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Discussion on the Soil and Water Conservation Model in Mountain Photovoltaic Power Generation Project

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Abstract In the context of rising global energy demand and increasing awareness of environmental protection, photovoltaic power generation, as a clean and renewable form of energy, has become increasingly important and has received widespread attention and application worldwide. However, during the construction and operation of mountain photovoltaic power generation projects, water and soil erosion has become a major challenge, which not only restricts the sustainable development process of the project, but also has a significant negative impact on the local ecological environment. This article deeply analyzes the multiple causes, extensive impacts and effective prevention and control strategies of water and soil erosion in mountain photovoltaic power generation projects. The results show that rainfall intensity, terrain slope, soil type and vegetation coverage are the four key factors leading to soil erosion. Soil erosion not only causes a sharp decline in soil fertility, but also aggravates the problem of sediment deposition in rivers and reservoirs, and poses a direct threat to the stability and operating efficiency of photovoltaic equipment. In order to deal with the above problems, this paper innovatively puts forward a series of soil and water conservation technologies, covering multiple dimensions such as engineering measures, plant measures, farming measures and temporary measures, and deeply discusses the application models and management strategies of these measures in key stages such as planning and design, construction, operation and maintenance. Through specific case analysis, the successful practical experience of soil and water conservation is refined and summarized, and the key role of community cooperation, technical support and modern monitoring technology in preventing and controlling soil and water erosion is further emphasized. This article aims to achieve a win-win situation of ecological environment protection and energy development and utilization through scientific planning and effective governance, and contribute to the construction of a green, low-carbon, and sustainable energy system.

Key words Mountain photovoltaic power generation, Soil erosion, Prevention and control measures, Sustainable development

1 Introduction

With the continuous growth of global energy demand and the increasing awareness of environmental protection, photovoltaic power generation, as a clean and renewable form of energy, has become more and more important and has gained widespread attention and application. However, during the construction and operation of mountain photovoltaic power generation projects, the problem of water and soil erosion has become a key challenge that needs to be solved urgently. This problem not only threatens the sustainable development of the project, but also has a negative impact on the local ecological environment that cannot be ignored. Therefore, it is of extremely important practical significance and urgency to deeply discuss the prevention and control model of soil erosion in mountain photovoltaic power generation projects.

Mountain photovoltaic power generation, as an emerging power generation model, has been widely promoted and applied in areas with sufficient sunshine. However, as the number of mountain photovoltaic projects continues to increase, the aggravating effect of rain wash on soil erosion has gradually emerged, becoming a problem that cannot be ignored. The impact of rainwater on mountain photovoltaic systems is double-sided: on the one hand, an appropriate amount of rainwater erosion helps to remove pollutants on the surface of photovoltaic panels and keep them clean, thereby improving photoelectric conversion efficiency; on the other hand, continuous heavy rainfall may cause serious soil erosion problems, leading to the occurrence of soil erosion. The installation process of photovoltaic facilities will inevitably damage the vegetation below, so the soil becomes loose. In addition, the laying of photovoltaic panels changes the distribution pattern of surface rainwater, making it easier for rainwater to concentrate on the lower edge of the photovoltaic panels to form water flow or water column, thus causing a strong erosion effect on the surface, especially under the impact of heavy rains in the rainy season, the problem of soil erosion is more serious.

The construction of mountain photovoltaic power generation projects is often accompanied by large-scale land leveling and vegetation clearing efforts. These activities can cause damage to surface structures, thereby increasing the risk of soil erosion. Especially in areas with high rainfall intensity, the problem of soil erosion is particularly prominent. The artificial rainfall experiment conducted by Wang *et al.* in southwestern Henan Province showed that the increase of rainfall intensity significantly exacerbated the loss of soil nutrients[1]. This discovery is also of warning significance for mountain photovoltaic power generation projects, and due to the complexity of mountain terrain, the prevention and control of water and soil erosion faces greater challenges.

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In addition, the water and soil erosion problems in mountain photovoltaic power generation projects will not only adversely affect soil fertility and vegetation restoration, but may also cause sedimentation problems in rivers and reservoirs, thereby negatively affecting water resources management and ecological environment in downstream areas. While studying soil conservation projects in the Philippines, Catacutan and Cramb pointed out that the problem of soil erosion in sloping agriculture needed to be addressed together through community collaboration and technical support[2]. This experience also has important reference value for the prevention and control of water and soil erosion in mountain photovoltaic power generation projects. This study aims to systematically analyze the causes, impacts and prevention measures of soil and water erosion in mountain photovoltaic power generation projects. Through study and in-depth analysis of existing literature, this article will explore the applicability and implementation effect of different prevention and control models, in order to provide a valuable reference for research and practice in related fields. Chen *et al*. pointed out that a reasonable site selection and construction scheme of photovoltaic power station was of great significance for effectively controlling soil erosion[3] when studying photovoltaic construction in coal mine subsidence areas. Therefore, this study will focus on how to explore soil erosion prevention and control models suitable for mountain photovoltaic power generation projects to achieve a win-win goal of ecological environment protection and energy development.

