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Green Energy Growth: Enhancing Agricultural Sustainability through Agrivoltaic Solutions in the Modern Era

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Abstract

Agrivoltaic is a system that integrates agricultural activities with the production of solar photovoltaic electricity on the same piece of land. Agrivoltaic systems are gaining popularity in Indonesia since they enable farmers to generate renewable energy while making efficient use of agricultural land. This research technique employs the analytical descriptive approach, which aims to offer a comprehensive description or overview of the topic of study using acquired data or samples without undertaking further analysis to draw generalizable conclusions. An instance of agrivoltaic in Indonesia involves the placement of solar panels above crops to provide shade and minimize water evaporation. Simultaneously, these solar panels generate energy to operate irrigation systems or other agricultural machinery. Nevertheless, the use of agrivoltaic in Indonesia remains restricted and need further investment and assistance from both the government and private sector to enhance the acceptance of this technology in the agricultural industry.

Keywords: Agrivoltaic, Solar Panels, Adoption, Technology, Agriculture.

Agrivoltaics, the integration of solar photovoltaic (PV) systems with agricultural practices, have gained significant attention in modern agriculture due to their potential to address multiple challenges faced by the agricultural sector. Research has shown that agrivoltaic systems offer a strategic and innovative approach to combine renewable energy generation with agricultural production (Pascaris; Schelly; Pearce, 2020). These systems have been found to have a high potential to attenuate negative effects of drought on crop growth, thereby increasing the resilience of agricultural production under variable environmental conditions (Schweiger; Pataczek, 2023). Moreover, agrivoltaics have been identified as a means to enhance food production by integrating PVs into agricultural frameworks such as greenhouses (Haroon; Janjua, 2021). The surge in the worldwide population has resulted in a corresponding escalation in energy demands (Haslinah et al., 2024).

Studies have indicated that agrivoltaic systems can provide various benefits to agriculture, including increased crop yields, plant protection from excess solar energy and hail, improved water conservation, and maintenance of agricultural employment and local food supplies(PEARCE, 2022). Furthermore, the co-location of solar PV and agriculture in agrivoltaic systems has been recognized as a solution for low-carbon electricity generation while maintaining or even increasing agricultural output(PASCARIS et al., 2021). The potential economic benefits of agrivoltaic systems have been highlighted, with findings showing over a 30% increase in economic value compared to conventional agriculture (Horowitz; Macknick; Margolis, 2020).

Agrivoltaics have been studied globally, with researchers exploring key factors such as vegetation establishment, soil characteristics, microclimate conditions, hydrology, ecological services, and solar technology cost and performance (Khele; Szabo, 2021). In regions like East Africa, agrivoltaic systems are seen as a way to increase community resilience against climate change impacts by improving water use efficiency and reducing heat stress for crops (Warmann, 2024). Additionally, agrivoltaics have been identified as a climate-smart agriculture approach for Indian farmers, offering benefits such as rural electrification, water conservation, yield improvement, sustainable income generation, and reduced pesticide usage (Derner et al., 2023). The extension is a proactive approach that necessitates direct interaction between the extension worker and the subject in order to initiate a process of behavior modification (Sulandjari et al., 2022).

Agrivoltaics, the practice of combining solar photovoltaic systems with agricultural activities, has gained significant attention in recent years due to its potential to address multiple challenges faced by modern agriculture. Research has shown that agrivoltaic systems offer various benefits, including increased crop yields, protection for plants from excessive solar energy and hail, improved water conservation, and enhanced land-use efficiency (Pearce, 2022; Proctor; Murthy; Higgins, 2020). These systems have the capacity to mitigate the negative impacts of drought on crop growth, thereby increasing the resilience of agricultural production under changing environmental conditions (Schweiger; Pataczek, 2023). Climate change is the result of several causes. Building is one of the variables that exert effect on climate change (Munawaroh et al., 2022).

Studies have indicated that agrivoltaic systems can lead to a substantial increase in economic value for farms that integrate shade-tolerant crop production with solar electricity generation (Andrew et al., 2021). Furthermore, the implementation of agrivoltaics has been associated with positive outcomes such as consistent income for farmers and sustainable agricultural production (Shukla; Kumar; Shukla, 2022). Agrivoltaic arrays have been found to be beneficial for powering drip irrigation systems efficiently and supporting vertical growing methods that use minimal water compared to traditional field-based crops (Jamil; Bonnington; Pearce, 2023).Furthermore, the use of generator power during the drilling process leads to the emission of air pollutants, which may have detrimental effects on the respiratory system, specifically respiratory inorganics (Rosyidah et al., 2022a).

