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RESEARCH ARTICLE

Primary energy consumption structure and the influencing factors in China: an income decomposition and post-economic crisis era perspective

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Abstract
China's coal-based energy structure makes its carbon peak and neutrality goals very challenging. As a result, optimizing the energy structure has become an important means, and researching its influencing factors and trends has become the foundation and prerequisite for policy formulation related to energy structure optimization. Especially after the severe economic crisis, the economic structure has undergone profound changes, and the impact of related factors on the energy structure has also changed. This study adopts regression methods considering heteroskedasticity and cross-section correlation to study the panel data of 30 provinces in China and obtains the changes in the relationship between fossil and non-fossil fuel consumption in different regions and their influencing factors after two global financial crises. Research results show that China's energy consumption tends to decouple from GDP. Income structure changes, especially trade changes, are important factors in influencing energy consumption and energy structure. The deviation between energy resource distribution and consumption distribution tends to increase. Regional heteroskedasticity is evident in the impact of urbanization development models, energy prices, and efficiency.

Keywords Energy consumption structure · Income structure · Panel data · Primary energy structure · Coal-based energy structure · Decomposition methodology

Introduction

With the development of a low-carbon economy, governments are paying more and more attention to the optimization of energy structure. Due to the characteristics of resource endowment, China's energy consumption has long been dominated by coal. Therefore, the optimization of energy consumption structure has attracted much attention today due to the increase in environmental pressure. The Chinese government has continuously introduced policies to encourage the development and utilization of new energy sources and to optimize energy structure and reduce pollutant emissions through technologies and policies. However, due to the characteristics of the development stages of urbanization and industrialization, such as the economic characteristics of investment-driven and administrative guidance, may offset the effects of these policies. On the other hand, there are significant regional differences in economic development in China, and there is a certain imbalance between the distribution of energy resources and energy consumption. Figures 1, 2, and 3 show the changes in China's primary energy structure, the primary energy consumption structure of 30 provinces in China, and the resource endowments in each region. The combination of the three figures shows that there are huge differences in energy consumption and resource endowment in different regions, and it is necessary to optimize relevant energy consumption policies. As Zhang and Lahr (2014) said, as a spatially large and heterogeneous country, it is crucial to identify the key driving forces of the growth in energy use for each region to design appropriate regional energy conservation policies.

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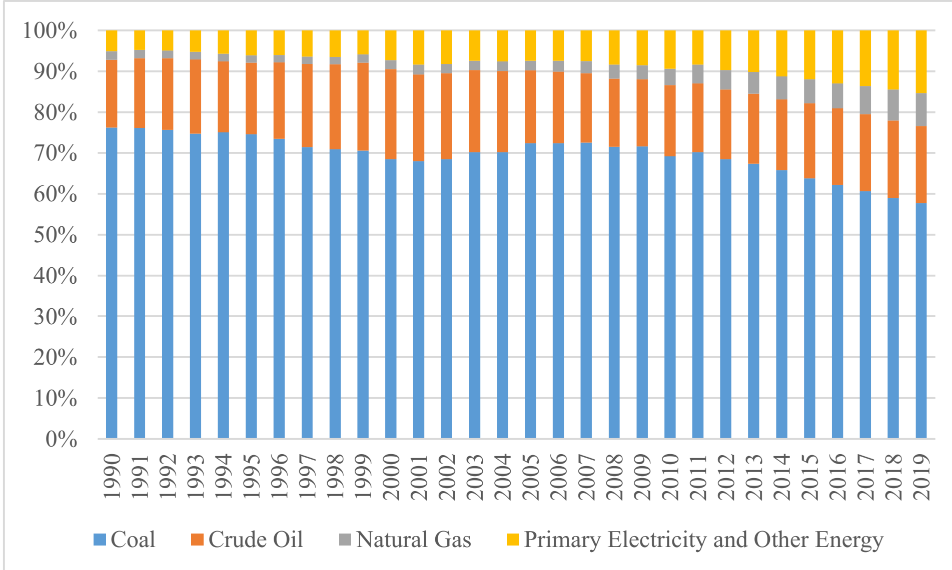

Fig. 1 China's primary energy consumption structure. Sources: NBSC (2021a)

What is more, economic crises have had a profound impact on the global economy. After the severe economic crisis, the economic structure has undergone profound changes, which also makes the impact of related factors on the energy structure likely to change. Some scholars have also paid attention to the relationship between the economic crisis and energy consumption. However, little research has been done in China on this issue.

Based on existing research and understanding of China's energy consumption and regional differences, this study will comprehensively consider macro-level factors, including income, income structure, urbanization, energy price, and efficiency, from the perspective of geographic location and economic development similarity, using regional panel data and regression models to study the relationship between these factors and the main primary energy consumption, the differences before and after the economic crisis, and then draw some policy implications.

The other parts of the paper are arranged as follows: The second part is a literature review. Based on the literature review, the variables, research methods, and data used in the empirical tests are introduced in the third part. The empirical research results and discussion are given in the fourth part, and the fifth part encapsulates the main points of the study and gives some policy implications.

Literature review

There are numerous empirical studies on energy consumption structure. A literature review for this study would examine the literature which focused more on income perspective and financial crisis.

A review of the literature on the structure of energy consumption and the factors that influence it

There is relatively little direct research on the structure of energy consumption in the academic community. There are also some studies involving energy consumption in different categories (Wang and Lin 2017; Wandji 2013; Bilgen 2014; Park and Hong 2013; Tugcu and Topcu 2018; Saboori and Sulaiman 2013). Many studies have focused on the impact of energy structure on energy efficiency and carbon emission efficiency (Chen and Chen 2016; Wang and Xie 2015; Liu et al. 2016; Zhang et al. 2016; Chen et al. 2018). The above-mentioned studies mostly focus on the relationship between energy structure and energy efficiency, carbon emissions, etc., and seldom directly study energy structure and its influencing factors. The research on China's energy consumption is mainly about primary energy consumption, terminal energy consumption, or a specific energy consumption pattern, rarely involving changes in energy structure. As Liao and Wei (2010) said, most previous studies directly used the aggregate energy data provided by China's National Bureau of Statistics or International Energy Agency, and this approach sometimes may not be scientific when precisely investigating the energy–economy interactions is needed. Research involving the structure of energy consumption, either using a gray model (Li et al. 2006; Tsai 2016; Yuan et al. 2010) or studying the energy consumption structure of certain production sectors (Wei et al. 2007; Zhou et al. 2009). Some researchers also studied energy consumption or energy intensity in different categories (Chang et al. 2003; Fan et al. 2007; Yuan et al. 2008; Fan and Xia 2012; Fisher-Vanden et al. 2004; Feng et al. 2009). However, they have

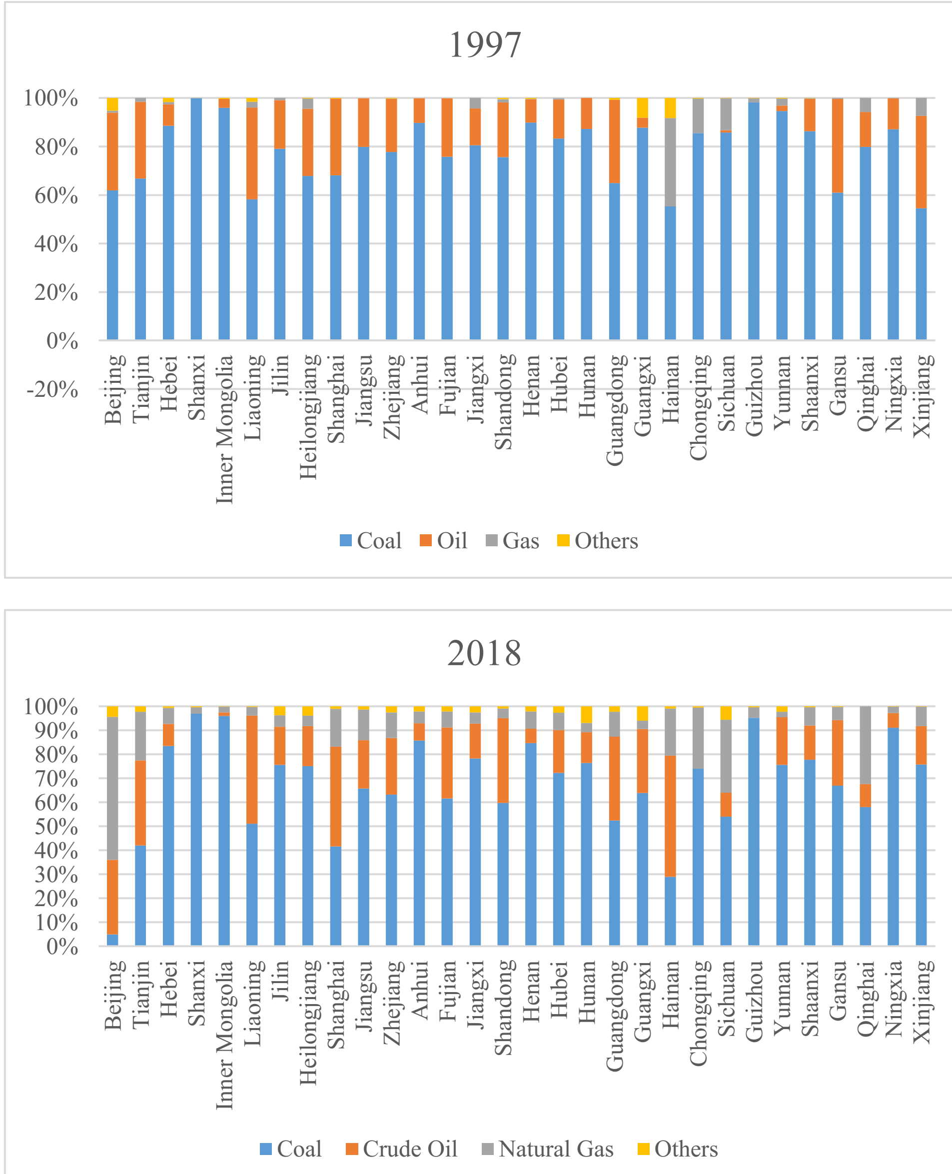

Fig. 2 Primary energy consumption structure of China's 30 provinces in 1997 and 2018. *Sources*: NBSC (2020)

rarely considered the issue of energy consumption structure, especially the structure of fossil energy consumption.

