Research on Input-Output Efficiency of Listed Companies of Solar-Thermal Power Concept Based on DEA-BCC Model

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Abstract. This paper uses DEA-BCC model to construct a system of input-output indicators to measure the input-output efficiency of China's listed companies of solar-thermal power generation concept using panel data of 24 listed companies of solar-thermal power generation concept in China from 2017–2021 as research samples. The results indicate that the overall level of input-output efficiency of listed companies in the solar-thermal power concept is not high. From the perspective of pay for scale, the number of companies with constant pay for scale shows a "V-shaped" fluctuation, but the change is relatively flat; the number of companies with increasing pay for scale and decreasing pay for scale shows a large fluctuation in 2019. In terms of economic regions, the technical efficiency and pure technical efficiency are higher in the eastern and central regions compared to the western region; while in terms of scale efficiency, there is not much difference among economic regions. Therefore, in order to better improve the input-output efficiency of the listed solar-thermal power company, the company needs to strengthen resource allocation, improve resource utilization, and adjust the scale of the enterprise to further improve the technology research and development capability to achieve technological progress.

Keywords: solar-thermal power · DEA model · input-output efficiency

1 Introduction

With global climate change and frequent natural disasters, environmental pollution and energy use issues have become key factors limiting the world's economic development. This calls for an urgent need to develop alternative energy sources. Internationally, solar-thermal power is seen as an important technological pathway and as the main energy source of the future. According to the projection of the European Energy Center, solar-thermal power will account for 20%–30% of the energy composition in 2050, while by 2100, this proportion will reach 60%–70%. The solar-thermal power industry started earlier abroad, and has conducted more than 50 years of research in materials,

J. Yen et al. (Eds.): ICBIS 2023, AHCS 14, pp. 660–668, 2023.
https://doi.org/10.2991/978-94-6463-198-2_68

design, process and theory of solar thermal-power generation, and has been commercially applied, with a cumulative global installed capacity of 6.69 million kilowatts in 2020. China's solar thermal power generation started late, but since the 13th Five-Year Plan, technology and industry have been developing rapidly, and there are cost advantages compared with foreign countries. The first demonstration projects have enabled China's solar-thermal technology and products to have actual operating projects and experience, and a more complete industrial chain has been initially established, and some products are now exported abroad.

Solar-thermal power generation is a capital and technology-intensive industry with high industry threshold. State-owned enterprises will become the main promoters and dominators in the field of solar-thermal power generation due to their strong financial strength. Crun's core products are used in the field of solar-thermal power generation, and it has completed the research and development of the demonstration project of "50 MW tower-type solar-thermal power generation fixed sun mirror hydraulic drive system" in China. Zhenjiang Co., Ltd. belongs to the leading solar thermal support, with rich project experience, and has participated in the 700 MW solar thermal project of Dubai Muhammud Solar Park built by Shanghai Electric so far in 2018, which is the largest solar thermal project in the world. Lanpec Technologies is focusing on building a perfect molten salt thermal storage system for solar-thermal power generation, and in 2019, out of the country, Shanghai Lanbin undertook the implementation of 11 molten salt storage tanks in the world's largest solar-thermal power generation project – 700 MW solar thermal project in Dubai, UAE. It can be seen that more and more companies are actively involved in the industry chain related to solar-thermal power generation in order to enhance their strength and competitiveness, and these companies are also classified as "solar-thermal power generation concept stocks" by the market. In the context of the rapid development of the solar-thermal power industry, further consideration should be given to the efficiency of the company's inputs and outputs, such as whether the allocation of resources is reasonable, whether the scale of the enterprise is appropriate, whether the investment in technological research and development is sufficient and whether the technology achieves progress. In response to such problems, scholars at home and abroad have conducted research from various perspectives, and scientific and reasonable assessment of enterprise efficiency is one of the research hotspots in recent years.

