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Review on cases of potential photovoltaic implementation in duck farming

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ABSTRACT

This review objective is to find case of implementable photovoltaics technology for duck farming. To be included, the studies must mention about place of implementation, photovoltaics technology used, photovoltaics implementation, and photovoltaics impacts. The studies does not have to be specifically about duck farming, but the design must be implementable to duck farming. We have included research journal and proceedings articles from Scispace Database from 1980 to present. We have extracted four specific data from each articles, place of implementation, photovoltaics technology used, photovoltaics implementation, and photovoltaics impacts. We use tabulation for data synthesis. We have screened 20 articles to be included in this study. Photovoltaic systems can significantly reduce energy consumption in duck farming by providing a renewable energy source. Similarly, the integration of agrivoltaic systems in agricultural settings can optimize land use while generating clean energy, making it a viable solution for duck farming. The integration of photovoltaic systems in duck farming offers numerous benefits, including energy efficiency, cost reduction, and improved animal welfare. However, the success of such implementations depends on careful design, economic viability, and supportive policies. By addressing these factors, photovoltaic systems can play a key role in promoting sustainable and profitable duck farming operations. Grant No. PRJ-78/LPDP/2019.

Keywords: *Review, Cases, Potential Photovoltaic Implementation, Duck Farming*

1. INTRODUCTION

A systematic review on the implementation of photovoltaics in duck farming is needed due to several compelling reasons highlighted in the existing literature on agrivoltaic systems and renewable energy applications in agriculture. Firstly, the integration of photovoltaic (PV) systems with agricultural practices, known as agrivoltaics, has been shown to optimize land use by allowing simultaneous agricultural production and energy generation, addressing the increasing competition for land driven by population growth and food demand [1], [2]. However, the specific impacts of PV systems on different types of farming, such as duck farming, remain underexplored. Current research predominantly focuses on crops and livestock like poultry, with limited studies on the unique requirements and impacts on duck farming [3], [4]. Moreover, the environmental and economic benefits of agrivoltaic systems, such as improved land use efficiency and potential energy savings of up to 85% in poultry farming, suggest significant advantages that could be applicable to duck farming as well [5]. Despite these benefits, there are challenges related to the configuration of PV systems, such as panel elevation, spacing, and tilt, which can affect both agricultural and energy outputs [1]. A systematic review would help identify these specific challenges and opportunities within the context of duck farming, providing a comprehensive understanding of how PV systems can be optimized for this particular agricultural practice. Additionally, given the global push towards renewable energy to mitigate climate change, understanding the role of PV systems in diverse agricultural settings, including duck farming, is crucial for developing sustainable and efficient agrivoltaic systems worldwide [2], [6]. Therefore, a systematic review would not only fill existing knowledge gaps but also guide future research and policy-making to enhance the sustainability and productivity of duck farming through the integration of photovoltaic technology.

This review objective is to find case of implementable photovoltaics technology for duck farming. This review aim to find cases of photovoltacs implementation, where and how the technology is implemented, and what are the impacts of photovoltaics technology.

2. METHODS

This review is made following PRISMA Reporting Guidance [7], [8], supported by Scispace [9], [10] and Zotero [11], [12]. We have included research journal and proceedings articles from Scispace Database from 1980 to present. We utilise Scispace to assist in creating this review [9], [10].

We have included studies which mentioned cases about photovoltaic implementation in duck farming. We have searched Scispace Database, which consist of about 120,000 academic journals, using two keyphrases, "What is an example of photovoltaic implementation in duck farming?" and "Are there any specific case studies or examples of successful photovoltaic implementation in duck farming?". To be included, the studies must mention about place of implementation, photovoltaics technology used, photovoltaics implementation, and photovoltaics impacts. The studies does not have to be specifically about duck farming, but the design must be implementable to duck farming. First stage screening done by Scispace deep review [9], [10], while second stage screening is done by agreement of three independent researchers, before included in final article.

We have extracted four specific data from each articles, place of implementation, photovoltaics technology used, photovoltaics implementation, and photovoltaics impacts. We have assessed bias based by the absence of each data. Both task done with Scispace [9], [10]. We use tabulation for data synthesis.

3. RESULTS

We found 1750 records in database searching. After automated screening, we screened about 175 records, from which we are screened 20 articles to be included in this study (Figure 1, Table 1). 155 articles are excuded by lack of mentions about place, technology, implementation, and impact of photovoltaics.

