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Valuing the carbon assets of distributed photovoltaic generation in China

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ABSTRACT

Distributed photovoltaic generation has advantages in energy savings and emissions reduction, but its economic value is still unclear. This paper examines the carbon value of distributed photovoltaic generation, analyzes the influencing factors and further illustrates how these factors affect the value. First, it introduces the method of carbon asset valuation to distributed photovoltaic generation, which produces lower carbon emissions than most other energy sources. Second, based on mean estimates of the internal determining factors for the carbon assets of distributed photovoltaic generation, this paper provides an estimated value of the carbon assets. Third, under uncertain conditions and accounting for the time factor, it uses Monte Carlo simulation to analyze the sensitivity of the carbon asset value of distributed photovoltaic generation. The results indicate that (1) distributed photovoltaic generation has a carbon asset value; (2) the carbon asset value of distributed photovoltaic generation is determined by the carbon reduction level, the power generation capacity and the carbon price; and (3) carbon price fluctuations affect the carbon asset value of distributed photovoltaic generation much more than the power generation capacity. This paper provides academic support to promote carbon asset trading in distributed photovoltaic generation and for distributed photovoltaic generation to reduce carbon emissions.

1. Introduction

Distributed photovoltaic generation has received considerable attention recently, as it plays an increasingly important role in energy savings and emissions reduction. Distributed photovoltaic generation serves the current demand for not only electrical energy but also increased electrified heating, cooling and transport, so it has sound advantages for achieving the sustainability objectives of energy policy at low cost (Hancevic et al., 2017; Bell and Gill, 2018). Driven by technological advancements and policy encouragement, distributed photovoltaic generation has had developed rapidly in China in recent years (Dong et al., 2016; Nerini et al., 2016; Anaya and Pollitt, 2017; Feng et al., 2017; He et al., 2017). Its cumulative installed capacity reached 6.06 GW at the end of 2015, and the average annual increase will be 12.79 GW during the 13th Five-Year Plan of China, which implies that there is a very substantial development space for distributed photovoltaic generation in the future.

Although the economic value of distributed photovoltaic generation is recognized, and it has developed rapidly in many countries such as China, its potential environmental value in energy savings and emission reduction is still very ambiguous (Holtmeyer et al., 2013; Zhao et al., 2015; Brouwer et al., 2016; Luo et al., 2016). To analyze the potential environmental value of distributed photovoltaic generation, this paper applies the theory of carbon asset valuation advanced by Han et al. (2015) to value the carbon asset of distributed photovoltaic generation. We further analyze the influencing factors on the carbon asset value of distributed photovoltaic generation and illustrate how these factors affect the value.

Carbon assets refer to the economic and environmental value of carbon reduction in all green production or consumption processes, so such assets are quite extensive. However, the study of carbon assets is limited to only a few fields; to the best of our knowledge, there are still no specific studies on the carbon asset value of distributed photovoltaic generation. Because distributed photovoltaic generation provides considerable benefits with regard to energy conservation and carbon reduction, its carbon asset value should be considered. This paper examines the carbon asset value of distributed photovoltaic generation, which will contribute to the understanding of the economic and environmental effects of distributed photovoltaic generation and the literature on the assessment of carbon assets' value.

According to Han et al. (2015), the value of carbon assets depends on the abetment ability of the project, its production amount and the carbon price in the market. Distributed photovoltaic generation has overwhelming superiority in energy savings and emissions reduction, as

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during the 13th Five-Year Plan of China, the carbon dioxide emissions from solar power are expected to be 33–50 g/kW h and those from coal are expected to be 796.7 g/kW h. As the market size of distributed photovoltaic generation in China expands, the National Energy Bureau has encouraged distributed photovoltaic generation as part of voluntary carbon reduction systems. The public carbon price will be formed in the carbon trading market launched by the State Council of China in 2018. All these conditions make it possible to study the influencing factors on the carbon asset value of distributed photovoltaic generation in China, which will increases the understanding of how the carbon asset value of distributed photovoltaic generation is determined and how it changes.

The reminding of this paper proceeds as follows: Section 1 reviews the literature related to the carbon assets of distributed photovoltaic generation. Section 2 introduces the methodology to evaluate the carbon assets of distributed photovoltaic generation and derives the influencing factors in theory. Section 3 introduces the data and variables used in the paper. Section 4 presents the empirical results with some analysis. Section 5 discusses the findings from the empirical results and the economic and environmental significance of understanding the carbon assets of distributed photovoltaic generation. Section 6 concludes and discusses the implications of the paper.

2. Literature review

The economic value of carbon assets, as a new type of resource in finance or environmental studies, has been gradually recognized by scholars. Ortas and Álvarez (2015), for example, depicted the comovement of carbon assets and energy commodities through wavelet decomposition, which illustrates the efficiency of the European Union Emissions Trading Scheme (EU-ETS). By examining the time-varying correlations between carbon allowance prices and other financial indices during the third phase of the EU-ETS, Zhang et al. (2017) found that carbon assets were relatively independent of other financial assets and thus argued for the diversification benefits of including carbon assets in financial portfolios. The relation between the price of energy commodities and that of carbon assets is also a popular topic in academia (Reboredo, 2014; Kanamura, 2016; Wen et al., 2017; Wang and Guo, 2018; Uddin et al., 2018). Knowing the value of carbon assets is the basis for their exchange in the market and for inducing the participants to engage in low-carbon behavior. However, only a few of papers have evaluated the carbon value of environmental protection embedded in economic activities.

