Transactions on Economics, Business and Management Research
ISSN: 2960-1789, eISSN: 2960-2254 | Volume 4
EMSD 2023

Comprehensive Utilisation and Performance Optimisation of Agro-electricity and Agro-photovoltaic Complementary Systems in Agricultural Production

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Abstract. Agroelectricity agro-photovoltaic (APV) complementary systems are increasingly attracting attention in the field of agricultural production as a way of integrating and utilising renewable energy resources. The aim of this study is to investigate the integrated utilisation and performance optimisation of agro-electricity agro-photovoltaic (AEPV) systems in agricultural production in order to improve the efficiency of agricultural production, conserve energy resources, and protect the environment. The integrated utilisation section explores the application of agroelectricity agro-photovoltaic systems in different types of agricultural production, emphasising the importance of integrated energy utilisation strategies to improve energy and economic efficiency. The Performance Optimisation Methods and Strategies section describes optimisation methods for system operation, equipment performance, energy dispatch and storage to improve system performance and reliability. The section on sustainability and environmental impacts emphasises the environmental friendliness and sustainability of agropower agro-photovoltaic systems, and discusses related environmental protection strategies and social responsibility. The research and application of agro-power agricultural and photovoltaic complementary systems are expected to bring more sustainable and cost-effective solutions to agricultural production.

Keywords: Agro-electricity and Agro-photovoltaic Systems; Agricultural Production; Renewable Energy; Integrated Utilisation; Performance Optimization.

1. Introduction

As one of the world's most important industries, agriculture not only provides critical support to the global food supply, but also plays a vital role in socio-economic and rural livelihoods. However, with a growing global population and the threat of finite resources, agricultural production faces increasing challenges. One of these is the tension between the demand for energy and sustainability, which has prompted a greater focus on renewable energy and energy efficiency [1][4].

Against this background, agro-power agro-photovoltaic systems have emerged. Agropower agro-photovoltaic systems are innovative solutions that integrate the use of renewable energy sources such as solar and wind, aiming to provide reliable electricity and heat for agricultural production [5]. Through proper layout, operation and performance optimisation, this system can increase the efficiency of agricultural production and reduce the waste of energy resources, while reducing the dependence on traditional fossil fuels, which is beneficial for reducing greenhouse gas emissions and protecting the ecological environment [6].

The objective of this study is to investigate the integrated use and performance optimisation of agro-electricity and agro-photovoltaic (APV) systems in agricultural production to address energy and environmental challenges[7]. Through an in-depth study of system construction, performance evaluation, integrated utilisation strategies and performance optimisation methods, we aim to provide a more efficient and sustainable solution for agricultural production, while improving the availability of electricity in rural areas and the livelihoods of farmers [8].

2. Construction and Performance Evaluation of Agro-electricity and Agro-photovoltaic Complementary System

The construction and performance evaluation of the agroelectricity agro-photovoltaic complementary system is a key part of the study. The agropower agro-photovoltaic (APAP) system is a multi-energy integration system, which mainly consists of solar photovoltaic (PV) modules, wind turbines, battery storage systems, inverters and power management systems. These components work together to provide a stable power supply. Specific construction steps include: the selection of solar PV modules and wind power generation equipment, the performance and efficiency of the system depends on the selected PV modules and wind power generation equipment [9]. Appropriate modules must be selected based on the meteorological conditions and energy requirements of the region. System layout and design, after selecting the appropriate components, the layout of the system must be designed. This includes the arrangement and placement of the components to ensure maximum energy capture and optimal system efficiency [10]. Safety and reliability considerations, agri-power agri-photovoltaic systems need to be considered for safety and reliability, especially in rural environments. This includes the implementation of lightning, wind and fire safety measures [11]. System operation principle, agropower agro-photovoltaic systems harvest energy through solar PV and wind power and then store it in batteries. The inverter converts the DC power to AC power for use by the agricultural equipment. The system can also be connected to the grid for two-way energy flow.

In the case of agri-electricity agri-photovoltaic systems, performance evaluation is key to ensuring their effective operation. To understand how well the system is performing, solar PV and wind power capacity must be evaluated. This includes monitoring the energy output of the system under different meteorological conditions [12]. The efficiency of the system is an important indicator, including the energy conversion efficiency and the number of hours the system is at full load. The match between energy output and consumption is also an important performance parameter [13]. Evaluating the economic performance of the system includes investment costs, operation and maintenance costs, and economic indicators such as return on investment and expected present value. Reliability indicators of the system include system failure rate, failure recovery time and operational stability evaluation. These indicators can help determine the reliability and availability of the system.

