Research on comprehensive efficiency evaluation technology of regional photovoltaic power generation

Xujuan Miao¹, Zhao Xin¹, Men Yan¹, Chen Chao²,*

¹ Economic and Technological Research Institute, State Grid Xinjiang Electric Power Co., Ltd., Wulumuqi, Xinjiang Uygur Autonomous Region 830011, China
² School of Economics and Management, North China Electric Power University, Beijing 102206, China
'Corresponding author’s e-mail: juzen123@163.com

Abstract. Under the background of global potential energy crisis and regional environmental pollution, China's photovoltaic power generation still faces the key issue of sustainable development under the good prospect of large-scale development and utilization. Based on the identification and analysis of the factors affecting the overall efficiency of photovoltaic power generation, the system dynamics model is introduced to construct a comprehensive evaluation model of photovoltaic power generation, and the comprehensive efficiency transmission mechanism of photovoltaic power generation is studied. The comprehensive efficiency of photovoltaic power generation in Xinjiang in 2015-2017 is studied. The research results can provide support for the sustainable development of photovoltaic power generation and provide guidance for improving the efficiency of photovoltaic power generation.

1. Introduction

As a kind of clean energy, solar energy has become the focus of attention of all countries. Photovoltaic power generation plays an important role in promoting the clean and diversified power supply and the transformation of energy structure in China[1].

Due to its abundant solar energy resources, photovoltaic power generation is developing rapidly in Xinjiang, and its installed capacity has been at the forefront of the country. At the same time, it faces various problems[2]. The hours of equipment utilization are low and the phenomenon of light abandonment is serious. Therefore, this paper studies the development status and problems of photovoltaic power generation in Xinjiang, identifies the trends and influencing factors of photovoltaic power generation efficiency, analyzes and evaluates the photovoltaic power generation efficiency in Xinjiang, and puts forward a rationalized policy for the optimization of the overall efficiency of photovoltaic power generation in the future. The proposal is of great significance for understanding and improving the current status of photovoltaic power generation efficiency in Xinjiang. At the same time, the research results can provide reference for national and provincial decision makers in planning and developing photovoltaic power generation.

2. Analysis of the transmission mechanism of photovoltaic power generation based on system dynamics

The overall efficiency of photovoltaic power generation is closely related to society, economy, environment and technology. Based on the basic process of photovoltaic power input and output, this
paper deeply explores the impact of various factors on the overall efficiency of photovoltaic power generation and its impact mechanism[3]. The overall efficiency conduction mechanism model of photovoltaic power generation based on system dynamics is shown in the following figure:

![System dynamics conduction diagram](image)

Figure 1. System dynamics conduction diagram.

It can be seen from the figure that resource efficiency, development efficiency, and utilization efficiency measure the overall efficiency of photovoltaic power generation from the perspective of resource input, planning and construction, and power utilization, and all have a positive correlation with overall efficiency. The optimal level of overall efficiency is the result of a combination of three efficiencies.

### 3. Construction of evaluation index system

#### 3.1. Evaluation index selection

This paper combines the practical problems of photovoltaic power generation in Xinjiang, combined with the comprehensive efficiency influencing factors of photovoltaic power generation and the concept of sustainable development, to build an input-output rating index system from multiple perspectives (Table 1).

| Indicator category      | Input indicator          | Output indicator         |
|-------------------------|--------------------------|--------------------------|
| New installed capacity  | Equipment utilization hours | Internet power          |
| Fixed asset investment  | Per capita GDP           |

#### 3.2. Evaluation index data acquisition

Due to the short history of photovoltaic power generation industry in China and the poor standardization and persistence of relevant data disclosure, this paper comprehensively combines the actual characteristics of Xinjiang with the extensive data collection, and analyzes the data. Relevant statistics from the National Development and Reform Commission.
Table 2. 2015-2017 indicator data sheet.

