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ORIGINAL PAPER

Exploring influence factors governing the changes in China's final energy consumption under a new framework

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Abstract In this paper, China's final energy consumption has been divided into two parts: production energy consumption and resident energy consumption. Under this framework, the LMDI method is used to study the nature of the factors governing the changes in final energy consumption. Thus, seven factors are defined in this paper: energy mix effect, energy intensity effect, economic structure effect, economic growth effect, resident income effect, urbanization effect, and population effect. The production energy consumption almost accounted for 90 % of total final energy consumption in 2011. The annual growth rate of resident energy consumption increased to 8.7 % during 2001–2011. The gap in resident energy consumption per capita between urban and rural decreased during 1991–2011. Our results show that the energy intensity effect plays an important role in decreasing final energy consumption. However, the economic growth effect is found to be primarily responsible for driving final energy consumption growth over the study period, followed by resident income effect, population effect, economic structure effect, and urbanization effect. Though the urbanization rate increased rapidly over the period 1991–2011, the urbanization effect plays minor contribution to the increase in final energy consumption among all factors.

Keywords LMDI method · Final energy consumption · China

1 Introduction

Nowadays, China has become one of the largest energy consumers in the world (Zhang et al. 2011a). Along with industrialization, urbanization, and the improvement in resident living standards, China's future energy demand will increase rapidly. However, the

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combustion of fossil energy is the main source of CO_2 emission, which makes China government face great pressure to guarantee energy supply security and energy-related environment security. To demonstrate its commitment to reduce global emission, the Chinese government announced that it would cut its CO_2 emission per unit of gross domestic product (GDP) by 40–45 % in 2020 from 2005 in 2009. Therefore, to better draw up energy-saving policy, exploring the influence factors governing China's final energy consumption is meaningful.

The influence factors governing the energy consumption and energy-related CO_2 emission have been studied by many scholars in recent years (Li et al. 2012). Currently, there are two well-known methods, which have been widely used by many researchers. One is structural decomposition analysis method (SDA). The other is index decomposition analysis method (IDA). The theory foundation of SDA is input–output analysis (Su and Ang 2012). The SDA method was utilized to examine the sources of changes in energy use of the Brazilian economy of industries and households from 1970 to 1996 (Ulrike et al. 2009). Based on the SDA method, the hybrid energy input–output model was used to decompose driving factors to identify how these factors impacted changes in energy intensity (Fan and Xia 2012). The changes in direct material inputs were also studied by Muñoz and Hubacek (2008) based on the SDA method.

If the energy consumption or CO_2 emission can be expressed as a Kaya identity, the contributor of different factors can be computed according to the IDA theory. The IDA method also includes two different methods: complete decomposition analysis and Log-Mean Divisia Index (LMDI) method. The details on two kinds of IDA methodologies were given by Sun (1998) and Ang and Zhang (2000), respectively. The complete decomposition analysis was utilized by Zhang et al. (2009) to study the energy-related CO_2 emission in China for the period 1991–2006 divided into three equal time intervals. The LMDI method was applied by Zhao et al. (2012) to decompose China's urban resident energy consumption during the period of 1998–2007 at disaggregated product/activity level using data collected from a wide range of sources.

The SDA method can give detailed reasons of the change in energy consumption. But the input–output table is not issued annually. The priority of IDA is the use of time-series data year by year. In 2004, Ang (2004) gave a review of all decomposition techniques and concluded that the LMDI method had been the best method used to study influencing factors. Because there are the logarithmic terms in the LMDI formulae, complications arise when the data set contains zero values. Then, eight strategies to handle zero values in LMDI method were given by Ang and Liu (2007).

So far, the LMDI method has been widely utilized by many scholars to explore China energy issues (Wang et al. 2010; Ren and Hu 2012). Based on the LMDI method and provincially aggregated data, the evolution of energy-related CO_2 emission from 1985 to 1999 and the underlying driving forces were explored by Wang et al. (2005). Liu et al. (2007) also utilized the LMDI method to analyze the change in industrial carbon emission from 36 industrial sectors during 1998–2005. Malla (2009) used systematically the LMDI technique on the CO_2 emission from electricity generation in China. The LMDI technique was used to find the nature of the factors governing the changes in energy consumption of China transportation sector (Zhang et al. 2011b). The energy-related CO_2 emission from urban and rural resident energy consumption from 1991 to were estimated and compared by Zha et al. (2010). Based on C-D production function, Wang et al. (2014) generalized the LMDI method, which was utilized to analyze the driving factors governing China's production energy consumption.

The above analysis shows that the existing references only study the energy consumption of one sector, such as resident energy consumption, production energy consumption, or the secondary industry sector. So far, no paper has explored the driving factors governing the changes in total China's final energy consumption. This paper divides China's final energy consumption into two parts: production energy consumption and resident energy consumption. Under this framework, the LMDI method is used to decompose the China's final energy consumption into seven influencing factors: energy mix effect, energy intensity effect, economic structure effect, economic growth effect, resident income effect, urbanization effect, and population effect.

The rest of this paper is organized as follows. The next section describes the methodology and related data used in this paper. Section 3 presents the empirical analysis. The last section concludes this study.

2 Methodology and data

2.1 Study framework and data presentation

Total final energy consumption in China has been divided into two parts: production energy consumption and resident energy consumption, as shown in Fig. 1. Production energy consumption sector includes three industries: the primary industry, secondary industry, and tertiary industry. Agriculture and its related activities: farming, husbandry, forestry, fishing, and secondary production, are the primary industry. The secondary industry includes manufacturing, mining, water supply, electricity generation and supply, the hot water, steam, and gas sectors, and construction. The tertiary industry includes transport, storage and post, wholesale, retail trade and hotel, restaurants, and other related sectors. Resident energy consumption sector includes only two subsectors: urban resident and rural resident.

