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Ecological Product Value Calculation of "Agriculture + New Energy" Projects under the "Dual Carbon" Goals

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Abstract: *As a clean and renewable energy source, solar energy plays a significant role in achieving the goals of carbon peaking and carbon neutrality. The agrivoltaic complementary power station is a relatively popular photovoltaic utilization method nowadays, but there are relatively few studies on its ecological benefits. Therefore, this project takes the Xintai Agro-Photovoltaic Complementary Power Station as the research object, constructs an ecological benefit evaluation model of the agro-photovoltaic complementary power station, and conducts value calculation for its ecological products. The research results show that the agricultural photovoltaic complementary model effectively improves the production and utilization efficiency, bringing high ecological and economic benefits. This study provides a new idea for the coordinated development of photovoltaic resource development and ecological product value, and at the same time provides a scientific basis for the healthy and sustainable development of the photovoltaic industry.*

Keywords: *Agricultural and Photovoltaic Complementarity, Ecological Benefits, Carbon Neutrality and Carbon Peaking, Photovoltaic Power Stations*

1. Introduction

Under the background of carbon peaking and carbon neutrality, China is comprehensively promoting the high-quality development of renewable energy, among which solar energy is a clean and renewable energy source. Photovoltaic power generation is one of the most common forms of utilizing solar energy resources and plays a significant role in achieving the goals of carbon peaking and carbon neutrality. Tai 'an is a major traditional agricultural city in Shandong Province, with abundant agricultural resources. Vigorously carrying out the "agriculture + new energy" project and developing and promoting low-carbon agriculture is an inevitable path for transforming the city's economic development mode, high-quality promoting the process of agricultural modernization, and building a characteristic agricultural modernization path and an ecological civilization path.

With the continuous development of the photovoltaic industry, photovoltaic power stations have formed an agriculture-photovoltaic complementary model that combines with fishery, livestock breeding, forestry and other industries in accordance with local conditions [1]. The agricultural and photovoltaic complementary model has gradually become the development trend of photovoltaic power generation projects. At present, scholars' research on the agricultural and photovoltaic complementary model mainly focuses on the physical and chemical properties of the soil in the power station and the regional microclimate, the design of photovoltaic panel installation in the agricultural and photovoltaic complementary power station, and the yield of crops grown under the photovoltaic panels. For instance, *Barron-gafford* et al. found through empirical research that the nighttime temperature in the areas where photovoltaic power stations operate for power generation is usually 3-4°C higher than that in the control areas of wasteland. This study demonstrated the impact of agro-photovoltaic complementary power stations on the regional microclimate. Wei Lai *et al.* analyzed the growth and development of sweet potatoes in the agricultural-photovoltaic coupling system. The installation of photovoltaic panels would reduce the light intensity, resulting in a significant decrease in the total leaf area and leaf mass per plant. However, the installation of photovoltaic panels would significantly increase the economic benefits per unit area. These studies have certain reference value for the promotion of the agrivoltaic complementary model. However, such studies focus more on power generation and the economic benefits of crops under the panels, and only study one aspect of the impact [2]. There is still a lack of systematic assessment of

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the ecological benefits of power stations. In addition, photovoltaic power generation plays a very important role in achieving the dual carbon goals, and the agricultural and photovoltaic complementary model is gradually becoming a trend in the construction of photovoltaic power stations. Therefore, it is urgently necessary to conduct a scientific and quantitative assessment of the ecological benefits of agrivoltaic complementary power stations.

Agricultural photovoltaic complementary power stations use the land beneath photovoltaic panels for agricultural production and are usually equipped with corresponding agricultural facilities. Therefore, they can be regarded as a kind of facility farmland ecosystem. In addition to having a high supply product value, the farmland ecosystem also has a huge regulatory service value, such as soil conservation, water conservation, carbon sequestration, and oxygen release. This study adopts the functional value method, combines the characteristics of the agricultural photovoltaic complementary power station, comprehensively considers the supply products and regulation services, and takes the photovoltaic power generation project in the coal mining subsidence area of Xintai, the first of its kind in China built under the agricultural photovoltaic complementary model, as a case to calculate the value of ecological products.The research results of this project are expected to provide a reference for the ecological benefit assessment of the agro-photovoltaic complementary model, offer technical support for further enhancing the ecological benefits of agro-photovoltaic complementary power stations, provide new ideas for the coordinated realization of photovoltaic resource utilization and ecological product value, and at the same time provide quantitative basis for the development of low-carbon agriculture in Tai 'an City.