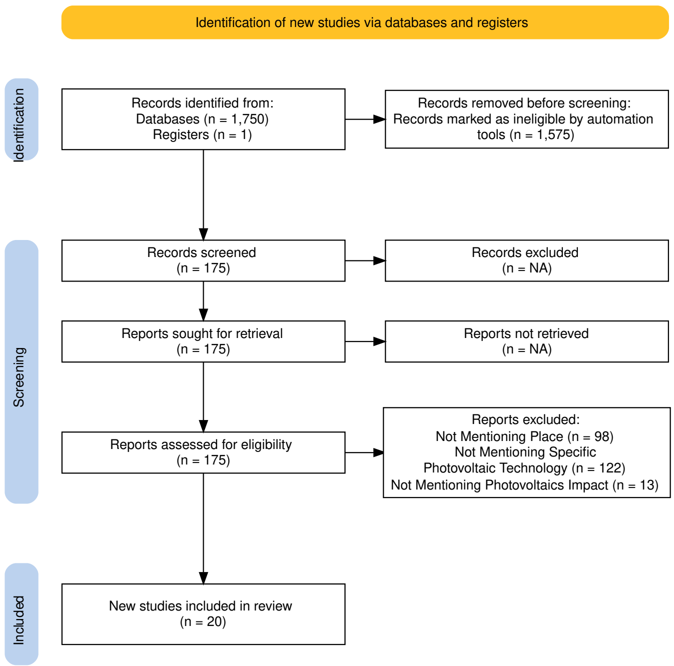

Figure 1. Identification of new studies via databases and registers. Each studies can be excluded for more than one reason, hence discrepancies in calculation. Graph are generated using R packages provided by Prisma Executive [45].

4. DISCUSSION

The integration of photovoltaic (PV) systems in duck farming represents a promising approach to enhance energy efficiency, reduce operational costs, and promote sustainable agricultural practices. This response explores the key factors, benefits, and challenges associated with photovoltaic implementation in duck farming, drawing insights from relevant research papers.

Photovoltaic systems can significantly reduce energy consumption in duck farming by providing a renewable energy source. For instance, a study on a poultry farm in Algeria highlights the potential of solar PV systems to reduce greenhouse gas emissions and lower energy costs [13]. Similarly, the integration of agrivoltaic systems in agricultural settings can optimize land use while generating clean energy, making it a viable solution for duck farming [14], [15].

The microclimate created by photovoltaic panels can provide shade for ducks, reducing heat stress and improving their overall welfare. Research on agrivoltaic systems in livestock farming has shown that such setups can create a more comfortable environment for animals, which is particularly beneficial in hot climates [2], [16].

Agrivoltaic systems can help reduce water evaporation from the soil, which is crucial for maintaining water resources in agricultural settings. This is especially important for duck farming, where water is a critical resource for both the animals and the farm's operations [17], [18].

Agrivoltaic systems are designed to maximize land productivity by combining solar energy generation with agricultural activities. Studies have shown that these systems can achieve a land equivalency ratio (LER) greater than 1, indicating that the combined productivity of energy and agricultural output exceeds that of separate land uses [19], [20].

The selection of crops and their compatibility with photovoltaic systems is crucial for successful implementation. For example, shade-tolerant crops or those that benefit from the microclimate created by solar panels are ideal for agrivoltaic systems. Similarly, the placement and height of solar panels must be carefully considered to ensure they do not negatively impact the movement or welfare of ducks [21], [22].

The economic feasibility of photovoltaic systems in duck farming depends on several factors, including the initial investment costs, government incentives, and the revenue generated from energy sales. Research has shown that agrivoltaic systems can be economically viable, especially when supported by policies that promote renewable energy adoption [23], [24].

The high upfront costs of photovoltaic systems can be a barrier to adoption for many farmers. However, studies have shown that the long-term benefits of these systems, including reduced energy costs and potential revenue from energy sales, can offset the initial investment [19], [24].

The design of photovoltaic systems for duck farming requires careful consideration of factors such as panel placement, height, and spacing to ensure they do not interfere with the movement or welfare of the ducks. Additionally, the systems must be designed to withstand local climatic conditions, such as wind loads and extreme temperatures [16], [25].

The success of photovoltaic implementation in duck farming also depends on the policy and regulatory frameworks in place. Governments can play a crucial role in promoting the adoption of agrivoltaic systems through incentives, subsidies, and supportive regulations [26].

The integration of photovoltaic systems in duck farming offers numerous benefits, including energy efficiency, cost reduction, and improved animal welfare. However, the success of such implementations depends on careful design, economic viability, and supportive policies. By addressing these factors, photovoltaic systems can play a key role in promoting sustainable and profitable duck farming operations.

There are some limitations for this review. This review is about photovoltaics technology that can be implemented in duck farming system, rather than the actual photovoltaics duck farm, which is scarce. That also means whether the technologies are actually implementable to duck farming system is subject to further studies. The 1st screening phase is fully automated as opposed to done by expert [9], [10].

5. CONCLUSIONS

The integration of photovoltaic (PV) systems into duck farming presents a compelling pathway towards more sustainable and economically viable operations. As discussed, these systems offer a multifaceted approach to enhancing energy efficiency, reducing operational costs, and promoting animal welfare.

Key benefits include a significant reduction in energy consumption and greenhouse gas emissions, leading to lower energy costs. The creation of a favorable microclimate under PV panels provides crucial shade for ducks, mitigating heat stress and improving their well-being, particularly in warmer climates. Furthermore, agrivoltaic setups enhance land use efficiency by combining energy generation with agricultural activities, often achieving a Land Equivalency Ratio (LER) greater than 1. The potential for reduced water evaporation from the soil beneath panels also contributes to water resource conservation, a vital aspect of duck farming.