Energy types used in China final sector are aggregated into five groups: coal products, oil products, electricity, heating, and natural gas. The coal products include coal, cleaned

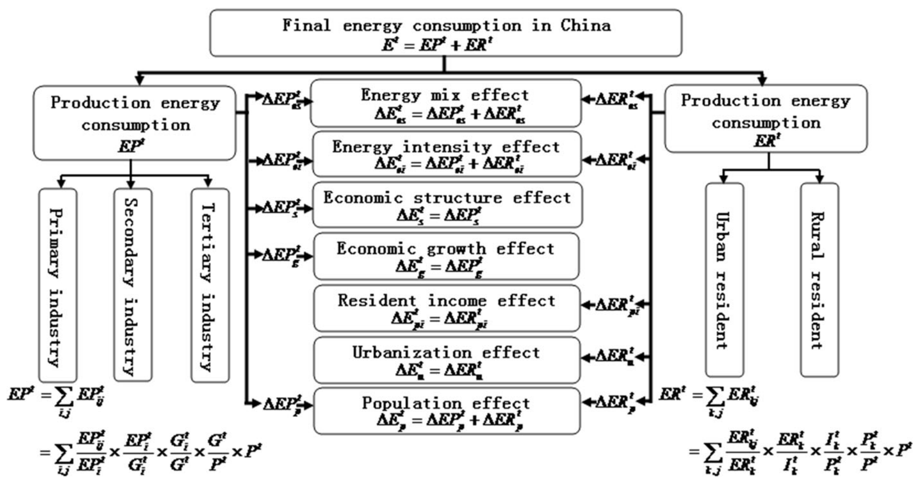

Fig. 1 Framework of the finial energy consumption

coal, other washed coal, coke, briquettes, coke oven gas, other gas and other coking products. Oil products are composed of rude oil, kerosene, gasoline, diesel oil, LPG, fuel oil, refinery gas, and other petroleum products.

The study period in this paper is 1991–2011. The data used in this study have been collected from various issues of the China Statistical Yearbook (CSY 2012) and China Energy Statistical Yearbook (CESY 1997, 2000, 2003, 2004. 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012). The GDP is measured in billion yuan in constant 1991 price. The unit of energy data is standard coal consumption in Mtce (million tones of coal equivalent). The population is measured by 10,000 persons. The resident income is measured in yuan in constant 1991 price.

2.2 Methodology description

According to Fig. 1, the final energy consumption in China in year ***t*** (E^t) can be expressed as Eq. (1)

$$\begin{aligned} \mathrm{E}^t &= \mathrm{EP}^t + \mathrm{ER}^t = \sum_{i,j} \mathrm{EP}_{ij}^t + \sum_{k,j} \mathrm{ER}_{kj}^t \\ &= \sum_{i,j} \frac{\mathrm{EP}_{ij}^t}{\mathrm{EP}_i^t} \times \frac{\mathrm{EP}_i^t}{G_i^t} \times \frac{G_i^t}{G^t} \times \frac{G^t}{P^t} \times P^t + \sum_{k,j} \frac{\mathrm{ER}_{kj}^t}{\mathrm{ER}_k^t} \times \frac{\mathrm{ER}_k^t}{I_k^t} \times \frac{I_k^t}{P_k^t} \times \frac{P_k^t}{P^t} \times P^t \\ &= \sum_{i,j} \mathrm{PES}_{ij}^t \times \mathrm{PEI}_i^t \times \mathrm{PS}_i^t \times \mathrm{PG}^t \times P^t + \sum_{k,j} \mathrm{RES}_{kj}^t \times \mathrm{REI}_k^t \times \mathrm{RI}_k^t \times \mathrm{RU}_k^t \times P^t \end{aligned} \tag{1}$$

where t: the time in years; i: industrial sector; j: fuel type; k: resident sector; EP^t: energy consumption of production sector in year t; ER^t: energy consumption of resident sector in year t; EP_{ij}^t: energy consumption of the jth fuel type of ith industrial sector in year t; ER_{kj}^t: energy consumption of the jth fuel type of kth resident sector in year t; EP_i^t: energy consumption of the ith industrial sector in year t; ER_k^t: energy consumption of the kth resident sector in year t; G_i^t: the GDP of the ith industrial sector in year t; G^t: the GDP in year t; I_k^t: the net income of the kth resident sector in year t; P^t: the population in year t; P_k^t: the population of the kth resident sector in year t; $\mathrm{PES}_{ij}^t = \frac{\mathrm{EP}_{ij}^t}{\mathrm{EP}_i^t}$: the share of the jth energy form to total energy consumption of the ith industrial sector in year t; $\mathrm{PEI}_i^t = \frac{\mathrm{EP}_i^t}{G_i^t}$: the energy intensity of the ith industrial sector in year t; $\mathrm{PS}_i^t = \frac{G_i^t}{G^t}$: the economic share of the ith industrial sector in year t; $\mathrm{PG}^t = \frac{G^t}{P^t}$: the GDP per capita in year t; $\mathrm{RES}_{kj}^t = \frac{\mathrm{ER}_{kj}^t}{\mathrm{ER}_k^t}$: the share of the jth energy form to total energy consumption of the kth resident sector in year t; $\mathrm{REI}_k^t = \frac{\mathrm{ER}_k^t}{I_k^t}$: the energy intensity of the kth resident sector in year t; $\mathrm{RI}_k^t = \frac{I_k^t}{P_k^t}$: the net income per capita of the kth resident sector in year t; and $RU_k^t = \frac{P_k^t}{P^t}$: the share of the kth resident sector population to total population in year t;

The change in final energy consumption between a base year 0 and a target year t, denoted by $\Delta E_{\mathrm{tot}}^t$, can be expressed as the following formula:

$$\begin{aligned} \Delta E_{\mathrm{tot}}^t &= E^t - E^0 = (\mathrm{EP}^t + \mathrm{ER}^t) - (\mathrm{EP}^0 + \mathrm{ER}^0) \\ &= (\mathrm{EP}^t - \mathrm{EP}^0) + (\mathrm{ER}^t - \mathrm{ER}^0) = \Delta \mathrm{EP}_{\mathrm{tot}}^t + \Delta \mathrm{ER}_{\mathrm{tot}}^t \end{aligned} \tag{2}$$

where $\Delta \mathrm{EP}_{\mathrm{tot}}^t$: the change in final energy consumption of production sector between a base year 0 and a target year t and $\Delta\mathrm{ER}^t_{\mathrm{tot}}$: the change in final energy consumption of resident sector between a base year 0 and a target year t.