A literature review on energy consumption structure and the financial crisis

In recent decades, two major economic crises, including the 1998 economic crisis and the 2008 economic crisis, have had a profound impact on the global economy. Some scholars have also paid attention to the relationship between the economic crisis and energy consumption.

By using a multi-scale integrated analysis of societal and ecosystem metabolism, Andreoni (2020) investigated energy requirements, economic trends, and population for the years 2008 and 2015 and discussed how the deceleration of economic growth that followed the financial crisis of 2008 influenced the energy efficiency, allocation, and use of 18 European countries. Andriosopoulos et al. (2017) investigated whether and to what extent events in financially troubled EU markets (Greece, Ireland, and Portugal) affected energy prices during the EU financial crisis. Hofman and Huisman (2012) presented a research project that examined whether the preferences of investors in Europe and the USA changed due to the financial crisis and found that the popularity of 11 out of 12 policies decreased. Selcuk and Durusoy (2019) pointed out that the transportation sector is an energy-intensive sector that needs more attention from policymakers due to its contribution to the increase in energy intensity after the crisis years as well as its increasing contribution to overall energy intensity. Some scholars

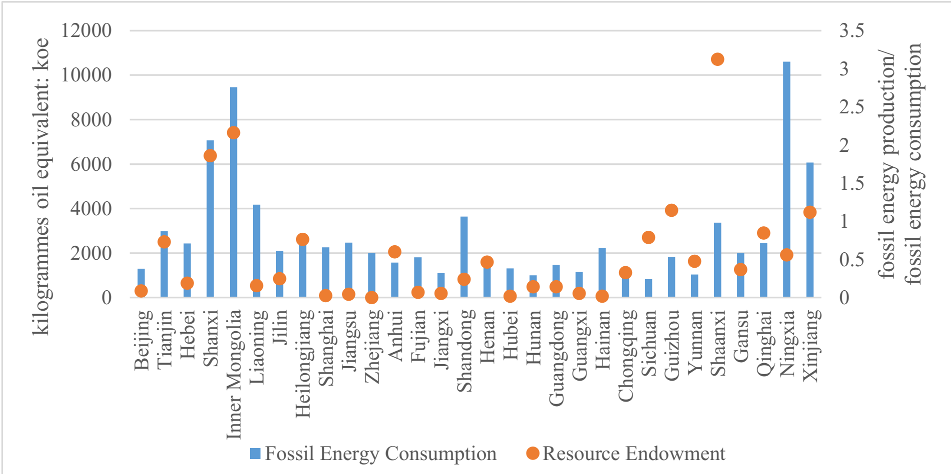

Fig. 3 Per capita fossil energy consumption and fossil resource endowment coefficient in China's provinces in 2018. *Sources*: NBSC (2020). Note that the fossil resource endowment coefficient here is a simple indicator of the energy supply capacity of the fossils in the region and equals to fossil energy production/fossil energy consumption. Fossil fuels are made from decomposing plants and animals. These fuels are found in the Earth's crust and contain carbon and hydrogen, which can be burned for energy. Coal, oil, and natural gas are examples of fossil fuels. Non-fossil fuels are alternative sources of energy that do not rely on burning up limited supplies of coal, oil, or natural gas. Examples of these fuels include nuclear energy, wind or water generated energy, and solar power

have found that after the 2008 crisis, there has been a trend of decoupling between energy consumption or carbon emissions and GDP (Mentis et al. 2015; Sadorsky 2020). For Asian countries, Setyawan et al. (2020), Bekhe and Yasmin (2014), and Lin (2010) have discussed the influence of the Global Financial Crisis on energy consumption and economic growth.

As Timma et al. (2016) said, there is a need to evaluate the effect of the economic recession in other regions and countries. Moreover, decomposition analysis can be further expanded to include the aggregate of energy carried in order to account for the shift toward renewable energy at a sectorial level. Thus, the structure of the income is also important. In China, like the energy consumption structure, important changes are also taking place in the structure of various parts of the GDP in the macroeconomic body, especially after the 2008 global financial crisis. The changes in the overall environment have caused major changes in China's foreign trade environment, and exports have suffered more with strong resistance, while imports have grown rapidly, as shown in Fig. 4. In addition, in order to promote economic development, various regions have increased their investment. From the perspective of the GDP structure of expenditure method, as shown in Fig. 5, the proportion of total capital formation in GDP has increased. However, few scholars have so far discussed the relationship between the changes in the proportion of expenditures of various sectors in the GDP using the expenditure method and energy consumption, especially the energy structure.

In this study, the primary energy structure in China is considered, and the relationship between coal, oil, natural gas, and GDP will be studied, respectively. At the same time, this paper also added the income structure as an influencing factor from the perspective of the expenditure method of GDP accounting to discuss the relationship between it and energy consumption and supplement the existing research.

Variables and data

From the method point of view, the panel data model is widely used in the study of energy consumption in different countries or regions (for example, Narayan and Popp 2012; Li and Lin 2015; Li et al. 2011; Wang and Lin 2019). Based on the literature, from the perspective of macroeconomics, the influencing factors of primary energy consumption generally include income, price, economic structure, population, and technical progress. Considering the representation and availability of data, the dependent variables and data selected in this paper are as follows: per capita total primary energy consumption (*TOT*), per capita coal consumption (*COA*), per capita oil consumption (*OIL*), per capita natural gas consumption (*GAS*), and per capita other fuel consumption *(OTH*), which includes primary electricity and other non-fossil fuels. The energy consumption data are from NBSC (2020).

Per capita GDP is also included. GDP represented by expenditure includes household final consumption expenditure, capital formation, general government final consumption expenditure, and exports and imports of goods and services. As the levels and shares of these variables in GDP reflect the region's economy and social structure

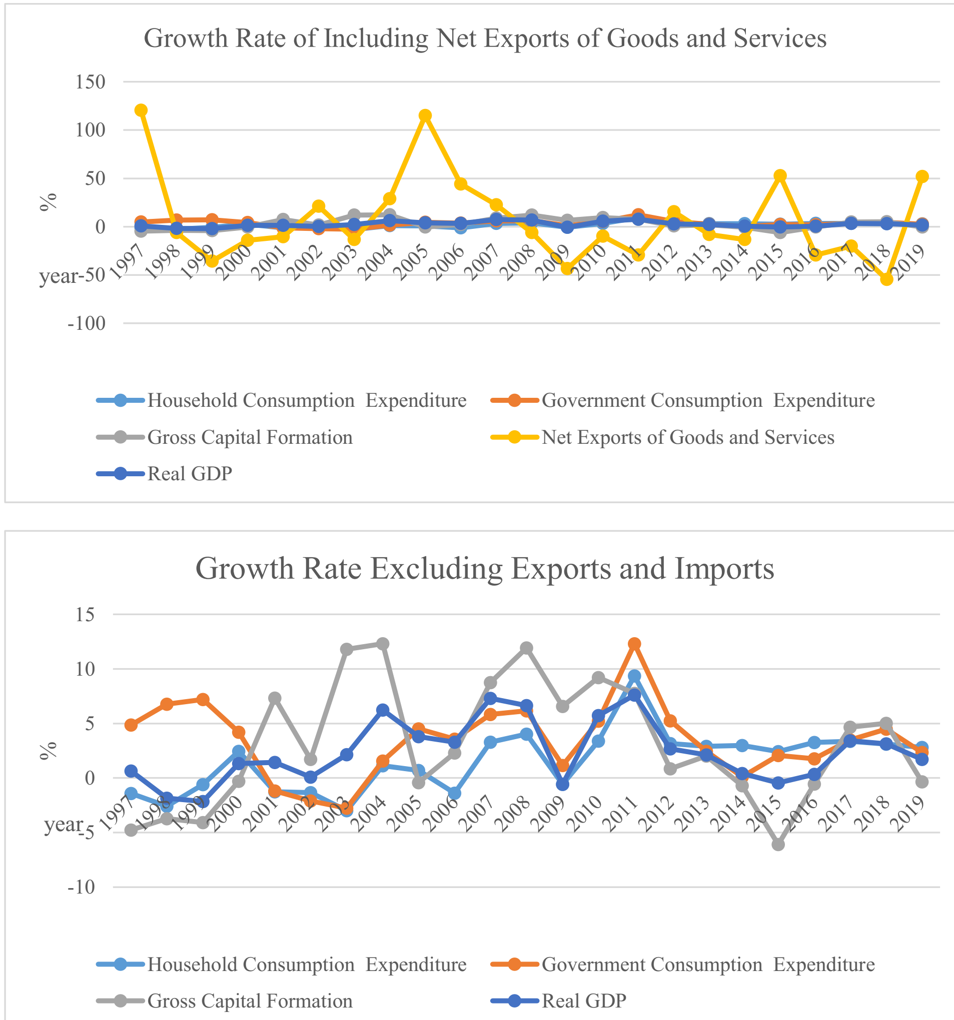

Fig. 4 Growth rate of components of per capita real GDP by expenditure method. *Sources*: NBSC (2021b). Note that since net exports are more volatile, in order to more clearly show the growth rate comparison of consumption, government expenditure, and investment, there presents two growth rate charts, one of the graphs contains the growth rate of net exports, and the other excludes this growth rate

characteristics, this paper uses these variables to analyze the influence of income structure on energy consumption for better comparisons and understanding. These variables include per capita real GDP (*GDP*), household final consumption expenditure share in GDP (*SCON*), gross capital formation share in GDP (*SINV*), general government final consumer expenditure share in GDP (*SGOV*), exports of goods and services in GDP (*SEXP*), and imports of goods and services in GDP (*SIMP*), which are calculated by the expenditure method and can reflect economic structure. And the data are from NBSC (2021b) (constant 2008 RMB).

