Research on the spatiotemporal evolution and driving mechanism of coupling coordination between energy structure transformation and common prosperity

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Abstract: Promoting the transformation of energy structure is the important method to realize common prosperity in China. This paper estimates China's energy structure transition, explores the spatial evolution characteristics of the coupling and co-ordinated development of energy structure transformation and common prosperity, and analyzes its driving mechanism. The results show that the comprehensive evaluation index and coupling coordination degree of energy structure transformation and common prosperity show a steady improvement trend. The coupling coordination type is between low-degree and high-degree coordination. The coupling coordination degree presents a spatial allocation pattern of high in the east and low in the west, high in the center and low in the south. The transformation of energy structure and the drive of common prosperity are greatly affected by macroeconomics and policies. This study provides an empirical reference for promoting the transformation of energy structure and the realization of common prosperity.

1. Introduction

With the continuous deepening of institutional reform, taking into account multi-layered goals such as economic and social development, energy security and environmental protection, energy development must embark on a path of common prosperity with Chinese characteristics. In this context, it is of great significance to accurately grasp the impact, transmission mechanism and action law of China's energy structure transformation on common prosperity to Speed up the green and low-carbon switch of China's energy structure, realize the decoupling of economic growth and carbon emissions, and complete the dual carbon goals as scheduled. Therefore, clarifying the coupling and harmonization relationships between energy structure transformation and common prosperity can provide important enlightenment for facilitating optimal layout and a high quality of growth of energy structure. The contribution of this paper is that, firstly, from the perspective of energy structure transformation, it explores the temporal evolution and driving mechanisms of its coupling and coordination for common prosperity. Secondly, this paper provides a scientific basis for the proposal of precise policies.

2. Mechanism analysis

2.1. Energy structure transformation on common prosperity

The transformation of energy structure is to achieve energy conservation, emission reduction and efficiency improvement by transforming the energy supply structure, optimizing the energy consumption structure, and promoting energy technology innovation[7]. The transformation of energy structure can improve the industrial structure, increase national income, bridge the gap between rich and poor, and then promote the realization of the target of common prosperity[1].

The transformation of the energy structure has accelerated the return of economic, human and social capital to rural areas[2], and continued to promote the application of new energy in new business formats such as agriculture and rural areas and rural tourism[5], thereby increasing farmers' incomes, promoting local economic growth, and promoting the realization of the goal of common prosperity[9].

2.2. Common prosperity on energy structure transformation

From the energy supply side, common prosperity can provide manpower and financial support for green technology innovation[10], and then promote the

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transformation of the energy structure[3]. From the energy demand side, common prosperity will increase people's income levels, further increase the market demand for clean energy[6], and provide a strong impetus for the transformation of the energy structure.

3.Methods

3.1. Efficiency measurement method

The slacks-based measurement (SBM) model not only solves input-output relaxation issues , but also efficiency evaluation with undesirable outputs[8]. Therefore, this paper uses the undesirable output SBM model to measure the total factor energy efficiency. The model treats each province as a production decision-making unit (DMU) and assumes that each province has inputs, desirable outputs, and undesirable outputs. The SBM model is as follows.

$$\rho = min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} s_i^-}{x_{io}}}{1 + \frac{1}{s_1 + s_2}\left(\frac{\sum_{r=1}^{s_1} s_r^g}{y_{ro}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{ro}^b}\right)}$$

s.t.

$$\begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda - s^g \\ y_0^b = Y^b\lambda - s^b \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases}$$

s indicates the amount of slack in inputs and outputs. λ is a weight vector. The objective function ρ is about s^- and s^g, strictly decreasing, and $0 \leq \rho \leq 1$. If and only if $\rho = 1$, i.e. $s^- = 0, s^g = 0, s^b = 0$, the DMU is efficient.

3.2. Coupling coordination

In this article, the following model is used to figure out the coupling relationship between energy structure transformation and common prosperity, as well as the overall efficacy and synergy between the two systems.

$$C = 2\left\{\frac{f(x) \times g(y)}{[f(x) + g(y)]^2}\right\}^{\frac{1}{2}}$$

C is the degree of system coupling (0≤C≤1). $f(x)$ represents total factor energy efficiency. $g(y)$ indicates the common prosperity development index. Owing to the fact that the coupling degree can only describe the degree of matching between total factor energy efficiency and shared prosperity, and cannot validly expose the coordinated development level of the two, the following coupling harmonization degree model is introduced.

$$D = \sqrt{C \times T}, T = \alpha f(x) + \beta g(y)$$

D is the degree of coupling harmonization. D∈[0, 1]. The D closer to 0, the lower the level of coupling harmonization. T is the integrated coordination index of the two, reflecting the overall synergy between the two. α and β are the weights of the two systems, which are 0.4 and 0.6, respectively.

$$E = \frac{f(x)}{g(y)}$$

In this study, the relative degree of development (E) is used to determine the synchronicity of total elemental power effect and common prosperity. If E > 1.2, it is the lagging type of common prosperity. If 0.8≤E≤1.2, it is simultaneous development. When E≤0.8, it is the lagging type of energy structure transformation.