According to the LMDI method given by Ang (2004), the $\Delta\mathrm{EP}^t_{\mathrm{tot}}$ can be decomposed into five determinant factors: (i) the industrial energy mix effect (denoted by $\Delta\mathrm{EP}^t_{\mathrm{es}}$), (ii) the industrial energy intensity effect (denoted by $\Delta\mathrm{EP}^t_{\mathrm{ei}}$), (iii) the economic structure effect (denoted by $\Delta\mathrm{EP}^t_{s}$), (iv) the economic growth effect (denoted by $\Delta\mathrm{EP}^t_{g}$), and (v) the industrial population effect (denoted by $\Delta\mathrm{EP}^t_{p}$). Thus, the difference $\Delta\mathrm{EP}^t_{\mathrm{tot}}$ is decomposed into its components in additive form, as illustrated in Eq. (3):

$$\Delta\mathrm{EP}^t_{\mathrm{tot}} = \Delta\mathrm{EP}^t_{\mathrm{es}} + \Delta\mathrm{EP}^t_{\mathrm{ei}} + \Delta\mathrm{EP}^t_{s} + \Delta\mathrm{EP}^t_{g} + \Delta\mathrm{EP}^t_{p} \tag{3}$$

Each effect in the right-hand side of Eq. (3) can be computed as follows:

$$\Delta\mathrm{EP}^t_{\mathrm{es}} = \begin{cases} 0, & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} = 0; \\ \sum_{ij} \frac{\mathrm{EP}^t_{ij} - \mathrm{EP}^0_{ij}}{\ln(\mathrm{EP}^t_{ij}) - \ln(\mathrm{EP}^0_{ij})} \ln\left(\frac{\mathrm{PES}^t_{ij}}{\mathrm{PES}^0_{ij}}\right), & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} \neq 0; \end{cases} \tag{3a}$$

$$\Delta\mathrm{EP}^t_{\mathrm{ei}} = \begin{cases} 0, & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} = 0; \\ \sum_{ij} \frac{\mathrm{EP}^t_{ij} - \mathrm{EP}^0_{ij}}{\ln(\mathrm{EP}^t_{ij}) - \ln(\mathrm{EP}^0_{ij})} \ln\left(\frac{\mathrm{PEI}^t_{ij}}{\mathrm{PEI}^0_{ij}}\right), & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} \neq 0; \end{cases} \tag{3b}$$

$$\Delta\mathrm{EP}^t_{\mathrm{s}} = \begin{cases} 0, & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} = 0; \\ \sum_{ij} \frac{\mathrm{EP}^t_{ij} - \mathrm{EP}^0_{ij}}{\ln(\mathrm{EP}^t_{ij}) - \ln(\mathrm{EP}^0_{ij})} \ln\left(\frac{\mathrm{PS}^t_{ij}}{\mathrm{PS}^0_{ij}}\right), & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} \neq 0; \end{cases} \tag{3c}$$

$$\Delta\mathrm{EP}^t_{\mathrm{g}} = \begin{cases} 0, & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} = 0; \\ \sum_{ij} \frac{\mathrm{EP}^t_{ij} - \mathrm{EP}^0_{ij}}{\ln(\mathrm{EP}^t_{ij}) - \ln(\mathrm{EP}^0_{ij})} \ln\left(\frac{\mathrm{PG}^t_{ij}}{\mathrm{PG}^0_{ij}}\right), & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} \neq 0; \end{cases} \tag{3d}$$

$$\Delta\mathrm{EP}^t_{\mathrm{p}} = \begin{cases} 0, & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} = 0; \\ \sum_{ij} \frac{\mathrm{EP}^t_{ij} - \mathrm{EP}^0_{ij}}{\ln(\mathrm{EP}^t_{ij}) - \ln(\mathrm{EP}^0_{ij})} \ln\left(\frac{P^t_{ij}}{P^0_{ij}}\right), & \text{if} \quad \mathrm{EP}^t_{ij} \times \mathrm{EP}^0_{ij} \neq 0; \end{cases} \tag{3e}$$

The change in final energy consumption of resident sector between a base year 0 and a target year t can be also decomposed into five determinant factors: (i) the resident energy mix effect (denoted by $\Delta\mathrm{ER}^t_{\mathrm{es}}$), (ii) the resident energy intensity effect (denoted by $\Delta\mathrm{ER}^t_{\mathrm{ei}}$), (iii) the income per capita effect (denoted by $\Delta\mathrm{ER}^t_{\mathrm{pi}}$), (iv) the urbanization effect (denoted by $\Delta\mathrm{ER}^t_{\mathrm{u}}$), and (v) the resident population effect (denoted by $\Delta\mathrm{ER}^t_{p}$). Thus, the difference $\Delta\mathrm{ER}^t_{\mathrm{tot}}$ is decomposed into its components in additive form, as illustrated in Eq. (4):

$$\Delta\mathrm{ER}^t_{\mathrm{tot}} = \Delta\mathrm{ER}^t_{\mathrm{es}} + \Delta\mathrm{ER}^t_{\mathrm{ei}} + \Delta\mathrm{ER}^t_{\mathrm{pi}} + \Delta\mathrm{ER}^t_{\mathrm{u}} + \Delta\mathrm{ER}^t_{\mathrm{p}} \tag{4}$$

Each effect in the right-hand side of Eq. (4) can be computed as follows:

$$\Delta \mathrm{ER}_{\mathrm{es}}^{t} = \begin{cases} 0, & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} = 0; \\ \sum_{kj} \frac{\mathrm{ER}_{kj}^{t} - \mathrm{ER}_{kj}^{0}}{\ln(\mathrm{ER}_{kj}^{t}) - \ln(\mathrm{ER}_{kj}^{0})} \ln\left(\frac{\mathrm{RES}_{kj}^{t}}{\mathrm{RES}_{kj}^{0}}\right), & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} \neq 0; \end{cases} \quad (4a)$$

$$\Delta \mathrm{ER}_{\mathrm{ei}}^{t} = \begin{cases} 0, & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} = 0; \\ \sum_{kj} \frac{\mathrm{ER}_{kj}^{t} - \mathrm{ER}_{kj}^{0}}{\ln(\mathrm{ER}_{kj}^{t}) - \ln(\mathrm{ER}_{kj}^{0})} \ln\left(\frac{\mathrm{REI}_{kj}^{t}}{\mathrm{REI}_{kj}^{0}}\right), & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} \neq 0; \end{cases} \quad (4b)$$

$$\Delta \mathrm{ER}_{\mathrm{pi}}^{t} = \begin{cases} 0, & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} = 0; \\ \sum_{kj} \frac{\mathrm{ER}_{kj}^{t} - \mathrm{ER}_{kj}^{0}}{\ln(\mathrm{ER}_{kj}^{t}) - \ln(\mathrm{ER}_{kj}^{0})} \ln\left(\frac{\mathrm{RI}_{kj}^{t}}{\mathrm{RI}_{kj}^{0}}\right), & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} \neq 0; \end{cases} \quad (4c)$$