2 Analysis of current situation of water and soil erosion in mountain photovoltaic power generation projects

2.1 Exploration on the main causes of soil erosion During the implementation of mountain photovoltaic power generation projects, the causes of water and soil erosion involve many factors. First of all, the intensity of rainfall and its frequency are the key meteorological conditions affecting soil erosion. The higher the rainfall intensity, the greater the increase of soil erosion and runoff, which leads to the greater loss of soil nutrients. Secondly, the size of terrain slope and the type of soil are also the core factors affecting soil erosion. Steep slope and unstable soil structure will increase the risk of soil erosion[4]. In addition, the impact of different land use patterns on soil erosion can not be ignored. For example, compared with forest land and grassland, farmland soil tends to have higher nutrient loss. Finally, the decrease of vegetation cover exposes the soil surface, further increasing the potential for erosion and runoff.

2.2 Characteristics of soil and water erosion Soil and water erosion in mountain photovoltaic power generation projects has obvious particularity and regularity. First of all, due to the complex terrain and steep slope of mountainous areas, surface runoff is easy to form after rainfall, which leads to the aggravation of soil erosion. Wang *et al*. believed that rainfall intensity was positively correlated with soil nutrient loss, and nutrient loss in sloping farmland was significantly higher than that in woodland and grassland[1]. Secondly, during the construction of mountain photovoltaic power generation projects, soil disturbances are large and vegetation coverage is reduced, further exacerbating the risk of soil erosion. Catacutan and Cramb pointed out that soil erosion is particularly severe in sloping agriculture, especially with high rainfall intensity[2]. In addition, mountain photovoltaic power generation projects are often located in ecologically fragile areas. Soil erosion not only affects the stability of the project itself, but may also have a negative impact on the surrounding ecological environment. Girolamo *et al*. pointed out that topography, soil type, and land use patterns are important factors affecting runoff and soil erosion[4]. Therefore, for the prevention and control of water and soil erosion in mountain photovoltaic power generation projects, it is necessary to comprehensively consider various factors such as topography, rainfall, and vegetation, and take scientific and reasonable prevention and control measures.

2.3 Effects of soil and water erosion Soil erosion has had a significant negative impact on mountain photovoltaic power generation projects and their surrounding environment. First of all, soil erosion will lead to the decline of soil fertility, affect the growth of vegetation, and then reduce the ecological service function of land. G. Wang *et al*. suggested that nutrient loss in farmland soil is more severe than in woodland and grassland under the condition of increased rainfall intensity[1]. This phenomenon is particularly evident during the construction of photovoltaic projects, as construction activities can destroy surface vegetation and increase the risk of soil erosion.

Secondly, soil erosion will also lead to sediment deposition in rivers and reservoirs, affecting the utilization efficiency of water resources. N. McDougald *et al*. pointed out that soil erosion caused by grazing activities is one of the main sources of river sediments[5]. In photovoltaic project areas, construction and maintenance activities may exacerbate this problem, leading to sediment deposition in downstream water bodies, affecting water quality and water ecosystems.

In addition, soil erosion can also cause damage to the photovoltaic equipment itself. Teiji Watanabe believed that topographic changes and soil erosion can affect equipment stability and operational efficiency[6]. In mountain photovoltaic projects, water and soil erosion may lead to instability in the equipment foundation, increasing maintenance costs and safety risks.

3 Technical measures for soil and water conservation

3.1 Engineering measures In mountain photovoltaic power generation projects, engineering measures are one of the important means to prevent and control soil erosion. Firsttly, reasonable terrain modification and drainage system design are the key. By building terraces, drainage ditches and other facilities, surface runoff can be effectively reduced and soil erosion can be prevented. The study of Wang *et al.* indicated that in the southwest mountainous area of Henan Province, it was found that the construction of terraces and drainage ditches significantly reduced soil erosion and nutrient loss through artificial rainfall experiments[1].

Secondly, vegetation restoration and slope protection projects are also important engineering measures. By planting adaptable plants, soil stability can be enhanced and soil erosion can be reduced. Chen *et al.* pointed out that the application of photovoltaic construction in coal mine subsidence areas not only improved the environment, but also achieved comprehensive management of soil erosion through vegetation restoration[3].