The urbanization rate (*URR*) is used to capture socio-demographic structure, and the data is from NBSC (2021a). The fuel Retail Price Index is used as a price variable (*EPR*) (with 2008 as the base year), and the data is from NBSC (2021b). The fossil resource endowment coefficient, which equals fossil energy production/fossil energy consumption (*REE*) and is introduced as a simple indicator of the energy supply capacity of the fossils in the region, is also introduced as a simple indicator of the energy supply capacity of the fossils in the region. The data are from NBSC (2020). The ratio of real GDP to electricity consumption is used as a technology variable (*EEF*) or efficient variable (Chong et al. (2017)), and the data are from NBSC (2021b). The definition of the specific variables used in this study, the unit measurements, and the sources of the data are listed in Table 1. In order to avoid the heteroscedasticity problem, the figures are transformed into logarithmic form. The logarithmic form is expressed as follows: Ln*TOT*, Ln*COA*, Ln*OIL*, Ln*GAS*, Ln*OTH*, Ln*GDP*, Ln*SCON*, Ln*SINV*, Ln*SGOE*, Ln*SEXP*, Ln*SIMP*, Ln*URR*, Ln*REE*, Ln*EPR*, and Ln*EEF*. And the time scale of the data is from 1998 to 2017. Table 2 provides the statistical review of the variables.

The basic relationship between the aforementioned variables is specified in Eqs. (1), (2), (3), (4), and (5), and the similar equations can be seen in Al-Mulali and Che (2012):

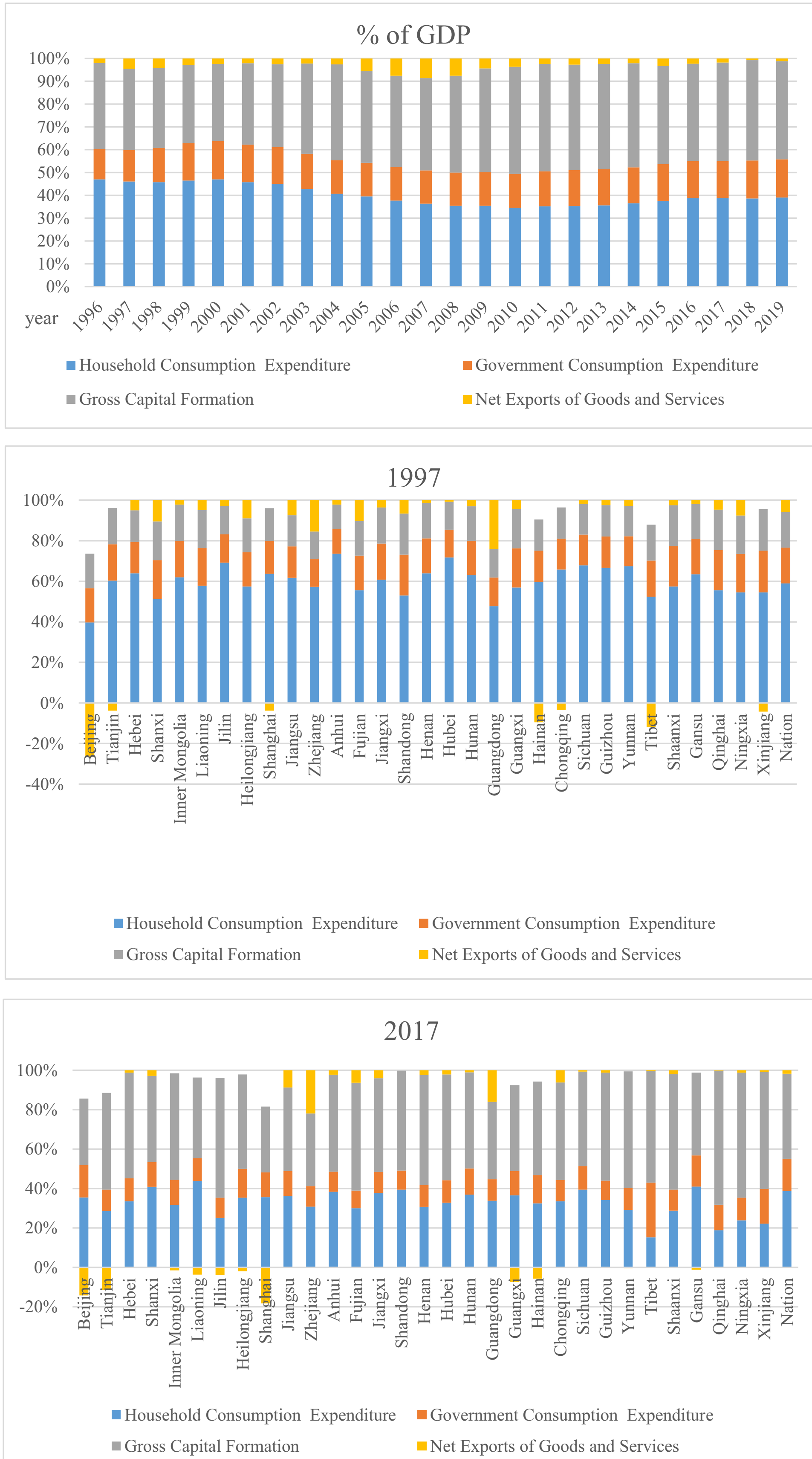

Fig. 5 Percentage of components of per capita real GDP by expenditure method. *Sources*: NBSC (2021a). It should be noted that the National Bureau of Statistics of China also indicated in the statistical data of various provinces that due to the adoption of hierarchical accounting, the total GDP of each region does not add up to the national total

Table 1 Definition of the variables used in the study

Variable	Definition	Units of measurement	Data source
TOT	Per capita total primary energy consumption	Kilogram of oil equivalent	NBSC (2020)
COA	Per capita coal consumption	Kilogram of oil equivalent	NBSC (2020)
OIL	Per capita oil consumption	Kilogram of oil equivalent	NBSC (2020)
GAS	Per capita natural gas consumption	Kilogram of oil equivalent	NBSC (2020)
OTH	Per capita other energy consumption	Kilogram of oil equivalent	NBSC (2020)
GDP	Per capita real GDP	Constant 2008 ¥	NBSC (2021b)
SCON	Share of household final consumption expenditure in GDP	%	NBSC (2021b)
SINV	Share of gross capital formation in GDP	%	NBSC (2021b)
SGOV	Share of general government final consumption expenditure in GDP	%	NBSC (2021b)
SEXP	Share of exports of goods and services in GDP	%	NBSC (2021b)
SIMP	Share of imports of goods and services in GDP	%	NBSC (2021b)
URR	Urbanization rate	%	NBSC (2021b)
REE	Endowment of fossil energy resources	1	NBSC (2020)
EPR	Fuel Retail Price Index	2008 as the base year	NBSC (2021b)
EEF	Ratio of real GDP to electricity consumption	Constant 2008 ¥/kWh	NBSC (2021b)

$$\begin{aligned} LnTOT_{i,t} = \beta_0 + \beta_1 LnGDP_{i,t} + \beta_2 LnSCON_{i,t} + \beta_3 LnSINV_{i,t} + \beta_4 LnGOV_{i,t} \\ + \beta_5 LnSEXP_{i,t} \beta_6 LnSIMP_{i,t} + \beta_7 LnURR_{i,t} + \beta_8 LnREE_{i,t} \\ + +\beta_9 LnEPR_{i,t} + \beta_{10} LnEEF_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{1}$$

$$\begin{aligned} LnOTH_{i,t} = \beta_0 + \beta_1 LnGDP_{i,t} + \beta_2 LnSCON_{i,t} + \beta_3 LnSINV_{i,t} + \beta_4 LnGOV_{i,t} \\ + \beta_5 LnSEXP_{i,t} + \beta_6 LnSIMP_{i,t} + \beta_7 LnURR_{i,t} + \beta_8 LnREE_{i,t} \\ + \beta_9 LnEPR_{i,t} + \beta_{10} LnEEF_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

$$\begin{aligned} LnCOA_{i,t} = \beta_0 + \beta_1 LnGDP_{i,t} + \beta_2 LnSCON_{i,t} + \beta_3 LnSINV_{i,t} + \beta_4 LnGOV_{i,t} \\ + \beta_5 LnSEXP_{i,t} + \beta_6 LnSIMP_{i,t} + \beta_7 LnURR_{i,t} + \beta_8 LnREE_{i,t} \\ + \beta_9 LnEPR_{i,t} + \beta_{10} LnEEF_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{3}$$

$$\begin{aligned} LnOIL_{i,t} = \beta_0 + \beta_1 LnGDP_{i,t} + \beta_2 LnSCON_{i,t} + \beta_3 LnSINV_{i,t} + \beta_4 LnGOV_{i,t} \\ + \beta_5 LnSEXP_{i,t} + \beta_6 LnSIMP_{i,t} + \beta_7 LnURR_{i,t} + \beta_8 LnREE_{i,t} \\ + \beta_9 LnEPR_{i,t} + \beta_{10} LnEEF_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{4}$$

$$\begin{aligned} LnGAS_{i,t} = \beta_0 + \beta_1 LnGDP_{i,t} + \beta_2 LnSCON_{i,t} + \beta_3 LnSINV_{i,t} + \beta_4 LnGOV_{i,t} \\ + \beta_5 LnSEXP_{i,t} + \beta_6 LnSIMP_{i,t} + \beta_7 LnURR_{i,t} + \beta_8 LnREE_{i,t} \\ + \beta_9 LnEPR_{i,t} + \beta_{10} LnEEF_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{5}$$