$$\Delta \mathrm{ER}_{\mathrm{u}}^{t} = \begin{cases} 0, & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} = 0; \\ \sum_{kj} \frac{\mathrm{ER}_{kj}^{t} - \mathrm{ER}_{kj}^{0}}{\ln(\mathrm{ER}_{kj}^{t}) - \ln(\mathrm{ER}_{kj}^{0})} \ln\left(\frac{\mathrm{RU}_{kj}^{t}}{\mathrm{RU}_{kj}^{0}}\right), & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} \neq 0; \end{cases} \quad (4d)$$

$$\Delta \mathrm{ER}_{p}^{t} = \begin{cases} 0, & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} = 0; \\ \sum_{kj} \frac{\mathrm{ER}_{kj}^{t} - \mathrm{ER}_{kj}^{0}}{\ln(\mathrm{ER}_{kj}^{t}) - \ln(\mathrm{ER}_{kj}^{0})} \ln\left(\frac{P_{kj}^{t}}{P_{kj}^{0}}\right), & \text{if} \quad \mathrm{ER}_{kj}^{t} \times \mathrm{ER}_{kj}^{0} \neq 0; \end{cases} \quad (4e)$$

According to the formula (2), this paper defines seven influence factors governing China's final energy consumption, listed as follows:

(i) The energy mix effect denoted by $\Delta E_{\mathrm{es}}^{t} = \Delta \mathrm{EP}_{\mathrm{es}}^{t} + \Delta \mathrm{ER}_{\mathrm{es}}^{t}$ reflects the changes in energy forms in total final energy consumption.

(ii) The energy intensity effect denoted by$\Delta E_{\mathrm{ei}}^{t} = \Delta \mathrm{EP}_{\mathrm{ei}}^{t} + \Delta \mathrm{ER}_{\mathrm{ei}}^{t}$ reflects changes in the improvement of energy efficiency.

(iiii) The economic structure effect denoted by $\Delta E_{\mathrm{s}}^{t} = \Delta \mathrm{EP}_{\mathrm{s}}^{t}$ reflects the changes in the relative shares of industry in total value added.

(iv) The economic growth effect denoted by $\Delta E_{\mathrm{g}}^{t} = \Delta \mathrm{EP}_{\mathrm{g}}^{t}$ reflects the changes in economic development.

(v) The resident income effect denoted by $\Delta E_{\mathrm{pi}}^{t} = \Delta \mathrm{ER}_{\mathrm{pi}}^{t}$ reflects the changes in the resident net income per capita.

(vi) The urbanization effect denoted by $\Delta E_{\mathrm{u}}^{t} = \Delta \mathrm{ER}_{\mathrm{u}}^{t}$ reflects the changes in process of economic and social modernization.

(vii) The population effect denoted by $\Delta E_{\mathrm{p}}^{t} = \Delta \mathrm{EP}_{\mathrm{p}}^{t} + \Delta \mathrm{ER}_{\mathrm{p}}^{t}$ reflects the changes in the amount of population.

Thus, the change in final energy consumption between a base year 0 and a target year t can be illustrated in Eq. (5):

$$\Delta E_{\mathrm{tot}}^{t} = \Delta E_{\mathrm{es}}^{t} + \Delta E_{\mathrm{ei}}^{t} + \Delta E_{\mathrm{pi}}^{t} + \Delta E_{\mathrm{u}}^{t} + \Delta E_{\mathrm{p}}^{t} + \Delta E_{\mathrm{s}}^{t} + \Delta E_{\mathrm{g}}^{t} \quad (5)$$

In the index number, we form

$$\frac{\Delta E_{\mathrm{es}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{ei}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{pi}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{u}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{p}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{s}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}+\frac{\Delta E_{\mathrm{g}}^{t}}{\Delta E_{\mathrm{tot}}^{t}}=1 \quad (6)$$

3 Results and discussion

3.1 General situation of final energy consumption in China, 1991–2011

As shown in Fig. 2, the final energy consumption in China increased from 814.21 Mtce in 1991 to 2470.8 Mtce in 2011, with an average annual growth rate of 5.7 %. The final energy consumption curve can be divided into three phases: a slow-growth phase between 1991 and 1996, a slow-decline phase over 1997–2001, and a rapid-growth phase from 2002 to 2011. The final energy consumption jumped from 1046.25 Mtce in 2002 to 2470.8 Mtce in 2011, and the annual growth rate increased twofold to 10 %. Figure 2 also shows that the most obvious trend is the increased percentage of production energy consumption. The share of production energy to total final energy consumption increased to 89.2 % in 2011 from 82.2 % in 1991.

The change trend of production energy consumption is similar to that of the total final energy consumption, as shown in Fig. 3. Nowadays, China is in the period of industrialization, which may lead to more energy consumption. The change in resident energy consumption exhibits two distinct stages, as shown in Fig. 3. Resident energy consumption decreased from 144.79 to 105.88 Mtce between 1991 and 1998 and then increased from 109.84 to 264.93 Mtce between 1999 and 2011.

In view of average annual growth rate, the tertiary industry is the fastest (8.06 %), followed by the secondary industry (6 %), the urban resident sector (3.5 %), and the rural resident sector (2.46 %). However, the average annual growth rate of the primary industry is 1.1 % during the study period. The changes in shares of industrial energy consumption in production sector over time are shown in Fig. 4. There is a substitution between the increasing shares of the tertiary industry (from 13.04 % in 1991 to 18.68 % in 2011) and a decreasing share of the primary industry (from 5.69 % in 1991 to 2.17 % in 2011) and the secondary industry (from 81.26 % in 1991 to 79.14 % in 2011).

The changes in the urban resident energy consumption per capita, like a U-curve, also exhibits two distinct stages, as shown in Fig. 5. Urban resident energy consumption per capita decreased from 258.01 Kgce (kg coal equivalent) in 1991 to 143.48 Kgce in 2001

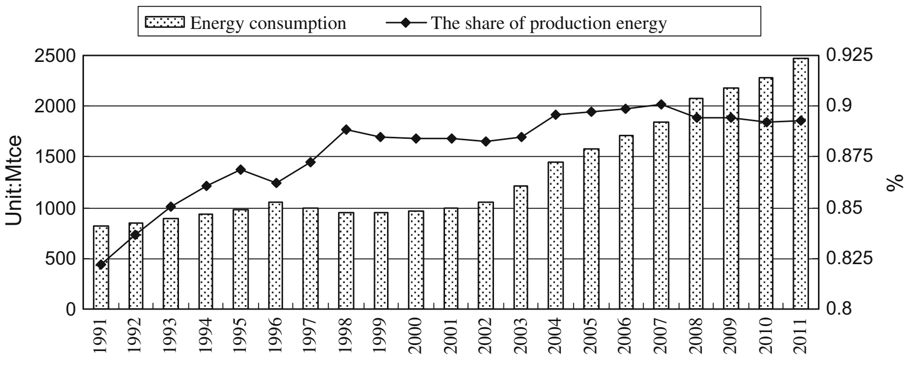

Fig. 2 China final energy consumption and the shares of production energy consumption during 1991–2011