In addition, reasonable construction management and maintenance are also important links in engineering measures. During the construction process, large-scale earth excavation should be avoided to minimize the damage to the original landform. Liu *et al.* believed that the application of accurate mechanical automation control system in power engineering can improve the construction efficiency and reduce the impact on the environment, thus reducing the risk of soil erosion[7].

Finally, the establishment of monitoring and evaluation systems is also indispensable. Through real-time monitoring of water loss and soil erosion, corresponding prevention and control measures can be taken in time. Watanabe evaluated the accuracy of the surface model through unmanned aerial vehicle and real-time dynamic GPS technology in his research in Japan, which provided a scientific basis for soil and water conservation[6].

3.2 Plant measures Plant measures play a crucial role in soil and water conservation in mountain photovoltaic projects. Water loss and soil erosion can be effectively reduced by growing plants adapted to local climate and soil conditions. Plant roots can enhance the stability of soil structure and reduce surface runoff, thus reducing the risk of soil erosion. Studies have shown that the higher the vegetation cover, the lower the soil erosion rate[1].

In photovoltaic power generation projects, reasonable selection and allocation of plant species is the key. Suitable plants can not only provide good ecological benefits, but also complement photovoltaic panels, to reduce surface temperature and improve the power generation efficiency of photovoltaic panels. Lei Chen *et al.* believed that the combination of photovoltaic construction and vegetation restoration can effectively control the soil erosion problem in coal mine subsidence areas, and at the same time promote the improvement of local ecological environment[3].

In addition, plant measures can also control soil erosion in the form of natural vegetation belt. CatacutanA and Cramb pointed out that the utilization of natural vegetation filter strips (NVS) as contour barriers in the southern Philippines is able to provide a simple, cost-effective solution to effectively control soil erosion[2]. This method is not only applicable to the Philippines, but can also be extended to other regions with similar topographic and climatic conditions.

In conclusion, plant measures have important application value in soil and water conservation of mountain photovoltaic power generation projects. Through scientific and reasonable plant allocation and management, soil erosion can be significantly reduced, ecological environment can be improved, and the sustainable development of the project can be promoted.

3.3 Farming practices In mountain photovoltaic power generation projects, reasonable farming measures play an important role in soil and water conservation. Firstly, the use of contour tillage techniques can effectively reduce surface runoff and soil erosion. Contour tillage preserves soil structure and fertility by reducing the velocity and erosiveness of water flows by performing tillage in the direction of the contour lines[3]. Secondly, the planting of cover crops is also an effective measure of soil and water conservation. Cover crops can increase the organic matter content of soil, improve soil structure, and reduce soil erosion and runoff[4]. In addition, a reasonable crop rotation system can improve soil fertility and reduce the occurrence of pests and diseases, thus reducing soil damage[5].

Finally, Ruijun Liu *et al.* believed that the use of mechanized farming equipment can improve farming efficiency, reduce labor costs, and at the same time perform more accurate soil management, thereby achieving better soil and water conservation effects[7]. The comprehensive application of these farming measures will help achieve the sustainable development of mountain photovoltaic power generation projects.

3.4 Provisional measures During the construction of mountain photovoltaic projects, the implementation of temporary soil and water conservation measures is crucial. These measures mainly include the rational layout of the construction site, the construction of temporary drainage system and vegetation protection. First of all, it is necessary to plan the construction site reasonably, minimize the damage to the original terrain, and avoid large area of bare soil to reduce the risk of soil erosion. Secondly, temporary drainage systems such as drains and grit chambers should be constructed to effectively control surface runoff and prevent soil erosion caused by rainwater scouring. Wang *et al.* believed that through artificial rainfall experiments, it can be found that different land use types have a significant impact on soil erosion, and the nutrient loss of farmland soil is greater than that of forest land and grassland[1]. Therefore, during the construction process, special attention should be paid to the protection of farmland and bare surface.

In addition, it is necessary to try to retain and protect the original vegetation, or restore the vegetation in time after the construction, so as to enhance the stability and erosion resistance of the soil. Catacutan and Cramb pointed out that vegetation filter belts have a significant effect in controlling soil erosion and the promotion of this method in the Philippines has been successful[2]. These temporary measures not only help reduce soil erosion during construction, but also lay the foundation for subsequent long-term soil and water conservation efforts.