Correlation study on energy consumption structure and influencing factors

First, the results of a national study would be presented and discussed. Then, heterogeneity analysis would be done at the provincial level, as the effects of influential factors on energy consumption structure could be heterogeneous based on location.

Results of a national study

For panel data, model selection between the fixed effects model and the random effects model is very important. A detailed explanation of the model selection is available in many studies (Wooldridge 2002; Lee 2005; Al-Mulali and Che 2012; Apergis and Payne 2009; Gozgor et al. 2018). Only the results of the Hausman test and the overidentifying test are reported in order to determine the selection of either a random or fixed effects model. This study would use the fixed effects model as the results are affirmed in Table 3. Furthermore, heteroscedasticity, serial correlation, and cross-sectional dependence tests are needed. In this paper, a modified Wald statistic for groupwise heteroskedasticity in the residuals is implemented, following Greene (2000), and the results are shown in Table 4. The test results for the hypothesis of serial dependence correlation are shown in Table 5, and this method has been discussed by Wooldridge (2002). The hypothesis of cross-sectional independence in panel data models with small T and large N can be implemented with two semi-parametric tests proposed by Friedman (1937) and Frees (1995, 2004), as well as the parametric testing procedure proposed by Pesaran (2004). The results are shown in Table 6.

It can be seen that there are different test results for different energy consumption equations, and the data of some equations may have the problems of heteroscedasticity, autocorrelation, and cross-sectional correlation. To solve these problems, regression with Driscoll-Kraay standard method (Driscoll and Kraay, 1998) has been adopted. In order to test whether there is a structural change in this time period, especially after the Asian financial crisis in 1998 and the global financial crisis in 2008 (Wen et al.

Table 2 Statistical reviews of variables

Variable		Mean	Std. dev	Min	Max	Observations
TOT	Overall	1226.97	1591.43	4.09	9677.66	*N* = 600
	Between		990.12	340.07	3897.24	*n* = 30
	Within		1258.34	−2628.21	7703.90	*T* = 20
OTH	Overall	19.93	25.44	0.01	254.54	*N* = 460
	Between		14.98	2.56	64.60	*n* = 30
	Within		21.58	−41.61	209.86	*T*-bar = 15.3333
COA	Overall	860.88	1294.51	0.01	7965.65	*N* = 600
	Between		883.54	274.3	3750.83	*n* = 30
	Within		959.11	−2884.9	5075.7	*T* = 20
OIL	Overall	245.96	303.9	0	2335.34	*N* = 545
	Between		190.36	0.01	649.08	*n* = 29
	Within		241.89	−400.04	1932.22	*T*-bar = 18.7931
GAS	Overall	83.83	140.76	0	926.23	*N* = 557
	Between		88.08	3.97	344.54	*n* = 30
	Within		109.38	−255.68	745.88	*T*-bar = 18.5667
GDP	Overall	5888.6	12,403.88	3.04	88,652.25	*N* = 600
	Between		8944.83	3.39	37,769.98	*n* = 30
	Within		8739.8	−31,084.3	57,947.1	*T* = 20
SCON	Overall	34.05	13.15	3.01	73.39	*N* = 600
	Between		5.95	26.31	49.62	*n* = 30
	Within		11.77	−10.95	57.82	*T* = 20
SINV	Overall	47.98	23.32	0.56	98.99	*N* = 600
	Between		7.74	36.56	63.75	*n* = 30
	Within		22.04	−8.24	106.02	*T* = 20
SGOV	Overall	6.46	7.58	0	46.61	*N* = 600
	Between		5.64	1.82	23.15	*n* = 30
	Within		5.16	−11.12	31.44	*T* = 20
	Overall	13.19	18.1	0.22	89.34	*N* = 600
SEXP	Between		16.24	2.81	68.73	*n* = 30
	Within		8.51	−45.96	58.61	*T* = 20
SIMP	Overall	12.43	17.92	0.23	97.83	*N* = 600
	Between		15.67	2.2	64.17	*n* = 30
	Within		9.13	−47.3	54.95	*T* = 20
URR	Overall	44.03	22.37	0.45	98.75	*N* = 600
	Between		13.56	28.44	83.12	*n* = 30
	Within		17.96	−27.64	97.67	*T* = 20
REE	Overall	0.64	0.74	0	7.36	*N* = 600
	Between		0.56	0.01	2.46	*n* = 30
	Within		0.5	−1.57	5.54	*T* = 20
EPR	Overall	38.05	32.34	0	99.66	*N* = 600
	Between		4.77	29.65	52.35	*n* = 30
	Within		31.99	−14.07	104.4	*T* = 20
EEF	Overall	7.43	8.12	0	54.56	*N* = 600
	Between		2.83	2.81	12.71	*n* = 30
	Within		7.63	−4.95	50.13	*T* = 20

2012; Dungey and Zhumabekova 2001), this paper will introduce dummy variables and test the joint significance of all dummy variables and their cross-term coefficients with explanatory variables. That is to say, the dummy variable "*d*" is introduced in the basic Eqs. (1)–(5). After 2008, $d = 1$; conversely, $d = 0$, and the interaction terms between the dummy variable "*d*" and each influencing variables are also introduced: $d\text{Ln}GDP = d * \text{Ln}GDP$,

Table 3 Hausman test and overidentifying test of energy consumption equation of national panel data

Equation	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)
Dependent variables	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
Hausman test statistic	14.57	18.95	21.48	23.35	41.44
Prob	0.2032	0.062	0.0287	0.0158	0
Sargan-Hansen statistic	18.508	64.738	41.206	26.717	47.230
P-value	0.047	0	0	0.0029	0

Table 4 Wald statistic test for groupwise heteroskedasticity

Equation	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)
Dependent variables	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
Wald test statistic	984.04	1185.56	459.5	14,019.48	2030.9
Prob	0	0	0	0	0

Table 5 Wooldridge test for autocorrelation in panel data

Equation	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)
Dependent variables	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
Wooldridge test statistic	11.396	8.154	14.996	48.566	213.128
Prob	0.0082	0.0189	0.0038	0.0001	0

Table 6 Test for cross-sectional independence in panel data

Equation	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)
Dependent variables	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
Pesaran's test	−1.987	N[2]	1.096	N	−2.818
Prob	0.0469	N	0.273	N	0.0048
Friedman's test	13.547	N	30.008	N	9.539
Prob	0.9934	N	0.4136	N	0.9998
Frees' test	1.312	N	3.025	N	3.467

Critical values from Frees' Q distribution: 0.10:0.1294; 0.05: 0.1695; 0.01:0.2468. For the equations of other energy consumption and oil consumption, the panels are highly unbalanced; there are not enough common observations across the panel to perform the test.

$d\mathrm{Ln}SCON = d * \mathrm{Ln}SCON$, $d\mathrm{Ln}SINV = d * \mathrm{Ln}SINV$, $\mathrm{dLn}SGOE = \mathrm{d} * \mathrm{Ln}SGOE$, $\mathrm{dLn}SEXP = \mathrm{d} * \mathrm{Ln}SEXP$, $\mathrm{dLn}SIMP = \mathrm{d} * \mathrm{Ln}SIMP$, $d\mathrm{Ln}URR = d * \mathrm{Ln}URR$, $d\mathrm{Ln}REE = d * \mathrm{Ln}REE$, $d\mathrm{Ln}EPR = d * \mathrm{Ln}EPR$, and $d\mathrm{Ln}EEF = d * \mathrm{Ln}EEF$. Table 7 shows that there was indeed a structural change after 2008. The coefficient estimates obtained by regressing the data from the two time periods, respectively, are shown in Table 8. The regression results of the data from 1998 to 2017 are also presented in Table 8.

Table 7 Joint significance test of coefficients of dummy variable and its interaction terms with explaining variables

Dependent variable	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
$F(11, 19)$	6.79	13.43	60.13	13.04	27.28
Prob > *F*	0.0002	0	0	0	0

According to the results of Table 8, from the national situation, the role of income (*GDP*) in energy consumption has shown a decline after 2008.

The increase in household final consumption expenditure in the income (*SCON*) is inhibiting total energy consumption, while there is a significant positive role in natural gas consumption, and the effect is stronger after 2008.