In order to evaluate the performance of agropower agro-photovoltaic systems more comprehensively, it is often necessary to use simulation tools, data collection and monitoring systems, and experimental studies [14]. These tools and methods can be used to collect performance data, verify system reliability, and perform performance optimization [15]. The construction and performance evaluation of agropower agro-photovoltaic systems are critical steps towards efficient energy use and sustainable agricultural production.

3. Integrated Use in Agricultural Production

The integrated use of agro-electricity and agro-photovoltaic systems in agricultural production is one of the core objectives of the technology, aiming to maximize the benefits of agricultural production, reduce energy waste and promote sustainable agricultural development [16].

The energy requirements for agricultural production include a variety of uses such as electricity supply, pumping irrigation, and greenhouse heating. These energy needs are highly variable from season to season and from one agricultural activity to another. The goal of integrated use is to meet these energy needs while reducing costs and environmental impacts [17]. Agropower agro-photovoltaic systems integrate solar photovoltaic (PV) and wind power, utilising different sources of energy. On sunny days and when there is plenty of wind, solar PV and wind power can work together to provide a steady stream of electricity [18]. This synergistic use reduces reliance on the grid and lowers electricity bills. Agri-power agri-photovoltaic systems often include battery storage systems to store excess power for use at night or during bad weather. This increases the availability of the system and allows agricultural production to operate with an uninterrupted supply of electricity [19]. In addition to electricity supply, thermal energy is also required in agricultural production, such as greenhouse heating and water heating. Agri-electricity agro-photovoltaic systems can utilise technologies such as solar thermal panels to collect and store thermal energy to meet these needs. The key to integrated use is to optimise the synergy of different energy sources. This includes intelligent power management systems for deciding when to source energy from solar, wind, batteries or the grid to maximise efficiency and economy [20]. Agri-electricity agro-photovoltaic systems should also include energy efficiency measures such as energy efficiency improvements, equipment upgrades and optimisation of agricultural production processes. These measures help to reduce energy waste and improve integrated utilisation. By reducing dependence on fossil fuels and reducing greenhouse gas emissions, agro-electricity agro-power systems help protect the environment and promote sustainable agricultural production. Comprehensive utilisation not only benefits the environment, but also reduces the cost of agricultural production in the long term, improves economic efficiency and increases farmers' incomes.

Comprehensive utilisation of agro-electricity, agro-power and agro-photovoltaic systems has a wide range of applications in different agricultural environments, and can be adapted to the energy needs and meteorological conditions of different regions, providing sustainable and efficient energy solutions for agricultural production.

4. Performance Optimisation Methods and Strategies

Performance optimisation is a key step in ensuring the efficient operation of agro-electricity agro-photovoltaic systems in agricultural production. Using advanced smart power management systems, system performance and energy demand can be monitored in real time. These systems can automatically adjust energy sources, such as power from solar, wind, batteries or the grid, to maximise efficiency [21]. Optimise load management of agricultural production equipment to ensure power supply matches demand. Rationalise the scheduling of agricultural activities to meet agricultural demand while using energy efficiently [22]. Adjust the system's mode of operation according to changes in meteorological conditions, seasons and energy output. For example, increase the output of wind turbines when there is sufficient wind, and increase the output of solar PV when there is sufficient sunlight.

Maintain the system's equipment in good working condition, through regular maintenance and overhaul to minimise the risk of breakdowns and ensure consistent performance. Upgrade the components of the system in line with technological advances and market availability to improve energy conversion efficiency and system reliability. Use sensors and monitoring equipment to monitor component performance in real time, as well as identify problems in advance and take action to prevent performance degradation. Effectively manage battery energy storage systems, including charge and discharge control, to maximise battery life and performance. Determine when to store excess energy in batteries for subsequent use to ensure that the system provides a stable power supply despite unstable weather conditions. Consider back-up power sources, such as diesel generators or back-up battery packs, to respond to system failures or special circumstances to ensure uninterrupted agricultural production. Develop suitable synergistic strategies for solar PV and wind power to work together to balance the system's energy supply. Designing systems so that new energy sources, such as biomass or small hydroelectric generators, can be easily integrated to increase the potential for multi-energy synergy optimisation. Use meteorological data analysis tools to predict future solar and wind resources to aid system scheduling and planning. Analyse energy consumption patterns in agricultural production to predict future demand and adjust system operations accordingly.