However, successful implementation hinges on addressing several challenges. The initial upfront costs of PV systems can be substantial, though long-term energy savings and potential revenue from energy sales can offset this investment. Careful system design is paramount, requiring consideration of panel placement, height, and spacing to ensure minimal disruption to duck movement and welfare, while also accounting for local climatic conditions. Finally, supportive policy and regulatory frameworks, including government incentives and subsidies, are crucial for promoting widespread adoption.

While the direct implementation of PV systems on duck farms is an area requiring further research due to its current scarcity, the principles and benefits observed in broader agricultural and livestock applications strongly suggest their viability. By strategically addressing design, economic feasibility, and policy support, photovoltaic systems can indeed play a pivotal role in fostering sustainable and profitable duck farming practices.

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Table 1. Studies included in this review.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
1	2024	A. H. Garrod, Shanza Neda Hussain, Aritra Ghosh [19]	- The agrivoltaic systems discussed in the research paper are viable in numerous locations around the UK. - Specific locations mentioned include Belfast, Canterbury, Cambridge, and Denbigh.	- The research paper discusses agrivoltaics, which combines photovoltaic systems with agricultural practices. - It specifically analyzes overhead-tilted and vertically mounted agrivoltaic systems. - The focus is on the performance and economic viability of these two types of photovoltaic technologies in conjunction with crop production.	- Photovoltaics are implemented in agrivoltaic systems, which combine photovoltaic and agricultural systems to utilize land more efficiently. - The photovoltaic system is installed at an increased height above the ground, which differentiates it from traditional ground-mounted photovoltaic systems. - The implementation involves overhead-tilted and vertically mounted configurations of the photovoltaic panels. - These systems are designed to generate energy while simultaneously allowing for crop production, creating a synergistic arrangement. - The performance of these systems is analyzed on both technical and economic bases, comparing them to stand-alone crop systems and ground-mounted PV farms.	- The implementation of photovoltaics in agrivoltaic systems allows for more efficient land utilization by combining agricultural and energy production. - Although the investment cost for photovoltaic systems in agrivoltaics is higher than traditional ground-mounted systems, the revenue generated results in a positive net present value over the system's lifetime. - Agrivoltaic systems can lead to an increase in annual operating profit, with an average increase of 210% across various locations studied. - The systems demonstrate a land equivalency ratio above 1 in all regions for tilted agrivoltaic systems, indicating that they are viable and profitable in numerous locations around the UK. - The performance of agrivoltaic systems can vary by location, with different net present values and land equivalency ratios observed in cities like Belfast and Canterbury.
2	2024	Eshwar Ravishankar, Shir Esh, Offer Rozenstein, Helena Vitoshkin, Abraham Kribus, Gur Mittelman, Sanjeev Jakhar, Ricardo Hernandez [27]	- The agrivoltaic farm discussed in the research is located in Yuma, Arizona.	- The farm implements spectral beam splitter integrated photovoltaic (BSIPV) modules. - Conventional opaque photovoltaic (PV) devices are also mentioned as part of the agrivoltaic system.	- Photovoltaics are implemented in the agrivoltaic farm using spectral beam splitter integrated photovoltaic (BSIPV) modules. - These modules are designed to be installed above arable land, allowing for simultaneous solar power generation and food production. - The BSIPV modules effectively transmit a high percentage (66%) of photosynthetically active radiation (PAR) to the plants while reflecting near infrared radiation (NIR) to adjacent bifacial opaque photovoltaic modules for power generation. - The modules are arranged in seven rows uniformly across the field at a height of four meters from the ground. - This implementation aims to improve land use efficiency and reduce the negative impact on crop yield compared to conventional opaque PV devices.	- Photovoltaics (PV) implementations can aid in addressing the shortage of available land for solar power generation and food production through agrivoltaics. - Conventional opaque PV devices absorb photosynthetically active radiation (PAR), which can reduce crop yield and increase variability in light distribution across agricultural fields. - The use of spectral beam splitter integrated photovoltaic (BSIPV) modules allows for a high percentage (66%) of PAR to be transmitted effectively to plants, enhancing crop growth. - BSIPV systems limit the drop in total daylight integral (TDLI) to 7% compared to open fields, significantly improving light availability for crops. - The coefficient of variation in TDLI across the field is reduced to 14% with BSIPV, indicating more uniform light distribution compared to conventional systems. - Overall, BSIPV shows a 36% improvement in TDLI relative to conventional opaque PV agrivoltaic farms, suggesting better land use efficiency and potential for higher agricultural productivity.
