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Identification of structural drivers of energy transition: empirical evidence from China

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Abstract

Using Data from China from 1995 to 2019, a Logarithmic Mean Divisia Index (LMDI) method is used to explore the impact of seven structural factors (including the production scales, energy intensity, industrial structure, income level, urbanization rate, and population size) and six sectors on the energy transition. The following basic conclusions are drawn: (1) The effect of China's energy transition is significant. During the study period, China's clean energy consumption continued to grow, with an average annual growth rate of 16.13%. (2) The impact of each driving factor on the energy transition varies. The production scale factor is the most important factor that promotes the energy transition, the energy intensity effect is the main factor that inhibits the energy transition, and the inhibiting effect of the energy intensity on the production sector is significantly higher than that of the residential sector. The influence of industrial structure changed from inhibition to promotion. The income level plays a promoting role, and the contribution value gradually increases. The factors of urbanization level and population size promote the energy transition, but their impact is relatively small. (3) Different driving factors have different impacts on the energy transition in different sectors. The service industry and industry are the sectors with the highest clean energy consumption in China.

Keywords: energy transition; driving factors; LMDI; carbon neutrality; China

1. Introduction

To address the two major problems of energy shortages and climate change, energy transition based on diversified and clean energy has received widespread attention in various countries [1]. According to previous studies, clean energy consumption and carbon emissions are negatively correlated [2]. Therefore, the energy transition in various countries is an important means to address climate change and alleviate the environment and energy crisis [3], and it has attracted significant attention from researchers and policy makers. China's energy structure is dominated by coal and is the world's heaviest CO_2 emitter, but its energy transition is relatively fast. According to BP's statistical data (2019), China's clean energy consumption has grown rapidly, and China has become the world's largest consumer of clean energy since 2004. The ability to accurately grasp the driving factors of the energy transition has become a key step in China's energy transition and has an important impact on both world energy security and global warming. In this context, exploring the driving factors of the energy transition has very important practical significance for advancing the energy transition process.

This paper uses the absolute and relative amounts of clean energy consumption between 1995 and 2019 to characterize the energy transition process in China and uses the LMDI model to analyse the driving factors that affect the energy transition to carbon neutrality at the national and sectoral levels. Compared with the previous literature, the contribution of this paper is in the following areas: (1) In the previous literature, the energy intensity factors that affect the energy transition are generally placed in one category, but the energy intensity of the residential sector and that of the production sector are different. Therefore, this study conducts a quantitative study on energy intensity factors from the perspectives of residential and production sectors. (2) Previous studies have mainly explored the driving factors of the energy transition from national or regional perspectives. In this study, we analyse the driving factors of the energy transition from structural and sectoral perspectives and more accurately explore the impact of the driving factors on the energy transition in detail. (3) In this study, the energy transition is characterized by the absolute and relative amounts of clean energy consumption, and each driving factor is quantified, which compensates for the deficiency of quantitative research on the energy transition.

2. Literature review

2.1 Evolution of the theoretical basis of the driving factors of the energy transition

A review of the literature reveals that previous studies on the driving factors of the energy transition mostly started from the perspective of the techno-economic paradigm. For example, Xie et al argued that energy-saving technologies can improve energy efficiency and the proportion of clean energy, thereby accelerating the energy transition [4]. Guo et al proposed the view that energy technology innovation drives energy transition based on the techno-economic paradigm [5]. With the development of relevant research, scholars have realized that the energy transition is not only a process of techno-economic paradigm change but also a form of social -technological transition [6]. However, these studies lack the ability to specifically analyse the impact of structural drivers such as production scale, energy intensity, industrial structure, income level, urbanization rate, and population size on the energy transition, especially in the China scenario.

2.2 Driving factors of the energy transition from different perspectives

Most scholars believe that technological innovation and emerging energy market opportunities are the main factors affecting the energy transition. For example, Arranz [7] believes that energy transition must rely on technological innovation, and the state should play a key role in the energy transition. Wolfram and Wiedmann started with the development of emerging energy markets and emphasized that the market demand for emerging energy has an important impact on the energy transition [8]. Some scholars also believe that this impact is twofold.

Some scholars believe that the vision of energy transition and the goals of energy conservation and emission reduction also contribute to the energy transition [9]. Some analysed the driving factors of energy conservation and emission reduction in China and concluded that the improvement of energy productivity in the industrial sector, the reduction of energy consumption per unit of GDP in households, and the adjustment of economic structure have made a great contribution to energy conservation and emission reduction [10].