Performance optimisation methods and strategies help to ensure that agri-power agri-solar systems achieve optimal results in agricultural production. By continuously improving the design and operation of the system, it is possible to increase energy utilisation and reduce costs while improving system reliability and availability. These strategies will help to achieve sustainable agricultural production and efficient use of renewable energy.

5. Sustainable Development and Environmental Impacts

Sustainability and environmental impacts are crucial considerations in the research and application of agro-electricity agro-photovoltaic systems. Sustainability is one of the key objectives of agroelectric agro-photovoltaic systems, aiming to meet current agricultural production needs without compromising resources for future generations. The following are key points related to sustainability: agropower agro-photovoltaic systems utilise renewable energy sources, such as solar and wind, reducing the need for finite fossil fuels and helping to reduce the risk of resource depletion and energy price volatility. The use of renewable energy contributes to the reduction of greenhouse gas emissions and reduces the risk of climate change. This contributes to the preservation of ecosystems and reduces the adverse impacts of erratic weather events on crops in agricultural production. Agro-electricity, agro-photovoltaic systems can reduce the cost of agricultural production, improve the economic efficiency of farmers, increase incomes in rural areas and promote rural economic development. Promoting the research and application of agro-electricity agricultural light complementary system also promotes the innovation of renewable energy technology and contributes to the sustainable development of the energy sector in the future.

The construction and operation of agropower agricultural photovoltaic complementary systems will have certain impacts on the environment, but these impacts are relatively small. Solar photovoltaic and wind power plants require land occupation, but their site requirements are usually low compared to traditional energy infrastructures. Proper land use planning can reduce the impacts of land occupation. The construction of agro-power agro-photovoltaic systems needs to consider the impacts on local ecosystems, especially wildlife and habitat protection. Compliant environmental assessment and protection measures are important to minimise environmental impacts. The manufacturing of PV modules and the solar power generation process generates a number of wastes that need to be properly managed and disposed of. This includes recycling of recyclable materials and safe disposal of hazardous waste. The cooling and cleaning processes of agri-power agro-photovoltaic systems require the use of water resources and therefore require rational planning and water conservation strategies.

In order to minimise environmental impacts, the design and operation of agri-power AFPS systems need to follow relevant environmental regulations and best practices to ensure environmental sustainability and protection. At the same time, the principle of sustainable development needs to be fully considered in the design and application of agro-power ASPAR systems in order to realise the dual objectives of environmental protection and socio-economic benefits.

6. Conclusion

As an innovative solution for the integrated utilisation of renewable energy, agro-electricity agro-photovoltaic (AEPV) systems have achieved remarkable success in agricultural production. Through an in-depth discussion of system construction, performance evaluation, integrated utilisation and performance optimisation, this study concludes that agro-electricity agro-photovoltaic (AEPV) systems show great potential in different types of agricultural production to meet the demand for electricity and thermal energy in agricultural production and to reduce the cost of energy. The application of performance evaluation methods and tools helps to effectively monitor and optimise system performance to ensure system reliability and availability. Integrated utilisation strategies, such as multi-energy co-optimisation and energy scheduling, can maximise energy utilisation efficiency and improve system economics. The sustainability of agropower ASP systems shows clear advantages, including reduction of greenhouse gas emissions, resource conservation and economic benefits. Despite the success of agro-power agro-photovoltaic systems, they still face a number of challenges in practice, including cost issues, sustainability management and environmental impacts.

Future research and applications can continue to improve and develop agropower APS systems for greater sustainability and performance optimisation. Continued investment and R&D can drive advances in solar PV and wind power technologies to improve energy conversion efficiency, reduce costs, and lower the environmental impacts of the systems. Research and application of advanced energy storage technologies, such as high-performance batteries and energy storage systems, to improve system availability and efficiency. Smarter power management systems can optimise system operation through data analysis and forecasting to improve overall utilisation efficiency. Improve the stability and reliability of rural power grids to better support the application of agro-power and agro-photovoltaic systems. Governments and relevant stakeholders can provide incentives, such as subsidies and tax concessions, to promote the widespread use of renewable energy in agricultural production. Enhance public education and participation to promote awareness and support for sustainable agricultural production and energy use.

Through continued research and innovation, agropower agro-photovoltaic systems are expected to provide more sustainable and efficient energy solutions for agricultural production while promoting the development of rural areas and the sustainable use of resources. Future endeavours will help to achieve cleaner and greener agricultural production and energy supply.

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