3	2024	Lia Rapella, Philippe Drobinski, Davide Faranda [25]	- The research focuses on the Iberian Peninsula and the Netherlands as the locations for assessing agrivoltaics (AVs) configurations.	- The research paper discusses the implementation of three specific photovoltaics (PV) configurations in agrivoltaics systems: fix-tilted array, sun tracking, and sun antitracking. - These configurations are assessed for their performance in relation to crop types and climate conditions.	- Photovoltaics (PV) is implemented in agrivoltaics (AVs) by placing PV panels over crop fields. - This implementation allows for the simultaneous generation of clean energy and agricultural production, avoiding land-use competition between solar energy and agriculture. - The PV layer in the AVs model simulates the effects of PV panels, altering solar radiation and wind speed based on atmospheric conditions. - The altered variables, along with other atmospheric inputs, are used in conjunction with the soil-vegetation-atmosphere-transfer model ORCHIDEE to assess the impact on crop ecosystems. - The integration of PV systems within the AVs framework enables a comprehensive evaluation of crop productivity, water use efficiency, and energy potential in relation to climate conditions.	- Photovoltaics (PV) panels can significantly reduce greenhouse gas emissions by providing clean energy, thus helping to mitigate climate change. - The implementation of PV systems in agrivoltaics (AVs) can avoid competition for land-use between solar energy and agriculture, allowing both to coexist. - PV panels can alter solar radiation and wind speed, which can impact crop productivity positively by mitigating the effects of climate change. - The integration of PV systems with agricultural practices can enhance Net Primary Production (NPP) and Water Use Efficiency (WUE), contributing to a sustainable and circular food economy. - Different configurations of PV systems, such as fix-tilted arrays and sun tracking, can yield varying performance outcomes depending on climate conditions, crop types, and locations.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
4	2024	Marta Victoria, Johannes Wilhelmus Maria Pullens, Gabriele Torma, Magnus Lindhardt, Kamran Ali Khan Niazi, Maryam Rahimi Jahangirlou, Yannick El Khoury, Jessica Aschemann-Witzel, Carl-Otto Ottosen, Uffe Jørgensen [28]	- The farm is located in Denmark.	- The farm implemented vertically mounted and tilted bifacial solar panels. - These solar panels are part of an 89-kW pilot system.	- The implementation of photovoltaics in the farm involves the use of vertically mounted and tilted bifacial solar panels. - An 89-kW pilot system was established in Denmark, specifically designed to integrate solar electricity generation with agricultural practices. - The vertical solar panels were positioned to act as wind shelters for the crops grown between the rows. - This setup allowed for the measurement of microclimate variables and electricity production over the course of one year. - The system demonstrated similar crop yields to those in open fields and higher yields compared to south-oriented 25º-tilted solar panels. - The daily electricity generation profile of the vertical solar panels was found to align better with electricity demand.	- The implementation of photovoltaics in the form of vertical agrivoltaic systems can enhance crop yields by providing wind shelter, resulting in similar yields to open fields and higher yields compared to conventional south-oriented tilted solar panels. - Vertical solar panels align better with daily electricity demand, improving the efficiency of electricity generation. - Social acceptance of vertical agrivoltaic systems is generally more positive compared to traditional solar panels, indicating a favorable perception among the community. - The integration of solar electricity generation with agriculture offers a sustainable strategy for land use in temperate climates.
5	2024	Mert Temiz, I. Dincer [29]	- The farm community mentioned in the research paper is located in California.	- The research paper discusses agrivoltaics, which combines solar photovoltaics with food crops on the same land. - It mentions different orientations of agrivoltaic systems, including vertical-fixed, tilted-fixed, and tracking orientations. - The paper also introduces concentrated solar power (CSP) systems, referred to as "agri-CSP," which generate process heat and electricity. - The specific photovoltaic technologies implemented in the farm are not detailed in the provided context.	- Photovoltaics are implemented on agricultural lands through the concept of agrivoltaics, which combines solar photovoltaics with food crops on the same land. - The study assesses different orientations of agrivoltaic systems, including vertical-fixed, tilted-fixed, and tracking orientations, to optimize electricity generation. - The proposed agri-CSP (concentrated solar power) system generates process heat and electricity, contributing to the overall energy needs of the farm community. - The implementation aims to maximize the effective and efficient utilization of land, generating significant amounts of electricity, fresh water, and hydrogen for sustainable agriculture.	- Photovoltaics, when implemented in agrivoltaic systems, maximize the benefits of land by allowing the simultaneous cultivation of food crops and energy generation. - The integration of photovoltaics with concentrated solar power (CSP) systems can generate significant amounts of electricity, contributing to the energy needs of agricultural communities. - The proposed systems can produce fresh water and hydrogen, addressing multiple resource demands in a sustainable manner. - Different orientations of agrivoltaic systems can lead to varying electricity generation efficiencies, with tracking orientations yielding the highest output. - The overall energy and exergy efficiencies of the integrated systems are reported to be 59.95% and 41.01%, respectively, indicating effective utilization of resources.
