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Evaluation of Core Competitiveness of New Energy Industry and Analysis of Obstacle Factors Taking Shandong Province as an Example

Mingming Zhang, Zikun Yang, Ying Lu *, Wenwen Song and Fangting Chen

School of Economics and Management, China University of Petroleum (East China), Qingdao 266580, China; zmmupcem@upc.edu.cn (M.Z.); upcyzk@163.com (Z.Y.); 13012456637@163.com (W.S.); cftgray@163.com (F.C.)
* Correspondence: lysci89@163.com

Abstract: The new energy industry serves as a key driver for green growth, and unlocking its core competitiveness is essential for achieving sustainable development. This study focuses on the new energy industry in Shandong province from 2010 to 2021, constructing an evaluation system for core competitiveness across three dimensions: industrial competitive environment, industrial competitive strength, and industrial competitive potential. Utilizing the entropy weight TOPSIS method and the obstacle degree model, this paper delves into the evolving characteristics and hindering factors affecting the core competitiveness of the new energy industry in Shandong province. The findings reveal the following: (1) over the study period, the core competitiveness of the new energy industry in Shandong province underwent stages of small fluctuations, slow growth, and rapid expansion, indicating an overall upward trajectory. (2) The primary obstacle to improving core competitiveness lies in the industrial competitive environment, particularly highlighted by factors such as the number of industrial service departments, existing policies, the growth rate of investment in the new energy industry, and the number of research and development personnel in large-scale new energy enterprises.

Keywords: high-quality development; Shandong province; new energy industry; core competitiveness; obstacle factors

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1. Introduction

In May 2022, the National Development and Reform Commission and the National Energy Administration issued the "Implementation Program on Promoting the High-Quality Development of New Energy in the New Era". This signifies that China's new energy industry has entered a stage of accelerated growth and enhanced quality. Shandong province, a major hub for energy production and consumption, characterized by a manufacturing and heavy chemical industry structure, faces a challenging emission reduction scenario under the constraints of the "double carbon target". Achieving high-quality development in the new energy industry is pivotal as a breakthrough in the stainable development strategy. In recent years, the new energy sector in Shandong province has witnessed significant advancements. In 2021, the installed capacity of new energy power generation reached 58.49 million kilowatts, marking a year-on-year increase of 28.8% (The data were obtained from the following website: https://gov.sdnews.com.cn/szyw/202203/t20220304_3997061.htm, accessed on 30 November 2023) Although the new energy sector in Shandong province has seen early development and an increasing number of enterprises, there are persistent bottlenecks that need addressing, including a small total industrial scale, weak industry driving force, and a lack of leading enterprises. These challenges significantly impede the high-quality development of new energy in Shandong province. Driven by the imperative for industrial development, evaluating the core competitiveness of the new energy industry and identifying obstacles hindering its improvement hold great theoretical and practical significance. This evaluation can pave the way for the adoption of targeted policy measures, facilitating Shandong province in realizing the goal of "making the new energy industry bigger and stronger".

Sorting the existing literature on industrial competitiveness evaluation models and the construction of industrial core competitiveness indicators, we found that, firstly, the existing literature on industrial competitiveness evaluation models can be categorized into two major categories: qualitative and quantitative. The mainstream model of the qualitative category is Porter's five forces model, while the quantitative category of research methods mainly includes the multiple indicator evaluation method, principal component analysis, deviation share analysis, and entropy weight method [1–4]. González-Rodríguez et al. (2023) [5] utilized the entropy weight method to construct the tourism industry competitiveness index. Secondly, in terms of index selection, Quan [6] proposed that industrial competitiveness is composed of four levels of the industrial environment, productivity, market share, and profitability. Focusing on new energy-related industries, Liu et al. (2022) [7] concluded that production factors, demand conditions, corporate strategy and peer competition, and the government are the main factors affecting the competitiveness of new energy in the automobile industry. He et al. (2023) [8] use the directional distance function and the global Malmquist–Luenberger productivity index to evaluate the green competitiveness of 33 industrial sub-sectors in China from 2002 to 2017 and analyze the influencing factors.

The obstacle degree model is often used to analyze the obstacle factors affecting the development of things, which is mainly applied in the study of agricultural economy, environmental science and resource utilization, economic system reform, and other disciplines [9,10]. Kineber et al. (2016) [11] constructed a barrier degree model to analyze the factors affecting the digital twin and compare the trend in the main barrier factors. You Liu Rongqing and Cui Maoshen (2023) [12] used the barrier degree model to analyze the barrier factors of rural digital economy development. In recent years, scholars have also begun to use the barrier degree model to explore related topics such as green development [10,13]. Chun et al. (2018) [14] used the obstacle degree model to analyze the obstacle factors for the improvement of the green development level of the old industrial base in Northeast China. Adu et al. (2019) [15] mined the key constraints on the sustainable development of China's low-carbon economy. Liu et al. (2022) [16] used the barrier degree model to empirically analyze the impact of green trade barriers on agricultural green total factor productivity.