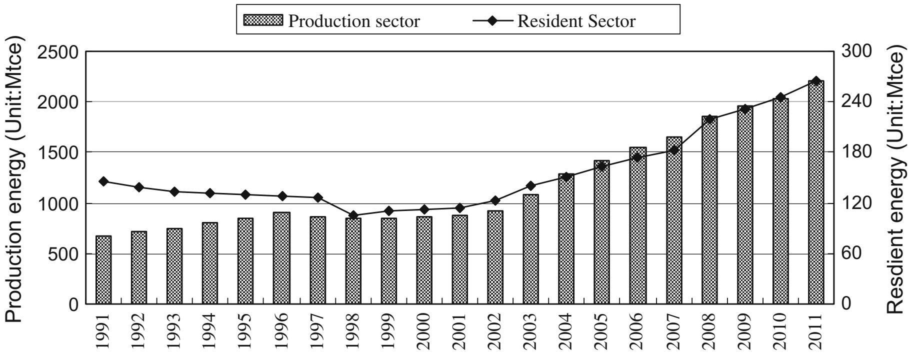

Fig. 3 Production energy consumption and resident energy consumption

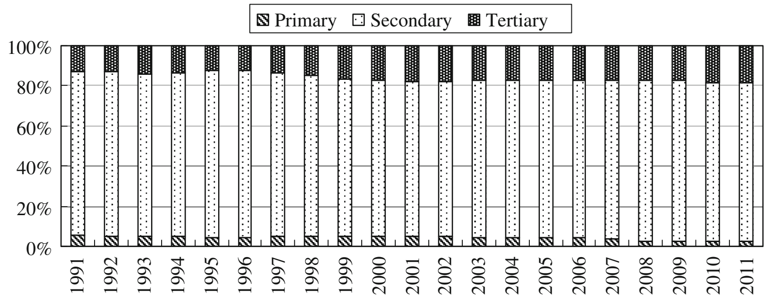

Fig. 4 Shares of industrial energy consumption in production sector

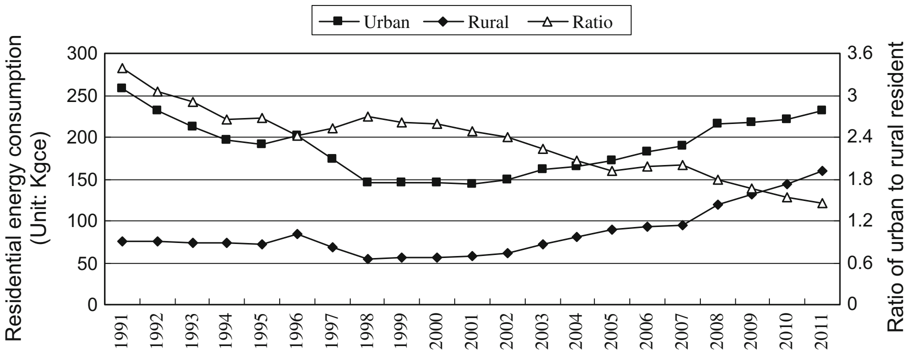

Fig. 5 Residential energy consumption per capita in urban and rural areas

and then increased from 148.45 to 231.93 Kgce between 2002 and 2011. The curve of rural resident energy consumption per capita can be divided into two phases: a slow-decline phase from 1991 to 2001 and a rapid-growth phase between 2002 and 2011. The rural resident energy consumption per capita jumped from 61.78 kgce in 2002 to 159.49 kgce in 2011, representing an annual growth rate of 11.1 %.

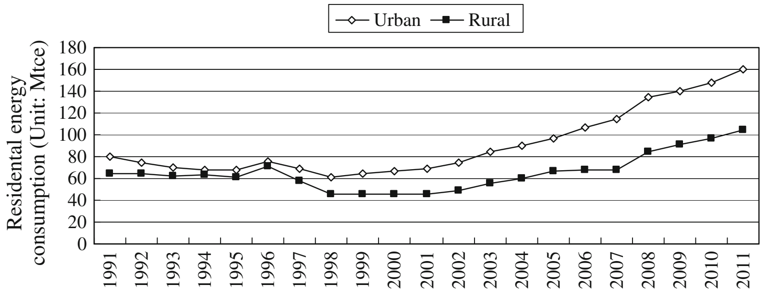

Fig. 6 Residential energy consumption in urban and rural areas

The gap in resident energy consumption per capita between urban and rural decreased from 3.39 in 1991 to 1.45 in 2011. The curve of the gap in resident energy consumption per capita between urban and rural can be divided into three phases: a rapid-decrease phase between 1991 and 1996, a slow-growth phase from 1997 to 1998, and a rapid-decrease phase between 1999 and 2011. Affected by urbanization, the gap between the resident energy consumption for urban and rural regions narrowed and then widened, as shown in Fig. 6. The urban resident energy consumption increased from 80.5 Mtce in 1991 to 160.22 Mtce in 2011, with an average growth rate of 3.5 %. However, the rural resident energy consumption rose from 64.28 Mtce in 1991 to 104.71 Mtce in 2011, with an average growth rate of 2.46 %.

3.2 Energy intensity effect

Table 1 shows that the energy intensity effect plays an important role in decreasing final energy consumption in China at the aggregate level. The aggregate change in final energy consumption contributed by energy intensity effect is 1012.58 Mtce, which accounts for 62.7 % of the overall change over the period of 1991–2011. The negative contribution happened only during 2002–2004 and 2007–2008.

Figure 7 shows that the change trend of energy intensity for all sectors declined in a wave pattern over the study period. In terms of the annual decline rate, the secondary industry is the fast. The energy intensity of the secondary industry decreased from 0.59 Kgce/yuan in 1991 to 0.23 Kgce/yuan in 2011, representing an annual change rate of 4.5 %. The curve of energy intensity of the secondary industry sector can be divided into two phases: a rapid-decrease phase from 1991 to 2002, a steadily wave-decrease phase between 2003 and 2011. It is also observed that the energy intensity of urban resident decreased by 21.4 % over the study period. However, the energy intensity of rural resident decreased by 37.3 % during the study period. The energy intensity of rural resident is higher than that of urban resident, as shown in Fig. 7. Based on the available data, the net income of rural resident instead of disposal income is used to calculate the energy intensity of rural resident. The change in energy intensity of the secondary industry can explain why the energy intensity played negative effect in 2002–2004 and 2007–2008.