A review of the literature reveals that the factors driving the energy transition include technical and social factors. The main factors that promote energy efficiency are technical factors, such as the increase in energy efficiency due to the improvement of the technology level, which in turn promotes the energy transition [11, 12]. The main obstacles to the energy transition are some social factors. In summary, the research results of the above influencing factors are not uniform, and further empirical analysis is needed; additionally, the analysis of various factors in the literature is partial and random and is not analysed within a framework. Therefore, this paper provides a feasible space for the quantitative study of seven structural factors, such as the scale of production, within the socio-technological framework.

3. Methodology and data

3.1 Decomposition method

In 1989, Kaya [13] proposed an identity to measure the relationship between carbon emissions generated in the process of human social activities and factors such as economy, policy, and population in the

United Nations Intergovernmental Panel on Climate Change (IPCC). The specific formula of Kaya identity is shown in Equation (1):

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

where P represents the total population, reflecting the degree of impact of population size on carbon emissions; G/P is the per capita GDP that is an important indicator for analysing a country's macroeconomic environment; E/G represents energy consumption intensity, refers to the amount of energy consumption per unit of GDP in a certain period of time, reflects the relationship between economic growth and energy consumption, and is an important reference standard for measuring the energy use efficiency of a country or a region; and C/E represents carbon emission intensity per unit of energy consumption, namely, the energy utilization efficiency.

With the continuous research of scholars, [14, 15] applied the extended Kaya identity to the energy field. Based on their research, this study applied the Kaya identity to the field of clean energy consumption and extended the Kaya identity, as shown in Equation (2).

$$NE=NE_1+NE_2=\frac{NE_1}{G_{1,s}}\times\frac{G_{1,s}}{G}\times G+\frac{NE_2}{Y_{2,s}}\times\frac{Y_{2,s}}{P_{2,s}}\times\frac{P_{2,s}}{P}\times P \quad (2)$$

where NE_1 and NE_2 represent clean energy consumption in the production sector and clean energy consumption in the residential sector, respectively.

The LMDI model was first proposed by Ang and Choi and was widely used in the Kaya identity to investigate the impact of different factors on energy consumption [16, 17]. This study divides the driving factors of China's energy transition into the following seven factors: production scale, energy intensity (production sector and residential sector), industrial structure, income level, urbanization rate, and population size. Due to the large difference in energy intensity between the production sector and the residential sector, if the two are quantified uniformly, a large deviation will occur [18]. Therefore, the energy intensity factor is divided into the production sector and the residential sector, as shown in Equation (3). where j represents the sector (j = 1, 2…6; agricultural sector, industrial sector, construction sector, service sector, urban residential sector, and rural residential sector); k represents the type of energy consumption in each sector (k = 1, 2, 3; natural gas, hydroelectricity, and nuclear power).

$$NE=\sum_{j=1}^{6}\sum_{k=1}^{3}NE_{jk}=\sum_{j=1}^{4}\sum_{k=1}^{3}\frac{NE_{jk}}{G_j}\times\frac{G_j}{G}\times G+\sum_{j=4}^{6}\sum_{k=1}^{3}\frac{NE_{jk}}{Y_j}\times\frac{Y_j}{P_j}\times\frac{P_j}{P}\times P$$

$$=\sum_{j=1}^{4}\sum_{k=1}^{3}EGI_j\times S_j\times G+\sum_{j=5}^{6}\sum_{k=1}^{3}EYI_j\times AVY_j\times U_j\times P \quad (3)$$

3.2 Index and Data source

Based on previous studies, this study combines the relative and absolute amounts of clean energy consumption to better and more comprehensively study the current energy transition situation.

Based on the availability of data, the study period of this paper is between 1995 and 2019. By referencing the periods of the Five-Year Plan of China's national economic and social development, the impact of each driving factor on China's energy transition can be more accurately analysed. The period is divided into five subintervals (i.e., 1995-2000, 2000-2005, 2005-2010, 2010-2015, and 2015-2019).

China's clean energy consumption between 1995 and 2019, GDP (converted at the 1995 benchmark price), industrial added value, disposable income, and population data are from the 1996-2020 China Statistical Yearbook. Among these data, the population data are the arithmetic mean of the total population at the end of the previous year and the current year. The energy consumption of each sector between 1995 and 2019 came from China Emission Accounts and Datasets [19].

4. Results and discussions

4.1 Overall driving factors on clean energy use in China

During the study period between 1995

and 2019, the amount of clean energy used in China increased by 549.87 Mtce, with a growth rate of 1012.14% (Fig.1).