Reviewing the above literature, there are still two research gaps in the existing research. Firstly, many scholars have carried out relevant studies on industrial competitiveness evaluations, but fewer of them have combined the connotation of regional characteristics, the concept of high-quality development, and the concept of low-carbon development to construct the index system. Secondly, the existing research on the obstacles to low-carbon transformation and new energy development is relatively sparse, and there is an urgent need to explore the obstacles to industrial development and analyze the systematic obstacles to the new energy industry.

In order to bridge the gaps in the above research, firstly, this article constructs an evaluation system for the core competitiveness of the new energy industry in Shandong province, which includes 3 guideline layers and 20 specific indexes. Secondly, the entropy weight TOPSIS model is adopted to measure the index weights of the core competitiveness of the new energy industry in Shandong province and score the core competitiveness of the new energy industry in Shandong province. Finally, the obstacle degree model is used to explore the obstacle factors hindering the core competitiveness of the new energy industry in Shandong province. To this end, the marginal contributions of this paper to the existing research are as follows: firstly, the evaluation system of the core competitiveness of the new energy industry in Shandong province is constructed by combining the characteristics of the new energy industry in Shandong province and considering the connotations of the concept of low-carbon development and the concept of high-quality development. Secondly, the obstacle factors hindering the enhancement of the core competitiveness of the new energy industry in Shandong province are explored by using the obstacle degree model.

The rest of the paper is arranged as follows: Section 2 presents the research design, Section 3 denotes the results analysis, and Section 4 shows the conclusions and policy implications.

2. Research Design

The researchers took the data about the new energy industry in Shandong province during 2010–2021 as the research sample. Firstly, we constructed the evaluation system of the core competitiveness of the new energy industry, which contained 20 specific indexes in three criterion layers. Secondly, we used the entropy weight TOPSIS method to analyze the indexes' weights and the evolution characteristics of the core competitiveness of the new energy industry. Finally, we applied the obstacle degree model to explore the obstacles that hindered the enhancement of core competitiveness of the new energy industry in Shandong province.

2.1. Indicator System Construction

The researchers followed the principles of scientificity, operability, quantifiability, and reflecting regional characteristics to set and screen the indicator system. Based on the connotation of industrial competitiveness theory [6,17,18], low-carbon development theory, and high-quality development theory, this paper construct a core competitiveness evaluation system for the new energy industry in Shandong province which contains a total of 20 specific indexes in the three levels of industrial competitive environment, industrial competitive strength, and industrial competitive potential. The details are shown in Table 1.

Table 1. Evaluation system of core competitiveness of the new energy industry.

Standardized Layer	Element Level	Indicator Layer	Interpretation of Indicators (Units)	Causality
Industrial competitive environment	Policy support efforts	Number of existing policies (×1)	Number of existing policies (pcs)	+
	Infrastructure construction	GDP growth rate (×2)	GDP growth rate (%)	+
		Growth rate of investment in fixed assets (×3)	Growth rate of investment in fixed assets (%)	+
	Related industrial development	Total value of industrial estates (×4)	Total value of industrial estates (billion yuan)	+
Industrial competitive strength	Profitability	Profit income from new energy industry (×5)	Operating income from new energy power generation industry (billion yuan)	+
		Growth rate of value added of new energy industries (×6)	Growth rate of value added of new energy industry (%)	+
	Marketability	Market share (×7)	Proportion of new energy vehicle ownership to total vehicle ownership (%)	+
		Export intensity (×8)	Proportion of new energy vehicle exports to total vehicle exports (%)	+
	Resource transformation capacity	Ratio of installed new energy generation capacity to electricity generation (×9)	Ratio of new energy generation to installed capacity (%)	-
		New energy industry commissioning ratio (×10)	Ratio of revenue to investment in new energy generation industry (%)	+
	Technological innovation capacity	Sales of new products (×11)	Revenue from sales of new products (billion yuan)	+
		Number of new projects developed (×12)	Number of new projects developed (pcs)	+

Table 1. *Cont.*

Standardized Layer	Element Level	Indicator Layer	Interpretation of Indicators (Units)	Causality
Competitive potential of the industry	Innovative resource inputs	Growth rate of investment in new energy industry (×13)	Growth rate of investment in new energy industry (%)	+
		Investment in technology research and development (×14)	Investment in technology R&D by enterprises above designated size (billion yuan)	+
	Human resources conditions	Number of employees in the new energy industry (×15)	Number of employees in new energy enterprises above designated size	+
		Number of technical research and development staff (×16)	Number of technical R&D personnel in new energy enterprises above designated size	+
	Natural resource conditions	Average sunshine hours per year (×17)	Average annual sunshine hours (hours)	+
		Annual wind power utilization hours (×18)	Annual wind power utilisation hours (hours)	+
	Strategy and management resource conditions	Industry value added as a share of GDP (×19)	Value added of industries as a share of GDP (%)	+
		Number of service sectors (×20)	Number of relevant trade associations and industry services	+

Firstly, at the level of the industrial competitive environment, the number of current policies, GDP growth rate, fixed asset investment growth rate, and total value of the industrial industry are selected. At the level of industrial competitive strength, the profit income of the new energy industry, growth rate of the value added of the new energy industry, market share, export intensity, the ratio of new energy power generating capacity to power generation, the ratio of new energy industry put into operation, the income from the sale of new products, and the number of new projects in development are selected. Secondly, at the level of industrial competitiveness, the growth rate of investment in the new energy industry, technical R&D investment of enterprises above scale, the number of employees of new energy enterprises above scale, the number of technical R&D personnel of new energy enterprises above scale, the annual average sunshine hours, the annual utilization hours of wind power, the proportion of industrial added value to GDP, number of related industry associations and industry service departments are considered.