To encourage the adoption of agrivoltaics, policymakers are advised to consider implementing financial incentives such as feed-in tariffs and tax breaks to facilitate long-term agreements between solar developers and farmers (Taylor; Munsen, 2022). Despite initial concerns, a significant proportion of participants in the U.S. have shown openness to exploring the use of agrivoltaics on their properties, highlighting the potential for widespread acceptance and adoption of this innovative approach (Taylor; Munsen, 2022).

The integration of agrivoltaic systems in modern agriculture presents a promising approach to combine solar photovoltaic energy generation with agricultural activities. Agrivoltaics, which involve the co-location of solar energy development and agricultural practices, offer a symbiotic strategy for sustainable renewable energy and food production (Abidin; Mahyuddin; Zainuri, 2021). These systems have the potential to enhance land-use efficiency, increase resilience to environmental conditions such as drought, and improve crop growth (Schweiger; Pataczek, 2023). By leveraging agrivoltaics, farmers can concurrently produce crops and electricity on the same land, enriching their portfolios and mitigating climate-related risk (Thompson et al., 2020). The SCOR (Supply Chain Operations Reference) model is a diagnostic tool for Supply Chain Management (SCM) that enables users to get a comprehensive understanding of all activities inside a corporate organization (Rosyidah et al., 2022b).

Research on agrivoltaics emphasizes the importance of extending the application of these systems to various crops beyond shade-tolerant greens like lettuce. Future work is needed to explore the implementation of agrivoltaics with crops such as arugula, chard, kale, spinach, and more (Dinesh; Pearce, 2016). Additionally, studies have shown that agrivoltaic systems can lead to increased crop yields, plant protection from excessive solar energy, hail, and improved water conservation, while supporting local food supplies and agricultural employment (Sharpe et al., 2021). The Smart Energy, Public Street Lighting app enables police to monitor the procedure in real time (Masri et al., 2024).

Agrivoltaic systems not only offer environmental benefits but also align with economic goals. They can contribute to the economic potential of regions, support investment in rural economies, and align with sustainability goals such as the Green New Deal (Proctor; Murthy; Higgins, 2020). Furthermore, the integration of agrivoltaics can optimize clean system efficiency, improve yield, and enhance comprehensive economic benefits for farmland (Othman Et Al., 2020; Zheng et al., 2021).

Methods

Possible research methodologies for studying agrivoltaic usage in Indonesian agriculture may include the following approaches and techniques; (1) Conduct a comprehensive literature review to obtain information pertaining to the use of agrivoltaic systems in agriculture, both on a worldwide scale and specifically in Indonesia. The literature review may include prior investigations, scholarly publications, governmental reports, and other pertinent materials; (2) Field Survey: Perform on-site surveys to directly gather data from farmers, stakeholders, and local communities about the implementation of agrivoltaic practices in Indonesian agriculture. Field surveys may be carried out using methods such as interviews, questionnaires, and direct observation in the field; (3) Perform geographical analysis to determine suitable sites for implementing agrivoltaics in the agricultural sector of Indonesia. The study may need the use of geographic information systems (GIS) to visually represent land conditions, climate, terrain, and other pertinent aspects; (4) Conduct case studies at many agricultural locations in Indonesia that have adopted agrivoltaic systems to get insights into the implementation process, advantages, and issues encountered. Case studies provide profound insights into the use of agrivoltaic in the agricultural environment of Indonesia; (5) Perform a quantitative study to assess the effects of agrivoltaic systems on agricultural output, land use efficiency, decrease of land use conflicts, and other relevant factors. This study may include the comparison of data collected before to and after the adoption of agrivoltaics, along with the application of pertinent statistical analysis.

Community Participation: Facilitate the active involvement of farmers, stakeholders, and local communities at all stages of the research process, including planning and execution. Engaging the community may enhance the level of acceptability and long-term viability of integrating agrivoltaic systems into the agricultural sector in Indonesia.

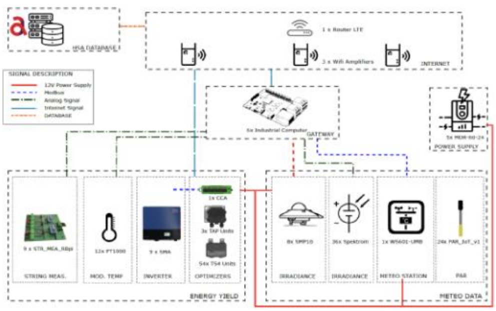

Figure 1. Designing the monitoring measurement layout for the AgriPVPlus demonstration
Source : Sánchez et al., 2022

Through the utilization of diverse research methodologies such as literature reviews, field surveys, spatial analysis, case studies, quantitative analysis, and community involvement, conducting research on the application of agrivoltaics in Indonesian agriculture can yield a comprehensive comprehension of the potential, advantages, effects, and implementation of agrivoltaics within the agricultural context of Indonesia.