3.3. Geographic detector model

The integration and coordinated development of energy structure transformation and common prosperity is the result of the comprehensive effect of multiple factors. In this paper, the level of economic growth, scientific and technological innovation, the level of opening-up, and the degree of government intervention are selected as drivers of "two" harmonized development[11]. The geographic detector model is used to study the influencing factors of the coupling coordination degree between energy structure transformation and common prosperity, and to explore its driving mechanism on the coupling coordination degree[4]. The formula is as follows.

$$Y = 1 - \frac{1}{n\sigma^2}\sum_{i=1}^{m} n_i\sigma_i^2$$

Y represents the force of factors affecting the degree of coupling coordination of energy structure transformation and common prosperity, and the value range is [0,1]. The larger the Y value, the stronger the explanatory power of the influencing factor on the coupling coordination degree. n and σ^2 are the sample size and variance for the whole region. n_i and σ_i^2 are the sample size and variance of the sub-regions.

4.Indicators

4.1. Energy structure transformation

Total factor energy efficiency can comprehensively reflect the economic efficiency and environmental benefits of energy use, so this paper uses total factor energy efficiency as a proxy variable for energy structure transformation.

4.2. Common prosperity index

In this paper, 3 first-level indicators, 10 second-level indicators and 21 third-level indicators are constructed from the three aspects of development, share ability, and sustainability of common prosperity.

5. Empirical results

5.1. Temporal evolution trend

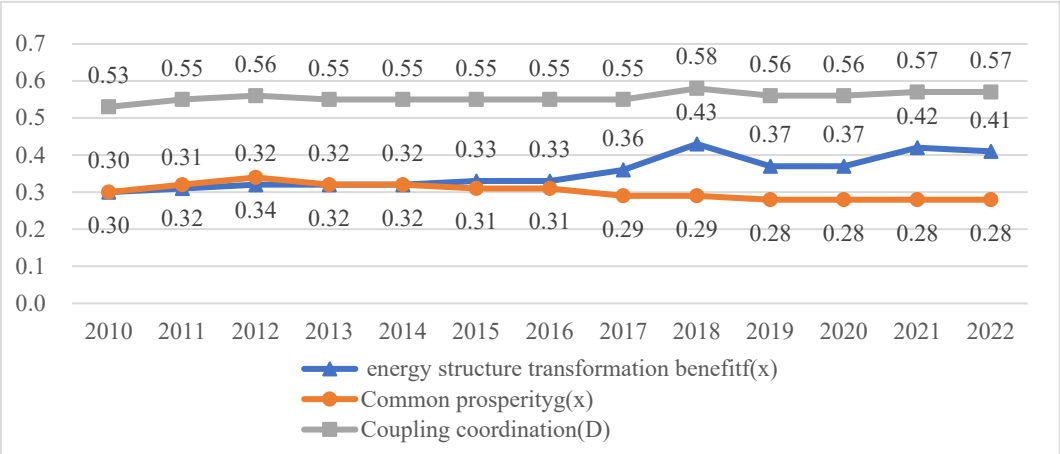


Figure 1. Coupling coordination degree.

Figure 1 shows the degree of coupling coordination between China's energy structure transition and common prosperity. The value of common prosperity remains stable during the study period, which is also in line with the current situation of unbalanced and insufficient long-term development in China. The development trend of coupling coordination between China's energy structure transformation and common prosperity is basically consistent with the development trend of energy structure transformation value. From 2010 to 2018, it increases from 0.53 to 0.58, then declined significantly in 2019, and resumes growth in 2021. This indicates that the coupling degree between China's energy structure transformation and common prosperity is relatively high and stable, and the correlation between the two systems continues to increase.

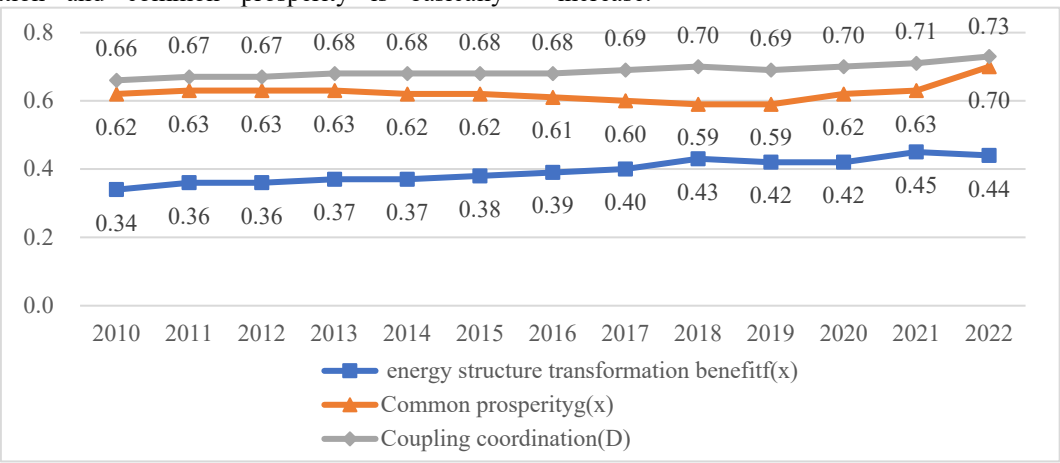
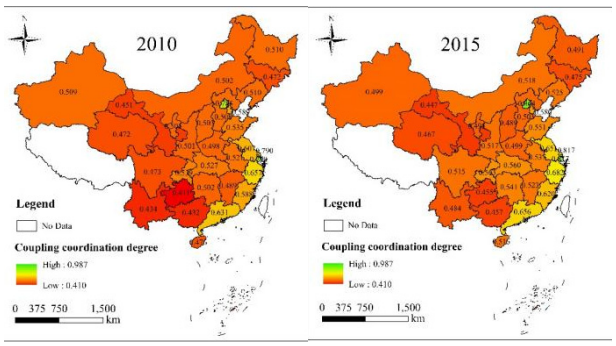