2.2. Research Methodology

Entropy Weight TOPSIS Method

The study utilizes the entropy weight method and TOPSIS method to conduct the analysis. The TOPSIS method is a multidimensional decision-making approach that prioritizes evaluated objects based on their relative proximity to the optimal goal [19]. By employing a blend of the entropy weight method and the TOPSIS method, it is possible to impartially and precisely rank and evaluate the assessed objects in a lucid manner [20,21]. This approach helps in portraying the genuine magnitude of the evaluated objects in a more objective fashion. Firstly, the entropy weight method was adopted to calculate the weights of the indicators, the main principle being that the entropy weight method can overcome subjective bias in the evaluation system [6,22,23]. Secondly, the index data are weighted and then quantitatively ranked with the help of the TOPSIS method to compare the size of the relative distance between the industrial competitiveness and the ideal point.

The specific calculation steps are as follows:

Step 1: Assuming that there is one evaluation object and one evaluation indicator, the original data matrix is as follows:

$$X = \begin{Bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{Bmatrix}$$

where x_{ij} is the initial value of the new energy industry core competitiveness evaluation index in year i, $i = 1, 2, \cdots, m$, $j = 1, \quad 2, \quad \cdots, \quad n$.

For the positive indicators:

$$x'_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{1}$$

For the negative indicators:

$$x'_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \tag{2}$$

Through dimensionless quantization of the matrix, a new matrix $R = (x'_{ij})\ n \times m$ is obtained.

Step 2: Normalize the matrix as follows:

$$y_{ij} = Ax'_{ij} + B \tag{3}$$

where $A + B = 1$. To ensure the validity of the data, take $B = 0.01$, obtaining the normalization matrix $P = (p_{ij})\ n \times m$.

$$p_{ij} = \frac{y_{ij}}{\sum\limits_{i=1}^{m} y_{ij}} \tag{4}$$

Step 3: Calculate the information entropy of each indicator:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij} \tag{5}$$

where $k = \frac{1}{\ln n}$.

Then, the redundancy level, which measures the difference between the indicators, is calculated:

$$d_j = 1 - e_j \tag{6}$$

In addition, the weights w_j for each indicator x_j were calculated from $w_j = \frac{d_j}{\sum\limits_{j=1}^{n} d_j}$.

Step 4: Construct the weighted normalization matrix. Apply the normaliztion matrix to perform a weighted normative decision matrix transformation.

$$Z = w_j \cdot P = \begin{Bmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{Bmatrix} \tag{7}$$

Step 5: The positive ideal solution and negative ideal solution obtained through calculation are:

$$\text{Optimal program}: \ z_j^+ = \left(z_1^+, z_2^+, \cdots z_m^+\right) \tag{8}$$

$$\text{Worst program}: \ z_j^- = \left(z_1^-, z_2^-, \cdots z_m^-\right) \tag{9}$$

Step 6: Calculate the Euclidean distance between the subject of evaluation and the best and worst options for each year.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^+)^2} \quad (10)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^-)^2} \quad (11)$$

Step 7: Calculate the closeness of the evaluation object to the optimal solution for each year C_i.

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (12)$$

The larger the value of Equation (12), the closer the score of the year is to the optimal value, indicating that the core competitiveness level of the new energy industry of the evaluation object is higher.

Barrier Degree Evaluation Model

By introducing the obstacle degree model, we can measure the obstacle degree of each criterion layer indicator to the overall level of core competitiveness of the new energy industry in Shandong province, as well as the obstacle degree of the criterion layer indicator to the overall level of core competitiveness of the new energy industry in Shandong province. The specific calculation formulae are as follows:

$$F_i = w_i \quad (13)$$

$$U_{ij} = 1 - x'_{ij} \quad (14)$$

$$M_{ij} = \frac{(F_i \times U_{ij})}{\sum_{i=1}^{m} (F_i \times U_{ij})} \times 100\% \quad (15)$$

$$Z_i = \sum_{j=1}^{n} M_{ij} \quad (16)$$

Among them, the factor contribution F_i indicates the degree of contribution of a single indicator i within the guideline layer to the core competitiveness level of the new energy industry in Shandong Province, i.e., the weight of the single indicator i in the guideline layer is w_i. The indicator deviation U_{ij} is the difference between the actual value of the indicator and the optimal target value. M_{ij} and Z_i are the degree of impediment to the core competitiveness level of the new energy industry at the level of the single indicator and the guideline, respectively.

