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Social and Economic Impact Assessment of Coal Power Phase-Down at the Provincial Level: An Entropy-Based TOPSIS Approach

Changhong Zhao [1], Jiaxuan Chen [1], Xiaowen Yang [1] and Jiahai Yuan [1,2,*]

[1] School of Economics and Management, North China Electric Power University, Beijing 102206, China; zchh21@126.com (C.Z.); 120222206368@ncepu.edu.cn (J.C.); 120212106018@ncepu.edu.cn (X.Y.)
[2] Beijing Key Laboratory of New Energy and Low-Carbon Development, North China Electric Power University, Beijing 102206, China
* Correspondence: yuanjiahai@ncepu.edu.cn

Abstract: With the rollout of the carbon peak and neutrality targets, conventional coal-fired power plants will gradually be phased down in China's power system in an orderly manner. The economic and social impact of the energy transition is a vital topic that requires scientific measurements and evaluation. In this paper, we establish a comprehensive approach to assess the impact of provincial coal power phase-down with 11 indicators covering dimensions of economy, society, and industry. An entropy-based Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) approach is adopted to calculate entropy weight, relative closeness, and other evaluation benchmark data. Then, the influence degree in 30 provinces is ranked based on the assessment. The results show that there is a significant regional imbalance in the process of coal power phase-down, among which Shanxi, Inner Mongolia, and other coal base provinces are the most vulnerable regions bound by their huge raw coal production and coal industry employment. Although the coal power industry is less affected than the coal industry, it will face pressure from the optimization of coal power units, followed by the dual impact of taxation and employment issues. Finally, the potential impacts of coal power phase-down and policy implications are proposed.

Keywords: coal power; energy transition; social impact; economic impact; entropy weight TOPSIS; provincial disparity; vulnerable regions

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1. Introduction

Climate change is one of the greatest ecological and social challenges of the twenty-first century [1]. To minimize the potential negative impacts and risks of climate change, net-zero goals corresponding to the Paris Agreement have been formally adopted, announced, or taken into consideration by countries across the globe [2]. As the world's second-largest economy, China is an important participant in global climate governance. In 2020, China announced that it would be scaling up its national commitments, aiming to reach a CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060, reflecting China's strong determination to deal with global climate change with clear action plans.

The power sector is currently the biggest emitter of greenhouse gases in China, with approximately 3.6 billion tons of CO_2 emissions in 2020, accounting for 37% of the country's total CO_2 emissions [3]. It is less difficult for the power sector to achieve carbon neutrality goals and even negative carbon emissions than other sectors, and this sector is regarded as the core sector in terms of promoting the low-carbon transition of society at large [4]. Although the existing power system in China is dominated by coal power, the coal power supply will gradually decrease under the carbon neutrality target, while non-fossil renewable power will become the mainstay of power supply in the long term. According to the Guidance for Carbon Neutrality, non-fossil renewable power will account for more than 80% of China's energy supply by 2060 [5]. The State Council mentioned in the "peak carbon dioxide emissions Action Plan before 2030" that one of the current key tasks is to "promote coal consumption substitution and transformation and upgrading. Accelerate the pace of coal reduction, strictly and reasonably control the growth of coal consumption during the 14th Five-Year Plan period, and gradually reduce it during the 15th Five-Year Plan period [6]". Although the gradual withdrawal of the coal-fired power industry will bring positive environmental and health benefits [7,8], its socio-economic impact is also worthy of attention. By the end of 2022, the installed capacity of coal power in China reached 1.12 billion kilowatts [9]. These coal-fired power units and the upstream coal-mining industry not only provide strong support for the safe and stable supply of energy and electricity in China but also provide a large number of employment opportunities and financial income for society.

The gradual phase-down of coal power will bring about a series of economic and social issues, such as ignoring the reality, blindly phasing out coal, and campaigning for "carbon reduction", which may affect the electricity supply without long-term planning and effective management [10]. Meanwhile, there are great differences between China's regional energy structure, resource endowment, and industrial structure. The impacts of coal phase-down vary from province to province because of regional imbalances. As evidenced in some of the local carbon-peaking and carbon neutrality plans that have been introduced, the general idea tends to be the same in different regions, lacking geographical uniqueness and specificity. The Action Plan also emphasizes that each region should accurately grasp its development position and promote carbon peaking in an orderly and sequential manner [5]. Therefore, determining how to scientifically measure and assess the economic and social impacts of regional coal power phase-down is a major academic and policy issue that needs to be studied.