Charnes and Cooper (1978) used DEA to evaluate firm performance. Since then Cooper (2004) and others have analyzed the use of DEA data analysis in different countries and found that the method is highly applicable and accurate [1]. Fu Xiumei et al. evaluated the input-output efficiency of China's marine biomedical industry through DEA model and found that the overall efficiency of the industry was low and the industry efficiency was in the rising stage on the whole [2]. Wu Yiding (2015) conducted a study on the operating performance of front-end enterprises and back-end enterprises in the industrial chain of listed companies in the rare earth industry based on DEA, and found that the operating efficiency of front-end rare earth enterprises is higher than that of back-end rare earth enterprises [3]. Therefore, in order to deeply study whether the input and output of listed companies labeled "CSP(Concept of Solar-thermal Power)" are in an ideal state and whether the efficiency can be optimized, this paper selects 24 listed companies of CSP stocks in my country as the research object, constructs a DEA model, and conducts research on the input-output efficiency of listed companies of CSP.

2 DEA-BCC Model and Data

2.1 Research Methods and Index System

Data packet analysis (Data Envelopment Analysis, DEA for short) [4]. It was put forward by the famous American operations researcher Charnes et al. in the 1970s. At present, it has become one of the most widely used methods in the evaluation of the operating efficiency of listed companies.

2.1.1 DEA-BCC Model

The DEA method is a non-parametric method for evaluating the relative validity of decision units (DMUs) with multiple input and multiple output relationships. Among the DEA methods, CCR model and BCC model are the most representative. Among them, the CCR model assumes that the return to scale is constant (VRS), and mainly measures the technical efficiency (TE) of the decision-making unit; the BCC model assumes that the return to scale is variable (CRS), and decomposes the technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE).), the technical efficiency is the product of the two, that is, TE = PTE * SE. Since it is difficult to realize the constant return to scale in actual production, and the BCC model is more general, this paper uses the BCC model to measure the input-output efficiency of each listed company from a static perspective.

Assuming that the efficiency of k DMU decision-making units is calculated, each $DMU_j(j = 1, 2, \cdots, k)$ consumes $x_{ij}(i = 1, 2, \cdots, m)$ inputs to obtain n outputs $y_{rj}(r = 1, 2, \cdots, n)$, v_i is the weight of the i-th type of input and u_r is the weight of the r-th type of output, then the efficiency value of each DMU_j is:

$$h_j = \frac{\sum_{r=1}^{n} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}, j = 1, 2, \cdots, k \tag{1}$$

And meet the constraints:

$$h_j \leq 1, j = 1, 2, \cdots, k \tag{2}$$

Precisely, larger h_j indicates that DMU_j relatively more output can be obtained with relatively few inputs. Therefore, it can be checked DMU_j whether it is the optimal scale by examining the h_j maximum value when u and v are changed as much as possible.

The specific model of the DEA-BCC model is as follows:

$$\begin{cases} \min \theta \\ s.t. \sum_{j=1}^{k} \lambda_j x_{ij} + s^+ = \theta x_{id}, i = 1, 2, \cdots, m \\ \sum_{j=1}^{k} \lambda_j y_{rj} - s^- = y_{rd}, r = 1, 2, \cdots, n \\ \sum_{j=1}^{k} \lambda_j = 1, j = 1, 2, \cdots k \end{cases} \tag{3}$$

θ No constraints, $s^+ \geq 0$, $s^- \geq 0$.

In the above equation,θ denotes the efficiency value of the decision unit DMU_j, λ_j denotes the weight coefficient of the decision unit DMU_j, x_{ij} is the input variable,y_{rj} is the output variable, s^+ and s^- denotes the input slack variable and output slack variable.

The efficiency of each decision unit can be evaluated based on the results of the model calculations.

If $\theta = 1$, and $s^+ = s^- = 0$, then it indicates that the decision unit is fully effective and both inputs and outputs are at optimal scale; if $\theta = 1$, and $s^+ \neq 0$ or $s^- \neq 0$, then the decision unit is weakly effective and can also optimize the efficiency of inputs or outputs; if $\theta < 1$, then it indicates that the decision unit is not effective.

2.1.2 Evaluation Index System

Reference to previous literature on input-output efficiency studies of listed companies [5, 6], the input-output evaluation index system constructed in this paper is shown in Table 1, including 2 input indicators and 3 output indicators.

