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Performance efficiency assessment of photovoltaic poverty alleviation projects in China: A three-phase data envelopment analysis model

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ABSTRACT

Based on the idea of coordinated and sustainable development, the photovoltaic poverty alleviation project (PPAP) supplies clean electricity and assists poverty-stricken households, which receives widespread attention from the society. However, the existing efficiency assessment models can neither well consider both the economic and social benefits of the PPAP nor provide pertinent site selection suggestions. To accurately evaluate the performance efficiency and explore the influencing factors, a modified three-phase model is proposed: First of all, a two-step approach combining Pearson correlation coefficient and super-efficiency analysis is adopted to screen out unreasonable variables and outliers, which improves the reliability of subsequent calculations; Next, the bootstrapping algorithm is introduced to optimize the data envelopment analysis model, which effectively corrects the bias and guarantee the model accuracy; Finally, the potential environment variables are extracted from both the electricity conversion process and the poverty alleviation procedure, and further verified by Tobit regression, which provides managers with more comprehensive decision support. According to the results, the performance efficiency of PPAPs in China is generally low due to the unreasonable production scale. Most projects are suffering excessive labor input. Moreover, improper site selection is also a cause for low efficiency, and some corresponding suggestions are proposed.

1. Introduction

With the continuous development of social economy, gradually emerging environmental problems and increasingly intensive energy supply and demand contradictions have seriously hindered people from pursuing a better life. Due to the environmental-friendly, recycling and renewable advantages, photovoltaic power generation is regarded as one of the most promising energy conversion mode and receives great support from all walks of life [1]. According to energy statistics, solar photovoltaic power supply has increased year by year, and the photovoltaic net installed capacity reached 220.2 GW in 2015 [2]. As a developing country with considerable potential in photovoltaic power generation, China manages to reduce the poverty rate while solving the energy crisis. For the reasons above, China combined photovoltaic power generation with the precision poverty alleviation target and formally launched the first PPAP in 2014 [3]. Fig. 1 shows the installed capacity of photovoltaic generation and the poverty-stricken population in China from 2010 to 2016 [4]. During the 7 years, the cumulative installed capacity of solar photovoltaic generation kept increasing, and a remarkable wave of photovoltaic generation in 2013 lays the technical and practical foundation for the proposal of the PPAP. Moreover, as expressed in the picture, it was not until 2014 that the poverty alleviation rate recovered and started to keep increasing, which is in accord with implementation time of PPAPs.

PPAPs can be divided into two common modes: one is that with the help of government guarantee and supporting policies, the poor households get a loan from credit cooperatives or banks and then complete installation, operation and maintenance independently; the other is that power enterprises or interest groups take responsibility for the village-level power station and help the poor with a certain electricity sale income. Compared with the household photovoltaic mode, the village-level photovoltaic poverty power station has the advantages of high power quality, grid connected safety, stable income and favorable poverty alleviation efficiency, thus receiving rapid promotion in recent years. However,

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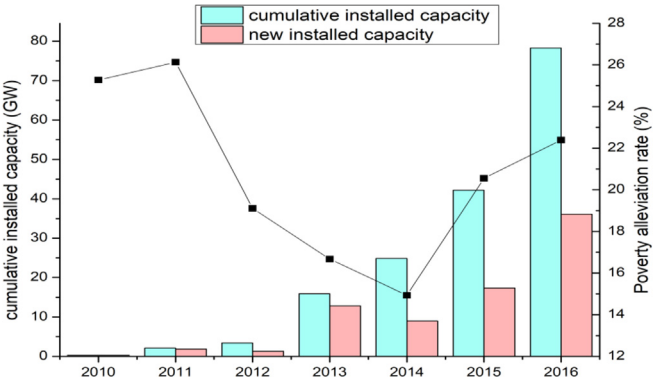

Fig. 1. Photovoltaic power capacity and poverty-stricken population in China (2010–2016).

since the PPAP started late in China, the corresponding supervision experience and management system has not yet been mature, which brings difficulties in identifying inefficient projects and relieving subsidy pressures. Therefore, it is imminent to make an effective assessment for PPAP operational performance efficiency.