2.3. Data Sources

Based on new energy industry-related data collected manually for the period of 2010–2021 in Shandong Province, this paper measures the core competitiveness of the new energy industry in Shandong Province and analyzes the obstacle factors. The data are obtained from «Shandong Provincial ≥ Government Portal», «Shandong Provincial Energy Bureau Portal», «Shandong Provincial Statistical Yearbook», «Shandong Provincial National Economic and Social Development Statistical Bulletin», «China Electricity Statistical Yearbook», «China Science and Technology Statistical Yearbook», «China Industrial Statistical Yearbook», and «Shandong Provincial National Economy and Social Development Statistical Bulletin». Some missing values are calculated through linear interpolation.

3. Results Analysis

3.1. Weighting Analysis of Core Competitiveness Indicators

Table 2 shows the weight coefficients of the core competitiveness evaluation system of the new energy industry in Shandong province.

Table 2. Evaluation index system and weights.

Normative Layer	Factor Layer	Indicator Layer	Weights
Industrial competitive environment (0.321)	Strength of policy support (0.103)	Number of existing policies	0.103
	Infrastructure construction (0.145)	GDP growth rate	0.072
		Growth rate of fixed asset investment	0.073
	Development of related industries (0.073)	Total value of industrial estates	0.073
Industrial competitive strength (0.301)	Profitability (0.074)	New energy industry revenue	0.029
		Growth rate of value added of new energy industry	0.045
	Marketable capacity (0.094)	Market share	0.049
		Export Intensity	0.045
	Capacity for resource transformation (0.075)	Ratio of installed new energy generation capacity to electricity generation	0.028
		New energy industry commissioning ratio	0.047
	Technological innovation capability (0.058)	New product sales	0.031
		Number of new projects developed	0.027
Industry competitive potential (0.378)	Resource inputs for innovation (0.077)	Growth rate of investment in new energy industry	0.046
		Investment in technology research and development	0.031
	Human resource conditions (0.086)	Number of employees in the new energy industry	0.037
		Number of technical research and development staff	0.049
	Natural resource conditions (0.073)	Average annual sunshine hours	0.029
		Annual wind power utilisation hours	0.044
	Strategy and management resource conditions (0.142)	Value added of industries as a share of GDP	0.036
		Number of related services	0.106

Firstly, at the criterion level, the weight coefficient of industrial competitive potential is the highest, indicating that this criterion level has the greatest influence on competitiveness. At the factor level, the top three weight coefficients are infrastructure construction, strategic and management resource conditions, and policy support. These three most important factors come mainly from the criterion layer of the industrial competitive environment.

Secondly, at the indicator layer level, the number of related service sectors has the highest weight coefficient, and the number of existing policies has the second highest weight coefficient, indicating that the number of existing policies has the second strongest impact on the core competitiveness of new energy industry development after the number of related service sectors. This is consistent with Li Suxiu et al. (2016) [24], who found that an increase in the number of industrial policies has a positive impact on the development of China's new energy automobile industry and that the promulgation of relevant policy documents supporting the development of the new energy industry can provide new energy enterprises with the resources they need, create an environment for industrial development, and promote industrial development.

Thirdly, the lowest weighting coefficients of the indicators such as the number of new projects developed, the ratio of installed new energy power generation capacity to power generation, the revenue of the new energy industry, and the average number of hours of sunshine in a year indicate that these indicators have the least impact on competitiveness.

3.2. Shandong New Energy Industry Core Competitiveness Evaluation Results

3.2.1. Overall New Energy Industry Core Competitiveness Level

The entropy weight TOPSIS method is used to comprehensively evaluate the core competitiveness of the new energy industry in Shandong province from 2010 to 2021, and the results are shown in Table 3. The average value of the comprehensive score of core competitiveness of the new energy industry in Shandong province from 2010 to 2021 is 0.436, and it reaches the highest value of 0.722 in 2021. It reaches the minimum value of 0.333 in 2011, with a standard deviation of 0.117. The level of core competitiveness of the new energy industry in Shandong province in 2010–2021 shows an overall upward trend, with an increase of 92.021 percent; a rapid growth rate indicating that the core competitiveness of the new energy industry in Shandong province has been improving year-by-year, showing significant development.

Table 3. Evaluation results.

Year	Positive Ideal Solution Distance D^+	Negative Ideal Solution Distance D^-	Relative ProximityC
2010	3.758	2.268	0.376
2011	3.772	1.885	0.333
2012	3.411	1.841	0.351
2013	3.222	1.813	0.360
2014	3.273	1.735	0.346
2015	3.278	1.683	0.339
2016	3.041	1.888	0.383
2017	2.910	2.135	0.423
2018	2.532	2.446	0.491
2019	2.511	2.599	0.509
2020	2.090	3.112	0.598
2021	1.520	3.950	0.722

During this period, the core competitiveness of the new energy industry in Shandong Province can be divided into three phases (shown in Figure 1, where the dotted line is the trend line): the fluctuation period, the slow-growth period, and the rapid-growth period.

