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The Wind and Sand Mitigation Benefits of solar Photovoltaic development in Desertified Regions: An Overview

Jinwei Bian[1], Ziyuan Sun[1], Saige Wang[2*], Bin Chen[1,2*]

[1] *School of Resources and Environment, Hunan University of Technology and Business, Changsha 410205, China*

[2]*State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China*

*Corresponding Author: wsgbnu@163.com, chenb@bnu.edu.cn

ABSTRACT

In the context of energy transformation and environmental governance, the development of the photovoltaic (PV) industry not only alleviates the conflict between energy using and environmental protection, but also provides wind and sand fixation services for the region. This paper firstly summarized the model of calculation on wind prevention and sand fixation service at home and abroad. Then we analyzed the modification and improvement of the Revised Wind Erosion Equation (RWEQ) model. In terms of the benefit accounting of wind prevention and sand fixation service in photovoltaic industry, this paper analyzed the research of experts in the field of ecosystem services evaluation, and summarized the research status and limitations of the benefit accounting related to wind prevention and sand fixation service in the photovoltaic industry. This paper provided recommendations on benefit accounting to improve the accuracy of ecosystem services assessments.

Keywords: Ecosystem services; wind prevention and sand fixation service; RWEQ model; solar photovoltaic (PV)

1. INTRODUCTION

The Photovoltaic (PV) industry has emerged as a prominent and effective strategy for China to address the reduction of fossil energy consumption in recent years. It has played a crucial role in reshaping the national energy landscape, advancing ecological sustainability, and promoting poverty alleviation and economic development. In 2013, China introduced a series of policies to foster the growth of the PV industry, and to date, it has achieved a substantial level of success. Desertified areas, known for their unique advantages in harnessing solar and wind energy, have become prime locations for the development of solar energy and other renewable sources. Photovoltaic power plant construction projects have become pivotal in China's efforts to conserve energy and reduce emissions. According to the National Energy Administration, China's solar power generation capacity reached 253 million kWh in 2020, marking a year-on-year growth of 24.10 percent. Photovoltaic panels are typically categorized as ground-based and rooftop installations. However, the constraints associated with rooftop installations, including limited available space, have hindered their widespread adoption in China. The desert regions of Northwest China stand out as ideal areas for ground-mounted PV panels, benefiting from low land costs and abundant solar energy resources.

The development of the solar photovoltaic in desertified areas presents both advantages and disadvantages for local wind and sand fixation. The challenge stems from the arid climate, limited vegetation, and water resources in these areas, where the ecological environment is notably harsh and fragile. In particular, the construction of solar photovoltaic power plants can disturb the surface soil, leading to an increase in wind and sand transportation. However, the benefits of photovoltaic projects extend beyond their power generation and supply functions. They primarily manifest through the alteration of the wind and sand movement patterns in the downflow field. This modification disrupts the existing equilibrium of surface

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power distribution and changes the laws governing sand movement[1]. This alteration in surface wind and sand movement has indirect, positive effects on sand transport circulation in desertified regions, contributing significantly to wind and sand services management within the ecosystem. Notably, it serves as a primary contribution of the photovoltaic industry to the provisioning of ecosystem services. Furthermore, the reduction in sand transport resulting from changes in surface wind and sand movement patterns not only decreases government expenditure on environmental management but also leads to economic benefits achieved through the combination of reduced sand transport and reduced unit management costs.

This paper introduces the theme of the photovoltaic (PV) industry and its service function of wind and sand conservation as well as the development status of ecosystem services as the background. Methodologically, the accounting of wind and sand services of the PV industry is divided into two perspectives: the evaluation of wind erosion models and the accounting of ecosystem benefits. In the wind erosion model, the RWEQ model is the mainstream wind erosion model at the present stage due to its comprehensive consideration and good prediction effect, and the model is revised and optimized by combining it with the existing literature. The ecosystem service benefit accounting mainly takes Costanza and Ouyang Zhiyun's view as the core. Finally, this paper also puts forward certain suggestions on the shortcomings of ecosystem service benefit accounting. The specific technical line of research is shown below:

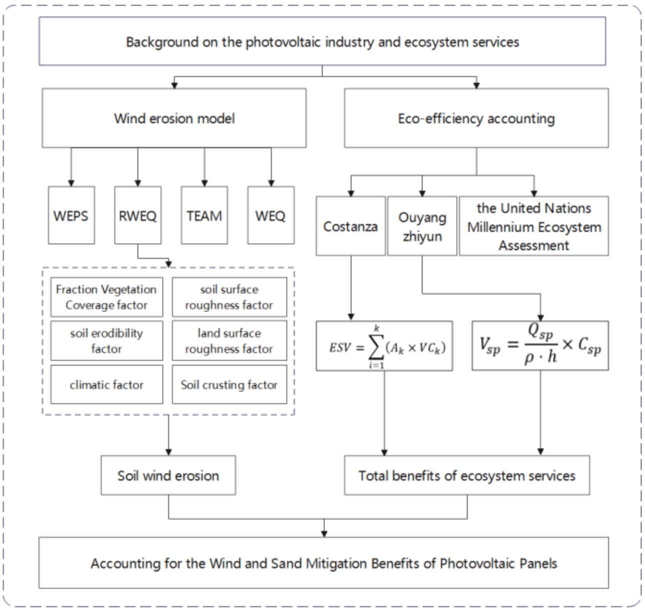

Fig. 1 Technology Roadmap

2. METHODS

2.1 Wind erosion model evaluation

With the advancement and application of remote sensing and geographic information technology, wind erosion models have seen widespread adoption in the scientific research community. Presently, the prominent research models encompass the Wind Erosion Equation (WEQ) proposed by Woodruff et al[2], the Wind Erosion Loss Volume Model proposed by Dong Zhi Bao[3], the Process-Based Wind Erosion Prediction System (WEPS)[4], the Texas Erosion Analytical Model (TEAM) based on the development of wind speed profiles[5], and the Bocharov model involving anthropogenic factors in the former Soviet Union[6], the Modified Wind Erosion Equation Model (RWEQ)[7]. Among these models, the RWEQ model stands out as particularly valuable due to its comprehensive consideration of various factors, including wind intensity, surface cover, soil physicochemical properties, soil crusting, surface roughness, and others. It excels in assessing and calculating the extent of regional soil wind erosion at high spatial-temporal resolutions. This model is particularly instrumental in accurately predicting windbreaks and sand fixation in land wind erosion and control applications, making it a widely utilized tool in this field.

$$Q_{\max P} = 109.8 \times (WF \times E\bar{F} \times \mathrm{SCF} \times K') \quad (1)$$

$$S_P = 150.71 \times (WF \times EF \times \mathrm{SCF} \times K')^{-0.3711} \quad (2)$$

$$S_{LP} = \frac{2Z}{S_P^2} Q_{\max P} \times e^{-(Z/S_P)^2} \quad (3)$$

$$Q_{\max} = 109.8 \times (WF \times EF \times \mathrm{SCF} \times K' \times C) \quad (4)$$

$$S = 150.71 \times (WF \times EF \times \mathrm{SCF} \times K' \times C)^{-0.3711} \quad (5)$$

$$S_L = \frac{2Z}{S^2} Q_{\max} \times e^{-(Z/S)^2} \quad (6)$$

$$SP = S_{LP} - S_L \quad (7)$$

SP is the amount of sand fixation per unit area (kg/m²); Z denotes the distance downwind (m); S_{LP} is the amount of potential wind erosion (kg/m²); S_{LP} is the amount of actual wind erosion (kg/m²); $Q_{\max P}$ is the maximum amount of actual wind and sand runoff; S is the length of critical plots (m); S_P is the length of potential critical plots (m); WF is the climatic factor (kg/m); EF is the erodibility factor for soils; SCF is the crusting factor for soils; C is the vegetation cover factor;

and K' is the roughness factor for the ground surface.

However, as scientific research advances and temporal and spatial conditions within studied regions evolve, the basic RWEQ model has exhibited limitations in terms of precision and applicability. Consequently, numerous researchers have undertaken modifications to tailor the model to specific regional requirements. For instance, Li Hancong and colleagues implemented significant enhancements to the RWEQ model by adjusting meteorological factors and surface roughness parameters. They replaced the conventional 10m wind speed with near-surface wind speed at 2m, providing a more accurate representation of local conditions. Additionally, they computed suitable land roughness factors through raster processing, aligning them with actual surface roughness and topographic features in the region[8]. Similarly, Gong Guoli and collaborators, in their analysis of soil erosion patterns in Xilingol League during the 1990s, identified and incorporated key factors influencing soil erosion into the RWEQ model. This adaptation customized the model to the region's specific conditions by refining soil crust and soil erodibility factors[9]. Wang et al. conducted a comprehensive analysis of wind erosion prevention and control services on the Tibetan Plateau from 2000 to 2015 using a modified RWEQ wind erosion model. They focused on the temporal aspects of wind erosion prevention and control services, examining the effects of anthropogenic and natural factors, as well as their interactions in the temporal patterns of changes in wind erosion control services[10]. Huang Lin and colleagues calculated the rate of change in meteorological factors, such as rainfall and temperature, using the least squares method, and dynamically categorized these factors based on quarterly cycles[11]. Additionally, Wang et al. combined geographically weighted regression analysis with the influencing factors of the RWEQ model to elucidate the role of each factor in the model[12]. In summary, substantial progress has been made in estimating sand transport and wind and sand activity flux within wind and sand control services, particularly in terms of research methodology, correction of influencing factors, and model enhancement. This progress furnishes a precise, rational, and effective tool for subsequent wind erosion prediction and assessment. However, there remains room for more profound research when applying the model to measure the wind and sand conservation capacity on a regional scale with substantial topographic relief and complex surface structure, which warrants further improvements.