Developed countries such as the United States and European nations have started the process of energy transition earlier, with clear paths for coal power phase-down. Some studies have analyzed a series of impacts of coal power phase-down on technology, environment, economy, and society at the national and regional levels [11–14]. Some scholars conducted more precise research with accurate data support, such as exploring the relationship between coal employment and community economic development at the county level [15] and the possible impact of the closure of a coal power station [16]. In China, most research on coal power phase-down focuses on the analysis of barriers, pathways, and related policy analysis [17–20]. Studies on the economic and social impacts of coal power phase-down are based on the transition process of other countries and provide an overview of how China may be affected in the future. He et al. (2020) reviewed the current energy policies and existing obstacles in China and pointed out the possible impacts on environmental health and social employment in the transition process [20]. Zhang et al. (2021) summarized the employment impact of climate change and countermeasures and analyzed the conceptual connotations and development trend of just transition [21]. Li et al. (2021) proposed a downscaling method for coal power macro forecasting based on the Monte Carlo Method that narrowed the scale gap between regional projection and unit data [22]. Though the existing research on the impact of coal power phase-down has made some progress, there is still a research gap regarding the data-based economic and social impacts of regional coal power phase-down, especially for China.

In recent years, scholars in various fields have used different evaluation methods to carry out related research, including data envelopment analysis, multi-criteria decision making, the entropy weight TOPSIS method, and so on [23–25]. The entropy weight TOPSIS method combines the objective weighting of the entropy weight method with the multi-attribute decision-making ranking of the TOPSIS method. In the process of constructing a weighted normalized matrix using the TOPSIS method, the weights obtained via the entropy weight method are used for calculation [26]. In the process of selecting the evaluation method in this paper, we considered that the quantitative data to be used could be obtained from the statistical yearbook. The entropy TOPSIS method is widely used in evaluating the influencing factors of economic development and economic, social, and ecological impacts [27,28], so this method was used to select indicators with large amounts of information and objectively quantify the impact of coal-fired power elimination according to relative closeness so that the evaluation results would be more realistic. In this study, we conducted a comprehensive evaluation of the economic and social impacts of coal power phase-down in 30 Chinese provinces (excluding Tibet, Hong Kong, Macau, and Taiwan) and decomposed the economic and social impacts of coal power phase-down into three aspects: economy, society, and industry. To obtain a more objective judgment result of the influence of provincial coal power phase-down, the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method was used to eliminate the influence of different indicator scales by assigning and ranking the influence degrees of each indicator. The provinces were classified to further explore the regional imbalance in the process of coal power phase-down. This procedure was conducive to establishing and improving corresponding policies, measures, and safeguard mechanisms in advance.

The rest of this paper is organized as follows: In Section 2, the establishment of an evaluation index system and an evaluation process using the entropy TOPSIS method are introduced. In Section 3, the index weights and relative closeness are quantified, and the results obtained are presented. Based on the results, the potential impact of the gradual reduction in coal-fired power is discussed. Finally, in Section 4, we discuss our conclusions and limitations and make policy suggestions according to the significance of the conclusions.

2. Materials and Methods

2.1. Assessment Indicator Systems

A comprehensive evaluation of the economic and social impacts of coal power phase-down at the provincial level requires a systematic evaluation index system. In 2020, 2.09 billion tons of power coal were consumed by China's power industry, accounting for 53.6% of the country's raw coal production [29]. On the national level, total power generation amounted to 7417 TWh, of which 60.8% came from coal power generation [30]. The coal industry and the coal power industry are interdependent and have different focuses regarding the impacts of coal power phase-down. To propose an economic and social impact evaluation index system for coal power phase-down, this study evaluates the impact of coal power phase-down from two dimensions, namely, the coal industry and the coal power industry. Limited by the available data in 30 provinces in China, this assessment system is based on specific evaluation indicators, including the proportion of GVA (Gross Value Added), the proportion of tax revenue, the proportion of employment, the proportion of average wages, the proportion of power generation, raw coal production, the installed coal power capacity and the average operating age of coal power units in operation, etc.

GVA and tax are key indicators reflecting an economic situation, so proportion of GVA and proportion of tax revenue are used to reflect the influence of coal power phase-down on the regional economy. The proportion of employment reflects the proportion of people engaged in coal and coal-fired power production in all industries in the province, the proportion of average wages represents the income level of people engaged in the coal industry for the whole industry, and the proportion of electricity generation reflects the dependence of social electricity consumption on coal-fired power industry in various provinces, so these indicators are used to reflect the social impact of coal power phase-down. Raw coal production can reflect the demand of the coal industry in each province. The installed coal power capacity and the average operating age of coal power units in operation reflect the development status of coal-fired power plants in each province, so they are used to reflect the industry impact of coal power phase-down. The specific evaluation indicators are shown in Tables 1 and 2.