Results and Discussion

Agrivoltaics, the integration of solar photovoltaic systems with agricultural practices, has gained significant attention due to its potential to address multiple sustainability goals. Research has shown that agrivoltaic systems can offer synergistic benefits by combining food production with renewable energy generation (Walston et al., 2022). These systems have been found to enhance land productivity, with the potential to increase biomass for various crops (Heath Et Al., 2022; Jamil; Pearce, 2023). Additionally, agrivoltaics can help mitigate the negative impacts of environmental stressors like drought on crop growth, thereby increasing the resilience of agricultural production (Schweiger; Pataczek, 2023).

Studies have highlighted the importance of factors such as vegetation establishment, soil characteristics, microclimate conditions, and solar technology performance in the success of agrivoltaic systems (Macknick et al., 2022). Furthermore, research has indicated that agrivoltaics can contribute to achieving United Nations Sustainable Development Goals by providing ecosystem services and addressing food-energy-environmental needs (Jamil; Pearce, 2023). However, challenges such as high initial costs and limited accessibility, especially for small farmers, have been identified as barriers to the widespread adoption of agrivoltaics (Matulić, 2023).

Efforts are being made to optimize agrivoltaic system design to manage trade-offs between energy production, crop productivity, and water consumption (Warmann, 2024). Research has also focused on assessing the economic feasibility and microclimatic impacts of agrivoltaic systems, emphasizing the need for even lighting to maximize comprehensive economic benefits (Adeh; Selker; Higgins, 2018; Zheng et al., 2021). Additionally, comparative analyses of different photovoltaic configurations for agrivoltaic systems have been conducted to enhance system performance (Niazi; Victoria, 2023).

Agrivoltaic, the integration of solar panels into agricultural practices, has gained significant popularity in Indonesia's agricultural sector in recent years. Agrivoltaic is a method that combines the cultivation of crops with the generation of solar electricity, enabling the effective use of farmland for both energy production and agriculture at the same time. Due to the growing recognition of the significance of renewable energy and agricultural sustainability, agrivoltaic has emerged as an appealing alternative for farmers in Indonesia. By maximizing the use of scarce land resources, farmers may enhance their agricultural output while also generating renewable energy. Furthermore, agrivoltaic systems may contribute to the mitigation of carbon emissions and decrease reliance on fossil fuels. Despite being in the developmental phase, the implementation of agrivoltaic in Indonesia shows significant promise in enhancing farmers' well-being and facilitating the shift towards a more sustainable agricultural system.

The use of agrivoltaic practices in Indonesian agriculture is impacted by several underlying elements, such as; (1) Land scarcity is a pressing issue as urbanization and land conversion continue to reduce the availability of agricultural land. Agrivoltaic offers a viable solution by integrating agriculture and solar power production to maximize land use; (2) Reliance on fossil energy: The majority of farmers in Indonesia continue to depend on fossil energy for their agricultural operations. Implementing agrivoltaic systems may assist in diminishing this dependency by transitioning to renewable energy sources (Fandom, 2024); (3) Climate change is now exerting its influence on weather patterns and agricultural output in Indonesia. Agrivoltaic systems may mitigate the negative effects of intense sunshine on crops and minimize water evaporation, therefore enhancing agricultural resilience in the face of climate change; ($) Government policy: The Indonesian government has actively promoted the use of renewable energy by implementing a range of regulations and incentives, especially targeting the agriculture sector. This policy endorsement may incentivize the implementation of agrivoltaic systems in Indonesia.