6	2023	Ana Flávia P. A. Faria, Alex Sandro Campos Maia, Gustavo André Bernado Moura, Vinícius de França Carvalho Fonsêca, Sheila Tavares Nascimento, Hugo Fm Milan, Kifle G. Gebremedhin [30]	- The research study was conducted in Brazil, specifically focusing on dairy heifers in tropical areas. - The heifers were managed in open-pasture fields or paddocks located between a southern latitude of 5 and 20.	- The farm implemented photovoltaic panels as part of the Animal Agrivoltaics system. - The specific model of the photovoltaic panels used is the Canadian Solar model CS6Ue335P, which has a peak efficiency of 16.72%. - Each panel has dimensions of 1.0 m x 2.0 m and a nominal power of 335 W. - A total of ten photovoltaic panels were installed to provide shade for the heifers while generating electricity.	- Photovoltaics are implemented on the farm through the installation of ten photovoltaic panels, each measuring 1.0 m x 2.0 m, with a peak efficiency of 335 W. - The panels are arranged to provide shade for the dairy heifers, creating a shaded area of approximately 19.3 m^2, or 2.76 m^2 per animal. - The system is designed to generate renewable electrical energy while simultaneously improving the thermal comfort of the heifers. - Over a one-year period, the photovoltaic panels produced a total of 4869.4 kWh of electricity, contributing to cost savings for the farm. - The implementation of photovoltaics also plays a role in offsetting enteric methane emissions from the heifers, promoting environmental sustainability.	- Photovoltaics implementations provide artificial shade for dairy heifers, improving their thermal comfort and wellbeing. - The shade from solar panels reduces the heat load on the animals, cooling their body surface and skin temperatures. - It decreases the costs of thermoregulation, as indicated by a lower requirement for panting among the heifers. - Photovoltaics contribute to the generation of electrical energy, which can offset enteric methane emissions from the animals. - A specific area of solar panels (4.1 m^2 per animal) is necessary to achieve net-zero methane emissions. - The implementation of photovoltaics can lead to significant savings in electricity costs, providing extra income to farmers. - Overall, photovoltaics support sustainable intensification of dairy production in tropical areas, combining energy generation with animal welfare benefits.
7	2023	Hassan Abdulmouti, Abdrabbi Bourezg, Ranjeet Ranjan [31]	- The proposed agrivoltaic dates farm is located in the UAE.	- The research discusses the use of semitransparent photovoltaic technology in the agrivoltaic system for the proposed dates farm in the UAE. - It highlights the efficiency of semitransparent flexible photovoltaic materials for maximizing land utilization under photovoltaic panels for farming. - The semitransparent photovoltaic panels are noted for their ability to enhance crop yield while also reducing the impact of dust and sand on solar panel performance.	- Photovoltaics are implemented in the agrivoltaic system by utilizing semitransparent photovoltaic panels that allow for both power generation and crop production simultaneously. - The shading effect of the photovoltaic panels is analyzed to determine its impact on crop yield, ensuring that the land is effectively used for both energy and agriculture. - Innovative semitransparent flexible photovoltaic materials are considered ideal for the agrivoltaic system, enhancing land utilization under the photovoltaic panels for farming. - This implementation also helps reduce the effects of dust and sand on the solar panels, thereby improving their performance.	- Photovoltaics (PV) systems can enhance agricultural productivity by allowing for simultaneous food production and energy generation. - The shading effect of photovoltaic panels can positively impact crop yields, as it provides a microclimate that may benefit certain crops. - The use of semitransparent photovoltaic materials is noted to be efficient in land utilization, allowing for better crop yields under the panels. - PV systems can reduce the adverse effects of dust and sand on solar panels, thereby improving their performance. - Implementing agrivoltaic systems can contribute to food, water, and energy security, which are critical for modern economies, particularly in regions like the UAE.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
8	2023	Joshua M. Pearce [32]	- The research paper discusses agrivoltaic potential in Canada. - It quantifies this potential by province using geographical information system analysis of agricultural areas. - Therefore, the farms referred to in the context are located across various provinces in Canada.	- The research paper mentions the use of bifacial photovoltaic (PV) systems. - It also discusses single-axis tracking and vertical system configurations as part of the agrivoltaic potential in Canada.	- Photovoltaics are implemented in agriculture through agrivoltaics, which involves the co-development of solar photovoltaic (PV) systems alongside conventional farming practices. - The study highlights the use of bifacial PV systems that can be configured for single-axis tracking and vertical arrangements. - These configurations allow for the continued farming of field crops while potentially increasing their yield. - Agrivoltaics can utilize only 1% of current agricultural lands to meet a significant portion of Canada's electrical energy needs, demonstrating an effective integration of solar energy into farming operations.	- The implementation of photovoltaics (PV) through agrivoltaics can significantly contribute to reducing greenhouse gas (GHG) emissions in Canada. - Agrivoltaics allows for the co-development of solar energy systems and agriculture, enabling conventional farming to continue while potentially increasing crop yields. - The study indicates that agrivoltaics could provide between a quarter and more than one third of Canada's electrical energy needs using only 1% of current agricultural lands. - This approach can help Canada achieve its goal of having 90% of electricity generation from non-emitting sources by 2030. - The potential of agrivoltaic systems extends beyond electricity generation, as they can also support the electrification and decarbonization of transportation and heating sectors. - Additionally, agrivoltaics can create economic opportunities by powering the growing computing sector and facilitate the export of green electricity to the U.S., aiding in the reduction of fossil fuel dependence.