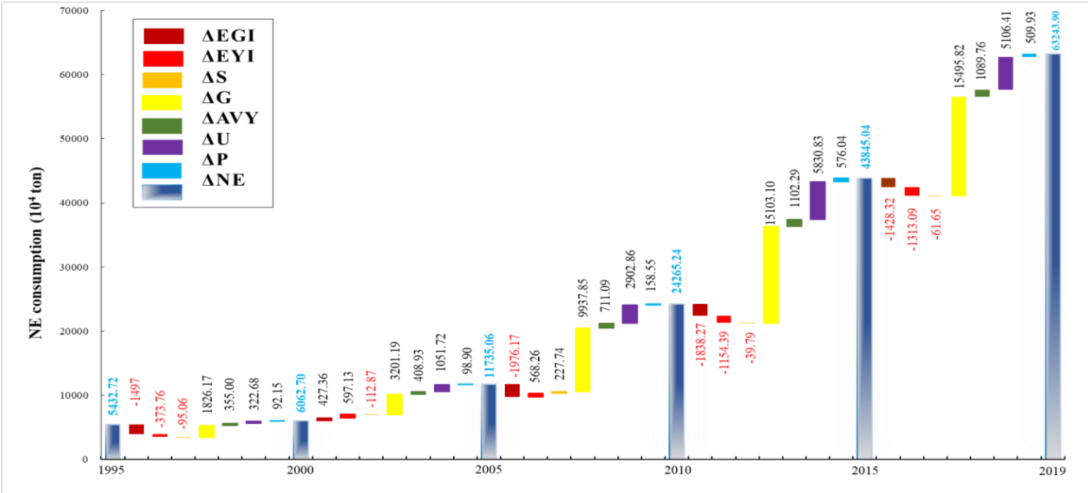

Fig.1 Waterfall of the LMDI decomposition results on clean energy consumption during 2000–2019.

According to Figure 1, the production scale factor (ΔG) in the five subintervals is the most important positive factor leading to the increase in the clean energy consumption, and the contribution value is as high as 455.64 Mtce. However, the energy intensity effect of the production sector (ΔEGI) is the main negative driving factor leading to the gradual slowdown of the increase in clean energy consumption, with a contribution of -63.12 Mtce. The specific analysis follows.

Between 1995 and 2019, the production scale factor (ΔG) showed rapid growth, from 39.68% in 1995 to 1012.14% in 2019. This trend stems from the rapid growth of China's economy, which drives energy demand. In the process of energy supply growth, the level of energy development and utilization has also been continuously improved [21].

Energy intensity factors are divided into production sector (ΔEGI) and the residential sector (ΔEYI).Between 1995 and 2019, the contribution values of ΔEGI and ΔEYI fluctuated, changing from -14.97 Mtce and -3.74 Mtce in 1995-2000 to -32.66 Mtce and -24.67 Mtce in 2010-2019, respectively. This finding is mainly attributed to the different influencing effects produced by the technological level.

In terms of the industrial structure (ΔS) factors, China's ΔS showed a shift from the negative driving effect during 1995-2005 (1995-2000: -0.95 Mtce; 2000-2005: -1.12 Mtce) to a positive driving effect during 2005-2019 (2005-2010: 2.27 Mtce; 2010-2015: -0.39 Mtce; 2015-2019: -0.61 Mtce) during the entire study period.

About the influence of income increases factors (ΔAVY), the clean energy consumption was positively promoted, and the contribution value gradually increased, from 3.56 Mtce in 1995 to 10.89 Mtce in 2019, which is different from traditional energy. The clean energy consumption is not an inverted U-shape [20], which indicates that China's energy transition is at a rapid advancing stage, and the advancing speed is relatively fast.

Factor of urbanization level (ΔU) play a positive role in promoting the change in energy consumption, i.e., the promotion of urbanization is conducive to increasing the clean energy consumption and promoting the energy transition process. However, its impact is relatively small, from 3.23 Mtce in 1995 to 51.06 Mtce in 2019, and the total contribution driving value is 152.15 Mtce.

From the perspective of population (ΔP), in the period between 1995 and 2019, ΔP played a role in promoting clean energy consumption, from 0.92 Mtce in 1995 to 5.09 Mtce in 2019; however, the impact was very small.

4.2 Overall driving factors on clean energy consumption among different sectors

This section analyses the impact of each driving factor on clean energy consumption in different industrial sectors. Figure 2 shows that between 1995 and 2019, the urban residential sector accounted for the largest proportion of clean energy consumption (approximately 27%), followed by the service sector (approximately 21%). The sectors that accounted for the smallest proportions are the rural residential and agricultural sectors, which were approximately 5% and 12%, respectively. The driving factors of the six sectors will be analysed individually below.