Table 1. Provincial evaluation indicator system of the coal industry.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Measurement
Establishment of a sub-provincial evaluation indicator system (coal sector)	Economy	Proportion of GVA (Gross Value Added)	Ratio of annual provincial coal sector GVA to annual provincial GDP
		Proportion of tax revenue	Ratio of annual provincial coal mining revenue to tax revenue and annual provincial tax revenue
	Society	Proportion of employment	Ratio of annual provincial employment in coal-mining and -washing industry to annual provincial employment
		Proportion of average wages	Ratio of average provincial yearly wages from coal mining and washing to average provincial yearly wages in all industries
	Industry	Raw coal production	Provincial annual raw coal production

Source: China Statistical Yearbooks and provincial statistical yearbooks in 2020.

Table 2. Provincial evaluation indicator system of the coal power industry.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Indicator Measurement
Establishment of a sub-provincial evaluation indicator system (coal power sector)	Economy	Proportion of GVA	Ratio of annual provincial GVA of the coal power sector to annual provincial GDP
		Proportion of tax revenue	Ratio of provincial annual tax revenue from electricity and heat production and supply to provincial annual tax revenue
	Society	Proportion of employment	Ratio of annual provincial employment in the coal and electricity industries to annual provincial employment
		Proportion of electricity generation	Ratio of annual provincial thermal power generation to total annual provincial power generation
	Industry	Installed coal power capacity	Provincial annual installed coal power capacity
		Average operating age of coal power units in operation	Annual average operating age of coal power units in operation in provinces

Source: China Statistical Yearbooks and provincial statistical yearbooks in 2020.

2.2. Entropy and TOPSIS Methods

According to the evaluation indicator system and purpose of the impact of provincial coal power phase-down, the TOPSIS model based on entropy weight was used to calculate the severity of the economic and social impacts of provincial coal power phase-down [31]. The entropy method can be used to calculate the weight of an evaluation indicator based on the amount of information it contains, which can effectively reduce the empirical errors caused by the subjective perception of the evaluator. The TOPSIS model is an analytical model for comparing multiple indicators and solutions. Firstly, it is necessary to calculate the positive (negative) ideal solution, which is the set of all the best (worst) evaluation data. Then, it is necessary to calculate the distance between the evaluation object and the positive (negative) ideal solution, termed relative closeness. Finally, the degrees of relative closeness are ranked to find the best and worst values between the indicators. This ranking method is widely used to solve basic decision-making and comprehensive evaluation problems. The data calculation process is simple and trustworthy.

2.3. Assessment Process

The process of assessment combining entropy method and TOPSIS is as follows.

(1) Construction of evaluation matrix.

$$F = (f_{ij})_{m\times n} = \begin{pmatrix} f_{11} & \cdots & f_{1n} \\ \vdots & \ddots & \vdots \\ f_{m1} & \cdots & f_{mn} \end{pmatrix} \quad (1)$$

Here, m represents evaluation objects, and n represents evaluation indicators; i = 1, 2, ……, m ; $j = 1,\ 2,\ \ldots\ldots,\ n$.

(2) Standardization of indicators. As the scales of each indicator and magnitude are different, the raw indicator data need to be standardized and divided into positive standardized indicators (benefit indicators) and negative standardized indicators (cost indicators). The indicators listed in this paper are all positive indicators.

$$f'_{ij} = \frac{f_{ij} - \min(f_{ij})}{\max(f_{ij}) - \min(f_{ij})} \quad (2)$$

(3) Calculate the entropy value of the jth evaluation indicator.

$$e_j = -\tfrac{1}{\ln n}\sum_{i=1}^{m} (f'_{ij}/\textstyle\sum_{i=1}^{m} f'_{ij}) \ln(f'_{ij}/\textstyle\sum_{i=1}^{m} f'_{ij}) \quad (3)$$

(4) Calculate the entropy weight of the jth evaluation indicator

$$\omega_j = (1 - e_j)/(n - \textstyle\sum_{i=1}^{n} e_j) \quad (4)$$

in which $\sum_{j=1}^{n} \omega_j = 1, 0 \le \omega_j \le 1$.