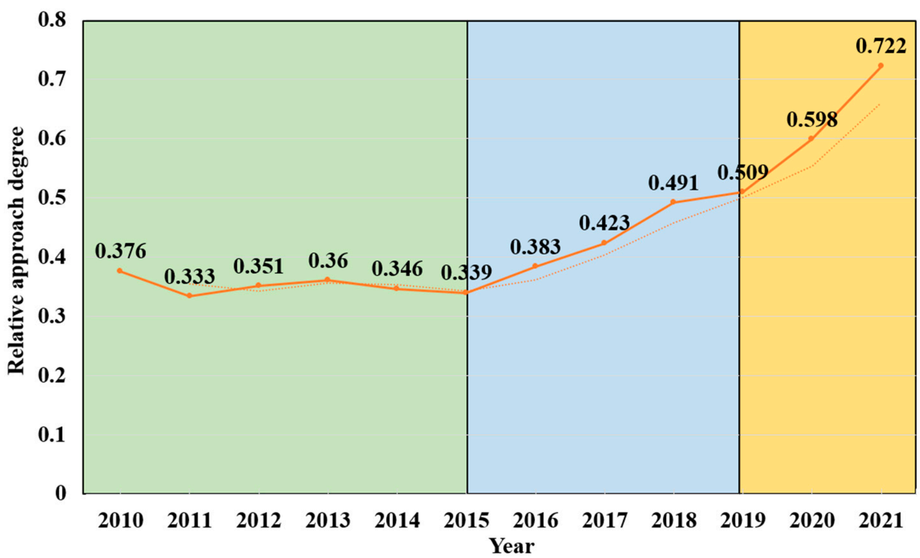

Figure 1. Core competitiveness score.

Firstly, 2010–2015 is the fluctuation period, and the comprehensive score shows a small fluctuation trend. During this period, the new energy industry in Shandong province was in the budding stage, and the new energy industry had not received enough attention. The industrial chain was not sound, and the competitiveness of the industry was weak. According to the policies related to the new energy industry issued by the Shandong government portal, most of the development plans related to the photovoltaic industry and the green low-carbon industry were issued in 2013–2014. At the same time, the number of employees and technicians in the new energy industry only began to show a significant growth trend in 2013–2014. Considering the lagging effect of policies, this became a key factor for Shandong province's core competitiveness in the new energy industry to enter the initial exploration stage from the budding stage in 2015.

Secondly, the period of 2015–2019 was a period of slow growth, and the comprehensive score kept improving, showing a small upward trend. At this stage, Shandong province's new energy industry entered the preliminary exploration stage, and with the investment and construction of photovoltaic and wind power industries and the continuous improvement of the upstream and downstream industrial chain, the core competitiveness of the new energy industry began to steadily improve year-by-year.

Finally, 2019–2021 was the period of rapid growth, and the comprehensive score rose sharply by 41.847%. On the one hand, Shandong province enacted more than ten new energy industry-related policies in 2020–2021, covering renewable energy power generation, energy storage, hydrogen energy, new energy vehicles, and other segments of the new energy industry. On the other hand, the growth of new energy vehicle ownership and export volume, new product development, new product sales revenue, and other indicators contributed to the booming development of the new energy industry.

3.2.2. Level of Core Competitiveness of the New Energy Industry at Each Guideline Level

Overall, the system scores of the three criteria layers all show an upward trend (as shown in Figure 2), with the system score of industrial competitive strength ranking the first with an average annual growth rate of 5.172 percent, followed by the system of industrial competitive potential at 3.645 percent and the system of the industrial competitive environment at 2.954 percent. There are some differences in the scores of the systems at each criterion level.

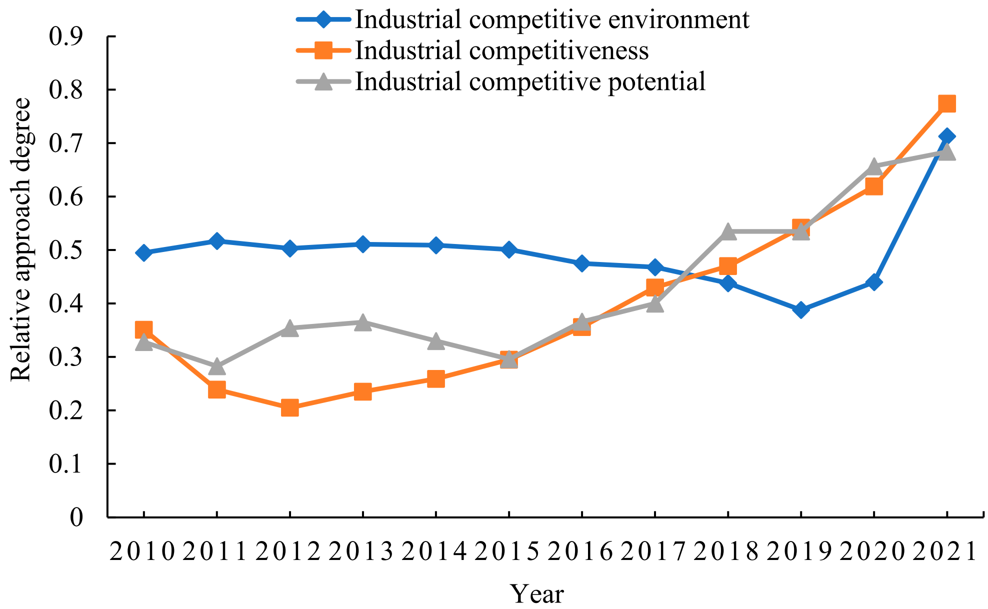

Figure 2. Guideline scores of the new energy industry in Shandong province.