This paper aims at exploring a PPAP efficiency assessment method with high precision, so as to identify undesirable projects and figure out potential external influencing factors effectively. The main contributions are as follows: First, since few researches focus on the PPAP performance efficiency assessment, this study can enrich the literature materials and perfect the related theoretical system; Next, the overall ranking and the efficiency score analysis can not only offer government supervision departments a list of troubled projects, but also point out the resource waste situation and the corresponding improvement direction; Last but not least, the potential efficiency influencing factors in both natural and social environment are further analyzed, which may assist policy makers and project managers in making better decisions, such as determining the site selection or the investment scheme. Possible innovations can be summarized in three parts: First, a two-step approach combining Pearson correlation coefficient and super-efficiency analysis is adopted to screen out unavailable data and outlier decision making units (DMUs), which can improve the reliability and rationality of the efficiency assessment model; Second, due to the fact that the PPAP started late in China and most project data has not been announced yet, introducing the bootstrap method to optimize the conventional efficiency assessment model can effectively reduce the deviation caused by small samples and guarantee the model accuracy; Third, taking into account the whole life cycle of the PPAP, including the power conversion process and the poverty alleviation process, this paper extracts potential influencing variables from both the natural environment and the social environment so as to provide managers with more comprehensive decision support.

The remainder of this study is organized as follows: Section 2 briefly probes the research situation of production efficiency assessment and some relative processing techniques regarding with PPAP features. Section 3 interprets the research framework and main methods. Section 4 explains variable definitions and the data sources. Section 5 carries out the efficiency assessment on 30 PPAPs in China and analyzes the uncontrollable factors on this basis. Finally, Section 6 draws a conclusion.

2. Literature reviews

The production efficiency assessment of a power generation project can identify the input redundancy, the output insufficiency and the influencing factors, and further point out the efficiency improvement direction, which is favored by many decision-makers. At present, mainstream production efficiency models can be divided into two categories: the stochastic frontier analysis based parametric analysis model [5] and the data envelopment analysis based nonparametric assessment model [6]. Compared with stochastic frontier analysis, the latter model can work out efficiency scores under the “multiple inputs and outputs” environment without knowing the production frontier function [7]. And electric power production projects tend to involve many factors and complex interactions, which makes it difficult to determine the specific production function.

Therefore, many scholars adopt the DEA-based models to analyze the production efficiency of power generation projects and obtain scientific conclusions: i) Thermal power projects: Using data on generator capacity, operation expenditure, net generation and sulfur dioxide emissions, Liu et al. [8] evaluate cross efficiency of 23 typical coal-fired power plants and effectively deal with the issue of the undesired output calculation. Treating pollutants as the cohesion, Bi et al. [9] divide the coal fired generation system into two subprocesses, including the production subprocess and the pollutant abatement subprocess, and further employ a two-stage network DEA model to realize the performance assessment of 28 observed DMUs, which well satisfies the emission reduction requirements of conventional energy generation projects. ii) Wind power projects: Wu et al. [10] select three inputs and two outputs to evaluate the production efficiency of China’s wind farms and further utilize the Tobit model to figure out the actual impacts of uncontrollable variables, such as age, wind curtailment rate and dummy for group. Similarly, based on the DEA efficiency evaluation and the Tobit regression results of 39 States’ Wind Power, Ümit Sağlam [11] concludes the current situation of wind power industry in America and explores the improvement direction, which provides a reasonable reference for practitioners and decision-makers. Later, Ümit Sağlam [12] simplifies the input and output variables and further quantitatively measures the relative operational performance efficiency of 236 large utility-scale wind farms by conducting a multi-criteria decision-making tool. Based on data of 95 large utility-scale wind farms’ operation, Ümit Sağlam [13] employs DEA models to evaluate relative performance efficiency by computing pre-determined variables, and subsequently conducts Tobit regression to figure out the reasons for production inefficiency. iii) Photovoltaic power projects: Toshiyuki and Goto [14] draw a comparison on performance efficiency among 160 photovoltaic power stations in Germany and the United States from the perspective of solar energy and land use and further discuss policy issues regarding cost allocation based on the DEA results. Further, they discuss how to classify the type of Returns to Scale in the DEA production analysis framework and explore the reasons for inefficient operation based on data of large photovoltaic power stations in American and German [15]. Liu, Long and Song [16] incorporate panel data from 2005 to 2015 of China’s photovoltaic power generation into the super-efficient data envelopment analysis model and propose political suggestions on the operation optimization and management improvement. Denoting annual average irradiation, annual average temperature, number of modules, total cost as inputs while capacity and electricity generation as outputs, Wang and Sueyoshi [1] use the nonparametric DEA approach to evaluate the performance efficiency of 855 large commercial rooftop photovoltaic installations in California. Later, they conduct a detailed analysis of operation inefficiency from the perspective of the scale efficiency and returns to scale [17]. Taking nameplate capacity, photovoltaic panel area, insolation, daylight hours and net generation as the basic parameters in the slack based DEA model, Wang et al. [18] provide the objective production performance