(5) Construct a weighted standardized decision matrix.

$$Z = (z_{ij})_{mn} = \left(\omega_j \times f'_{ij}\right)_{mn} \quad (5)$$

(6) Determine the positive and negative ideal solutions for each indicator.

$$J_j^+ = (J_1^+, J_2^+, \ldots, J_n^+) = (\max\{J_{11}, J_{21}, \ldots, J_{m1}\}, \ldots, \max\{J_{1n}, J_{2n}, \ldots, J_{mn}\}) \quad (6)$$

$$J_i^- = (J_1^-, J_2^-, \ldots, J_n^-) = (\min\{J_{11}, J_{21}, \ldots, J_{m1}\}, \ldots, \min\{J_{1n}, J_{2n}, \ldots, J_{mn}\}) \quad (7)$$

(7) Calculate the Euclidean distance.

$$R_i^+ = \sqrt{\textstyle\sum_{j=1}^{n} \left(z_{ij} - J_j^+\right)^2}, (1 \le i \le m) \quad (8)$$

$$R_i^- = \sqrt{\textstyle\sum_{j=1}^{n} \left(z_{ij} - J_j^-\right)^2}, (1 \le i \le m) \quad (9)$$

(8) Calculate the relative closeness of the evaluation object to the ideal solution.

$$C_i = R_i^- / (R_i^+ + R_i^-) \quad (10)$$

The impact size of coal power phase-down is expressed in terms of closeness, which means C_i is the composite score of each evaluation object, and its value has the following range: [0, 1]. The magnitude of this value is proportional to the size of the impact of coal power phase-down of the object under evaluation.

3. Results and Discussion

3.1. Quantifying Indicator Weights

The results of the indicator weights calculated using the entropy method are shown in Table 3, where ω_1 and ω_2 are the indicator weight coefficients of the coal industry and the coal power industry, respectively.

Table 3. Calculation results for the entropy method (coal industry and coal power industry).

Indicators	Weighting Factor ω_1 (Coal Industry)	Indicators	Weighting Factor ω_2 (Coal Power Industry)
Proportion of GVA	5.24%	Proportion of GVA	3.56%
Proportion of tax revenue	18.14%	Proportion of tax revenue	22.71%
Proportion of employment	30.88%	Proportion of employment	21.36%
Proportion of average wages	5.87%	Proportion of electricity generation	10.86%
Raw coal production	39.86%	Installed coal power capacity	34.82%
/	/	Average operating age of coal power units in operation	6.69%

Source: authors' calculations.

3.2. Quantifying Relative Closeness

Based on the model formula of entropy weight TOPSIS, the closeness value of the economic and social impacts of coal power phase-down at the provincial level was calculated. The sum of the relative proximity of the coal and coal power industry was taken as the basis for the total score, and 30 provinces were ranked. C_1 and C_2 represent the relative closeness of the coal and coal-fired power generation sectors, respectively. The larger the total score ($C_1 + C_2$), the more affected the provinces were by the coal power phase-down. The results of the calculation and ranking are shown in Table 4.

Table 4. Calculations results and ranking of relative closeness (30 provinces).

Province	Coal Relative Closeness C_1	Coal Power Relative Closeness C_2	Total Score (C_1+C_2)	Ranking	Province	Coal Relative Closeness C_1	Coal Power Relative Closeness C_2	Total Score (C_1+C_2)	Ranking
Shanxi	0.963	0.448	1.411	1	Heilongjiang	0.146	0.244	0.390	16
Inner Mongolia	0.571	0.653	1.224	2	Gansu	0.147	0.237	0.384	17
Xinjiang	0.423	0.400	0.823	3	Yunnan	0.078	0.264	0.342	18
Shaanxi	0.458	0.312	0.770	4	Zhejiang	0.007	0.328	0.335	19
Shandong	0.148	0.537	0.685	5	Jilin	0.085	0.226	0.311	20
Ningxia	0.270	0.367	0.637	6	Fujian	0.039	0.256	0.295	21
Jiangsu	0.048	0.471	0.519	7	Guangxi	0.068	0.208	0.276	22
Henan	0.117	0.400	0.517	8	Hubei	0.038	0.230	0.268	23
Hainan	0.076	0.380	0.456	9	Sichuan	0.047	0.204	0.251	24
Anhui	0.117	0.334	0.451	10	Hunan	0.044	0.192	0.236	25
Qinghai	0.039	0.407	0.446	11	Jiangxi	0.049	0.177	0.226	26
Guangdong	0.042	0.384	0.426	12	Tianjin	0.037	0.155	0.192	27
Liaoning	0.133	0.287	0.420	13	Beijing	0.024	0.167	0.191	28
Hebei	0.099	0.315	0.414	14	Shanghai	0.017	0.164	0.181	29
Guizhou	0.143	0.268	0.411	15	Chongqing	0.045	0.127	0.172	30

Source: authors' calculation.