Firstly, the industrial competitive environment system score shows a small fluctuation and then a downward trend. The score of the industrial crystal high environment system in Shandong province showed a gradual decline from 2010 to 2019 and showed a sharp upward trend after reaching its lowest value in 2019, indicating that the industrial competitive environment system achieved a turnaround in 2019. The main reason is that the relevant policies of the new energy industry in Shandong province were first promulgated in 2013, and since then, it showed a yearly growth trend. The number of new energy industry policies in Shandong province in 2019–2021 has increased significantly under the leadership of the national green development and the "double carbon" goal [25]. The strong support of policies has led the new energy industry in Shandong province to gradually improve its competitive mechanism. Under the guidance of strong policy support, the competition mechanism of the new energy industry in Shandong province is gradually improved and the support policy for industrial development is gradually improved, which makes the score of Shandong province's industrial competitive environment system show a significant growth trend after 2019 [26].

Secondly, the industrial competitive strength system score shows an inverted U-shaped trend. It reaches a minimum value of 0.205 in 2012 and a maximum value of 0.774 in 2021, with an increase rate of 6.322% per year. The main reason for this trend is as follows: since 2011, in Shandong province, the amount of new energy project development that the power generation industry put into operation and new product sales revenue increased significantly, coupled with the new energy installed capacity and power generation ratio of the gradual reduction in the new energy installed capacity. Therefore, Shandong province invested in the completion of its new energy power generation installed capacity to continually improve the utilization of efficiency.

Thirdly, the system score of industrial competitive potential shows a fluctuating trend. The growth rate of investment in the new energy industry in Shandong province reached the inflection point in 2011 and 2015, which is consistent with the trend in the industry competitive potential system score, indicating the profound impact of new investment in the new energy industry on the industry's competitive potential.

3.3. Analysis of Factors Constraining the Enhancement of the Core Competitiveness of the New Energy Industry in Shandong Province

3.3.1. Degree of Impairment of Individual Indicators

In order to effectively analyze the obstacle factors restricting the enhancement of the core competitiveness of the new energy industry in Shandong province, we firstly apply the obstacle degree model to analyze the obstacle degree of single indicators of the core competitiveness of the new energy industry in Shandong province. The results are shown in Table 4. According to the influence size of the obstacle factors, this paper presents the top five factors in order of the obstacle degree of the indicator layer in 2010–2021.

Firstly, the obstacle factors hindering the enhancement of the core competitiveness of the energy industry in 2010–2014 mainly include the number of related service departments, the number of existing policies, the total value of the industrial industry, the ratio of new energy automobile ownership to the total automobile ownership, and the new energy enterprises above the large-scale number of technical R&D personnel. This result is similar to refs. [8,27]. It can be seen that the industrial competitive potential and the industrial competitive environment are important obstacles to the improvement of the core competitiveness of the new energy industry in Shandong province.

Secondly, since 2015, the growth rate of investment in the new energy industry has become one of the important obstacles to the improvement of the core competitiveness of the energy industry. This result is consistent with ref. [19], indicating that the investment in the new energy industry began to become an important obstacle factor hindering the improvement of the core competitiveness of the new energy industry.

Table 4. Ranking of major obstacles.

Year	Categories	Ranking of Indicators				
		1	**2**	**3**	**4**	**5**
2010	Obstacles factor	×20	×1	×4	×7	×16
	Degree of obstruction/%	14.805	14.414	10.193	6.821	6.821
2011	Obstacles factor	×20	×1	×4	×7	×16
	Degree of obstruction/%	14.340	13.961	8.472	6.607	6.607
2012	Obstacles factor	×20	×1	×4	×7	×16
	Degree of obstruction/%	14.972	14.576	7.945	6.898	6.683
2013	Obstacles factor	×20	×1	×4	×7	×16
	Degree of obstruction/%	15.362	13.805	7.235	7.077	6.806
2014	Obstacles factor	×20	×1	×7	×4	×16
	Degree of obstruction/%	15.108	11.880	6.961	6.461	6.425
2015	Obstacles factor	×20	×1	×7	×13	×16
	Degree of obstruction/%	15.040	11.264	6.876	6.553	6.394
2016	Obstacles factor	×20	×1	×16	×6	×7
	Degree of obstruction/%	15.949	11.945	6.424	6.342	6.076
2017	Obstacles factor	×20	×1	×18	×16	×13
	Degree of obstruction/%	16.801	12.582	6.994	6.395	6.370
2018	Obstacles factor	×1	×6	×2	×3	×16
	Degree of obstruction/%	14.511	9.080	8.978	8.816	7.009
2019	Obstacles factor	×3	×2	×1	×6	×18
	Degree of obstruction/%	15.184	11.287	10.736	9.408	7.821
2020	Obstacles factor	×2	×3	×18	×1	×8
	Degree of obstruction/%	18.995	11.899	11.284	10.423	6.821
2021	Obstacles factor	×13	×3	×2	×9	×17
	Degree of obstruction/%	29.211	26.667	15.675	13.787	11.250