2. Analysis of Ecological Benefits of Agro-Photovoltaic Complementary Power Stations

The agricultural and photovoltaic complementary power station not only generates economic benefits but also brings about good ecological benefits, mainly manifested in enhancing the ecology

System services, such as regulating microclimate, preventing wind erosion and sand fixation, and regulating water sources, etc. More studies adopt qualitative assessment methods to explore their ecological value, while a small number of studies calculate the value of ecological products through quantitative methods. For instance, in Gansu Province, photovoltaic power stations have been organically integrated with vegetation, achieving a good sand prevention effect and realizing a win-win situation of sand prevention and control as well as poverty alleviation. Large-scale photovoltaic power stations in arid areas can also enhance the pollination service function of the local ecosystem and improve biodiversity.

The ecological effects of photovoltaic power stations and the environment are mainly manifested in three aspects: local microclimate, soil physical and chemical properties, and the influence mechanism of crops under photovoltaic panels [3]. Under normal circumstances, the temperature under photovoltaic panels will rise. The nighttime temperature in the photovoltaic power station area is usually 3 to 4 degrees Celsius higher than that in the wasteland control area. This is the impact of the agricultural photovoltaic complementary power station on the local microclimate. The reduction of solar radiation is an important cause of microclimate change. The crops grown under the photovoltaic panels will make the microclimate of the power station more suitable for photovoltaic panel power generation, thereby enhancing the power generation efficiency of the photovoltaic panels. By increasing the spacing between the panels and rationally setting up the photovoltaic panel array, not only shade-loving crops can be grown under the photovoltaic panels, but also other crops such as winter wheat and corn can be planted through the reasonable arrangement of the photovoltaic panel array. Meanwhile, other studies have shown that compared with the surrounding areas outside the photovoltaic field, the soil nutrient elements inside the photovoltaic field have undergone significant changes. For instance, soil organic matter, soil moisture content, and available phosphorus have increased significantly, but the electrical conductivity and PH value have decreased significantly. Seven years after the vegetation restoration in the photovoltaic field area, the carbon and nitrogen contents of the soil in the field area were still significantly lower than those in the control area outside the field [4]. The nutrient cycle of the soil had not been fully restored, and the soil particles showed coarsening. In addition, the changes in the microclimate under photovoltaic panels can also cause severe disturbances to soil respiration, affecting the carbon cycle of terrestrial ecosystems. Moreover, as plants are highly sensitive to changes in the microclimate, photovoltaic panels can also indirectly alter soil conditions through alterations in the composition of plant communities. In the early stage of photovoltaic development, the excavation and compaction of the ground surface will affect the growth of surrounding plants. However, due to the usually short construction period, although it may lead to a reduction in the number of individual species in the short term, it will not cause the extinction of that species. During the operation period, human interference is

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reduced, and the shading effect of photovoltaic panels redistributes rainfall, which will affect the environment of the plant community. More studies have focused on the two aspects of photovoltaic development on plant community diversity and biomass[5].

The agricultural and photovoltaic complementary power station uses the land under and between photovoltaic panels for agricultural production. Usually, it is also equipped with corresponding agricultural facilities (such as sprinkler or drip irrigation facilities), so it can be regarded as a kind of facility agriculture and belongs to the farmland ecosystem. In addition to having a high supply product value, the farmland ecosystem also has a huge regulatory service value, such as soil conservation, water conservation, carbon sequestration, and oxygen release. At present, many studies on the assessment of farmland ecosystem services have been carried out at home and abroad, and a good foundation for the value calculation of ecological products in farmland ecosystems has been accumulated. The earliest constructed framework for calculating the value of ecological products in New Zealand's farmland ecosystem consists of four parts: supply products, support services, regulation services, and cultural services, with a total of 14 indicators. Some scholars have calculated the total value of farmland ecosystem services in different time periods in Qingdao, Shandong Province. The results show that the four types of ecosystem services, namely product supply, carbon sequestration, oxygen release and soil conservation, account for a large proportion in the total value of farmland ecosystem services in the whole city and continue to increase [6]. The assessment of the value of ecological products in farmland ecosystems can quantitatively reflect ecological benefits, and the calculation results have great guiding significance for agricultural production.