3.3. Results

In this section, the results of the calculation are represented systematically (Figures 1 and 2). Among the regions analyzed, Shanxi and Inner Mongolia are the most affected, with high scores that greater than other provinces. Twenty-two provinces have scores that are below 0.5 and thus low. They are relatively less affected by coal power phase-down. We used

0.5 and 1.0 as the dividing lines, and 30 provinces were divided into the following three regions according to the evaluation results:

- Zone I: Shanxi and Inner Mongolia.
- Zone II: Xinjiang, Shaanxi, Shandong, Ningxia, Jiangsu, and Henan.
- Zone III: Anhui, Qinghai, Guangdong, Liaoning, Hebei, Guizhou, Heilongjiang, Gansu, Yunnan, Zhejiang, Jilin, Fujian, Guangxi, Hubei, Sichuan, Hunan, Jiangxi, Tianjin, Beijing, Shanghai, and Chongqing.

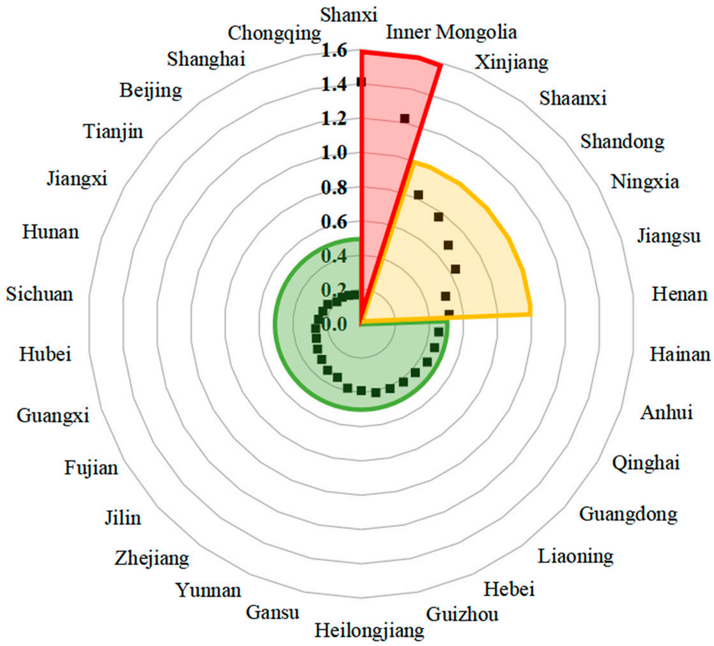

Figure 1. Radar chart of comprehensive evaluation results.

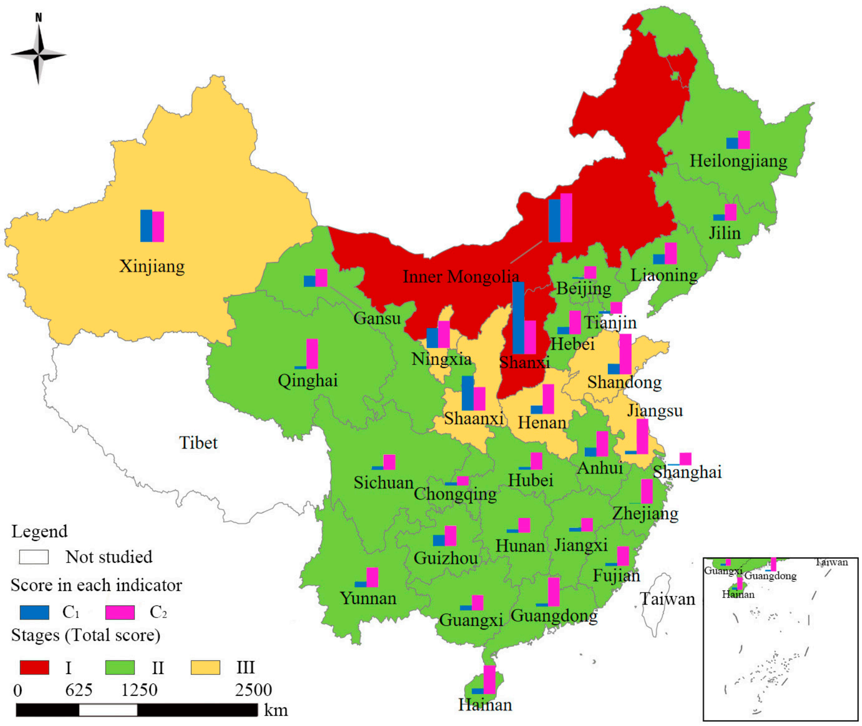

Figure 2. Total scores for 30 provinces in the comprehensive evaluation.