The research on the use of agrivoltaic systems in Indonesian agriculture offers several significant benefits, which include; (1) Agrivoltaic, the integration of solar panels with agriculture, enhances land use efficiency and optimizes the use of resources such as water and electricity, leading to increased agricultural productivity. This study has the potential to determine the most effective methods for optimizing agrivoltaic systems in order to enhance agricultural output in Indonesia; (2) Indonesia is confronted with significant obstacles with land use conflicts arising from the competition between agricultural and infrastructural or industrial development. Agrivoltaic is a potential solution that allows for the simultaneous use of land for both agricultural purposes and renewable energy generation. This study may aid in the identification of prospective land that is ideal for agrivoltaic systems, with the aim of mitigating disputes related to land usage; (3) Enhanced Climate Resilience: Given the escalating impact of climate change, the agricultural sector in Indonesia must bolster its ability to withstand severe weather events and adapt to changing climatic conditions. Agrivoltaic systems may mitigate the negative effects of intense sunshine on crops and decrease water evaporation, therefore enhancing agricultural resilience. This study aims to determine the advantages of agrivoltaic systems in enhancing the climate resilience of agriculture in Indonesia; (4) Indonesia is seeking to shift towards renewable energy sources in order to decrease greenhouse gas emissions and decrease reliance on fossil fuels, therefore supporting the energy transition. Agrivoltaic is a potential option to aid the energy transition in the agricultural industry. This study may facilitate the identification of the potential and advantages of agrivoltaic in bolstering the energy transition in Indonesia.

Agrivoltaic, a unique idea, integrates two distinct technologies, solar panels and agriculture, with the agricultural practices of Indonesia. Through the integration of solar panel systems onto farms, farmers may optimize land use by producing electrical energy for agricultural needs or for sale to the grid. Furthermore, the use of agrivoltaic systems may provide supplementary advantages, like shielding crops from excessive sunlight, diminishing water evaporation, and augmenting agricultural output. While agrivoltaic is a relatively new idea in Indonesia, it has significant promise to enhance the well-being of farmers and aid government initiatives in mitigating greenhouse gas emissions. With the backing of the government, research institutes, and private firms, the use of agrivoltaic is anticipated to see tremendous growth in Indonesia, emerging as a viable option to address future energy and agricultural challenges.

Therefore, conducting research on the use of agrivoltaic in Indonesian agriculture is crucial in order to promote sustainable, efficient, and eco-friendly farming practices, and to aid Indonesia in addressing the difficulties posed by climate change and the shift to renewable energy sources.

Currently, the use of agrivoltaic practices in Indonesian agriculture is still in the phase of research and testing. The use of agrivoltaic in agriculture in Indonesia has yielded many documented outcomes and advantages, including; (1) Agrivoltaic enhances land use efficiency by integrating solar panels on farms, enabling the use of the same area for both electricity generation and cultivation. This may aid in mitigating land use conflicts between agricultural activities and the expansion of renewable energy infrastructure; (2) Agrivoltaic adoption may provide revenue diversification prospects for farmers via the sale of solar panel-generated electrical energy, in addition to their usual agricultural output (Syerly, 2024). This has the potential to enhance the economic resilience of farmers and mitigate financial risks; (3) Agrivoltaic in agriculture may contribute to climate change mitigation by lowering greenhouse gas emissions via the decreased reliance on fossil energy and the transition to renewable energy sources (Syerly, 2024); (4) Agrivoltaic structures, which combine solar panels with crops, provide a means of safeguarding crops from severe temperatures, including intense heat and heavy rainfall. This has the potential to enhance the well-being of plants and increase agricultural output; (5) Enhanced Community Well-being: The deployment of agrivoltaics may provide socio-economic advantages for local communities, including the establishment of new employment opportunities, enhanced accessibility to clean energy, and an overall improvement in the quality of life. This has the potential to significantly enhance sustainable development at the local level; (6) Agrivoltaic deployment may enhance socio-economic conditions in local communities by expanding the availability of clean energy. This may aid in reducing reliance on fossil fuels and enhance the quality of life within the community (Fandom, 2024).

Despite being in the developmental phase, the use of agrivoltaics in Indonesian agriculture has promising potential to provide substantial advantages to farmers, the environment, and society at large. Through ongoing research, development, and implementation of agrivoltaic systems, the aim is to establish renewable energy as a sustainable alternative for enhancing agricultural output and mitigating the adverse effects of climate change.

Although agrivoltaic in agriculture in Indonesia has several advantages, it still faces some obstacles that must be addressed, including substantial upfront expenses, intricate maintenance requirements, and the need for favorable regulatory support. Through ongoing research, technological advancements, and collaboration among stakeholders, agrivoltaic implementation in Indonesian agriculture holds promise as a sustainable solution to promote eco-friendly farming practices and alleviate the adverse effects of climate change.

Agrivoltaics Concept

Agrivoltaics is a fusion of agricultural and solar power production with the goal of enhancing land use efficiency. By deploying solar panels on agricultural land, farmers may simultaneously produce electrical energy and continue their agricultural operations. Hence, the notion of Agrivoltaics may enhance agricultural output and diminish reliance on fossil fuel energy sources.

