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Solar powered Farming: Revolutionizing Agriculture with Agrivoltaic Systems

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Abstract

As global populations rise and the demand for both food and energy intensify, the concept of agrivoltaic systems—integrating solar energy production with agriculture—has emerged as a pioneering solution. Agrivoltaics, also known as agrophotovoltaics (APV), allow for the simultaneous use of land for farming and solar power generation. This dual-purpose approach not only increases land use efficiency but also offers environmental benefits such as improved water retention and reduced crop heat stress. With promising research outcomes highlighting improved crop yields and reduced irrigation needs, agrivoltaic systems represent a key strategy in addressing climate change, food security, and renewable energy goals. However, challenges like high initial investment, technical expertise requirements, and regulatory hurdles must be overcome for widespread adoption. As nations seek sustainable solutions, agrivoltaics offer a forward-thinking pathway for transforming the agricultural and energy sectors.

Introduction

The global demand for renewable energy, coupled with the need for sustainable farming practices, has led to innovative solutions that merge energy production with agriculture. One such emerging technology is agrivoltaics, which involves the integration of solar photovoltaic (PV) systems with agricultural activities. By utilizing the same land for both energy generation and crop cultivation, agrivoltaic systems (AVS) offer a unique opportunity to address two critical global challenges: meeting rising energy demands while ensuring food security. Solar-powered farming through AVS leverages underutilized agricultural lands to host solar panels, which can generate electricity without significantly disrupting crop growth. In fact, agrivoltaics can create a symbiotic relationship between energy production and farming. The solar panels provide shade to crops, reducing excessive heat and moisture loss, while crops beneath the panels help to cool the surrounding environment, improving the efficiency of the solar panels. This mutual benefit can result in increased crop yields and optimized energy production, making AVS an attractive option for both energy companies and farmers.

Countries like India, the United States, Japan, and Germany have already started

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embracing agrivoltaic systems as part of their sustainable energy and agricultural development strategies. With the potential to optimize land use, improve rural livelihoods, and reduce the environmental footprint of farming, agrivoltaics represents a promising pathway toward the future of agriculture. Additionally, AVS allows farmers to diversify their income by selling solar-generated electricity to the grid, offering a financial cushion in the face of unpredictable agricultural returns. As the world moves toward renewable energy and climate resilience, agrivoltaics has the potential to revolutionize traditional farming practices, providing a sustainable, integrated solution to the energy-agriculture nexus.

Fig. 1.0 Aerial view of Agrivoltaic research site at PJTAU, Hyderabad.

What is an Agrivoltaic System?

Agrivoltaic systems integrate photovoltaic (PV) panels with agricultural land, enabling farmers to cultivate crops while producing solar energy. These systems vary in design, from solar panels mounted above crops to integrated designs optimized for sunlight exposure. The shading provided by the solar panels can reduce heat stress on crops, conserve soil moisture, and in some cases, improve yields.

How Do Agrivoltaics Work?

Agrivoltaic systems function by placing solar panels over agricultural fields, generating renewable energy without reducing farmland availability. The solar panels provide partial shade, which has been shown to benefit crops sensitive to heat stress. The energy generated can be used to power farm operations, or sold back to the grid, creating an additional revenue stream for farmers.

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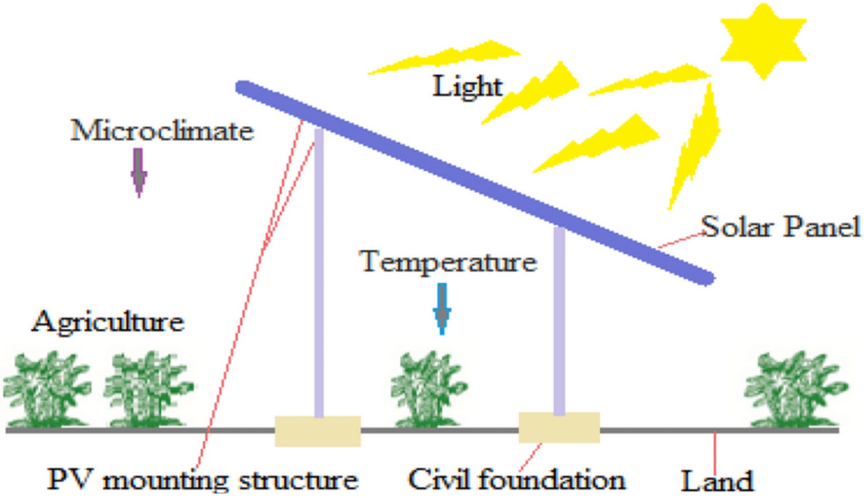