The increase in the proportion of gross capital formation in GDP (*SINV*) has a certain forward pulling effect on total energy consumption, but the role is smaller, and after 2008, the role is not significant. Before 2008, an increase in this proportion played a forward role in other energy consumption, but after 2008, its role became negative and the role of natural gas consumption changed to a significant forward direction.

Table 8 Coefficient estimations of national panel data by time period based on fixed-effects regression with Driscoll-Kraay standard

Dependent variable	Ln*TOT*			Ln*OTH*			Ln*COA*			Ln*OIL*			Ln*GAS*		
Time span	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017
Ln*GDP*	−0.008	**0.163***	0.001	**0.035***	1.178	0.009	−0.018	**0.237***	−0.002	**−0.026***	0.103	−0.025	−0.035	0.08	0.013
Ln*SCON*	**−0.678*****	**−0.56*****	0.048	**−3.073*****	**−4.3****	0.731	**−0.838*****	**−0.772****	**−0.268***	**−1.18*****	**−1.328*****	0.048	−0.823	−0.37	**1.615****
Ln*SINV*	**0.087****	0.02	−0.013	0.214	**1.263****	**−0.419***	0.068	**−0.102****	−0.017	−0.061	−0.106	0.018	−0.057	**−0.197***	**0.153***
Ln*SGOV*	**−0.164*****	**−0.208*****	−0.048	0.251	−0.274	0.657	**−0.182*****	**−0.243*****	0.103	−0.179	−0.086	0.088	−0.103	−0.393	**0.290*****
Ln*SEXP*	−0.038	0.052	−0.005	0.299	−0.067	**−0.378***	0	0.049	0.001	**−0.245*****	−0.089	−0.132	−0.137	**−0.332***	−0.037
Ln*SIMP*	**0.055****	**0.087*****	**−0.028***	−0.444	−0.113	0.082	**0.053****	**0.103*****	0.045	**0.286*****	0.044	**0.23***	**−0.268***	−0.171	−0.066
Ln*URR*	**0.4*****	**0.391****	**0.072***	0.086	**−1.157*****	0.201	**0.335*****	**0.184****	**0.172*****	0.313	−0.017	**0.176****	−0.439	**−1.392****	−0.086
Ln*REE*	−0.008	0.026	**−0.099****	−0.147	0.186	−0.036	0.007	−0.051	−0.023	**−0.292*****	**−0.205****	**−0.424*****	**−0.631*****	**−0.55****	**−0.166****
Ln*EPR*	**0.167*****	**0.158***	**0.605*****	**0.930*****	0.427	0.187	**0.191****	**0.185****	**0.741*****	**−0.431*****	−0.25	**0.542****	**1.397*****	**0.996*****	**1.635***
Ln*EEF*	**−0.404*****	**−0.310*****	**−0.159*****	**−0.553*****	**−0.73*****	−0.185	**−0.331*****	**−0.271*****	**−0.119****	**−0.561*****	**−0.444***	**−0.313*****	**−1.122*****	**−2.396*****	−0.315
_cons	**8.524*****	**6.744*****	**4.805*****	**8.684*****	9.978	−0.269	**8.867*****	**7.692*****	**3.992****	**11.787*****	**11.744*****	1.592	5.707	**13.23****	−9.392

*Significant at 10% level.

**Significant at 5% level.

*** Significant at 1% level.

The proportional change in general government final consumption expenditure (*SGOV*) and the change in total energy consumption have reversed relationships, and this effect is no longer significant since 2008. The reverse relationship between the proportional change in government consumption and coal consumption has become more remarkable after 2008, and after 2008, it has had a forward relationship with natural gas consumption.

The change in exports (*SEXP*) has shown a significant reverse relationship with natural gas consumption before 2008. Since 2008, it has had a significant reverse relationship with oil consumption. According to the data, China has been affected by the global economic situation in 2008, exports account for a reduction in GDP after 2008, and this change has promoted China's oil consumption. After 2008, the proportion of imports in China's GDP improved, and it also promoted the increase in China's oil consumption. That is, the comprehensive trade factors in recent years have also shown that China's internal economic cycle has improved. This process may increase the demand for oil consumption during internal transportation.

The urbanization process (*URR*) has a pulling effect on the increase in total energy consumption, but the role is significantly smaller after 2008. For other energy consumption, that is, non-fossil energy consumption, the urbanization process before 2008 shows its inhibitory effect, while after 2008, the inhibitory effect is no longer significant.

On the whole, there is a clear negative relationship between fossil energy security capabilities (*REE*) and natural gas and oil consumption. To a certain extent, it indicates that there is a clear geographic deviation between the distribution of oil and gas resources and the distribution of oil and gas consumption in China. After 2008, the deviation of oil resource distribution and consumption distribution has become more significant, while the deviation of natural gas became smaller. Changes in fuel prices did not restrain total energy consumption.

From the perspective of the fuel price index (*EPR*), China's fuel prices showed an upward trend during the study period. However, fossil energy consumption was not restrained by prices, and the price elasticity was positive and has increased since 2008. But the changes in fuel prices have also played a significant role in promoting the development of non-fossil energy and the consumption of natural gas, and there has been no significant change in time. Based on these results, the increase in the fuel price index cannot contribute to energy saving, but it can optimize the energy structure to a certain extent. During the study period, the improvement in energy efficiency had a restraining effect on energy consumption, but according to the staged regression, this effect showed a downward trend.

Results of regional study

Considering that there are strong geographical characteristics in both consumption and resource distribution of energy in China, a sub-regional analysis is conducted in this paper. Based on the division of NBSC in 2011, China's mainland can be divided into four major economic regions: east, central, west, and northeast, as shown in Table 9.

Based on the results of Table 10, the Hausman test of total primary energy, coal, and other energy consumption in the northeast is not significant, and the Hausman test of all types of energy consumption in various regions indicates that a fixed effect model should be adopted. Moreover, heteroscedasticity, serial correlation, and cross-sectional dependence tests are also presented in Tables 11, 12, and 13. For regional panel data in this study, as the data section unit (N) is less than the data time span (T), the Breusch-Pagan statistic is better for testing cross-sectional independence in the residuals of a fixed effect regression model, following Greene (2000). Based on the results of Tables 11, 12, and 13, as most equations of most energy consumption in most regions have heteroscedasticity, autocorrelation, and inter-group correlation problems, regression with the Driscoll-Kraay standard method is adopted. Results of Table 14 presented the significance test of coefficients of a dummy variable and its interaction terms with explaining variables and indicated that there was a structural change in the year of 2008. The coefficient estimates obtained by regressing the data from 1998 to 2017 and the two time periods of 1998–2008 and 2009–2017, respectively, are shown in Tables 15, 16, 17, and 18.

According to the results of the regression of the eastern region, income increase is still the driving factor of per capita total energy consumption and coal consumption, while it is not yet a driving factor for non-fossil energy consumption, or even a restraining factor.

The increase in the proportion of household consumption in GDP has not become an opportunity for the development

Table 9 Chinese economic regions division

East	Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Shandong, Shanghai, Tianjin, Zhejiang
Middle	Anhui, Henan, Hubei, Hunan, Jiangxi, Shanxi
West	Chongqing, Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, Yunnan
Northeast	Heilongjiang, Jilin, Liaoning

The data sources for this article include provinces in mainland China, and as there is no energy consumption data for Tibet, this region is not included in the analysis of this paper.

Table 10 Hausman test of energy consumption equation of regional panel data

	Dependent variable	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
East	Hausman test statistic	92.79	44.62	103.95	65.16	63.21
	Prob	0	0	0	0	0
Middle	Hausman test statistic	58.79	33.34	78.8	11.06	46.35
	Prob	0	0	0	0.0259	0
West	Hausman test statistic	119.32	60.97	137.09	147.48	129.44
	Prob	0	0	0	0	0
Northeast	Hausman test statistic	3.8	3.17	4.33	22.38	14.61
	Prob	0.1499	0.2049	0.115	0	0.0007

Table 11 Wald statistic test for groupwise heteroskedasticity of regional panel data

	Dependent variable	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
East	Wald test statistic	96.46	291.51	195.38	646.36	3701.45
	Prob	0	0	0	0	0
Middle	Wald test statistic	49.05	1259.37	71.83	154.93	8.43
	Prob	0	0	0	0	0.2086
West	Wald test statistic	340.5	236.43	69.21	4129.43	201.26
	Prob	0	0	0	0	0
Northeast	Wald test statistic	21.5	109.32	16.5	57.77	0.04
	Prob	0.0001	0	0.0009	0	0.9982

Table 12 Wooldridge test for autocorrelation in panel data

	Dependent variable	Ln*TOT*	Ln*OTH*	*LnCOA*	Ln*OIL*	Ln*GAS*
East	Wooldridge test statistic	11.396	8.154	14.996	48.566	213.128
	Prob	0.0082	0.0189	0.0038	0.0001	0
Middle	Wooldridge test statistic	16.87	26.038	32.405	0.264	23.291
	Prob	0.0093	0.0038	0.0023	0.6342	0.0048
West	Wooldridge test statistic	20.547	12.551	7.085	14.019	47.883
	Prob	0.0011	0.0053	0.0238	0.0046	0
Northeast	Wooldridge test statistic	3.789	16.037	0.01	31.108	58.606
	Prob	0.191	0.0571	0.9284	0.0307	0.0166

Table 13 Test for cross-sectional independence in panel data

	Dependent variable	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
East	Breusch-Pagan LM test statistic	92.574	73.364	107.164	68.184	154.023
	Prob	0	0.0048	0	0.0144	0
Middle	Breusch-Pagan LM test statistic	16.997	24.651	23.711	5.705	31.393
	Prob	0.319	0.0548	0.0702	0.8394	0.0078
West	Breusch-Pagan LM test statistic	76.237	N[a]	93.613	N[a]	88.172
	Prob	0.0306	N[a]	0.0009	N[a]	0.003
Northeast	Breusch-Pagan LM test statistic	1.156	10.197	2.984	3.953	4.248
	Prob	0.7635	0.017	0.3941	0.2666	0.2359

[a]N indicates too few common observations across the panel.