The indicators are explained below.

a. Input indicators: including total assets and cost of main business at the beginning of the period. Total assets at the beginning of the period reflect the production scale of the enterprise, which is the material base of the enterprise and the most direct response to the intensity of the enterprise's input. The cost of main business is the direct cost that

Table 1. Evaluation index system based on DEA model

Tier 1 Indicators	Secondary indicators	Units
Input Indicators	Total assets (x_1)	CNY
	Cost of goods sold (x_2)	CNY
Output Indicators	Main business income (y_1)	CNY
	Net profit margin (y_2)	%
	Return on equity (y_3)	%

must be invested by an enterprise to produce and sell products or services related to its main business, mainly including raw materials, labor costs (wages) and depreciation of fixed assets.

b. Output indicators: including 3 indicators of revenue from main business, net profit and return on net assets. Revenue from main business refers to the revenue obtained through the main business activities of an enterprise, including revenue obtained from main business such as selling goods and providing labor services. Net profit margin is the percentage of net profit from operations to the main business income, or to the amount of invested capital, and this percentage can reflect the business efficiency of an enterprise or an industry. The return on net assets reflects the profitability of the capital invested by the owners of the enterprise and indicates the efficiency of various financial and its management activities such as financing, investment and asset operation.

2.2 Data Source and Description

In this paper, the listed companies belonging to the concept of solar-thermal power generation on the Tongdaxin client are used as the initial sample, and those listed for less than five years are removed through screening to finally obtain 24 listed companies with normal operation and complete data disclosure from 2017–2021, which are the 24 decision making units (DMUs) of the evaluation model. The data used in this paper are all from the annual reports of listed companies and the Guotai'an database. In addition, since the data of individual indicators that measure input-output efficiency have negative values, and the DEA model requires that the software input value cannot be negative, we can add a large enough value to this indicator to ensure that each indicator is positive., such an adjustment will not change the final measurement result and will not affect the analysis of the result.

3 Empirical Analysis

In this paper, Deap 2.1 software is used to analyze the relevant data of decision-making units, and according to the evaluation index system and the DEA-BCC model with variable returns to scale, the technical efficiency (TE), pure technical efficiency (PTE) and Scale technical efficiency (SE) of 24 decision-making units from 2017 to 2021 are calculated. The results are shown in Table 2. According to the characteristics of the econometric model, when the efficiency value is 1, the decision-making unit DEA is said to be effective. It can be seen from the results that among the 24 listed companies with the concept of solar-thermal power generation, only 3 companies reached the DEA effective in 2020, and the remaining companies that reached the DEA effective in the remaining four years were more than 15%. The results show that the input-output efficiency of listed companies with the concept of solar-thermal power generation The overall level is not high. From the perspective of pay for scale, the number of companies with constant pay for scale shows a "V-shaped" fluctuation, but the change is relatively flat; the number of companies with increasing pay for scale and decreasing pay for scale shows a large fluctuation in 2019. Based on this, the company in the decreasing state should reduce the number of input factors to improve the output, and the company in the increasing state

Table 2. Overall Results of Input-Output Efficiency of Listed CSP Companies, 2017–2021

Year	TE	PTE	SE	returns to scale						Percentage of DEA active companies
				Increasing (irs)		Unchanged (-)		Decreasing (drs)		
				Number	Proportion	Number	Proportion	Number	Proportion	
2017	0.849	0.899	0.939	7	29.2%	7	29.2%	10	41.6%	29.2%
2018	0.778	0.883	0.873	11	45.8%	4	16.7%	9	37.5%	16.7%
2019	0.773	0.900	0.859	1	4.2%	4	16.7%	19	79.1%	16.7%
2020	0.787	0.921	0.853	2	8.3%	3	12.5%	19	79.2%	12.5%
2021	0.785	0.937	0.838	3	12.5%	5	20.8%	16	66.7%	20.8%

needs to increase the input to achieve the increase of the output. According to the overall trend analysis of returns to scale, listed companies with the concept of solar-thermal power should avoid blindly expanding their business scale, further rationally allocate resources, and achieve the optimal state of scale benefits. In addition, this paper will further compare and analyze the specific calculation results from two aspects: regional division and time variation.