Fig. 2.0 Concept of Agrivoltaic system.


Fig. 3.0 Illustration of an agrivoltaic system.

***Source*: Trommsdorff M.; Gruber S.; Keinath,T et al. (2022)**

Benefits of Agrivoltaic Systems

Maximizing Land Use Efficiency

With the growing scarcity of arable land, agrivoltaic systems offer an innovative solution by enabling dual-use land. Farmers can cultivate crops while producing solar energy on the same land, optimizing space usage and boosting productivity.

Enhanced Crop Yields

Research indicates that certain crops, such as lettuce and spinach, thrive in the partial shade provided by solar panels. These crops experience reduced heat stress and improved soil moisture, leading to higher yields and lower irrigation requirements.

Renewable Energy Generation

By integrating solar energy production, agrivoltaic systems contribute to the global shift toward renewable energy. This not only helps reduce carbon emissions but also provides farmers with a new income stream from selling the electricity generated.

Climate Resilience

Agrivoltaics improve the resilience of agricultural systems by reducing water evaporation and providing crops with protection against extreme temperatures. This is especially beneficial in regions facing frequent droughts or high temperatures.

Challenges of Agrivoltaic Systems

High Initial Investment

While agrivoltaics offer long-term benefits, the initial costs of installing solar panels and associated infrastructure can be prohibitive. Financing options and government incentives will be critical to making these systems viable for farmers.

Technical Expertise Requirements

Implementing agrivoltaic systems requires specialized knowledge of both agricultural practices and solar technologies. Adequate training and support for farmers are essential for successful adoption.

Regulatory Hurdles

Land-use policies and regulatory frameworks vary by region, and some may limit the dual use of land for both agriculture and energy production. Governments will need to align policies to encourage the adoption of agrivoltaic systems.

Real-World Applications

Several countries are already exploring agrivoltaics as part of their renewable energy strategies:

Germany: A leader in agrivoltaics, Germany has implemented multiple pilot projects demonstrating how crops like wheat and barley can thrive under solar panels. The government elected in 2021 set a goal to expand photovoltaic (PV) capacity from 53 GWp in 2020 to 200 GWp by 2030. Currently, ground-mounted PV systems on agricultural land account for 12.7% of the total installed PV capacity, leading to the conversion of approximately 6,731 hectares of farmland. While the overall impact on farmland remains minimal, the increasing demand for PV installations on agricultural land has raised concerns among farmers, particularly over the potential rise in land rents. If a third of the planned PV capacity is met through ground-mounted installations, an estimated 49,000 hectares of farmland could be removed from production. This trend would conflict with Germany's goal of maintaining land degradation neutrality. Agrivoltaic (AV) systems, which allow for the simultaneous use of land for both farming and energy generation, offer a promising solution to balance the needs of agriculture and renewable energy production, reducing the pressure on farmland.

Japan: Agrivoltaics are particularly appealing in Japan, where limited arable land makes dual-

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use farming a practical solution. The country has launched initiatives that integrate solar panels with rice paddies and vegetable farms. The development of agrivoltaic farming in Japan traces back to the pioneering efforts of Akira Nagashima. In 2003, he introduced the concept of "solar sharing," a term synonymous with agrivoltaics, and made the technology freely accessible by waiving the patent in 2005. Nagashima's design of a narrow-width 24-cell PV module was key in minimizing shading and preventing splash erosion on crops beneath the panels. The first agrivoltaic farm in Japan was set up by him in 2004 in Chiba Prefecture, which later became a hub for the technology. His book, originally published in Japanese in 2015 and later translated into English in 2020, provided a comprehensive guide to solar sharing and became a foundational resource for early adopters of agrivoltaics in Japan.