Thirdly, the ratio of new energy power generation to the installed capacity and the average annual sunshine hours in 2021 became obstacle factors to the improvement of the core competitiveness of the new energy industry. This indicates that investment effectiveness and regional resource characteristics began to become important factors hindering the improvement of the core competitiveness of the new energy industry in Shandong province.

3.3.2. Degree of Obstacles at Each Guideline Level

Based on the results of calculating the obstacle degree of individual indicators, the obstacle degree of each criterion layer is further calculated (Figure 3a). The obstacle degree of industrial competitive potential is the largest in 2010–2017, followed by industrial competitive strength and the industrial competitive environment. After 2017, the obstacle degree of the industrial competitive environment rises sharply and becomes the criterion layer with the largest obstacle degree in 2021. The obstacle degree of industrial competitive potential fluctuates greatly and becomes the criterion layer with the second-largest obstacle degree in 2021, becoming the second guideline layer of obstacle degree. The obstacle degree of industrial competitive strength fluctuates slightly and shows a decreasing trend in general. It can be seen that in order to improve the core competitiveness of the new energy industry in Shandong province, it is necessary to start from the industrial competitive environment and industrial competitive potential.

As shown in Figure 3b, in the guideline layer of the industrial competitive environment, the obstacle degree of infrastructure construction increases at an average annual rate of 3.8% and becomes the element layer with the largest obstacle degree in 2018. It can be seen that as far as the industrial competitive environment is concerned, improving the core competitiveness of the new energy industry in Shandong province must start from infrastructure construction.