Agrivoltaics is the integration of agricultural practices with the production of solar electricity. The idea entails the installation of solar panels atop fields to provide electrical energy while still preserving agricultural activity below.

Agrivoltaics may provide several advantages by integrating agricultural with solar energy. Solar panels have the capability to produce environmentally friendly and sustainable power, which may be used for energy requirements, while allowing agricultural activities to continue below. Furthermore, positioning solar panels on agricultural land may provide shielding to crops from excessive sunshine and rainfall, thereby enhancing crop productivity.

Furthermore, agrivoltaics may mitigate land disputes between agricultural and solar power production by optimizing the use of land for both industries. Therefore, agrivoltaics may serve as a sustainable alternative to fulfill energy requirements while also preserving agricultural sustainability.

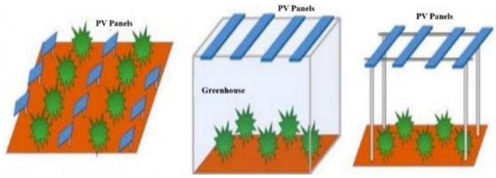

Figure 2. Agrivoltaics Development Concept

Implementing the agrivoltaics idea by installing solar panels in rice fields may provide several advantages for farmers and the surrounding ecosystem. Here are many advantages that may be derived from implementing agrivoltaics in rice fields; (1) Land conservation: Farmers may maximize land use by installing solar panels on paddy fields. Therefore, land often designated for agricultural purposes may also serve as a source of electrical energy; (2) Solar panels positioned over paddy fields might provide crop protection against excessive sunshine and rainfall. Implementing this method may enhance agricultural productivity by increasing both crop yields and crop quality; (3) Installing solar panels over paddy fields may decrease water evaporation from the soil, resulting in water savings. This may aid in conserving water use in agricultural practices and ensuring the continued availability of water for crop cultivation; (4) Renewable energy: Farmers may decrease reliance on fossil fuels and lower greenhouse gas emissions by harnessing solar energy for power generation (Fandom, 2024).

Supplementary revenue: Besides producing electricity, farmers may also gain extra cash by selling the electrical energy produced by the solar panels.

Figure 2. Agrivoltaics is the use of solar panels on rice fields.

By using agrivoltaics, which involves installing solar panels on rice fields, farmers may efficiently use their land and natural resources, leading to enhanced agricultural output. Additionally, this practice contributes to the advancement of renewable and sustainable energy sources.

Figure 3. Agrivoltaics is the use of solar panels on vegetable fields

The employment of solar panels as a means to power irrigation water pumps in rice fields is a very promising and beneficial usage. There are many advantages to using solar panels to power irrigation water pumps in rice fields; (1) Reduce operating expenses: By using solar energy to operate irrigation water pumps, farmers may decrease the costs associated with traditional fuel or electricity typically needed for operation; (2) Utilizing solar energy to power irrigation water pumps is an eco-friendly approach. This contributes to the mitigation of greenhouse gas emissions and the reduction of the carbon footprint associated with agricultural operations (Syerly, 2024); (3) Enhanced water stability: By using solar-powered irrigation water pumps, farmers may guarantee a more consistent and reliable water supply for their crops. Implementing this may enhance both production and the quality of crops; (4) Energy efficiency: Solar panels autonomously produce electrical energy, which may be stored in batteries for future use (Syerly, 2024). This facilitates the effective and ideal use of energy; (5) Enhanced agricultural productivity: By using solar-powered irrigation systems, farmers may optimize watering schedules with more precision and effectiveness. This has the potential to enhance the efficacy of water use and optimize the utilization of plant nutrients.

By using solar panels to power irrigation water pumps in rice fields, farmers may enhance their agricultural production, decrease operating expenses, and promote environmental preservation. This application exemplifies how technology may be used to bolster sustainable and effective agricultural practices.

Figure 4. Solar photovoltaic (PV) technology is used to operate a water pump specifically designed for irrigation purposes.

Conclusion

Agrivoltaic implementation in Indonesian agriculture provides a multitude of advantages, such as; (1) Optimizing land use via the integration of agricultural activities with solar power generating; (2) Reducing power expenses via the generation of self-produced electrical energy for agricultural use; (3) Plant sun protection and water evaporation decrease; (4) Contribute to the mitigation of climate change by decreasing the release of greenhouse gas emissions. However, the deployment of agrivoltaic systems in Indonesia is currently restricted and need further investment and assistance from both the government and private sector to promote the use of this technology in the agricultural industry.

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