3. Value calculation of ecological products in Agricultural and photovoltaic Complementary power stations

3.1 Overview of the Study Area

Xintai is located in the central part of Shandong Province, at the eastern foot of Mount Tai. Its terrain is mainly hilly and it is rich in mineral resources. In terms of climate, Xintai has a mid-latitude warm temperate monsoon continental climate, characterized by good sunlight, abundant heat and concurrent rainfall and heat. The average annual duration of sunshine within the territory is 2,445.6 hours. There are coal mines distributed in all 11 towns and sub-districts of Xintai City. The exploitable reserves of coal resources in Xintai City amount to 660 million tons. A total of 460 million tons have been mined, with about 200 million tons remaining. Relying on the mining of coal resources, Xintai's economy has developed rapidly and it has been selected as one of the top 100 counties in China for many years. However, coal mining has also caused significant environmental problems, with subsidence occurring in many areas.

The Xintai 2 million kilowatt agricultural and photovoltaic complementary photovoltaic power station is the first photovoltaic power generation demonstration base in China that adopts the agricultural and photovoltaic complementary model and is built in a coal mining subsidence area. In 2016, the first phase of the 500,000-kilowatt project was included in the second batch of national photovoltaic leading technology bases for coal mining subsidence areas and was among the first batch of photovoltaic leading technology bases in the province. With a total investment of 5 billion yuan, it built 6 photovoltaic power stations with complementary agriculture and photovoltaic power and 9,620 high-efficiency agricultural greenhouses of various types, covering 3 towns including Zhai Town, Quangou Town and Xizhangzhuang Town, and 49 villages. Among them, the Huaneng Xintai 100MW photovoltaic agricultural Project is located within Zhai Town, Xintai City, Shandong Province. It consists of the Qianyang area and the Zhai Nan area, covering an area of approximately 3.68 square kilometers. The installed capacity of photovoltaic power generation is 100MW, with 1,464 photovoltaic agricultural greenhouses covering an area of 106 hectares and an open-air planting area of about 80 hectares. Agricultural greenhouses adopt the integrated water and fertilizer irrigation technology. According to the growth needs of crops, the water and nutrients required by the crops are provided directly to the crops in a timely, quantitative and timed manner based on the different growth stages of the crops in proportion.

Agricultural photovoltaic complementary power stations utilize the space beneath photovoltaic panels for agricultural production activities. Essentially, it is a form of facility agriculture, capable of providing agricultural products and many regulation services that cannot be exchanged in the market. In this study, the indicators were screened based on the characteristics of the agro-photovoltaic complementary power station, and six accounting indicators, namely agricultural products, water conservation, soil retention, carbon sequestration, oxygen release and air purification, were determined.

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Among them, agricultural products refer to the grains, fibers and fuels obtained from the land beneath the photovoltaic panels, and they are one of the significant contributions of agriPV complementary power stations to human well-being. In addition, the agrivoltaic power station also has the functions of soil conservation and water source conservation. The nutrient circulation in the soil can ensure soil fertility and store water at the same time, providing necessary conditions for plant growth. Crops grown under photovoltaic panels have the functions of carbon sequestration and oxygen release, and carbon sequestration is characterized by a short cycle and a large accumulation volume. In addition, the crops under the photovoltaic panels have a certain absorption effect on pollutants such as sulfur dioxide, nitrogen oxides and dust in the atmosphere. In conclusion, the ecological product value calculation of the agrivoltaic complementary power station in this study includes two parts: supply products and regulation services. The supplied products mainly include agricultural products, which are the output of crops such as grains and fruits directly grown by the power station. Regulation services mainly include water conservation, soil retention, carbon sequestration, oxygen release, air purification and other aspects, and are mainly calculated through methods such as market value method and shadow engineering method. The data required for accounting mainly include those obtained through statistical yearbook surveys and on-site visits.

3.2 Valuation of ecological Products in the study Area

The value calculation of ecological products in the study area is shown in the table 1. Among agricultural products, the annual output of strawberries is 100 tons, the annual total output of vegetables is 250 tons, and about 3,000 chickens, ducks and geese are planted. Among the regulatory functions, the water conservation capacity is 5.28×10^{3} cubic kilometers, the soil retention capacity is 1 million tons, the carbon sequestration capacity is 6,620 tons, the oxygen release capacity is 4,800 tons, and the air purification capacity is 16 tons. These are the main components of the ecological product capacity. The calculation results have great guiding significance for agricultural production.