3.3 Energy mix effect

Followed by energy intensity effect, the energy mix effect is another factor that decreases final energy consumption during the study period. The aggregate change in produce energy

Table 1 Decomposition of final energy consumption in China during 1991–2011, (Mtce)

	ΔE^t_{es}	ΔE^t_{ei}	ΔE^t_{s}	ΔE^t_{g}	ΔE^t_{pi}	ΔE^t_{u}	ΔE^t_{p}	ΔE^t_{tot}
1991–1992	−1.51	−87.83	20.42	83.93	10.26	0.90	9.56	35.72
1992–1993	6.27	−106.72	34.58	87.27	8.22	0.84	9.86	40.32
1993–1994	−5.16	−54.15	−0.20	86.98	8.34	0.73	10.13	46.67
1994–1995	0.07	−56.29	6.77	77.06	6.43	0.77	10.10	44.91
1995–1996	0.04	−22.97	4.74	74.92	8.42	2.10	10.61	77.87
1996–1997	−0.22	−155.90	1.86	70.01	5.20	1.84	10.27	−66.93
1997–1998	−1.03	−98.27	−14.05	56.71	5.60	1.62	8.85	−40.57
1998–1999	−0.04	−65.52	−3.65	55.15	6.95	1.49	7.77	2.15
1999–2000	−0.69	−63.01	3.26	62.47	4.77	1.48	7.27	15.54
2000–2001	−1.42	−52.10	−7.68	63.08	7.01	1.41	6.78	17.08
2001–2002	−0.44	−30.91	−3.70	72.34	10.44	1.34	6.52	55.59
2002–2003	0.19	49.47	15.69	89.38	8.41	1.37	6.74	171.27
2003–2004	−0.76	94.98	3.29	106.55	9.67	1.15	7.74	222.61
2004–2005	−0.92	−37.72	20.83	137.24	11.47	1.06	8.85	140.81
2005–2006	−1.90	−73.61	11.60	168.94	13.63	1.15	8.64	128.45
2006–2007	−2.57	−100.84	−11.62	202.76	17.00	1.35	9.07	115.16
2007–2008	−1.48	54.14	2.48	151.96	14.20	0.92	9.80	232.02
2008–2009	0.03	−48.29	−28.36	158.46	17.78	0.98	10.24	110.85
2009–2010	0.18	−140.18	12.00	187.97	18.50	0.88	10.53	89.89
2010–2011	0.04	−16.87	−1.50	157.78	23.29	1.33	10.20	174.27
1991–2011	−11.30	−1012.58	66.76	2150.93	215.59	24.72	179.54	1613.65

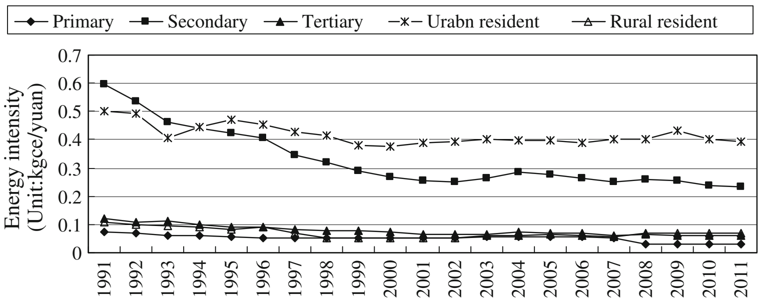

Fig. 7 Energy intensity of different sector

consumption contributed by energy mix effect is 11.3 Mtce, which accounts for 0.7 % of the overall change over the study period. The positive contribution only appeared during 1991–1992, 1993–1994, 1996–2002, and 2003–2008. As shown in Fig. 8, the energy mix effect is determined by the resident sector. Over the whole period, the contribution from energy mix effect of production section was negligible except 2009–2010.

There is a noteworthy improvement in resident energy consumption structure, as presented in Fig. 9. The share of coal products in resident energy consumption decreased from 87.8 % in 1991 to 28.1 % in 2011, whereas the share of oil products increased from 3.6 %

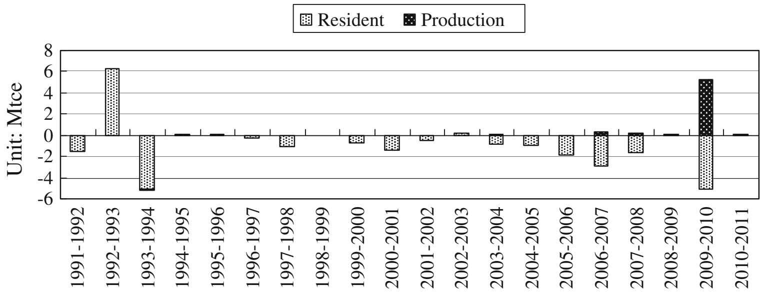

Fig. 8 Energy mix effect for production sector and resident sector

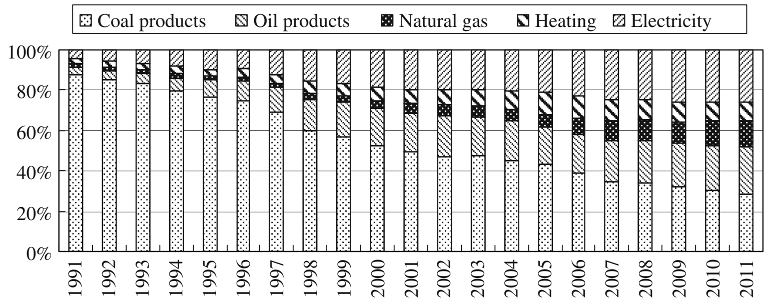

Fig. 9 Energy consumption structure in resident sector

in 1991 to 23.5 % in 2011, becoming the fastest growing energy type. With the growing popularity of electrical appliances, the share of electricity increased to 26.1 % in 2011 from 4.6 % in 1991. The share of natural gas increased to 13.27 % from 1.6 % during the study period. Additionally, the share of heating increased to 9.01 % in 2011, which reflects an improvement in urban resident living.