Figure 2. Coupling coordination degree in Zhejiang Province.

Figure 2 shows the coupling coordination degree of energy structure transformation and common prosperity in Zhejiang Province. The change trend of energy structure transformation value in Zhejiang Province is basically consistent with the change trend of energy efficiency value in China, and has been at a high level. All coordination degrees are higher than 0.66, which is higher than the maximum value of China's average coupling coordination degree of energy structure transition and common prosperity. Zhejiang Province attaches great importance to energy development. In 2022, Zhejiang Province issued the Notice on the 14th Five-Year Plan for Energy Development in Zhejiang Province, emphasizing the need to ensure energy supply, improve energy utilization efficiency and cleanliness, and ensure that energy reform and innovation are at the forefront. As a demonstration area for common prosperity in China, Zhejiang Province is also among the top in China, and the policy benefits enjoyed by Zhejiang Province are also better than the average level in China.

5.2. Spatial evolution trend



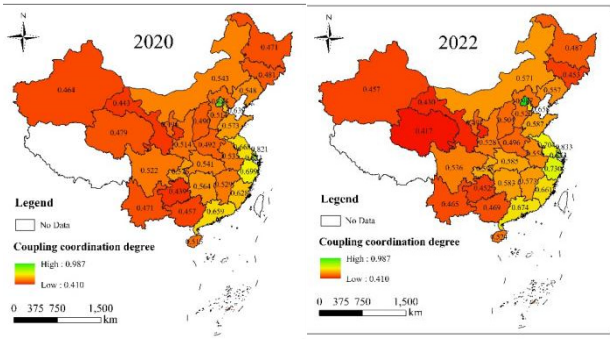


Figure 3. Spatial distribution of the coupling coordination degree.

Considering that all the values are above 0.4 and there are many provinces with values between 0.4 and 0.5, this paper sets the provinces with coupling coordination degree values between 0.4 and 0.5 as the low coupling coordination area, the provinces with values between 0.5 and 0.7 as the moderate coupling coordination area, and the provinces with values greater than 0.7 as the high coupling coordination area. Seen from Figure 3, the spatial distribution characteristics of the coupling coordination degree of energy structure transformation and common prosperity in China are significant, which is characterized by space patterns of high east and low west, high south and low north. The high and low coupling coordination areas show a trend of spatial expansion and convergence divergence, respectively. The spatial differentiation degree of coupling degree is gradually clear with the evolution of time.

6. Conclusions

The research conclusions are as follows: (1) From the perspective of coupling and coordination results, the comprehensive evaluation index and the degree of coupling and coordination for the coupling and coordinated development of energy structure transformation and common prosperity nationwide show a steady upward trend. The types of coupling and coordination between the two are between low coordination and high coordination, and some provinces have achieved transitions and regressions in coordination levels. Specifically, Zhejiang and Jiangsu in the eastern region have shifted from medium coupling coordination to high coupling coordination, while Heilongjiang and Xinjiang in the marginal regions have regressed from medium coupling coordination to low coupling coordination. (2) From the perspective of spatial distribution patterns, the coupling and coordination degree shows a "high in the east and low in the west, high in the central and low in the north and south" spatial distribution pattern, and the high and low coupling coordination areas respectively show a spatial "expansion-contraction" divergent change trend. Large central cities have a variety of energy types and more complex structures, making it easier for clean energy technology to emerge and be promoted in these areas. Pilot policies related to common prosperity and energy structure transformation are more likely to be carried out in these regions. Marginal regions have a weaker economic foundation. Not only is the energy structure single, but there are also fewer job positions, lower salary levels, and new energy technology is difficult to popularize in these areas, and common prosperity is also limited by the level of economic development. (3) From the perspective of influencing factors, the driving mechanisms of energy structure transformation and common prosperity are diverse, mainly including four aspects: economic operation conditions, innovation, market openness and cooperation, and policy regulation. They are greatly influenced by macroeconomic and policy factors, and less influenced by micro-individual factors.

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