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Economic Analysis Study of Agricultural and Solar Complementary System

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Abstract Agro-photovoltaic complementary system (APCS) is an innovative land use model combining agricultural production with photovoltaic power generation, aiming to realize dual land use and improve land use efficiency and economic benefits by installing photovoltaic panels on farmland. With the growth of global energy demand and the intensification of climate change, agro-photovoltaic (APV) systems have received widespread attention as a sustainable energy solution. Studies have shown that agro-photovoltaic systems exhibit significant economic benefits in different regions and crop types. Through reasonable system design and optimization, the agricultural and photovoltaic complementary system is not only technically feasible, but also has significant economic advantages, which provides a strong support for achieving the goal of sustainable development.

Key words Agricultural and photovoltaic complementary systems, Economic analysis, Land use efficiency, Cost-effectiveness

1 Introduction

Agro-photovoltaic (APV) systems, a combination of agricultural and photovoltaic (PV) power generation systems, are an innovative land use approach for at achieving the dual goals of agricultural production and solar power generation at the same time. With the increasing global energy demand and climate change, finding sustainable energy solutions has become particularly important. By installing photovoltaic (PV) panels on agricultural land, agro-photovoltaic (APV) systems can not only improve land use efficiency, but also provide stable power support for agricultural production, thus reducing dependence on traditional energy sources[1]. In a study in the Stuttgart region of Germany, agro-photovoltaic systems were shown to significantly increase agricultural gross margins, and despite poor results in certain crop rotation structures, had an overall positive impact on both agricultural and economic performance. Similarly, in studies in India, agro-photovoltaic systems have shown significant benefits in terms of energy output and crop yields in different seasons, demonstrating their potential in future energy and food security[2]. The economic analysis of agro-photovoltaic systems focuses on their cost-effectiveness and long-term sustainability. Through techno-economic analysis of different PV system configurations, the optimal system design and configuration can be determined to maximize the economic benefits. For example, in the study in northern Nigeria, by optimizing a hybrid PV/wind/battery/diesel system, it was found that such a hybrid system has significant economic and environmental advantages. In addition, in a study in Sri Lanka, the solar water pumping system also showed significant economic and environmental advantages compared to the conventional fuel water pumping system[3].

Therefore, the agro-photovoltaic system is not only technically feasible, but also has significant economic advantages. Through reasonable system design and optimization, a win-win situation of agricultural production and solar power generation can be achieved, thus providing strong support for achieving the goal of sustainable development.

2 Methods of economic analysis of agricultural photovoltaic complementary system

2.1 Cost-benefit Analysis Cost-benefit analysis plays an important role in the economic assessment of agricultural photovoltaic complementary system. By comprehensively considering the initial investment, operation and maintenance costs and expected benefits of the system, the economic feasibility of the agricultural solar hybrid system can be comprehensively evaluated. First, the initial investment includes the procurement and installation costs of PV modules, racking, inverters and other equipment. Second, the operation and maintenance costs cover the daily maintenance of the system, equipment replacement, and possible land lease costs. These cost factors need to be estimated in detail over the entire life cycle of the system.

By quantitatively comparing the costs and benefits, the net present value (NPV) and internal rate of return (IRR) of the system can be calculated to determine the economic feasibility of the project[4]. For example, in some regions, the average gross profit margin of an agro-photovoltaic system can be significantly higher, indicating that the system has high economic efficiency under specific conditions. However, the agricultural structure and PV power generation conditions vary greatly in different regions, so a regional analysis is needed to determine the optimal configuration of the

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agro-photovoltaic system.

2.2 Net present value (NPV) and internal rate of return (IRR) methods The NPV method and the IRR method are important tools for evaluating the economics of agro-photovoltaic systems. The NPV method evaluates the economic feasibility of a project by calculating the discounted value of its cash flows over its entire life cycle. Specifically, the NPV method discounts future cash flows to the current point in time and subtracts the initial investment cost. If the NPV is positive, it indicates that the project is economically feasible.

The IRR method evaluates the project's return on investment by calculating the discount rate that brings the project's NPV to zero. The higher the IRR, the more economically attractive the project is. For agro-photovoltaic systems, the IRR method can help decision makers compare the economic benefits of different projects and choose the optimal investment program.

In the application of agro-photovoltaic systems, the NPV method and IRR method not only consider the benefits of electricity production, but also need to comprehensively consider the value-added benefits of agricultural production. For example, in some regions, agro-photovoltaic systems can significantly increase the value of agricultural production, thereby increasing overall returns. In addition, these methods need to consider the impact of factors such as policy support and market price fluctuations on project economics.

Through the combined application of the NPV and IRR methods, decision makers can more comprehensively assess the economics of an agricultural photovoltaic system and thus make more scientific and reasonable investment decisions.