Table 1: Calculation Results of Ecological Product functional Quantities of Agricultural photovoltaic Complementary power Stations

Category	Indicator	Better understand (%)	Functional quantity
Supply products	Agricultural products	Strawberry	100t
		Vegetables	250t
		Chicken, duck and goose	3000
Adjustment service	Water source conservation		$5.28\times10^{3}km^{3}$
	Soil conservation		$100\times10^{3}t$
	Carbon sequestration		6620 t
	Release oxygen		4800 t
	Air purification		16 t

The comparison results of the quantity of each regulation service function in the case area show that the abundance of regulation services varies in different areas. The abundance of regulation services in the strawberry area is relatively high. The abundance of water conservation function is the largest in the vegetable area and is three times that of the smallest area aquaculture area. The abundance of soil retention function is the greatest in the aquaculture area, the abundance of carbon sequestration and oxygen release function is the greatest in the strawberry area, the abundance of air purification function is relatively high, and there is little difference among various regions. The results of the correlation analysis of the regulation services in the entire case area and each region show that there are strong positive correlations among the water conservation and air purification functions, carbon sequestration and oxygen release functions, and carbon sequestration and air purification functions of the agro-photovoltaic complementary power station, with correlation coefficients of 0.84, 1.00 and 0.79 respectively. However, the negative correlation between soil conservation function and water conservation is significant. The correlation coefficient is -0.07. The correlation coefficients of each region vary, but they are consistent with the overall region in terms of trend. Overall, the four types of ecosystem services, namely water conservation, carbon sequestration, oxygen release and air purification, work in synergy with each other, while soil conservation and the functions of water conservation and air purification show a trade-off relationship in most areas. The ecological value of "photovoltaic +" power stations can be better understood through the correlation analysis of regulation services.

The power generation of "photovoltaic +" is a clean energy source, which is conducive to improving the local energy structure. The clean electricity generated simultaneously can reduce the emission of air pollutants. The carbon reduction of the Xintai Agricultural Photovoltaic Complementary Power Station is mainly calculated based on the power generation substitution method. According to the field research data, the average annual power generation of the power station is approximately 200 million kilowatt-hours, which can save about 70,500 tons of standard coal for the power grid. Each year, it will reduce carbon dioxide emissions by approximately 185,000 tons, sulfur oxide emissions by about 599 tons, and nitrogen oxide emissions by about 522 tons.

4. Conclusion and Prospect

While generating good economic benefits, the agro-photovoltaic complementary power station also brings certain ecological benefits. The functional value method can be used to evaluate the ecological product value of the agro-photovoltaic complementary power station. The research results of the case area in this study show that the agro-photovoltaic complementary power station can achieve dual benefits of energy and agriculture, and is expected to promote the coordinated development of photovoltaic and agriculture. The ecological product value of the agro-photovoltaic complementary power station shows obvious spatial heterogeneity in different planting or breeding type areas. Therefore, the spatial layout of ecological products can be optimized in combination with the calculation results, thereby enhancing the ecological benefits and comprehensive benefits of the power station.

As a facility agriculture system, the agricultural and photovoltaic complementary photovoltaic power station has achieved good social and economic benefits as well as ecological benefits through the three-dimensional utilization technology of land. The agricultural and photovoltaic complementary model is the future development trend of photovoltaic power stations. Quantitatively evaluating the ecological benefits of the agricultural and photovoltaic complementary model is conducive to the development of the industry. The calculation of the ecological product value of photovoltaic complementary power stations is the basis for accurately assessing their ecological benefits and also an important basis for quantifying the ecological impact generated by the development of photovoltaic resources. However, unlike the calculation of ecological product value in administrative regions, the calculation at the scale of power station projects often lacks statistical and monitoring data. This study adopted the methods of field sampling and investigation to obtain relevant data, which also means that the quantitative assessment of other similar projects also requires field sampling and investigation. Therefore, when conducting large-scale promotion and establishing a long-term assessment mechanism, the cost issue needs to be considered. In the future, it is necessary to expand the application scenarios based on the value accounting results of ecological products in agricultural and photovoltaic complementary power stations (such as establishing agricultural carbon accounts and the ecological function occupation and compensation balance mechanism for project development), and establish an ecological product value application system.

The agricultural and photovoltaic complementary model is in line with the direction of green and sustainable development and plays an important role in the sustainable development of the power industry. Under the background of carbon peaking and carbon neutrality, the installed capacity of photovoltaic power stations, which are clean and green energy sources, is showing a continuous growth trend. In the future, we can actively explore diversified paths for the coordinated development of renewable energy with ecology, production and life, establish a comprehensive assessment system for renewable energy projects, carry out monitoring, assessment and simulation of ecological, economic and social comprehensive benefits, and provide scientific basis for different project management.

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