| index                        | unit                        | 2015  | 2016  | 2017  |
|------------------------------|-----------------------------|-------|-------|-------|
| New installed capacity       | Ten thousand kilowatts      | 131   | 333   | 44    |
| Equipment utilization hours  | hour                        | 1042  | 1090  | 1223  |
| Fixed asset investment       | Billion yuan                | 10729.32 | 9983.86 | 11795.64 |
| Per capita GDP               | Ten thousand yuan           | 4     | 4.2   | 4.5   |
| Internet power               | Billion kWh                 | 30    | 82    | 102.6 |

4. Input-output evaluation research

4.1. Introduction to the principle of DEA model

There are many types of DEA models, and the theory of the $C^2R$ model is relatively complete. The project group participating in the evaluation is a decision-making unit. There are a total of $n$ project groups. Each project group has $m$ types of input ($X$) and $s$ types of output ($Y$), and $DWU_j$

$$\begin{align*}
\max & \quad \frac{u^T Y}{v^T X} \\
\text{s.t.} & \quad \frac{u^T Y_j}{v^T X_j} \leq 1 \\
& \quad u \geq 0, v \geq 0
\end{align*}$$

Where $v = (v_1, v_2, L, v_n)^T$, $u = (u_1, u_2, L, u_m)^T$ represent the weight coefficients of the $m$ inputs and the $s$ outputs, respectively. The Charnes-Cooper transformation of the above formula can be transformed into an equivalent linear programming model:

$$\begin{align*}
\min & \quad \theta \\
\text{s.t.} & \quad \sum_{j=1}^{n} x_j \lambda_j \leq \theta x_0 \\
& \quad \sum_{j=1}^{n} y_j \lambda_j \geq y_0 \\
& \quad \lambda_j \geq 0, j = 1, 2, \ldots, n, \theta \in E_1^z
\end{align*}$$

The model after processing by non-Archimedes infinitesimal ($\varepsilon$):

$$\begin{align*}
\min & \quad [\theta - \varepsilon S^- + \varepsilon S^+] \\
\text{s.t.} & \quad \sum_{j=1}^{n} x_j \lambda_j + S^- = \theta x_0 \\
& \quad \sum_{j=1}^{n} y_j \lambda_j - S^+ = y_0 \\
& \quad \lambda_j \geq 0, j = 1, 2, \ldots, n, \theta \in E_1^z, S^- \geq 0
\end{align*}$$
Where \( e^T = (1,1,1)^T \), if \( \theta_0 = 1, \ s^- = 0, \ s^+ = 0 \) is satisfied, then \( DMU_{j0} \) is said to be valid for DEA.

Let the optimal solution of the model be \( \theta^0, \lambda^0, s^-, s^+ \), if \( \theta^0 = 1 \) and \( s^- = 0, \ s^+ = 0 \), then \( DMU \) is said to be DEA effective; if \( \theta^0 = 1, \) and \( s^0^- \neq 0, \ s^0^+ \neq 0 \), then \( DMU \) is said to be weak DEA; if \( \theta^0 < 1 \), then it is said that DMU is valid for non-DEA.

In order to judge whether the non-DEA effective decision-making unit is technically effective or scale-effective, the \( C^2 GS^2 \) model is cited. The difference between the \( C^2 GS^2 \) model and the \( C^2 R \) model is that the production set of the \( C^2 GS^2 \) model does not satisfy the cone axiom. Therefore, the constraint \( \sum_{j=1}^{n} \lambda_j = 1 \) can be added to the model \( C^2 GS^2 \) to obtain the model.

\[
\begin{align*}
\min & \quad \theta^T e^T S^- + e^T S^+ \\
\text{s.t.} & \quad \sum_{j=1}^{n} x_j \lambda_j + S^- = \theta x_0 \\
& \quad \sum_{j=1}^{n} y_j \lambda_j - S^+ = y_0 \\
& \quad \sum_{j=1}^{n} \lambda_j = 1 \\
& \quad \lambda_j \geq 0, \ j = 1, 2, \ldots, n, \theta \in E^*_+, \ S^- \geq 0
\end{align*}
\]

Let the optimal solution of the \( C^2 GS^2 \) model be \( \theta^0, \lambda^0, s^-, s^+ \). If \( \theta^0 = 1 \), the DMU is weak DEA; if \( \theta^0 = 1, \) and \( s^0^- = 0, \ s^0^+ = 0 \), then DMU is said to be valid for DEA, that is, the technology is effective.