9	2023	Lih-Chyi Wen, Chun-hsu Lin, Ying-Chiao Lee [33]	- The research paper discusses aquaculture practices in Taiwan, specifically in the southwestern region. - It highlights the integration of aquaculture lands, particularly aquaculture ponds, for solar power development in Taiwan.	- The context mentions the use of column-type photovoltaic facilities for the aquaculture-electricity symbiosis. - It indicates that the predominant form of aquaculture in the area is outdoor farming, which aligns with the implementation of these photovoltaic technologies. - The study assumes a ground-based photovoltaic installation capacity of 1 MW per hectare, resulting in a total installation capacity of 227 MW.	- Photovoltaics are implemented in the aquaculture farms through a symbiotic relationship with electricity generation. - The predominant form of aquaculture in the area is outdoor farming, where column-type photovoltaic facilities are installed. - The study assumes a ground-based photovoltaic installation capacity of 1 MW per hectare, leading to a total installation capacity of 227 MW. - Farmers collaborate with photovoltaic system operators to jointly plan and establish photovoltaic facilities. - The implementation requires compliance with local regulations, including obtaining written consent from original farmers and ensuring adherence to facility area and shade ratio requirements. - The system operates over a 20-year period, contributing to both energy production and environmental benefits.	- The implementation of photovoltaics in aquaculture can significantly reduce carbon emissions, with an estimated reduction of approximately 150,393.6 tons of CO2e per year. - It also leads to reductions in other pollutants, including 56.8 tons/year of SOx, 82.3 tons/year of NOx, 3.7 tons/year of PM2.5, and 4.6 tons/year of PM10. - The environmental benefits from these reductions are valued at approximately TWD 7626.43 million annually. - The symbiotic relationship between aquaculture and photovoltaics is economically viable, yielding a net economic return of approximately 4.34 for society as a whole. - The internal rate of return (IRR) for farmers participating in the aquaculture-photovoltaics projects is the highest among stakeholders at 19.75, indicating strong economic benefits for them. - The integration of photovoltaics with aquaculture aligns with Taiwan's renewable energy goals, contributing to the country's target of 20 GW of solar power by 2025 and net-zero carbon emissions by 2050. - The approach also serves as a model for sustainable food, drinking water, and energy production in the context of climate change adaptation.
10	2023	Noor Fadzlinda Othman, M. E. Ya'acob, L. Lu, Ahmad Hakiim Jamaluddin, Ahmad Suhaizi Mat Su, Hashim Hizam, Rosnah Shamsudin, Juju Nakasha Jaafar [34]	- The agrivoltaic farm mentioned in the context is located in Puchong, Malaysia.	- The research paper mentions the use of monocrystalline PV modules in the 2 MWp Puchong agrivoltaic farm. - It does not provide specific details about other types of photovoltaics technologies implemented in the farm.	- Photovoltaics are implemented in the farm through the integration of agrivoltaic systems, which combine agricultural practices with solar energy production. - The implementation involves the use of solar photovoltaic panels that are installed above agricultural plots, allowing for crop cultivation underneath. - The agrivoltaic approach not only generates electricity but also enhances crop production by providing natural cooling to the PV cells, which improves their efficiency. - The study conducted at the 2 MWp Puchong agrivoltaic farm demonstrated a significant increase in DC energy generation, averaging a 3% increase due to the agrivoltaic system. - The farm utilizes both active and passive cooling techniques to manage the temperature of the PV cells, thereby extending their lifespan and improving overall energy output.	- The implementation of photovoltaics (PV) systems can lead to increased energy generation efficiency, particularly when integrated with agrivoltaic systems that utilize natural cooling techniques. - PV systems can contribute to building resilient energy-generation and food-production systems, addressing both energy and agricultural needs simultaneously. - Effective cooling methods for PV cells can significantly improve their electrical efficiency and lifespan by reducing thermal stresses. - The integration of agriculture with PV systems can provide additional economic benefits to operators through the production of fresh crops alongside electricity generation. - The study suggests that the agrivoltaic approach can lead to a notable increase in DC energy generation, which is beneficial for solar farm operators.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
11	2022	Elizabeth Delfín-Portela, Luis Carlos Sandoval-Herazo, D. Reyes-Gonzalez, Humberto Mata.Alejandro, María Cristina López-Méndez, Gregorio Fernández-Lambert, Erick Arturo Betanzo-Torres [35]	- The farm is located in Tierra Blanca, Veracruz, Mexico.	- The research paper discusses the implementation of On Grid-PV (photovoltaic) systems in Nile Tilapia farms. - The photovoltaic technology is designed to support aeration, pumping, and lighting loads in aquaculture farms. - The system includes a photovoltaic array and a monitoring system integrated into the inverter to observe various electrical parameters online. - The study emphasizes the use of photovoltaic technology to minimize energy costs and environmental impacts in aquaculture production.	- The implementation of photovoltaics in the farm involves designing a grid-connected photovoltaic (On Grid-PV) system tailored for the specific energy needs of the aquaculture farm. - The system is designed to support aeration, pumping, and lighting loads essential for tilapia farming. - A photovoltaic array is installed, which is capable of generating sufficient energy to meet the farm's consumption objectives and reduce costs. - The sizing of the photovoltaic system is based on an energy consumption analysis and cost reduction goals. - The implementation process includes a field phase for energy diagnosis and a cabinet phase for calculating economic and environmental variables. - The system is monitored through an integrated inverter that tracks various electrical parameters in real-time. - The design adheres to the Mexican Official Standard for electrical installations and utilizes clean energy management software for analysis.	