Shanxi and Inner Mongolia in Zone I are traditional coal-producing regions, accounting for the largest coal production and consumption in China. Shanxi's high score stems from its high dependence on the coal industry for economic development and the uneven development of its coal industry and coal power industry. The energy industry in Shanxi province is still dominated by the production and sale of raw coal and secondary energy produced from the conversion of raw coal. The coal industry has contributed around half of its GDP in recent years [32]. As China's largest province in terms of coal production and outward transfer, Shanxi has accounted for over 70% of the country's inter-provincial outward transfer of coal for a long time, but this share began to slowly decrease after 2009 [33]. With coal production far exceeding consumption, its C_1 is much greater than C_2. Inner Mongolia's economic development occurred later than Shanxi's, and its forward-looking development plan has resulted in a more balanced development of the coal and coal power sectors than Shanxi. Inner Mongolia's rich coal deposits make its coal reserves account for 26.24% of the country's total coal production, ranking first in the country [34]. Compared to coal mines in Xinjiang and Gansu, Inner Mongolia's coal mines are closer to developed areas along the eastern seaboard, making it an ideal area for the "West-East Power Transmission" project. With large and stable annual coal production and high local conversion rates, its C_2 is slightly greater than its C_1. These two provinces have a large number of jobs related to coal and coal power, indicating that finding a way to accommodate laid-off workers and sustainable economic growth will be a major challenge for these resource-based provinces in the transition process.

Xinjiang, Shaanxi, and Ningxia in Zone II are similar to Zone I in that they are all relatively coal-rich regions with a relatively high reliance on coal. Shandong, Jiangsu, and Henan were able to be included in Zone II because of their higher C_2. To further explore the differences in the impact of regional coal power and coal industries, C_1 and C_2 were used as horizontal and vertical axes for the scatter plots shown in Figure 3 (only some provincial names are shown). If the dot is above the blue arrow, it indicates that C_2 is greater than C_1 in the corresponding province, and vice versa. Dot further away from the blue arrow show a larger gap between C_1 and C_2 in the corresponding province, and the two dots with the largest gaps, above and below, are marked with orange arrows. The C_2 of most provinces is greater than C_1, of which Jiangsu accounts for the largest difference at 0.423. Shandong and Henan are closely behind, with values of 0.389 and 0.283.

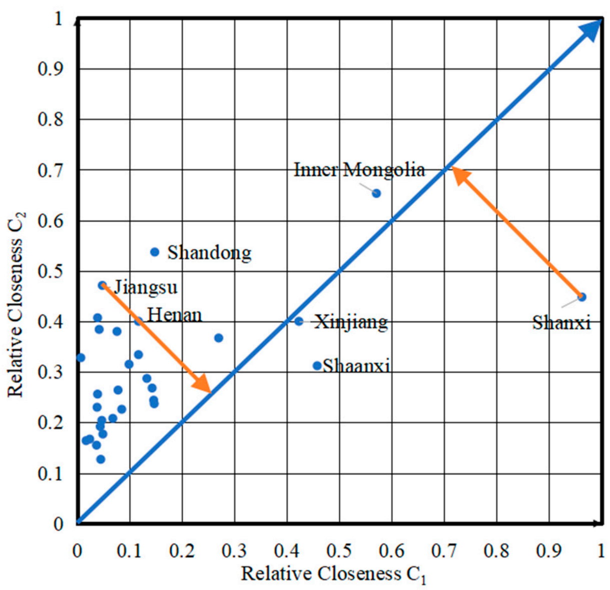

Figure 3. Scatter diagram of relative closeness.

Jiangsu, the second largest province in China in terms of GDP, does not produce much coal, but its coal use and consumption are much higher than most other provinces. As an input province for the "West-East Power Transmission" project, Jiangsu uses "incoming energy for local power generation + incoming power" as its energy supply model. Its large installed coal capacity makes Jiangsu's C_2 higher than that of most of the other provinces. By the end of 2020, Jiangsu had an installed thermal power capacity of 100.79 million kilowatts, second only to Shandong, with 111.35 million kilowatts [35]. This group of provinces faces two main issues in the coal transition process: the need to use more sustainable fuels to replace coal to vigorously develop clean energy and sustainable industries (the first) and the concern about the redistribution of laid-off workers from the coal power industry (the second).

Shandong and Henan face much tougher transition issues, as these two provinces have medium-level coal production but lower productivity compared to all the other provinces. Their large installed coal power capacity means that most of the lagging coal power capacity will be eliminated during the transition process. Lots of workers in the coal power industry associated with it will be at risk of losing their jobs. Though it will not be as challenging a situation as that for the provinces in Zone I, the social problems caused by workers losing their jobs should not be underestimated.