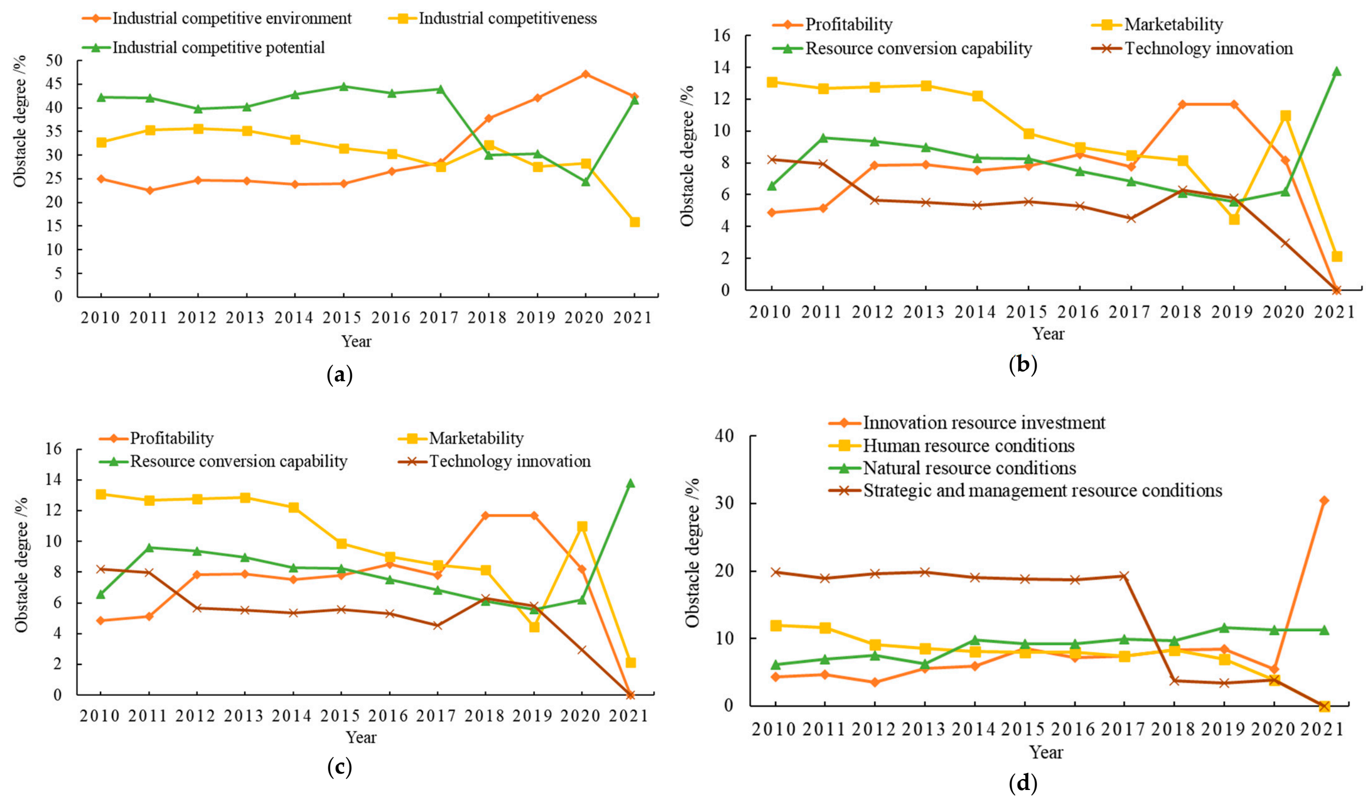

Figure 3. Trend chart of obstacle degree changes of each criterion layer of core competitiveness.

As shown in Figure 3c, in the industrial competitive strength criterion layer, the marketisation capacity has the largest obstacle degree in 2010–2017. In 2021, the resource transformation capacity becomes the factor layer with the largest obstacle degree. Therefore, in the aspect of industrial competitive strength, improving the core competitiveness of the new energy industry in Shandong province must start from the marketization ability and resource transformation ability.

At the level of industrial competitive potential (as shown in Figure 3d), the strategy and management resource conditions were the factor layer with the largest obstacle degree from 2010 to 2017. However, in 2018, the barrier degree of strategic and managerial resource conditions fell sharply by 15.608 percent. From 2018 to 2020, natural resource conditions became the most obstructive factor layer. In 2021, the obstacle of innovative resource inputs increased significantly by 25.022 percent, making it the most obstructive factor layer.

4. Conclusions and Policy Implications

Based on the data on the new energy industry in Shandong province from 2010 to 2021, this paper constructs a new energy industry core competitiveness evaluation system containing 20 specific indicators in three guideline layers and uses the entropy weight TOPSIS method to analyze the indicator weights and the evolution characteristics of the core competitiveness of the new energy industry. Then, it adopts the obstacle degree model to explore the obstacles impeding the enhancement of the core competitiveness of the new energy industry in Shandong province. The results show the following:

(1) The core competitiveness of the new energy industry in Shandong province experienced three stages of small fluctuation–slow growth–rapid growth from 2010 to 2021 and generally showed a steady increase. (2) The scores of each criterion layer show an upward trend during the study period, but the increase is slightly different. The industrial competitive strength system has the largest increase, and the industrial competitive environment system has the smallest increase. (3) In terms of the barrier degree of each

indicator, the most significant barrier factor in the study period experienced an evolution from the number of current policies in the relevant industrial service sector → fixed asset investment growth rate → GDP growth rate → growth rate of the investment amount in the new energy industry. The main obstacle factors affecting the core competitiveness of the new energy industry in Shandong province include the number of industrial service sectors, the number of existing policies, the growth rate of investment in the new energy industry, and the number of technical research and development personnel in new energy enterprises above scale. (4) In terms of the degree of obstacles at each criterion level, the industrial competitive environment was the primary factor affecting the enhancement of the core competitiveness of the new energy industry during the study period, followed by the industrial competitive potential system and the industrial competitive strength system. In addition, the obstacle degree of infrastructure construction in the industrial competitive environment system increased at an annual average rate of 3.8%. This shows that, in the future, more attention should be paid to the influence of infrastructure construction on the improvement of core competitiveness of the new energy industry in the system of the industrial competitive environment.

Based on the above conclusions, this paper puts forward the following policy recommendations: First there should be improvements in the government's guiding force, increased industrial policy, and guaranteed sustainable optimization of the new energy industry structure. Additionally, each new energy industry should introduce a more operable and direct policy package to the micro body. Secondly, the government should set up more industrial service departments, strengthen the construction of the energy regulatory system, and promote the sound upgrading of the new energy industry structure. Third, the government should create a favorable environment for industrial competition and cultivate and grow leading backbone enterprises. Additionally, a number of domestic leading, international first-class, and well-known enterprises and brands should be formed to vigorously enhance the level of development of the new energy industry and promote the quality and efficient development of the new energy industry. Fourth, a focus should be placed on science and technology innovation in the new energy industry. There is clearly a need to focus on supporting new energy innovation areas, establishing major technology and equipment research, and developing scientific and technological innovation for major projects. Additionally, financial support is needed to further establish new energy areas of a high-level, to recruit highly skilled personnel to introduce green channels, and to vigorously introduce the top or leading talent to the innovation team. Fifth, there should be a focus on new investment into the new energy industry. A number of high-growth and high-quality new energy enterprises should be selected for financial support from the government's financial investment to encourage and guide the community to invest in new energy industry innovation activities in order to ensure that the new energy industry receives stronger financial support for its stability and continuity.

Like other studies, this study also has some limitations. This study conducts a small regional analysis due to the limits of the data. Additionally, due to the limitation of the data length, we are unable to conduct a causal analysis on this issue. Therefore, in the future, we will conduct a more comprehensive econometric analysis on the core competitiveness of the new energy industry. Future improvements in the data will be beneficial for improving this issue.

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