3.4 Economic growth effect

As listed in Table 1, the economic growth effect is the critical factor in the growth of final energy consumption in China. The aggregate change in final energy consumption contributed by the economic growth effect is 2150.93 Mtce, which accounts for 133.29 % of the overall change over 1991–2011. Over the whole period, that effect makes the continual increase in energy consumption, as listed in Table 1. As shown in Fig. 10, GDP per capita increased to 11828.9 yuan in 2011 from 1880.55 yuan in 1991, with an annual growth rate of 9.6 %, which shows that the economic growth effect plays the dominant role in increasing final energy consumption.

3.5 Resident income effect

In China, the disposal income per capita of urban resident increased from 1700.6 yuan in 1991 to 8377.4 yuan in 2011, with an average growth rate of 8.29 %. Meanwhile, the net income per capita of rural resident jumped from 708.6 yuan in 1991 to 2373.5 yuan in 2011

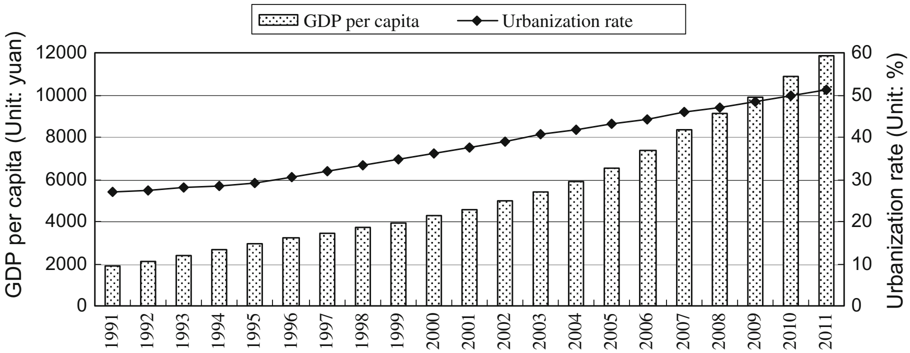

Fig. 10 GDP per capita and urbanization rate over 1991–2011

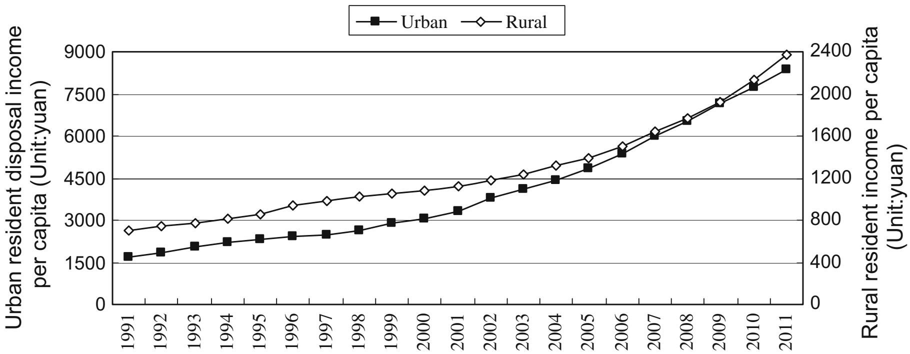

Fig. 11 Disposal income per capita of urban resident and net income per capita of rural resident over 1991–2011

and the annual growth rate reached 6.23 %, as shown in Fig. 11. From Table 1, we can see that the contribution from the income effect increased significantly over time, especially during 2001–2011. In the period of 2006–2007, 2008–2009, 2009–2010, and 2010–2011, final energy consumption increase from resident income effect was 17.0, 17.78, 18.50, and 23.29 Mtce, respectively, which shows that the resident income effect has become the most important contributor in the recent years. With the economic growth, the increase in resident income is continuing, which may lead to the gradual increase in final energy consumption.

3.6 Population effect

Over the study period, the increase in final energy consumption from the population effect fluctuated from 6.52 to 10.61 Mtce, which shows that the population effect is one of the most stable influence factors, as shown in Fig. 12. The aggregate change in final energy consumption contributed by the population effect is 179.54 Mtce (listed in Table 1), which accounts for 11.1 % of the overall change over 1991–2011. The contributor to resident energy consumption for the population effect is bigger than that to production energy consumption. In China, the population increased from 1158.23 million persons in 1991 to

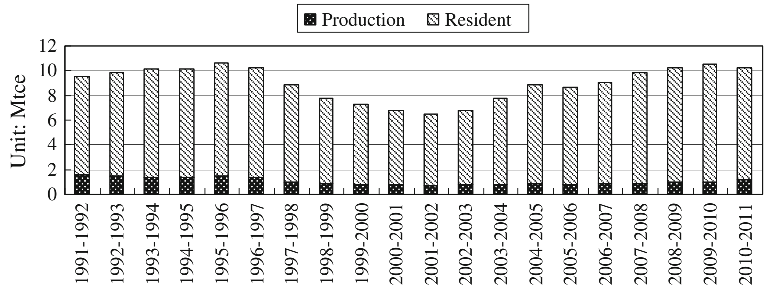

Fig. 12 Population effect for production sector and resident sector

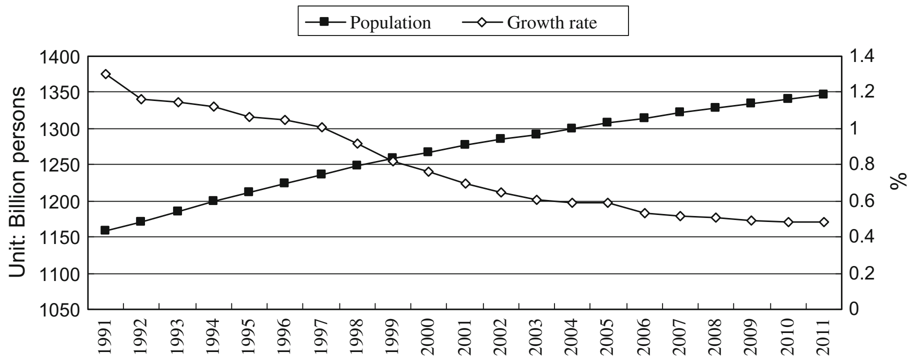

Fig. 13 Population and annual growth rate over 1991–2011

1347.35 million persons in 2011, an increase of 189.12 million persons which corresponds with a relative increase of 16.32 %, as shown in Fig. 13. Figure 13 also shows that the annual growth rate of population gradually increased over time. The change in population reflects the contributor of this effect.