3.1 Comparative Analysis from a Regional Perspective

The technical efficiency, pure technical efficiency and scale efficiency values of enterprises in different provinces and regions are shown in Table 3. According to the analysis in Table 3, the average technical efficiency of the 24 listed companies with the concept of solar-thermal power is 0.794, and the average values of pure technical efficiency and scale efficiency are 0.908 and 0.872 respectively, and the whole is above the medium level. Further analysis from the perspective of regions and provinces shows that each efficiency value presents certain differences. From the perspective of the three major economic regions, compared with the western region, the eastern region and the central region have higher technical efficiency and pure technical efficiency; while in terms of scale efficiency, the three major economic regions are not much different. It can be seen that although technical efficiency is comprehensively affected by pure technical efficiency and scale efficiency, the influence degree of pure technical efficiency is greater than that of scale efficiency. In addition, in areas with a higher level of economic development, the technical efficiency level of enterprises is easier to improve and achieve the optimal state. From the perspective of specific provinces, only one listed company in Guangdong has reached the effective status of DEA (that is, TE, PTE, and SE have all reached 1).

3.2 Analysis from Time Change Trend

From the time change trend (see Fig. 1), it can be seen that the technical efficiency of most CSP listed companies is in a fluctuating state, and only one company (Maxonic Automation Control) has maintained the optimal technical efficiency for five consecutive years. Further analysis, the technical efficiency values of listed companies including

Table 3. Decomposition of Average Input-Output Efficiency of Listed CSP Companies, 2017–2021

Region	Province/City	Listed company	TE	PTE	SE
East	Shanghai	Shanghai Electric	0.567	0.871	0.651
	Tianjin	Sinoma Energy Conservation	0.815	0.915	0.891
	Zhejiang	Xizi Clean Energy	0.790	0.957	0.825
	Jiangsu	Zhenjiang Co., Ltd.	0.777	0.918	0.846
		Shuangliang Eco-energy	0.879	0.982	0.895
		Baose Co., Ltd.	0.791	0.848	0.933
		THVOW Technology	0.530	0.789	0.672
		Wujin Stainless Steel Pipe	0.893	0.968	0.923
		Jin Tong Ling	0.703	0.852	0.825
		Changbao Co., Ltd.	0.752	0.831	0.905
		Aerosun	0.842	0.924	0.911
	Shandong	Sunway Chemical	0.873	0.935	0.934
		Liancheng Precision	0.857	0.910	0.942
	Guangdong	Maxonic Automation Control	1.000	1.000	1.000
	Anhui	East China Science and Technology	0.769	0.862	0.892
		Sinomach General	0.907	0.960	0.945
	Average		0.797	0.908	0.874
Middle	Henan	Ancai Hi-tech	0.878	0.977	0.899
		Luoyang Glass	0.733	0.929	0.789
	Average		0.806	0.953	0.844
West	Shaanxi	Baoguang Co., Ltd.	0.912	0.995	0.917
	Sichuan	Crun Co., Ltd.	0.749	0.81	0.925
		Dongfang Electric	0.715	0.925	0.773
	Gansu	Shouhang High-Tech	0.910	0.929	0.980
		Lanpec Technologies	0.733	0.843	0.870
		LS Heavy Equipment	0.683	0.863	0.792
	Average		0.784	0.894	0.876
Overall Mean Value			0.794	0.908	0.872

THVOW Technology, Shanghai Electric, Changbao Co., Ltd. fluctuated in the low-level range for five consecutive years, and the technical efficiency value was low. In addition, there are some companies with obvious fluctuations, such as Baoguang Co., Ltd., the technical efficiency was 0.753 in 2018, and increased to 1 in 2019, and maintained the optimal efficiency level for three consecutive years; Shuangliang Eco-energy was in a