2.2 Accounting for the benefits of wind and sand control services

Ecosystems and their ecological processes are of paramount importance for maintaining Earth's life support system, and they are essential for human survival and the advancement of human society. The assessment of ecosystem services and the accounting of ecological benefits have evolved into prominent research areas within the field of global environmental resources.

This paper focuses on a comprehensive review of the windbreak and sand fixation service benefits stemming from the development of the photovoltaic industry. Presently, the evaluation of eco-efficiency in wind and sand control services draws extensively from the work of the United Nations Millennium Ecosystem Assessment, Costanza, and Ouyang Zhiyun, among others.

Costanza, a renowned authority in the realm of ecosystem services, has made significant contributions to eco-efficiency accounting by providing a robust theoretical framework and analytical tools. He posits that, through an ecological economics perspective, both the economic system and the social system are integral components of the ecological service system. Moreover, the economic system operates as a subsystem within the broader social system, introducing a novel paradigm for analyzing ecosystem services. Costanza's approach to benefit accounting for ecosystem services advocates the direct or indirect estimation of individuals' 'willingness-to-pay' for ecosystem services, utilizing this metric as the governance cost for these services[13]. Costanza's formula for calculating the total value of ecosystem services is as follows:

$$ESV = \sum_{i=1}^{k} (A_k \times VC_k) \qquad (8)$$

ESV is the total value of ecosystem services (yuan); A_k is the area of class K land use type (hm^2); VC_k is the ecosystem service value coefficient of class k land ($yuan*hm^{-2}$)

Ouyang Zhiyun, who has made remarkable contributions to the field of ecosystem services in China, has a more detailed description of wind and sand control services among ecosystem services: ecosystems weaken the strength of the wind and the sand carrying capacity through their structures and processes to reduce soil erosion and wind and sand hazards. In his research on the ecological benefit accounting of wind and sand control services, Ouyang Zhiyun prefers to apply the alternative cost method. This method involves assessing the value of ecosystem wind and sand control functions by comparing them to the cost of treating sandy land per unit area. In this approach, the benefits of ecosystem services are quantified by measuring the cost savings achieved through the treatment process[14]. The accounting method is as follows:

$$V_{sp} = \frac{Q_{sp}}{\rho \cdot h} \times C_{sp} \tag{9}$$

V_{sp} is the value of windbreak and sand fixation (CNY/a); ρ is the soil bulk weight (t/m³); h is the thickness of soil sand cover (m); and C_{sp} is the cost per unit of sand control project (CNY/m²).

While the accounting of ecosystem service benefits has garnered substantial attention and research in the fields of global ecology and ecological economics, it is important to acknowledge that the existing literature has yet to offer a comprehensive and precise methodology for accounting the benefits of wind and sand control services. Consequently, when quantifying the ecological benefits of windbreak services, the assessed value often carries an inherent degree of uncertainty. The accounting of wind and sand services continues to present challenges and opportunities for refinement. Room for improvement in this accounting process remains, offering fertile ground for further research and methodological development.

3. CONCLUSIONS

Ecosystem services play a vital role in the total contribution of ecosystem services to human well-being at the global level. The vigorous development and promotion of the photovoltaic industry has made considerable contributions to both the development of clean energy and ecosystem management, providing a good example for reference for the healthy development of global ecosystem services.

The photovoltaic industry has demonstrated a certain degree of value in wind and sand services. Presently, a wealth of literature and models are available for calculating the circulating wind and sand volume pertaining to wind and sand control services. Among these, the RWEQ model distinguishes itself as a leading choice among various wind erosion models due to its comprehensive considerations, more accurate predictions, and targeted applications. Additionally, numerous scholars have put forth a series of improvement methods and perspectives, offering valuable insights for further study and reference, with a focus on influencing factors and research methodologies.

Regarding benefit accounting, the data systems and accounting methods present in existing literature hold significant scientific and practical value, providing valuable guidance to the field. However, prominent researchers such as Costanza and Ouyang Zhiyun consistently stress the potential overestimation of ecosystem services' value, primarily because these services often operate outside traditional market mechanisms and exhibit substantial uncertainty. Moreover, discrepancies in valuation indicators and methodologies can introduce considerable deviations in final results, rendering meaningful comparisons difficult and limiting the effectiveness of these findings in advancing the broader field of research. The accounting of ecosystem service benefits retains ample room for improvement. This paper suggests several avenues for enhancement based on fundamental principles of benefit accounting:

1.Incorporate Time Effects: Consider the temporal dimension, particularly accounting for time lags following the implementation of policies.

2.Account for Technological Progress: Recognize the decreasing costs of treatment attributed to advancements in technology.

3.Include Health Factors: Introduce health-related factors into cost considerations, particularly for issues such as pneumoconiosis, which may exhibit regional disparities in disadvantages or advantages.

DECLARATION OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. All authors read and approved the final manuscript.

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