Zone III is the least affected by the phase-down of coal but the largest in scope, which does not mean that the provinces contained therein can relax their vigilance. These provinces have a significantly lower proportion of coal electricity consumption than the other provinces, and some of them also have abundant amounts of clean energy, making it relatively less difficult to remove coal. The northeast has low electricity demand and sufficient power supply capacity. Supported by abundant hydropower resources, the southern and central regions have an overall high electricity demand and load but a low share of coal power consumption. Shanghai, which is in the same economically developed Yangtze River Delta region as Jiangsu, has achieved a status quo of high GDP and low total carbon emissions through the continuous outward expansion and transfer of heavy industry. A similar province is Beijing, which has become the only city in China to have retired from coal [36]. The impact of the coal transition in China varies from province to province. Therefore, a tailored strategy must be developed to meet the specific demands of each province.

3.4. Discussion on the Potential Impacts of Coal Power Phase-Down

Affected by the differences in regional resource endowments, China's coal and electricity industries are facing the problem of inconsistent regional supply and demand. At present, China's coal resources are mainly concentrated in the northwest, while coal consumption is concentrated in Central China and Eastern China, and a pattern of "transporting coal from the north to the south" and "transferring coal from the west to the east" has gradually developed. The transformation of power decarbonization will bring many social benefits, such as mitigating climate risks, realizing sustainable economic development, and improving environmental quality. However, as the main power source of the power system, the gradual withdrawal of coal-fired power will place burdens on some social groups or regions, resulting in social justice problems. First of all, coal-fired power and coal, as the economic pillar industries in some areas, will lead to a reduction in local fiscal revenue and economic recession. Secondly, the large-scale coal-fired generating units will be idle or retired, putting the financial sector and power enterprises at risk of running aground. Furthermore, a large number of workers involved in coal-fired power and its related industries will face unemployment, which will have an impact on families and society. In addition, the instability of new-energy power generation has not been effectively remedied, and the security of power supply will face challenges.

There is a huge market for energy resources and considerable economic benefits. For resource-reliant provinces such as Shanxi, Xinjiang, and Shaanxi, having abundant coal resources should have become a developmental advantage, as the endowment of energy resources can promote economic growth by promoting physical capital investment. However, the amount of non-renewable natural resources such as coal will decrease with development and utilization. Over-reliance on resources will have a "crowding-out effect" on human capital investment, hindering the inflow of foreign capital and the development of manufacturing industries. Government intervention will strengthen [37]. This is a short-sighted behavior born of seeking short-term gain at the expense of long-term development. Coal-rich regions are at greater risk of having stranded assets due to the sharply reduced demand for fossil fuels, and regional differences are likely to widen further. In short, the greater the dependence on coal resources, the greater the pressure on coal phase-down in the future, and the greater the impact of coal phase-down on the local economy and society.

The employment Issues caused by the phase-down of coal and coal power involve the transition of the entire coal supply chain. Workers in the coal industry, coal companies, major coal-producing areas, and electricity consumers will all be affected by the transition. Coal workers are at risk of losing their jobs, followed by crises relating to workers' household income, the future labor market, and occupational structure. In 2016, Shanxi's coal industry alone employed about 976,000 workers, accounting for about one-fifth of total employment in the national coal industry [15]. Various ancillary, upstream, and downstream sectors related to coal will also experience declines. Ren et al. (2017) used the input-output table of 139 departments in 2012 and economic census data from 2013 to estimate that the indirect impact of the coal industry on employment in other industries through intermediate inputs will reach two to three times its direct impact [38]. Guaranteeing the basic rights and interests of labor groups and protecting their livelihoods during the low-carbon transition will be key nodes in the process of phasing out coal. Although it is generally accepted that active mitigation of climate change can generally promote job growth, there is a mismatch in time, space, and skills between job creation and job loss in the process [21]. The new development impetus may even exacerbate the differences between regions. Enterprises that master low-carbon technologies will squeeze the living space of traditional enterprises. Provinces with leading low-carbon technologies will have a first-mover advantage [39].