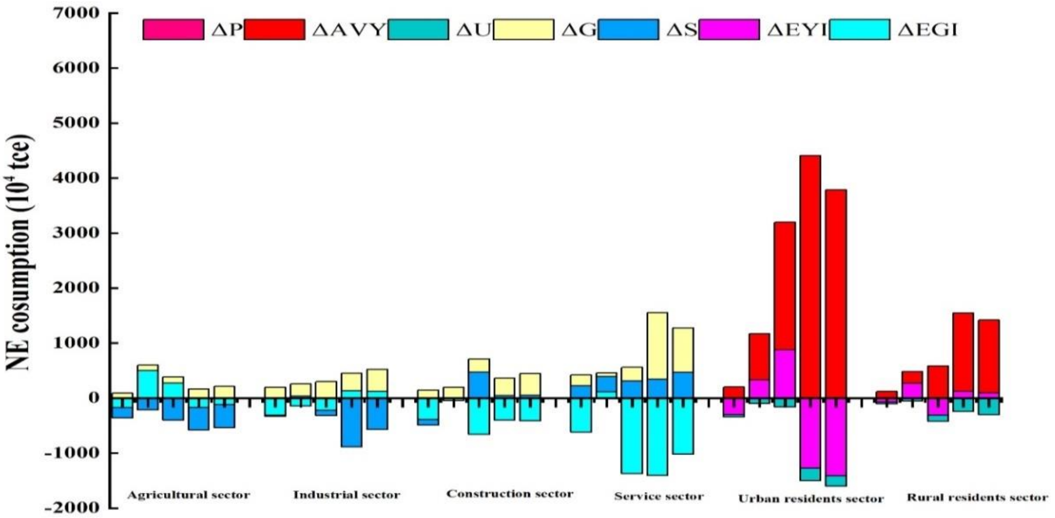

Fig.2 LMDI decomposition of clean energy consumption for each sector at different time intervals

The service sector is an important sector driving China's energy transition. The main factor that positively promoted the increase in clean energy consumption in the service sector in different time periods is the production scale factor (ΔG). Between 1995 and 2019, the total contribution was as high as 25.37 Mtce. The second is the industrial structure factor (ΔS). Between 1995 and 2019, the contribution value reached 16.21 Mtce, and the effect of production scale and industrial structure factors continuously increased.

About the construction sector, Figure 2 shows that the production scale factor (ΔG) showed a positive driving effect in all time periods. The total contribution between 1995 and 2019 was as high as 12.96 Mtce. In contrast, the energy intensity factor is the main factor inhibiting increase in clean energy consumption by China's construction sector.

As a major secondary industry, the industrial sector consumes a relatively large proportion of clean energy, which is closely related to its production scale. The industrial sector is a key sector for China's rapid economic growth. With the introduction of green industries, China is increasingly focusing on low-consumption, high-quality, high-efficiency, and low-pollution industrial production. While developing industry, we should pay attention to the utilization of clean energy technology and the use of clean energy. The production scale (ΔG) is the main reason leading to the increase in clean energy consumption in China's industrial sector.

For the agricultural sector, the proportion of clean energy is relatively low because the overall level of agricultural development in China is relatively low, and the main force of agricultural output remains in rural areas. And the main factor that promotes the energy transition of China's agricultural sector is the production scale factor (ΔG). Between 1995 and 2019, the contribution value reached 6.79 Mtce, and the main factor of inhibition was the industrial structure (ΔS). Between 1995 and 2019, the contribution value reached -16.14 Mtce.

In contrast to the rural sector, the urban sector accounted for a relatively high proportion of clean energy. As can be seen from Figure 2, the income increase factor promoted the process of energy transition of the urban household sector, and the contribution value reached 43.98Mtce from 1995 to 2019.

5. Conclusions

In this paper, the following basic conclusions are drawn: (1) The effect of China's energy transition is significant. During the study period, China's clean energy consumption continued to grow, with an average annual growth rate of 16.13%. (2) The impact of each driving factor on the overall energy transition varies. The production scale factor is the most important factor that promotes the energy transition, the energy intensity effect is the main factor that inhibits the energy transition, and the inhibiting effect of the energy intensity on the production sector is significantly higher than that of the residential sector. The influence of industrial structure changed from inhibition to promotion. The income level plays a promoting role, and the contribution value gradually increases. The factors of urbanization level and population size promote the energy transition, but their impact is relatively small. (3) Different driving factors have different impacts on the energy transition in different sectors. The service industry and industry are the sectors with the highest clean energy consumption in China. The main positive influencing factors are the production scale factor and the industrial structure factor, both of which increase over time, and the main negative influencing factor is the energy intensity factor. From the perspective of the construction industry, the production scale factor exhibits a positive driving effect in each period, while the energy intensity factor is the inhibiting factor.

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