3.7 Economic structure effect

The aggregate change in final energy consumption contributed by economic structure effect is 66.76 Mtce, which accounts for 4.1 % of the overall increase during the period of 1991–2011. The positive contribution in decreasing energy consumption happened in the period of 1993–1994, 1997–1998, 1998–1999, 2000–2001, 2001–2002, 2006–2007, 2008–2009, and 2010–2011. The largest positive contribution appeared from 2008 to 2009 accounting for 25.5 %.

The tendency of economic structure in China over 1991–2011 is presented in Fig. 14. The share of the primary industry gradually decreased from 24.5 % in 1911 to 10.1 % in 2011. However, the share of the secondary and tertiary industries increased in waved pattern. Over the study period, the share of the tertiary industry increased to 44.5 % from 33.6 %. Since 1993, the share of the secondary industry has accounted for more than 45 %, which shows that China economy mainly depended on the secondary industry. The decline

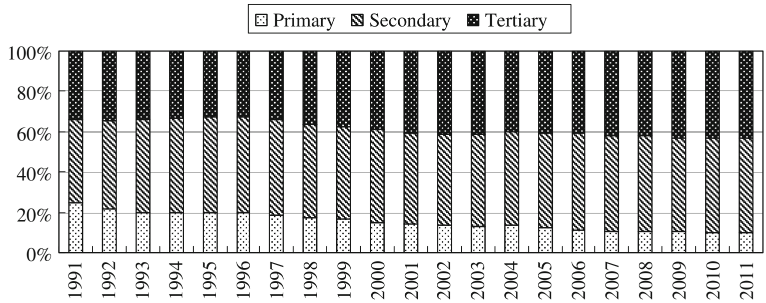

Fig. 14 Economic structure in China over 1991–2011

trend of the secondary industry can explain why the economic structure effect played a positive role in decreasing final energy consumption.

3.8 Urbanization effect

As listed in Table 1, the aggregate change in final energy consumption contributed by the urbanization effect is only 24.72 Mtce, which accounts for 1.53 % of the overall change over 1991–2011. However, the increase in final energy consumption from the urbanization effect fluctuated from 0.73 to 1.84 Mtce, which shows that the urbanization effect is another stable influence factor. Urbanization is a process of economic and social modernization, which transfers rural labor from an agricultural-based economy to urban areas where industrial and service sectors predominate. Figure 10 also shows that the urbanization rate in China went up from 26.9 % in 1991 to 51.3 % in 2011, with an average growth rate of 3.26 %. Rapid urbanization began in the mid-1990s. The urbanization rate increased from 29.04 to 40.53 % between 1995 and 2003, rising approximately 4.25 % annually. The contributor of this effect can be reflected by the change in urbanization rate.

4 Conclusions and policy implication

In this paper, we try to explain the sharp changes in final energy consumption in China from 1991 to 2011. The final energy consumption in China was divided into production energy consumption and resident energy consumption. Under this new framework, the LMDI method was utilized to study the factors governing the change in final energy consumption. Furthermore, this paper defined seven impact factors: energy mix effect, energy intensity effect, economic structure effect, economic growth effect, resident income effect, urbanization effect, and population effect. The following conclusions are drawn from the above results.

The final energy consumption jumped to 2470.8 Mtce in 2011, and the annual growth rate increased twofold to 10 % over the period 2002–2011. In 2011, the share of production energy to total final energy consumption increased to 89.2 %. However, the annual growth rate of resident energy consumption increased to 8.7 % during the period 2001–2011. In production sector, there is a substitution between the increasing shares of the tertiary industry and a decreasing share of the primary industry and the secondary industry. The gap in resident energy consumption per capita between urban and rural decreased during the study period. However, the gap between the resident energy consumption for urban and rural regions narrowed and then widened, which may be affected by urbanization.

The energy intensity effect plays an important role in decreasing final energy consumption at the aggregate level, followed by the energy mix effect. However, the economic growth effect is found to be primarily responsible for driving final energy consumption growth over the study period, followed by resident income effect, population effect, economic structure effect, and urbanization effect. In all factors, the urbanization effect is a stable influence factor and also plays minor contribution to final energy consumption.

According to the above conclusions, the following policies should be considered:

1. The production energy consumption almost accounted for 90 % of total final energy consumption in 2011, especially for the secondary industry. Furthermore, the economic growth effect and the economic structure effect also increased the energy consumption over the study period. Thus, strict restrictions should be applied to the development of energy-insensitive industry such as produce steel and cement. Various policies should be implemented for encouraging development of the higher value-added secondary industry and the tertiary industry. To reduce environmental degradation, the central government of China may properly reduce the speed of economic growth.
2. With the growth of resident income, people tend to consume more energy to obtain a quality life characterized with convenient travelling and comfortable living. The income effect is found to be another factor, which was primarily responsible for driving final energy consumption growth over the study period. Therefore, changing the residents' behavior can be a good way toward reducing energy consumption. The use of energy-saving products may be another means to save energy use, which can be encouraged by some subsidy policies.
3. The population effect is one of the most stable influence factors governing the increase in energy consumption. The central government of China issued new family planning policy in 2013, which may promote slowly increase in China population for a long period. In fact, the family planning policy has not strictly been implemented in many areas, such as country in western China, in which many families have two or more children. Thus, there will be great potential for reducing the growth of China population if the policy is strictly implemented.
4. Though the urbanization rate increased rapidly, the urbanization effect plays minor contribution to the increase in final energy consumption among all factors. Nowadays, the central government accelerates the process of urbanization. To prevent the urbanization effect becoming another main contributor to energy consumption, the central government should encourage local governments to save land for intensive use and prohibit them from blindly expanding cities. Furthermore, the resident living should be considered when setting urbanization goals.
5. The energy intensity effect plays an important role in decreasing final energy consumption. Compared with the developed countries, the energy efficiency in China has more room to improve. Thus, the central government should strengthen the utilization of new technologies and crafts by many financial subsidies and preferential policies and so on.
6. Our results show that the energy mix effect only plays an active role in reducing energy consumption in resident energy consumption. Thus, the government should promote the renewable energy use and increase the share of non-fossil fuel by tax benefits and financial incentives, especially in production section. Furthermore, the

direct combustion of coal should be reduced by some enforcement policy. On May 21, 2014, Chinese and Russian governments signed the "Sino–Russian cooperation project memorandum Eastern Gas." According to the two sides agreed that from 2018 onward, China began to supply Russian gas pipeline through Eastern Russia, gas volume growth year after year, eventually reaching 38 billion cubic meters per year, a total of 30 years, which may help change China energy structure.

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