From an industry perspective, the coal industry has been hit even harder in the process of transformation. As revealed by evaluating the dispersion degrees of the relative closeness of the coal and coal power industries, the range of C_1 in the coal industry is 0.956, and the range of C_2 in the coal power industry is 0.526. While the regional coal distribution varies significantly, the difference in the coal power industry is relatively low, and this is why the transformation has a greater impact on the coal industry. By the end of 2020, the total installed capacity of coal-fired power in China was 1.08 billion kilowatts, and the planned installed capacity of coal power was as high as 380 million kilowatts [17]. The rapid transition will require the early retirement of large amounts of coal power generation equipment as well as the cancellation of newly planned coal projects. With the development of new energy as the main power source, coal-fired power will be transformed from the main power source to an auxiliary power source, and coal-fired power units will begin to be gradually phased down in stages. For the areas with abundant coal resources in Zones I and II, the outdated small coal-fired power units with high energy consumption will be phased down first. Then, the flexible transformation of units and fuels will be carried out to further optimize the stock of coal-fired power units. In Zone III, areas rich in renewable resources can be given priority with respect to abandoning coal [17]. Provinces and cities in the central region that are less affected by the phase-down of coal power should strengthen their optimization of the local power supply structure and clarify the system function positioning of different power resources such as power supply and energy storage. The Eastern region should give full play to its existing advantages, vigorously developing new-energy power generation systems to meet the demand for electricity and realizing the transformation of the power supply structure. Regions can optimize cross-regional resource allocation through overcapacity cooperation to promote inter-regional connectivity and coordinated development. The paths of coal power phase-down vary at different time nodes and in different regions, and the aim in this context is to ensure the safe operation of the power system.

4. Conclusions and Policy Implications

4.1. Conclusions and Implications

To scientifically measure and assess the economic and social impacts of regional coal power phase-down, in this study, we established a comprehensive entropy weight TOPSIS evaluation approach considering both coal power and the upstream coal industry. We divided 30 Chinese provinces into three regions according to the impact degree of coal power phase-down based on the estimation results. We provided a targeted analysis of the three regions and outlined the barriers that each type of province may encounter in the energy transition. Comprehensively, most regions have a small impact on coal power phase-down, but regions such as Shanxi (1.411) and Inner Mongolia (1.224) will be negatively affected to a greater extent and deserve further policy interventions. From the perspective of industry, the regional coal power industry has a smaller impact than the coal industry. While the provinces most affected by the coal power industry are Inner Mongolia (0.653) and Shandong (0.537), those most affected by the coal industry are Shanxi (0.963) and Inner Mongolia (0.571). Finally, based on the experimental results and the actual situation in China, we analyzed the economic, social, and industrial impacts that may be brought about by the transition process.

The phase-down of coal power cannot be achieved overnight. At the national level, it is necessary to improve the macro energy policy system and accelerate the pace of low-carbon development. Planners of the long-term high-quality development of coal power should set out a timely roadmap of coal power phase-down, actively implement the national strategy to deal with climate change, and strictly control the scale of coal power in a backward manner based on clear goals. Energy policy should also reflect fairness. Compared with developed countries, developing countries have a larger population and a lower economic level. Extensive energy consumption will have a more obvious effect on energy demand. Neglecting employment justice in the transition process will lead to a series of serious social problems. In addition, international cooperation will also play an important role in establishing a green energy development community.

Regarding local governments, provinces should choose a suitable path of coal phase-down according to their resource endowments and local conditions, promoting the development of the new energy industry and accelerating the construction of an intelligent, clean, and diversified new power system. For provinces with large coal resources whose economic development is heavily dependent on the coal industry, outdated coal power production capacity must be eliminated, and the construction of new coal power plants should be stopped or delayed. Efforts should be made to resolve excess coal power production capacity and high energy consumption to ensure the implementation of coal capacity reduction reforms. The provinces and cities in the central region that are less affected by the phase-down of coal power should strengthen the optimization of their local power supply structure and clarify the system function positions of different power resources such as power supply, load, and energy storage. The developed eastern regions should vigorously develop new-energy power generation systems to meet the electricity demand and realize the transition of the power supply structure. Regions can also optimize cross-regional resource allocation and promote inter-regional connectivity and coordinated development.

Power generation enterprises should seize the technological innovations and industrial opportunities brought by climate change and the carbon targets and increase investment in energy technology to strengthen technology research and conquer new challenges.

4.2. Limitations

There are some limitations of this study. First, when assessing the impact of coal power withdrawal, this paper only considered basic indicators such as added value, employment, tax revenue, etc. But more factors should be taken into account, especially those that reflect the positive benefits, like renewable energy development planning and the pollutant emissions of power plants, because the positive benefits can better reflect the resilience of regions in coping with the low-carbon transition. Second, the impact on residents is also worth considering, although some areas will bear the risk of reducing employment opportunities and shrinking fiscal revenues in the short term, but in the long run, improved air quality can improve human health. This may require more data collection methods, including field research, questionnaires, etc. In addition, considering that the research object was coal power, TOPSIS was applied to carry out the analysis, and only the coal-mining industry was considered because there is not a more unified method of splitting the power sector in an input–output table. In future research, we can consider combining an energy-planning model and a macroeconomic model to study the broader impact—and, at the same time, carry out a longer series of studies—especially the future development trend.

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