3 Case analysis

3.1 Introduction to the case background In this study, an agro-photovoltaic system in the Stuttgart region of Germany is selected as a case for economic analysis. The Stuttgart region is one of the most important urban agglomerations in Germany and Europe with extensive and representative agricultural land. The application of agro-photovoltaic systems in this region aims to improve land use efficiency through simultaneous electricity production and agricultural activities. The study employs an integrated land use model that optimizes the use of agricultural land to maximize the total profit at the farm level and takes into account legal framework conditions such as regional planning as well as yield effect data from existing studies.

3.2 Economy analysis process When analyzing the economics of a farm-photovoltaic system, it is first necessary to identify the land use structure and crop types in the study area. By integrating the land use model, the use of farmland can be optimized to maximize the gross profit of the farm. In this process, legal framework conditions and regional planning need to be considered as constraints and analyzed in conjunction with yield effect data from existing studies.

Next, an economic model was used to assess the economic benefits of different crops under the farm-photovoltaic system. It was shown that the cultivation of specific crops such as strawberries showed high profitability under the agro-photovoltaic system, while the cultivation of root crops was relatively unfavorable. Therefore, the economic analysis of agro-photovoltaic systems must take into account the types of crops and land use structure in the region for a comprehensive assessment.

In addition, a detailed cost-benefit analysis is required, including initial investment costs, operation and maintenance costs, and life cycle costs of the system. By comparing the change in gross margins under conventional agriculture and agro-photovoltaic systems, the economic viability of agro-photovoltaic systems can be assessed. For example, in the study area, the average gross profit per hectare decreases by about 280 euros when more than 10% of the farmland area is utilized with an agro-photovoltaic system.

Finally, simulation and optimization tools, such as the HOMER Pro software, allow further optimization of the design and configuration of the agro-photovoltaic systems to ensure that they maximize the economic benefits in a given area[5]. This approach not only helps to identify priority implementation areas, but also provides decision support to policy makers and promotes the widespread application of agricultural solar hybrid systems.

Therefore, the economic analysis of agricultural and photovoltaic complementary systems needs to take into account various factors such as land use, crop types, legal frameworks, and cost-benefit, and be comprehensively evaluated through integrated models and optimization tools to ensure its economic efficiency and feasibility within a specific region.

3.3 Discussion of the results of the analysis When analyzing the economics of the agro-photovoltaic system, the results of the study show significant differences in the economic benefits of the system across crops and regions. Taking the Stuttgart region as an example, the study shows that the agro-photovoltaic system can realize an increase in the total agricultural profit on about 3% of the cultivated land. However, when the coverage of the agro-photovoltaic system exceeds 10%, the total agricultural profit decreases by about 280 euros per hectare on average. This suggests that the economic benefits of agro-photovoltaic systems are highly dependent on crop type and cropping structure.

Furthermore, the study points out that agro-photovoltaic systems show higher profitability in the cultivation of specific crops such as strawberries, whereas they are less suitable in areas where root crops are in rotation. This further emphasizes the importance of considering the diversity of agricultural land use structures and crop types when conducting economic assessment of agro-photonic systems.

4 Conclusion and prospects

The agro-photovoltaic system, as an innovative land use, realizes the dual objectives of agricultural production and solar power

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taxonomic levels were statistically analyzed. At the phylum level, Proteobacteria showed very obvious performance, and the relative abundance in rice and maize samples reached more than 17.3%. The fungi were compared with the database UNITE, species annotation was carried out, and different taxonomic levels were statistically analyzed. At the phylum level, the dominant phylum is Ascomycota. Alpha diversity refers to the number of species in local uniform habitat, which can reflect the coexistence results of microbial communities by competing for resources or utilizing the same habitat[13]. In the analysis of Alpha diversity of soil microbial community, the diversity of bacteria and fungi in rice soil is relatively abundant. In addition, it can enrich China's strain resource bank and promote the application of microbial fertilizers in agriculture.

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generation by installing photovoltaic panels on agricultural land. The results of the study show that agro-photovoltaic systems have significant advantages in increasing land use efficiency, providing renewable energy, and improving agricultural output. However, their economic benefits are affected by a number of factors, including crop type, seasonal variations, and land use structure.

The economics of agro-photovoltaic systems are highly dependent on crop type and cropping structure. Therefore, when designing and implementing agro-photovoltaic systems, priority should be given to selecting suitable crop types to maximize the economic benefits. Policy support and subsidies play a key role in the promotion of agro-photovoltaic systems. The government should formulate favorable legal frameworks and plans, and provide financial subsidies and tax incentives to encourage farmers and enterprises to invest in agro-photovoltaic systems. In addition, improving the efficiency and durability of PV modules through technological innovation and R&D, and lowering the initial investment and operation and maintenance costs of the system will also significantly improve its economics.

In the future, the development of agro-photovoltaic systems should further incorporate region- and crop-specific optimization designs. By comprehensively considering factors such as land use, crop types, and climatic conditions, advanced simulation and optimization tools should be used to develop a scientific and reasonable system configuration plan. At the same time, international cooperation and experience exchange should be strengthened, successful cases and best practices should be promoted, and the widespread application of agricultural and solar complementary systems should be promoted worldwide.

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