51 (−225.37)	0.04 (−5.97)	0.23 (−34.33)	−0.67 (100)
1997–1998	−0.03 (−4.62)	−0.09 (−13.85)	−0.98 (−150.77)	1.48 (227.69)	0.04 (6.15)	0.23 (35.38)	0.65 (100)
1998–1999	−0.21 (−35.00)	0.21 (35.00)	0.20 (33.33)	0.13 (21.67)	0.04 (6.67)	0.23 (38.33)	0.60 (100)
1999–2000	−0.41 (57.75)	0.53 (−74.65)	−2.61 (367.61)	0.96 (−135.21)	0.49 (−69.01)	0.32 (−45.07)	−0.71 (100)
2000–2001	0.04 (3.10)	0.31 (24.03)	−0.87 (−67.44)	1.71 (132.56)	−0.06 (−4.65)	0.17 (13.18)	1.29 (100)
2001–2002	−0.19 (−9.60)	0.14 (7.07)	−1.68 (−84.85)	3.31 (167.17)	0.22 (11.11)	0.17 (8.59)	1.98 (100)
2002–2003	0.08 (4.21)	−0.21 (−11.05)	−0.03 (−1.58)	1.85 (97.37)	0.04 (2.11)	0.17 (8.95)	1.90 (100)
2003–2004	0.55 (24.55)	0.49 (21.88)	−1.21 (−54.02)	2.19 (97.77)	0.04 (1.79)	0.18 (8.04)	2.24 (100)
2004–2005	0.36 (65.45)	0.89 (161.82)	−3.82 (−694.55)	2.68 (487.27)	0.25 (45.45)	0.18 (32.73)	0.55 (100)
2005–2006	−1.05 (−58.33)	1.07 (59.44)	−1.24 (−68.89)	2.71 (150.56)	0.13 (7.22)	0.18 (10.00)	1.80 (100)
2006–2007	−0.64 (−40.76)	1.69 (107.64)	−3.01 (−191.72)	3.19 (203.18)	0.16 (10.19)	0.18 (11.46)	1.57 (100)
2007–2008	0.55 (6.66)	0.17 (2.06)	5.28 (63.92)	1.87 (22.64)	0.19 (2.30)	0.20 (2.42)	8.26 (100)
2008–2009	−0.68 (−9.39)	0.27 (3.73)	4.76 (65.75)	2.48 (34.25)	0.17 (2.35)	0.23 (3.18)	7.24 (100)
2009–2010	2.45 (45.79)	1.45 (27.10)	−5.53 (−103.36)	4.28 (80.00)	0.50 (9.35)	2.20 (41.12)	5.35 (100)
2010–2011	−0.20 (−2.99)	0.85 (12.69)	−0.83 (−12.39)	6.12 (91.34)	0.44 (6.57)	0.31 (4.63)	6.70 (100)
2011–2012	−1.71 (−43.51)	1.03 (26.21)	−2.33 (−59.29)	6.24 (158.78)	0.4 (10.18)	0.31 (7.89)	3.93 (100)
2012–2013	−0.71 (−161.36)	0.91 (206.82)	−5.30 (−1204.55)	4.89 (1111.36)	0.30 (68.18)	0.35 (79.55)	0.44 (100)
2013–2014	−2.58 (2866.67)	1.78 (−1977.78)	−6.94 (7711.11)	7.03 (−7811.11)	0.29 (−322.22)	0.33 (−366.67)	−0.09 (100)
1995–2014	−4.76 (−10.89)	12.23 (27.98)	−31.38 (−71.79)	57.46 (131.46)	3.72 (8.51)	6.43 (14.71)	43.71 (100)

$$CI_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{CI^t_{ij}}{CI^0_{ij}}\right) \quad (15)$$

$$ES_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{ES^t_{ij}}{ES^0_{ij}}\right) \quad (16)$$

$$EI_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{EI^t_i}{EI^0_i}\right) \quad (17)$$

$$HPI_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{HPI^t_i}{HPI^0_i}\right) \quad (18)$$

$$U_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{U^t_i}{U^0_i}\right) \quad (19)$$

$$P_{effect} = \sum_{ij} L\left(C^t_{ij} - C^0_{ij}\right) \ln\left(\frac{P^t}{P^0}\right) \quad (20)$$

where

$$L\left(C^t_{ij} - C^0_{ij}\right) = \begin{cases} \dfrac{C^t_{ij} - C^0_{ij}}{lnC^t_{ij} - lnC^0_{ij}}, & C^t_{ij} \neq C^0_{ij} \\ C^t_{ij}, & C^t_{ij} = C^0_{ij} \end{cases} \quad (21)$$

Each letter used herein has the same meaning as that of its corresponding letter in Section 3.1, except for P_{effect}.P_{effect} is the population effect. It reflects the CO_2 emissions change caused by the change in population.

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