- The implementation of photovoltaic systems in aquaculture, specifically for Tilapia farming, can significantly reduce production costs associated with energy consumption for aeration and water pumping. - It is estimated that without the use of On Grid-PV systems, approximately 11,221 kg of CO2 equivalent would be released into the atmosphere, highlighting the environmental benefits of such systems. - The use of photovoltaic technology contributes to sustainability by minimizing negative environmental impacts in the agricultural sector. - The economic indicators from the study show a net present value of USD 41,517.44 and an internal rate of return of 38.2%, indicating a financially viable investment. - The implementation of On Grid-PV systems allows aquaculture farms to produce Tilapia at a lower production cost while also reducing their carbon footprint, thus supporting sustainable development in aquaculture.
12	2022	M. Varo Martínez, L.M. Fernández de Ahumada, M. Fuentes Garcia, P. Fernández García, F. Casares de la Torre, R. López-Luque [36]	- The agrivoltaic plant is located at the 'Torrealba' Educational Centre in Almodovar del Rio, Cordoba, Spain. - The specific coordinates of the location are 37°49'13.3"N 5°00'15.4"W.	- The agrivoltaic plant implemented at the 'Torrealba' Educational Centre utilizes photovoltaic (PV) technology. - It consists of 10 photovoltaic modules, each with a capacity of 535 Wp. - A single-phase inverter with a capacity of 5 kW is also part of the installation. - The PV panels are mounted on a support structure that is 1 meter above the ground, allowing for agricultural maintenance work beneath them.	- The agrivoltaic plant at the 'Torrealba' Educational Centre features a 5 kWp photovoltaic (PV) system. - The PV plant is mounted on an elevated structure, 1 meter above the ground, allowing for agricultural maintenance beneath the panels. - The installation consists of 10 photovoltaic modules, each rated at 535 Wp, connected to a single-phase inverter with wireless communications. - The PV system is designed to produce electricity for self-consumption by the educational centre. - The energy production of the PV plant is monitored and data is available in the cloud for analysis. - The PV panels create different solar irradiation conditions on the crop land, which is essential for studying the effects of shading on agricultural production.	- Photovoltaics (PV) implementations can significantly increase the productivity of agricultural land by combining energy production with crop cultivation. - The shading from PV panels can reduce incident solar irradiance and crop temperature, which may benefit certain types of crops. - Diversification of income sources through agrivoltaics reduces financial risk and improves the overall profitability of the land. - Agrivoltaics promotes the development of renewable energy, contributing to a more sustainable energy model. - The integration of PV technology in agriculture helps meet the growing demands for food and energy without compromising environmental sustainability.
13	2022	Peter Jansson, Michele Newberry, Sherrill M. Myers [37]	- The research paper discusses the use of agrivoltaics in utility-scale projects, particularly on cleared lands and rich agricultural lands. - It highlights the potential conflict between solar farm development and domestic food production. - However, the specific location of the farm is not mentioned in the provided context.	- The research paper discusses the use of bi-facial photovoltaic (PV) modules in utility-scale agrivoltaic applications. - It highlights that bi-facial modules are preferred over standard PV modules for certain crops, as they can enhance plant growth and yields. - The focus is on demonstrating the effectiveness of bi-facial PV technology in conjunction with permaculture practices on agricultural lands.	- Photovoltaic (PV) technology is implemented in utility-scale projects by deploying large solar farms on cleared and agricultural lands. - The research focuses on agrivoltaics, which combines solar energy production with agricultural practices under large PV arrays. - Bi-facial PV modules are utilized, which allow certain crops to flourish better compared to standard PV modules due to their ability to capture light from both sides. - The implementation aims to demonstrate that affordable permaculture production can occur beneath these solar arrays, potentially alleviating resistance to using farmland for solar energy. - The study seeks to identify plant species that thrive in these agrivoltaic settings, taking advantage of the altered light spectrum provided by the bi-facial modules.	- Photovoltaic (PV) technology is becoming the most affordable, reliable, and easily deployable electric generation technology. - The growth of utility-scale PV systems is rapidly increasing, surpassing roof-mounted systems in market share. - There is a potential conflict between the deployment of large solar farms on agricultural lands and domestic food production. - Resistance to PV systems is growing, particularly when they occupy farmland. - Agrivoltaics, which combines solar energy production with agriculture, may provide solutions to this conflict by allowing for permaculture applications under solar arrays. - Certain crops may thrive better under bi-facial PV modules compared to standard PV modules, potentially increasing yields. - The increased labor for planting and harvesting in agrivoltaic settings may be justified by the financial benefits of higher organic product output.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