Table 14 Joint significance test of coefficients of dummy variable and its interaction terms with explaining variables

	Equation	Ln*TOT*	Ln*OTH*	Ln*COA*	Ln*OIL*	Ln*GAS*
East	$F(11, 19)$	11.9	26.85	6.09	93.27	7.9
	Prob > F	0	0	0.0003	0	0.0001
Middle	$F(11, 19)$	23.07	22.11	8.71	4.85	61.61
	Prob > F	0	0	0	0.0013	0
West	$F(11, 19)$	19.76	54.62	12.56	100.04	19.24
	Prob > F	0	0	0	0	0
Northeast	$F(11, 19)$	73.11	21.33	68.03	38.76	8.25
	Prob > F	0	0	0	0	0

of non-fossil energy and has even become a significant restraining factor after 2008, but it is still a driving factor that promotes the increase in total energy consumption, coal and oil consumption.

The increase in the proportion of fixed asset investment significantly increases coal consumption and natural gas consumption in the region. The increase in the proportion of government expenditure has shown a certain inhibitory effect on total energy consumption, but has also shown a significant promotion effect on natural gas consumption after 2008. The trade changes in the eastern region are more consistent with the national situation; that is, the proportion of exports in GDP has declined since 2008, while imports have increased, and changes in exports and total energy consumption have an inverse relationship; that is, as the proportion of exports in the eastern region has fallen, per capita total energy consumption has increased, non-fossil energy consumption and natural gas consumption has increased, while coal and oil consumption showed a decrease change. An increase in the proportion of imports can play a role in restraining per capita total energy consumption. Urbanization is also one of the important factors driving total energy consumption in the eastern region, but its effect is also showing a downward trend. The development of eastern urbanization has even suppressed oil consumption, which may be related to the realization of the relatively higher public transportation network. Most provinces in the eastern region have relatively scarce fossil resources, and their own fossil energy consumption guarantee capacity is declining, which is beneficial to the development of non-fossil energy to a

Table 15 Coefficient estimations of east region panel data based on fixed-effects regression with Driscoll-Kraay standard

Dependent variable	Ln*TOT*			Ln*OTH*			Ln*COA*			Ln*OIL*			Ln*GAS*		
Time span	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2008–2017
Ln*GDP*	0.198*	0.071	0.136**	0.152	0.508	−0.88***	0.297	−0.129	0.242*	0.452**	−0.046	0.006	0.385	−0.229	−0.116
Ln*SCON*	−1.135***	−0.938***	−0.101	−0.635	−3.248**	1.759***	−1.46***	−0.927***	−0.423	−2.022***	−1.446**	0.794**	0.346	4.625***	3.252**
Ln*SINV*	0.102	0.009	0.015	−0.292	1.314	−0.482	0.265***	0.092	0.056	0.191	0.102	−0.147	0.562	−0.839	1.053***
Ln*SGOV*	−0.203**	−0.359***	−0.374**	−1.124**	−2.214***	0.797	−0.429**	−0.754***	0.437	0.225	−0.151	−0.427*	0.151	−2.488*	2.172***
Ln*SEXP*	−0.165***	−0.116	0.084	−0.192	−0.057	−1.25*	0.209**	0.129*	0.595**	−0.622***	−0.618	0.347**	−0.01	0.047	−0.942**
Ln*SIMP*	0.103	0.242**	−0.054**	−0.644*	−0.221	−0.506	−0.03	0.149***	−0.088	0.278	0.463	0.043	−0.866**	0.398	−0.579***
Ln*URR*	0.482***	0.539**	0.129**	0.592**	0.873*	0.093	0.471***	0.370**	0.243*	0.877***	1.053*	−0.19**	−0.704	−1.999	−0.298
Ln*REE*	−0.021	0.024	−0.109***	−0.277*	0.059	−0.047	−0.077	−0.076	−0.112	0.034	0.026	−0.412***	−0.821***	−0.428	−0.404*
Ln*EPR*	0.013	0.114	0.245***	0.307	0.334	2.058***	−0.044	0.073	0.866***	−0.197	0.112	0.461***	1.477	1.273**	1.717***
Ln*EEF*	−0.402***	−0.264**	−0.12*	−0.525***	−0.083	0.289	−0.173***	−0.164**	−0.02	−0.605***	−0.424*	−0.189*	−1.166*	−2.869**	0.36
_cons	9.607***	8.725***	6.378***	7.581*	7.796	−3.947*	8.486***	9.826***	−0.997	9.429***	8.089**	1.927	−2.023	5.785	−19.7***

*Significant at 10% level.

**Significant at 5% level.

***Significant at 1% level.

certain extent, but has not become a constraint to restrain its fossil energy consumption. The increase in the fuel price index has not become a factor that restrains total energy consumption. Although the consumption of oil and coal still rises with the increase in the fuel index, its promotion of non-fossil energy consumption and natural gas consumption is stronger, and this effect has become more effective after 2008, which shows that although the fuel price index increase cannot play a role in energy saving, it can promote the optimization of the energy structure of the region. In line with national estimates, the effect of energy efficiency improvement on energy conservation is diminishing.

The increase in income levels (*GDP*) in the central region does not seem to be the main driving factor for energy consumption; during the study period, the proportion of household final consumption (*SCON*) in the region has risen and fallen. According to coefficient estimates, the increase in the proportion of household final consumption will reduce the total per capita primary energy consumption, but it will increase coal consumption. The increase in the proportion of fixed asset investment in GDP (*SINV*) will significantly increase per capita primary energy consumption and natural gas consumption in the region. The increase in the proportion of government consumption (*SGOV*) has a positive effect on non-fossil energy consumption, but the effect is no longer significant after 2008, and the promotion effect on natural gas consumption is still relatively significant.

Different from the development of trade in the nation and the eastern region, the proportion of exports (*SEXP*) and imports (*SIMP*) in this region increased during the study period. According to the coefficient estimates, the increase in exports promoted the development of non-fossil energy consumption and oil consumption, and since 2008, natural gas consumption has significantly increased. The increase in the proportion of imports has a certain inhibitory effect on primary energy consumption and oil consumption, but the effect is small, and since 2008, natural gas consumption has also significantly increased. Overall, the increase in trade level has positive significance for energy conservation and emission reduction in the region.

The promotion of energy consumption by urbanization (*URR*) in this region is mainly reflected in natural gas consumption. As the central region's energy resource endowment (*REE*) of is also relatively lacking, it has not inhibited its primary energy consumption, and as its fossil energy security capacity has decreased, primary energy consumption has greatly increased after 2008. Compared with the whole country and the eastern region, the improvement of energy efficiency in this region still has a greater potential for energy conservation.

The increase in income levels (*GDP*) in the western region seems to have become a factor in restraining energy consumption, which is not in line with the level and stage of

Table 16 Coefficient estimations of middle region panel data based on fixed-effects regression with Driscoll-Kraay standard

Dependent variable	Ln*TOT*			Ln*OTH*			Ln*COA*			Ln*OIL*			Ln*GAS*		
Time span	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017
Ln*GDP*	0.013	$\mathbf{1.299}^{**}$	0.014	0.078	3.894	0.015	0.010	0.269	−0.004	0.019	0.910	$\mathbf{0.026}^{*}$	$\mathbf{0.117}^{*}$	$\mathbf{3.046}^{**}$	0.039
LnS*CON*	$\mathbf{-0.622}^{*}$	0.317	0.539	−2.413	$\mathbf{-3.223}^{*}$	0.311	$\mathbf{-1.029}^{***}$	$\mathbf{-1.257}^{***}$	$\mathbf{0.597}^{**}$	$\mathbf{-1.085}^{**}$	−1.808	−0.849	$\mathbf{-4.937}^{**}$	$\mathbf{-8.252}^{***}$	0.245
Ln*SINV*	$\mathbf{0.210}^{**}$	0.039	0.186	0.885	−0.511	0.507	−0.075	−0.005	$\mathbf{-0.149}^{*}$	−0.005	−0.024	0.275	$\mathbf{1.578}^{*}$	−0.45	−0.202
Ln*SGOV*	−0.137	0.056	−0.586	0.844	$\mathbf{3.226}^{**}$	−1.767	0.127	$\mathbf{0.192}^{**}$	0.266	0.030	0.444	−0.821	$\mathbf{2.767}^{***}$	$\mathbf{1.834}^{**}$	$\mathbf{1.567}^{*}$
Ln*SEXP*	0.062	$\mathbf{0.269}^{*}$	−0.050	$\mathbf{0.929}^{***}$	0.066	0.629	0.080	$\mathbf{0.236}^{***}$	−0.153	$\mathbf{0.267}^{***}$	−0.004	0.132	−0.152	0.239	$\mathbf{0.388}^{**}$
Ln*SIMP*	$\mathbf{-0.116}^{**}$	0.009	−0.009	0.133	0.843	0.299	−0.029	−0.069	0.059	$\mathbf{-0.183}^{*}$	−0.217	$\mathbf{-0.193}^{**}$	−0.683	−0.877	$\mathbf{0.448}^{**}$
Ln*URR*	0.127	0.014	−0.185	0.334	−0.446	0.450	0.203	−0.052	−0.067	0.325	0.574	0.320	$\mathbf{1.672}^{**}$	−0.016	0.500
Ln*REE*	$\mathbf{-0.142}^{*}$	0.135	$\mathbf{-0.276}^{**}$	−0.208	0.168	0.150	−0.020	0.013	−0.049	−0.190	−0.362	−0.091	$\mathbf{0.514}^{*}$	0.530	0.404
LnEPR	0.215	0.122	0.335	0.178	0.662	$\mathbf{-2.697}^{*}$	$\mathbf{0.35}^{*}$	0.259	$\mathbf{0.77}^{**}$	−0.095	−0.214	−0.267	0.734	0.586	0.452
Ln*EEF*	$\mathbf{-0.425}^{***}$	−0.244	$\mathbf{-0.342}^{**}$	$\mathbf{-0.911}^{*}$	0.17	$\mathbf{-0.875}^{***}$	$\mathbf{-0.277}^{***}$	−0.245	−0.074	0.054	0.301	$\mathbf{-0.389}^{***}$	$\mathbf{-1.552}^{***}$	−0.598	$\mathbf{-1.024}^{***}$
_cons	$\mathbf{8.371}^{***}$	−7.430	$\mathbf{5.88}^{***}$	3.132	−32.941	15.684	$\mathbf{8.838}^{***}$	7.771	2.059	$\mathbf{7.043}^{***}$	−0.462	$\mathbf{9.266}^{*}$	1.977	−0.090	−3.216