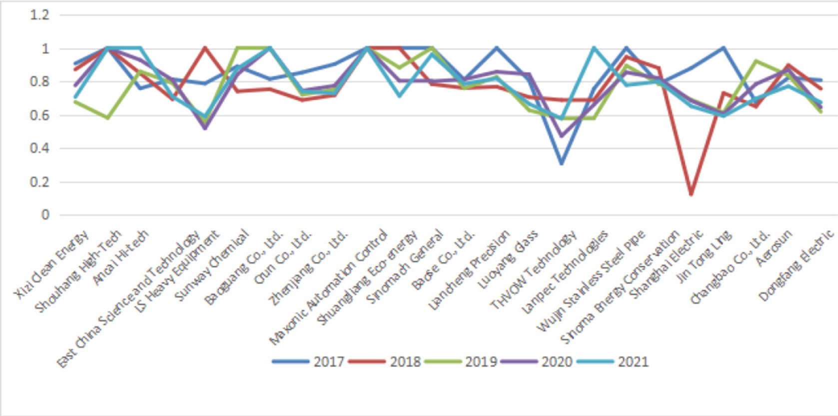

Fig. 1. Trend of Technical Efficiency Changes of Listed CSP Companies from 2017 to 2021

state of decline, and the technical efficiency value from 2017 to 2018 was 1, but it began to show a continuous downward trend from 2019. By 2021, the technical efficiency will drop to 0.712.

On the whole, the technical efficiency level of the 24 listed companies with CSP concept in my country has changed significantly. The main reason may be that CSP technology started late in my country, and its technical elements and specific applications are in the exploratory stage, while the relevant capital, technology and other inputs in the business process of each CSP concept listed company are unstable. Most listed companies need to adjust input factors according to the actual situation to further improve and improve input-output efficiency.

4 Conclusions and Recommendations

This paper constructs the performance review DEA model of CSP concept listed companies, and empirically analyzes the input-output efficiency of 24 CSP concept listed companies. According to the evaluation conclusions, corresponding policy suggestions are put forward for the development of the domestic CSP industry.

a. Optimize the industrial structure of CSP and promote the high-quality development of CSP. The evaluation results show that the average comprehensive technical efficiency of listed companies in the national CSP industry is 0.794, and there is still 20.6% room for improvement from the effective DEA. The comprehensive technical efficiency of most listed companies in the CSP industry needs to be improved. Therefore, China's CSP industry should not only develop the number of enterprises, but also pay attention to the quality of enterprises.
b. Promote technological innovation in the CSP industry and reduce the company's cost pressure. The CSP industry is still facing great pressure to reduce costs. If you want to gain a place in the accelerated change of the energy system, only by reducing the cost of CSP through the cooperation of all parties can you win the space for survival

and development. And how is it performed? Technological innovation is undoubtedly a right path, and it is also an important measure implemented by the United States as the leading solar thermal power generation country for many years. At the same time, due to the many technical routes and the complex system composition, there are many subdivisions that can implement technological innovation in the CSP industry, and sometimes multiple links and upstream and downstream enterprises are required to participate together.

c. It is suggested to adjust the scale of CSP industry enterprises. In addition to individual listed companies, the scale efficiency of listed companies in the national CSP industry is at a high level of about 0.9; the scale returns of the larger CSP listed companies are mostly in a state of decreasing scale, while the smaller CSP listed companies are mostly in a state of increasing scale. Therefore, it is recommended that larger CSP listed companies optimize investment and reduce redundancy, and that smaller CSP listed companies expand their scale. In particular, listed companies in Jiangsu, Gansu and other places, in addition to enhancing the management level and technical level of enterprises, should also pay attention to adjusting the scale of enterprises and give full play to the scale effect of enterprises.

References

1. Cooper W W, Seiford L M, Thanassoulis E, et al. DEA and its uses in different countries [J]. European Journal of Operational Research, 2004, 154 (2): 337-344.
2. Fu X M, Jiang S S, Su L R. Chinese Fisheries Economics, 2017,35(5):16-24.
3. Wu YD, Luo X. An empirical study on the comprehensive performance evaluation of rare earth listed companies[J]. Business Accounting.2014(02) :7-9.
4. Charnes A, Cooper W W, Rhodes E. Measuring the efficiency of decision making units.Eur J Opera Res, 1978, 2(6):429–444.
5. Liu, Z. F., Qin, Z. Y., Li, H. J.. Analysis of financing efficiency of high-tech listed companies from DEA perspective: Guangdong Province as an example. Business Accounting, 2020(3):45-49.
6. Xu Yue. An empirical study on investment efficiency of listed companies in transportation industry based on DEA model. Guangxi Quality Supervision Herald, 2020(2):190-200.