4 Soil and water conservation management model

4.1 Management in planning and design stage In the planning and design stage of mountain photovoltaic power generation projects, soil and water conservation management is crucial. Firstly, the topographic characteristics of the project area should be fully considered, and photovoltaic panels and related facilities should be rationally arranged to reduce the risk of damage to surface vegetation and soil erosion. Wang *et al.* believed that simulating the soil nutrient loss law under different rainfall intensities in the planning stage can provide a scientific basis for project design, thereby effectively controlling soil and water erosion[1].

Secondly, the project planning should design a reasonable drainage system based on local hydrological conditions to ensure that rainwater can be discharged quickly and avoid water accumulation under the photovoltaic panels. Ruijun Liu *et al.* pointed out that the application of open CAN bus control system can realize high real-time and intelligent equipment control, thus improving construction efficiency and reducing the impact of human intervention on the environment[7].

In addition, sufficient areas for vegetation restoration should be reserved during the planning stage to enhance soil stability and erosion resistance by planting suitable native plants. Lei Chen *et al.* proposed that photovoltaic construction can not only improve the environment, but also achieve comprehensive management of soil erosion areas, which provides strong support for the sustainable development of the project[3].

Through scientific and reasonable planning and design, water and soil erosion can be effectively reduced in the early stage of the project, ensuring the smooth implementation and long-term operation of mountain photovoltaic power generation projects.

4.2 Management in the construction stage During the construction phase of mountain photovoltaic power generation projects, soil and water conservation management is crucial. First, it should be ensured that existing water flows (rivers, streams, and irrigation canals) are maintained and restored during construction to prevent soil erosion. Ethiopia believed that the leakage of oils, lubricants and wastewater should be strictly controlled to prevent their entry into water bodies and ensure that stagnant water bodies are properly disposed of in pits to avoid problems such as mosquito breeding.

Secondly, measures should be taken during the construction process to reduce the impact caused by quarrying, earth excavation and construction work, especially in protected areas and arable land. These areas should be restored to acceptable levels after construction and soil erosion control measures should be implemented to avoid runoff and siltation[7].

In addition, the disposal of construction waste should follow standard waste management procedures to ensure public safety.

4.3 Management in the operation and maintenance stage

During the operation and maintenance phase of mountain photovoltaic power generation projects, soil and water conservation management strategies are crucial. First of all, the water loss and soil erosion situation in the project area should be monitored and evaluated regularly, so that corresponding prevention and control measures can be taken in a timely manner. Wang *et al.* believed that through artificial rainfall experiments, the nutrient loss laws of different soil types under different rainfall intensities can be effectively studied, thus providing a scientific basis for soil and water conservation[1].

Secondly, vegetation cover within the project area should be maintained well to reduce surface runoff and soil erosion. Catacutan and Cramb pointed out that the utilization of natural vegetation strips (NVS) can effectively control soil erosion, and the promotion of this method in the Philippines has achieved remarkable results[4]. Therefore, in mountain photovoltaic power generation projects, this method can be used for reference to enhance soil stability by planting suitable vegetation.

In addition, construction activities should be strictly controlled during project operation to avoid soil disturbance and erosion caused by construction. Liu *et al.* pointed out that high real-time and intelligent equipment control can be realized through the open CAN bus control system, thus reducing the impact of construction on the environment[7]. This technology is also applicable in the operation and maintenance of photovoltaic projects, and can reduce human interference through intelligent equipment management.

The drainage system should be maintained and cleaned regularly to ensure smooth drainage and prevent soil erosion caused by accumulated water. De Girolamo *et al.* pointed out that soil moisture and land use type are important factors affecting runoff, and rational drainage management can effectively control runoff and reduce soil erosion[4].

5 Conclusion

The problem of water loss and soil erosion in mountain photovoltaic power generation projects has attracted widespread attention, and the research shows that reasonable soil and water conservation measures are crucial to the sustainable development of the

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projects. Through engineering measures, plant measures, farming measures and temporary measures, soil erosion can be effectively reduced and ecological environment can be protected. However, there are still some shortcomings in the current research on the sustainability of technology promotion and the differences in applicability among different regions.

Future research should further explore soil and water conservation technologies suitable for different topographical and climatic conditions, especially the application effects under complex topography and extreme climatic conditions. In addition, research on soil erosion monitoring and assessment technology should be strengthened, and modern technical means such as unmanned aerial vehicles, remote sensing and big data should be used to improve monitoring accuracy and efficiency. At the same time, it is necessary to promote community participation and government support to form a multi-party collaborative soil and water conservation management model to ensure the effective promotion and application of technology.

In short, the research of soil and water conservation for mountain photovoltaic power generation projects requires multi-disciplinary and multi-field collaborative cooperation. Through continuous innovation and practice, it can provide scientific basis and technical support for achieving the win-win goal of ecological environment protection and energy development.

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