By March 2019, there were 1,992 agrivoltaic farms covering 560 hectares across 46 of Japan's 47 prefectures, with the exception of Toyama. Chiba Prefecture, where agrivoltaics first emerged, leads with 298 farms. The majority of agrivoltaic farms in Japan are small in scale, reflecting the country's agricultural structure. Of the 755 farms registered by May 2018, 65% were under 0.1 hectares, followed by farms ranging from 0.1 to 0.3 hectares (24%), 0.3 to 0.5 hectares (4%), 0.5 to 1 hectare (5%), and larger farms exceeding 1 hectare (3%). This trend mirrors the overall structure of Japan's agriculture, where more than half (52%) of the 1.19 million farm management entities operate on less than 1 hectare of land, while only a small fraction (2%) manage areas larger than 30 hectares.

United States:

The deployment of solar energy in the United States is expanding at a rapid pace, with more than 20 GWdc of capacity installed in 2021 alone. Solar photovoltaic (PV) technology dominates these projects, which can be installed on rooftops or as ground-mounted systems. Ground-mounted solar installations typically require between 3 and 10 acres per MWdc of capacity. By 2050, utility-scale PV installations are projected to need between 4 million and 11 million acres of land, depending on deployment scenarios. Agricultural lands are particularly well-suited for solar energy projects, as they offer favorable solar exposure and stable soil conditions that reduce project risks. Many farmlands are ideal for solar development due to existing infrastructure, such as grid connections, access roads, and flat terrain. Additionally, the increasing financial challenges faced by traditional farmers have prompted solar projects to be developed on agricultural land. However, solar installations in rural areas have faced community opposition, similar to that seen with the development of cellular towers, wind farms, and oil and gas projects in some regions of the United States.

The Indian Context

India, being a geographically expansive country situated above the equator, receives

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significant solar energy, estimated at around 5000 TWh annually. As of 2021, India's ground-mounted solar power capacity reached approximately 45 GW, placing it 4th globally. Agriculture plays a vital role in the country's economy, with over 50% of the workforce dependent on farming, contributing 20% to the GDP in FY 2020–21. Major crops are cultivated during three primary agricultural seasons: Rabi (winter), Kharif (monsoon), and Zaid (summer).

Recognizing this potential, the Indian government launched the KUSUM (Kisan Urja Suraksha evam Utthan Mahaabhiyan) scheme to promote sustainability in agriculture through solar energy. The Ministry of New and Renewable Energy (MNRE) has set an ambitious target of achieving 450 GW of renewable energy by 2030 (GoI, 2021a). As part of this initiative, farmers receive financial support to install solar photovoltaic (SPV) systems on their land, with capacities ranging from 0.5 to 2 MWp, connected to the grid. Farmers can sell the electricity generated to distribution companies (DISCOMs), providing them with an additional revenue stream. States such as Rajasthan, Gujarat, Maharashtra, Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Odisha, Madhya Pradesh, Bihar, and West Bengal are key regions where this technology can be effectively implemented. Nationwide adoption of agrivoltaic systems (AVS) could produce over 16,000 GWh of electricity, capable of supplying power to more than 15 million people.

Conclusion

Agrivoltaic systems represent a promising solution to the pressing challenges of food security and climate change. By harnessing solar energy while simultaneously growing crops, these systems offer a pathway toward more sustainable agricultural practices. As awareness of agrivoltaics grows and technology advances, the potential for these systems to transform both farming and energy production becomes increasingly clear. With the right policy support and investment, agrivoltaics could play a crucial role in shaping a more sustainable future for global agriculture.

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