*Significant at 10% level.

**Significant at 5% level.

***Significant at 1% level.

Table 17 Coefficient estimations of west region panel data based on fixed-effects regression with Driscoll-Kraay standard

Dependent variable	Ln*TOT*			Ln*OTH*			Ln*COA*			Ln*OIL*			Ln*GAS*		
Time span	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2008–2017
Ln*GDP*	$\mathbf{-0.021}^{**}$	0.168	0.003	0.012	$\mathbf{1.581}^{**}$	0.049	$\mathbf{-0.04}^{***}$	$\mathbf{0.199}^{**}$	$\mathbf{-0.021}^{**}$	$\mathbf{-0.055}^{***}$	$\mathbf{1.013}^{**}$	−0.003	−0.014	$\mathbf{-1.412}^{**}$	0.004
Ln*SCON*	$\mathbf{-0.483}^{*}$	−0.415	0.393	$\mathbf{-3.894}^{***}$	−0.248	-2.762^{**}	−0.346	−0.564	−0.063	$\mathbf{-2.801}^{***}$	−1.913	−0.217	$\mathbf{-1.895}^{***}$	$\mathbf{-1.324}^{***}$	−0.694
Ln*SINV*	0.028	0.014	−0.020	0.738	$\mathbf{2.191}^{**}$	−0.263	−0.05	−0.085	0.024	−0.233	0.041	0.057	$\mathbf{-0.359}^{*}$	−0.130	$\mathbf{-0.387}^{**}$
Ln*SGOV*	$\mathbf{-0.359}^{***}$	$\mathbf{-0.36}^{***}$	−0.025	−0.11	−0.623	1.606	$\mathbf{-0.286}^{***}$	$\mathbf{-0.309}^{***}$	−0.137	−0.443	0.158	0.026	−0.025	−0.252	−0.136
Ln*SEXP*	−0.062	0.095	−0.097	$\mathbf{1.226}^{***}$	0.364	0.497	$\mathbf{-0.122}^{***}$	−0.036	−0.123	$\mathbf{-0.262}^{**}$	0.155	−0.767	$\mathbf{-0.537}^{***}$	$\mathbf{-0.586}^{***}$	$\mathbf{-0.346}^{*}$
Ln*SIMP*	0.065	0.016	0.024	−0.025	−0.193	0.118	$\mathbf{0.065}^{***}$	0.044	0.075	0.140	0.095	0.718	$\mathbf{0.327}^{**}$	0.189	−0.029
Ln*URR*	0.108	0.086	−0.004	$\mathbf{-1.228}^{**}$	$\mathbf{-2.483}^{*}$	−0.455	0.204	$\mathbf{0.496}^{***}$	0.035	−0.624	$\mathbf{-4.064}^{***}$	$\mathbf{1.066}^{***}$	−0.301	$\mathbf{-1.685}^{**}$	$\mathbf{0.482}^{***}$
Ln*REE*	0.010	0.022	−0.070	0.441	1.076	−0.160	0.036	−0.028	−0.011	$\mathbf{-0.922}^{***}$	−0.357	−1.017	$\mathbf{-0.406}^{**}$	$\mathbf{-0.709}^{**}$	$\mathbf{-0.399}^{**}$
Ln*EPR*	$\mathbf{0.559}^{***}$	$\mathbf{0.424}^{*}$	$\mathbf{1.394}^{***}$	0.14	0.717	−0.948	$\mathbf{0.52}^{***}$	$\mathbf{0.345}^{**}$	$\mathbf{0.751}^{***}$	$\mathbf{-0.726}^{*}$	−0.624	1.115	$\mathbf{0.866}^{*}$	$\mathbf{1.566}^{**}$	0.895
Ln*EEF*	$\mathbf{-0.361}^{***}$	$\mathbf{-0.377}^{***}$	$\mathbf{-0.145}^{**}$	$\mathbf{-1.024}^{***}$	$\mathbf{-1.705}^{*}$	−0.094	$\mathbf{-0.384}^{***}$	$\mathbf{-0.274}^{***}$	$\mathbf{-0.363}^{**}$	$\mathbf{-0.793}^{***}$	$\mathbf{-1.268}^{*}$	−0.094	$\mathbf{-1.067}^{***}$	$\mathbf{-2.106}^{***}$	−0.191
_cons	$\mathbf{8.007}^{***}$	$\mathbf{6.63}^{***}$	0.213	$\mathbf{18.044}^{***}$	−7.745	14.705	$\mathbf{7.47}^{***}$	$\mathbf{5.726}^{***}$	$\mathbf{5.092}^{**}$	$\mathbf{24.084}^{**}$	$\mathbf{21.025}^{**}$	−4.695	$\mathbf{12.331}^{***}$	$\mathbf{26.905}^{***}$	3.848

*Significant at 10% level.

**Significant at 5% level.

***Significant at 1% level.

its economic development. The increase in the proportion of household final consumption in GDP (*SCON*) is a powerful energy-saving factor. The increase in the proportion of fixed asset investment (*SINV*) in this region was significant during the study period. It was a driving factor for the development of non-fossil energy before 2008, but for natural gas consumption, it was a restraining factor. Government consumption (*SGOV*) was also a restraining factor for primary energy and coal consumption before 2008.

In terms of imports and exports, the proportion of imports (*SIMP*) and exports (*SEXP*) of western provinces has risen and fallen. The increase in exports has a very positive effect on increasing non-fossil energy consumption and reducing fossil energy consumption. The increase in the proportion of imports has a boosting effect on natural gas consumption.

The development of urbanization (*URR*) does not seem to be beneficial to the consumption of non-fossil energy in the region, but the impact of this unfavorable factor is weakening. In addition, the development of urbanization has a significant role in promoting oil and natural gas consumption. The western region has strong fossil fuel security capabilities and is the main source of fossil fuel consumption in the country. However, the increase in resource security capabilities in the region has a clear reverse relationship with oil and natural gas consumption, indicating that more oil and gas have been shipped to the central and eastern regions. Rising fuel prices (*EPR*) have not become a factor in restraining energy consumption in the region, and even have a significant promotion effect on coal consumption, and have not promoted the development of non-fossil energy. The energy-saving effect of energy efficiency improvement in the region has also declined as a whole.

Increasing income (*GDP*) in the northeast is still one of the main driving factors for its energy consumption, but this effect is decreasing. An increase in income has a restraining effect on oil consumption, but this effect is also decreasing. The increase in the proportion of household consumption (*SCON*) will increase primary energy consumption and curb non-fossil energy consumption. The increase in the proportion of fixed asset investment (*SINV*) in the region was conducive to the development of non-fossil energy before 2008, but after 2008, it has significantly promoted the consumption of coal. The increase in the proportion of government expenditure (*SGOV*) in the region is conducive to the development of non-fossil energy and has a certain restraining effect on natural gas consumption.