Because the DEA effective decision-making unit under the \( C^2 GS^2 \) model is only technically effective, that is, when the output of the decision-making unit is \( Y_0 \), the corresponding input \( X_0 \) cannot be reduced. Therefore, for the same group of decision-making units, using the \( C^2 R \) model in combination with the \( C^2 GS^2 \) model, it can be judged whether each decision-making unit is effective in scale or technically effective.

**4.2. Empirical research**

According to the model principle, the input and output numbers are the most effective use in the year with comprehensive efficiency of 1, while the lower the comprehensive efficiency score indicates that the relative efficiency is lower, at least one input target value is not equal to the actual value. The difference between the actual value and the target value is the space for improvement of the relatively inefficient unit resources. The calculation results are as follows (Table 3).

| DMU   | Comprehensive efficiency | Pure technical efficiency | Scale efficiency |
|-------|--------------------------|--------------------------|-----------------|
| 2015  | 0.343                    | 1                        | 0.343           | irs             |
| 2016  | 0.944                    | 1                        | 0.944           | irs             |
| 2017  | 1                        | 1                        | 1               |                 |

Through analysis, it is found that in 2015 and 2016, the efficiency of pure technology is 1, the scale efficiency is not 1, and it is an increase in the scale of returns (irs), indicating that the technology and scale do not match in the past two years, there may be redundancy of scale investment, eliminating after the scale of redundancy, the pure technical efficiency will increase and the overall efficiency will also be improved. In 2017, the overall efficiency was 1, and it was at the forefront of efficiency, indicating that both inputs and outputs are used most effectively.
5. Conclusion
In this paper, the main influencing factors and transmission mechanism of photovoltaic power generation efficiency are analyzed by using system dynamics model system. Based on this, an input-output index system for measuring the comprehensive efficiency of photovoltaic power generation is constructed. Combined with DEA input-output evaluation model for Xinjiang The empirical research on the comprehensive efficiency of regional photovoltaic power generation provides theoretical and technical guidance for the scientific evaluation of the comprehensive efficiency level of photovoltaic power generation.

References
[1] Devabhaktuni V, Alam M, Robert II, Nims D, Near C. Solar energy: Trends and enabling technologies. Renew Sust Energ Rev, 2013, 19: 555-564.
[2] Sahu BK. A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. Renew Sust Energ Rev, 2015, 43:621-634.
[3] Xiao C, Luo H, Tang R, Zhong H. Solar thermal utilization in China. Renew Energy, 2004, 9: 1549-1556.
[4] Qiang Z, Sun H, Li Y, Xu Y, Su J. China’s solar photovoltaic policy: An analysis based on policy instruments. Appl Eng, 2014, 129:308-319.
[5] Tone K, Tsutsui M. Dynamic DEA: A slacks-based measure approach. Omega, 2010, 38:145-156.
[6] Bruni ME, Conforti D, Berald psi P, Tundis E. Probabilistically constrained models for efficiency and dominance in DEA. Int J Prod Econ, 2009, 117:219-228.
[7] Lian Qiang, Shi Lei, Kang Qinyi, Wang Jianjian. Study on the evaluation method of photovoltaic module power generation efficiency in practical environment[J]. Acta Energia Sinica, 2018, 39(06):1595-1599.
[8] Zhu Mingqi, Zhang Zhuoran, Zhou Hang. Comprehensive Evaluation of Photovoltaic Power Generation Based on Fuzzy Mathematics[J]. Science and Technology, 2011(11):185-186.
[9] Wang Yanli. Analysis of China's Electric Energy Utilization Efficiency Based on DEA Evaluation Model[J]. Science and Technology Communication, 2013, 5(06):54-55.
[10] Chang Yurui. Comprehensive Economic Benefit Evaluation of Distributed Photovoltaic Power Generation Projects[J]. Economic Research Guide, 2018(31):36-38.