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Characterizing the Spatially Distributed Differences in the Operational Performance of Solar Power Plants Considering Input Volatility: Evidence from China

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Abstract : China has become the world's largest energy producer and consumer, and its development of renewable energy is of great significance to global energy governance and the fight against climate change. The rapid growth of solar power in China could help achieve its ambitious carbon peak and carbon neutrality targets early. However, the non-technical costs of solar power in China are much higher than at international levels, meaning that inefficiencies are rooted in poor management and improper policy design and that efficiency distortions have become a serious challenge to the sustainable development of the renewable energy industry. Unlike fossil energy generation technologies, the output of solar power is closely related to the volatile solar resource, and the spatial unevenness of solar resource distribution leads to potential efficiency spatial distribution differences. It is necessary to develop an efficiency evaluation method that considers the volatility of solar resources and explores the mechanism of the influence of natural geography and social environment on the spatially varying characteristics of efficiency distribution to uncover the root causes of managing inefficiencies. The study sets solar resources as stochastic inputs, introduces a chance-constrained data envelopment analysis model combined with the directional distance function, and measures the solar resource utilization efficiency of 222 solar power plants in representative photovoltaic bases in northwestern China. By the meta-frontier analysis, we measured the characteristics of different power plant clusters and compared the differences among groups, discussed the mechanism of environmental factors influencing inefficiencies, and performed statistical tests through the system generalized method of moments. Rational localization of power plants is a systematic project that requires careful consideration of the full utilization of solar resources, low transmission costs, and power consumption guarantee. Suitable temperature, precipitation, and wind speed can improve the working performance of photovoltaic modules, reasonable terrain inclination can reduce land cost, and the proximity to cities strongly guarantees the consumption of electricity. The density of electricity demand and high-tech industries is more important than resource abundance because they trigger the clustering of power plants to result in a good demonstration and competitive effect. To ensure renewable energy consumption, increased support for rural grids and encouraging direct trading between generators and neighboring users will provide solutions. The study will provide proposals for improving the full life-cycle operational activities of solar power plants in China to reduce high non-technical costs and improve competitiveness against fossil energy sources.

Keywords : solar power plants, environmental factors, data envelopment analysis, efficiency evaluation
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