During the study period, the proportion of exports (*SEXP*) in the region has dropped significantly, and the proportion of imports (*SIMP*) has risen overall. According to the coefficient estimates, the decline in exports is not conducive to energy conservation, and the rise in the proportion of imports will significantly increase coal consumption. That

Table 18 Coefficient estimations of northeast region panel data based on fixed-effects regression with Driscoll-Kraay standard

Dependent variable	Ln*TOT*			Ln*OTH*			Ln*COA*			Ln*OIL*			Ln*GAS*		
Time span	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2009–2017	1998–2017	1998–2008	2008–2017
Ln*GDP*	**0.843****	0.665	0.173	6.277	**31.481*****	−4.976	**1.153****	**1.688****	0.663	−**0.871***	−**1.958*****	0.553	**2.898****	**2.426****	−0.068
Ln*SCON*	−0.303	−0.438	**0.227*****	−**5.52****	1.979	−2.433	−0.120	−0.603	**0.395*****	−0.289	−0.517	−0.035	−0.454	−0.718	1.486
Ln*SINV*	−0.046	−0.260	0.042	−0.598	**4.323***	−2.910	−0.014	0.030	**0.208*****	−0.043	−**0.354****	−0.066	−0.174	0.103	0.178
Ln*SGOV*	0.021	0.046	−0.035	2.950**	−1.364	0.946	0.147	−0.058	0.059	−**0.235****	−0.624	0.161	−**0.611****	0.264	−0.076
Ln*SEXP*	0.039	−0.079	−**0.035***	−**1.867***	−1.48	−1.320	−**0.266*****	−0.190	−0.045	0.046	−0.022	−**0.092*****	−**0.505****	−0.621	0.107
Ln*SIMP*	0.146	0.045	−**0.08*****	−0.465	3.348	−0.665	**0.249***	**0.419***	−**0.101***	−0.006	−0.154	0.050	−0.070	−0.100	−0.496
Ln*URR*	**0.568*****	0.637	−0.047	1.804	−4.627	0.235	0.086	−0.165	**0.095***	− −0.001	0.076	0.108	−**0.501*****	−0.424	−0.518
Ln*REE*	−0.108	−**0.564*****	0.007	1.198	2.733	0.296	0.048	0.029	**0.106*****	−0.074	−0.255	0.025	0.078	0.367	−0.032
Ln*EPR*	0.129	0.090	**0.588*****	0.865	0.273	1.172	**0.356****	0.151	**0.603*****	**0.149***	**0.121***	**0.254***	**0.588****	0.331	**2.403*****
Ln*EEF*	−**0.213****	−0.332	−0.009	−0.543	−3.496	0.416	−**0.187***	−0.091	−0.032	−0.105	−0.355	−**0.083***	−**0.672****	−0.831	−**0.231***
_cons	0.226	3.194	**3.54****	−30.116	−**200.416****	52.216	−2.057	−2.548	−2.239	**13.708*****	**25.125*****	1.224	−9.834	−7.394	−8.680

*Significant at 10% level.

**Significant at 5% level.

***Significant at 1% level.

is, the development of trade in the region lacks positive significance for energy conservation and emission reduction.

Urbanization (*URR*) in this area is the main driving factor of per capita primary energy consumption, and its effects seem to have not undergone significant structural changes. Historically, the region's fossil energy resource security capability was strong, and it has shown a downward trend in recent years. The decline in resource security capacity before 2008 has an inverse relationship with its per capita primary energy consumption. After 2008, the decline in resource security capacity had a certain inhibitory effect on its per capita coal consumption. The increase in fuel prices (*EPR*) has not suppressed the consumption of fossil fuels in the region, nor has it promoted the consumption of non-fossil fuels. The improvement in energy efficiency in this region is relatively small compared with other regions, and there is no obvious structural change as a whole.

Discussions

Some important reasons and implications emerge from the results presented.

First, from the perspective of income level, the results show that the role of income (*GDP*) in per capita total primary energy consumption has shown a decline after 2008, not only in China as a whole, but also in the middle, west, and northeast regions, showing the decoupling between energy consumption and GDP. However, income (GDP) growth continues to be a driving factor in per capita total energy consumption and coal consumption in China's east region. In fact, the above results are consistent with the literature, which finds that most developed countries have achieved relative decoupling between energy consumption and GDP to some extent and are now moving toward absolute decoupling, while most developing countries have not decoupled (de Freitas and Kaneko 2011; Roinioti and Koroneos 2017; Wang and Su 2020; Wu et al. 2018).

Second, from the perspective of income structure, overall, the effect of the proportion of gross capital formation in GDP (*SINV*) on total primary energy consumption has weakened, both at the national and provincial levels. Since 2008, China has undergone a structural change in aggregate investment from machinery and equipment-dominated non-residential structures (Bai 2016). The capital formation from the investment of machinery and equipment would have a long-lasting energy consumption effect, while for the latter, there is much less direct energy consumption-driven.

Third, the impact of *SCON*, *SINV*, and *SGOV* on natural gas consumption has turned positive and significant after 2008 in China as a whole. As a result of the construction and operation of China's west-to-east gas pipeline, the country has boosted its natural gas supply across the country and nearly 700 billion cubic meters of natural gas have been transported to eastern China since it was officially put into operation in 2004. According to China's statistics, household use of natural gas nearly tripled in 2010 compared to 2005. Also, the natural gas used in power generation increased from 2.5 billion cubic meters in 2005 to 19.0 billion cubic meters in 2010, almost 8 times.

Overall, China's trade situation is deeply affected by the economic crisis. The comprehensive trade factors in recent years have also shown that China's internal economic cycle is improved. This process may increase the demand for oil consumption during internal transportation. Whether there are technological spillover effects (Dogan and Seker 2016) from other countries still need to be further explored. The urbanization process has a pulling effect on the increase in total energy consumption, but the role is significantly smaller since 2008. For non-fossil energy consumption, the urbanization process before 2008 shows its inhibitory effect, while since 2008, the inhibitory effect is no longer significant. On the whole, there is a clear negative relationship between fossil energy security capabilities and natural gas and oil consumption. To a certain extent, it indicates that there is a clear geographic deviation between the distribution of oil and gas resources and the distribution of consumption in China. After 2008, the deviation of oil resource distribution and consumption distribution has become more significant, while the deviation of natural gas became smaller. Changes in fuel prices did not restrain total energy consumption. From the perspective of the fuel price index, China's fuel prices showed an upward trend during the study period. However, fossil energy consumption was not restrained by prices, and the price elasticity was positive and has increased since 2008. But the changes in fuel prices have also played a significant role in promoting the development of non-fossil energy and the consumption of natural gas, and there has been no significant change in time. Based on these results, the increase in the fuel price index cannot contribute to energy saving, but it can optimize the energy structure to a certain extent. During the study period, the improvement of energy efficiency had a restraining effect on energy consumption, but according to the staged regression, this effect showed a downward trend.

Conclusions

Whether it is the study of national panel data or the research of panel data by region, the results show that the decomposition of per capita GDP from the perspective of the expenditure method has different effects on energy consumption. At the same time, the energy consumption of different type responses differently to the influencing factors, and the impact of the global financial crisis on the economic situation also makes it have a structural transformation effect.

Firstly, for the whole country, the role of income in energy consumption has shown a decline in recent years, which means that energy consumption is tending to decouple from GDP. The pulling effect on total energy consumption from urbanization has also become smaller after 2008. For non-fossil energy consumption, the urbanization process before 2008 shows its inhibitory effect, while after 2008, the inhibitory effect is no longer significant.

Secondly, regarding the results of the regression of different regions and periods, it is found that income increase is still the driving factor of per capita total energy consumption and coal consumption in the east and northeast, although the effect in the northeast is decreasing. However, it has not been the driving factor in central and western regions. Instead, in the western region, it started to restrain energy consumption.

Thirdly, from the energy commodity perspective, the increase in the proportion of gross capital formation in GDP significantly increases coal and natural gas consumption in the east and significantly increases per capita primary energy consumption and natural gas consumption in the central region. Since 2008, it has significantly promoted the consumption of coal in the northeast, in the western, and in the northeast regions. The increase in the proportion of gross capital formation was a driving factor for the development of non-fossil energy before 2008.

Finally, with regards to the impact of price, in the eastern region, although the fuel price index increase cannot play a role in energy saving, it can promote the optimization of the energy structure of the region. However, in the central, western, and northeast regions, rising fuel prices have not suppressed the consumption of fossil fuels in the region, nor have they promoted the consumption of non-fossil fuels.

Policy implications

The above results have the following policy implications.

Since fixed asset investment and government spending are the main driving forces for economic development, in the process of investment and government budgeting, attention should be paid to the impact of fossil fuels, and guidance should be given on how to promote the development of non-fossil fuels and energy-saving technologies. On the whole, an increase in the proportion of household consumer consumption in GDP is conducive to energy conservation and emission reduction. Although there are certain differences in the trade development models of various regions in China, the overall development is conducive to energy conservation and optimization of the energy structure.

Regarding the trade model of the northeast, it is necessary to further study whether it follows the comparative advantage in the use of energy resources. China is still in the rapid development stage of urbanization, and its own development may be a driving force for the consumption of fossil fuels, which is not conducive to the development of non-fossil fuels. Therefore, it is of great practical value to explore the urbanization process of clean development.

For the whole country and many regions, the overall price increase and fossil fuel resource constraints seem to have little effect on fossil energy consumption, but they will also promote non-fossil energy consumption.

Limitations

We acknowledge the limitations of this study, particularly in terms of the availability and quality of sufficient data at a disaggregated level. At present, there is still a lack of micro-basic research, and the interpretation of its impact and in-depth policy recommendations are still subject to regional differences. Still, there is a lack of in-depth guidance on specific sectors.

Regarding to the limitations on research content, structural changes of the influential factors of energy consumption have not been explored in depth. This paper uses the expenditure method to explore the impact of the residential sector, private investment sector, government sector, and import and export sectors on the energy consumption structure. Due to the limitations of research methods and data, this paper does not explore the deep-seated structural changes in the influence of these factors before and after the economic crisis, and the lack of projections for the longer-term effects beyond the economic crisis. In particular, there is a lack of discussion on the impact of economic activities in other countries around the world on China's energy consumption before and after the economic crisis. Of course, these are also directions for further research and in-depth research in the future.

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Declarations

Ethics approval No ethics-related information.

Consent to participate I am free to contact any of the people involved in the research to seek further clarification and information.

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