Scholars have gradually recognized the economic value of carbon reduction behavior when calculating the carbon emissions emitted by a source or sequestered in a biomass sink. Bebbington and Larrinaga-González (2008) primarily took a monetary perspective and emphasized the valuation of assets and liabilities in reference to carbon emission and sequestration accounting. To evaluate organizational capabilities in carbon emissions management, Ratnatunga et al. (2011) introduced a metric called an Environmental Capability Enhancing Asset (ECEA) as the underpinning for converting non-monetary CO_2 emissions and sequestration measures into monetary values. Stechemesser and Guenther (2012) examined the measurement of emissions and removals and their implications for finance. They examined monetary aspects from an organizational perspective and described the internal and external application of carbon asset from an accounting perspective. Ascui and Lovell (2013) additionally highlighted that carbon assets can accumulate for mandatory or voluntary purposes and at different scales, for example, on a global, national or organizational scale. On this basis, Song et al. (2013) established a pricing model for evaluating carbon asset values in electricity markets. Han et al. (2015) introduced carbon asset theory into traditional high-tech evaluation methods and applied the method the authors developed to the carbon asset evaluation of wind energy technology. Wang et al. (2015) applied carbon asset theory to the comprehensive energy infrastructure and proposed that there is often a lack of explicit assessment when cost and environmental performance is taken into account. Although carbon asset valuation has been utilized in the forest system, the traditional power market, bank credit, wind power technology and other fields, there is still no research specifically on the carbon value embedded in distributed photovoltaic generation.

Scholars have also discussed the influencing factors for carbon assets when they study the carbon assets of an institution or a technique. Song et al. (2013) considered the influence of market demand, generation costs, baseline of carbon emissions and carbon emissions reduction costs on carbon asset values in electricity markets. Based on the carbon asset theory they advanced, Han et al. (2015) examined the carbon asset value of a high-tech innovation, which is determined by the baseline standard emissions of the industry, the emissions level when adopting a reduction technology, the enterprise's production and the price of carbon. Wang et al. (2015) applied the theory of carbon asset assessment to the comprehensive energy infrastructure and proposed that there is often a lack of explicit assessment when cost and environmental performance are considered. These studies provide references for our evaluation of the factors affecting the carbon value embedded in distributed photovoltaic generation.

Furthermore, how do the influencing factors affect carbon assets? Song et al. (2013) conducted a sensitivity analysis to assess the impact of these factors on the value of carbon assets. Using Sobol' sensitivity analysis method of variance, Han et al. (2015) evaluated the influencing factors for carbon asset values from high-tech innovation and found that carbon asset values vary across different technologies, in different industries and over time. Wang et al. (2015) conducted a descriptive analysis of simulated integrated energy interactions in an energy plan to illustrate the impact of technical emissions on integrated energy. Based on these studies, we further develop the sensitivity analysis method and then analyze how the influencing factors affect the value of carbon assets embedded in distributed photovoltaic generation.

By valuing the carbon assets in distributed photovoltaic generation and advancing new methods to analyze the influencing factors and their sensitivity to this type of asset, this paper, on the one hand, further develops the theory of carbon asset valuation. On the other hand, it also adds to the knowledge base related to the value of distributed photovoltaic generation.

A few scholars have discussed the economic value of distributed photovoltaic generation. Mitscher and Rüther (2012) analyzed the economic competitiveness of grid-connected, distributed solar photovoltaic generation through small-scale rooftop installations in Brazil. Holdermann et al. (2014) analyzed how the variation in specific investment costs and the discount rate affect the economic viability of distributed photovoltaic generation in residential and commercial sectors in Brazil. Burtt and Dargusch (2015) examined the cost-effectiveness of subsidies paid for by electricity consumers to support the installation of roof-top photovoltaic systems by households in Australia. Zhang (2016) studied the business models and financing mechanisms used for the distributed solar photovoltaic deployment in China and discussed the challenges and policies involved. Hancevic et al. (2017) quantified the potential effects that the massive adoption of distributed photovoltaic generation systems would have on household expenditures and welfare, subsidy reductions, pollution and water resource usage for Mexican residents. Nomaguchi et al. (2017), using a case study of the diffusion of photovoltaics in a Japanese dormitory town, analyzed subsidy policies for a distributed photovoltaic generation system for companies and citizens in the integrated planning of low-voltage power grids. Camilo et al. (2017) analyzed the financial and technical effects of distributed photovoltaic generation for consumers in Brazil. More broadly, the economic effects of other types of distributed generation, including the benefits, costs and risks, have also been examined (e.g., Huang and Söder, 2017; Bell and Gill, 2018). In addition to the above studies, the impacts of carbon reduction on the value of distributed photovoltaic generation have gained attention