14	2021	Chong Seok Choi, Sujith Ravi, Iskandar Z. Siregar, Fifi Gus Dwiyanti, Jordan Macknick, Michael Elchinger, Nicholas C. Davatzes [38]	- The farm is located in Indonesia. - It serves as a model system for investigating the combined land use of solar infrastructure and agriculture.	- The research paper focuses on solar photovoltaic (PV) technology, specifically multi-crystalline silicon PV technology, which is chosen for its high performance in tropical settings like Indonesia. - The paper discusses the implementation of solar PV systems in rural electrification projects, particularly in areas with limited access to grid electricity. - It highlights the potential of solar PV to be co-located with agricultural crops to optimize land use and provide additional economic benefits.	- Photovoltaics (PV) implementation in the farm involves co-locating low-density solar PV systems over existing crops, specifically designed for rural communities with limited land and capital. - The study focuses on Indonesia, where the integration of off-grid solar PV with high-value crop cultivation is explored to provide renewable energy services. - The economic feasibility of small-scale dual land-use systems is assessed, indicating that they can be viable in certain configurations. - The implementation aims to support rural electrification, replace diesel electricity generation, and provide electricity for local agricultural product processing. - The analysis shows that a half-density PV system can significantly lower capital costs while still meeting the energy demands of the community. - The approach minimizes the conversion of agricultural land to energy production, thereby addressing concerns related to food and energy competition.	- Photovoltaics (PV) implementations can lead to the conversion of arable lands to solar energy production, which may negatively impact agricultural activities. - The deployment of large-scale PV infrastructure can result in increased water consumption during maintenance, raising concerns about local water resources. - PV installations may alter the microclimate, carbon cycling, and other ecological variables, potentially affecting the land's ability to produce food and perform ecosystem services. - Soil under PV panels may experience heightened erosion and changes in nutrient levels, which can impact agricultural productivity. - The combination of PV with crop cultivation can mitigate some negative impacts by optimizing land use and reducing the need for deforestation. - Co-location of PV with agriculture can provide socioeconomic benefits, such as rural electrification and local economic stimulus through job creation.
15	2021	Max Trommsdorff, Maximilian Vorast, Neha Durga, Sachin Padwardhan [39]	- The agrivoltaic project is located in Maharashtra, India. - The specific site for the project is on more than 100 hectares of fertile agricultural land.	- The agrivoltaic project in Maharashtra utilizes bifacial glass-glass photovoltaic (PV) modules. - These bifacial modules are expected to raise electrical yield by 6.4% compared to mono facial modules.	- The implementation of photovoltaics in the farm involves the establishment of an agrivoltaic system, which combines food and electricity production on the same land. - The project analyzed a 50 MWp agrivoltaic system in Maharashtra, focusing on social impact and economic viability. - The system is designed to utilize bifacial glass-glass PV modules, which are expected to increase electrical yield by 6.4% compared to mono facial modules. - Approximately 100 hectares of the acquired 125 hectares of land will be dedicated to photovoltaic generation. - The agrivoltaic system aims to enhance land use efficiency, with an expected increase of 94% in combined output of electricity and agriculture per unit of land. - The implementation also considers water management strategies, including rainwater harvesting and irrigation, to ensure sustainability. - The project emphasizes the importance of involving the farming community in decision-making to address concerns and ensure smooth operation between agricultural and power plant activities.	- Photovoltaics (PV) implementations can lead to significant land use competition, particularly in densely populated regions where arable land is at risk. - The use of ground-mounted photovoltaic (GM-PV) systems can threaten farmers' livelihoods as they compete for land with PV investors. - Agrivoltaics, which combines land use for food and electricity production, can mitigate these conflicts by increasing land use efficiency, potentially doubling the output of electricity and agriculture per unit of land. - The economic feasibility of agrivoltaic systems is supported by expected low levelized cost of electricity (LCOE), which can enhance the financial viability of renewable energy projects. - The implementation of bifacial PV modules can increase electrical yield, contributing to better overall performance of the PV system. - Agrivoltaics can create employment opportunities, providing a steady income for farmers and contributing to socio-economic sustainability in the region. - The social impact of PV implementations can vary, with potential benefits for the farming community if they are involved in decision-making processes, but also risks of severe poverty for some farmers if not managed properly.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
16	2021	Zheng Jianan, Shoudong Meng, Xinyu Zhang, Honglong Zhao, Xiaolong Ning, Chen Fangcai, Altyeb Ali Abaker Omer, Jan Ingenhoff, Liu Wen [40]	- The farm mentioned in the study is located in Fuyang city, China.	- The research paper discusses the implementation of an improved agrivoltaic system known as the Even-lighting Agrivoltaic System (EAS). - The EAS incorporates a grooved glass plate designed to enhance light distribution for crops while allowing for electricity generation. - The system utilizes photovoltaic (PV) panels elevated above the farmland to facilitate crop growth and optimize light exposure. - Additionally, supplementary LED lamps are integrated into the EAS to provide extra illumination for the crops, enhancing their growth and nutritional content.	- Photovoltaics is implemented on the farm through the use of agrivoltaic systems, which combine crop planting and electricity generation on the same land. - The system involves elevating photovoltaic (PV) panels above the farmland, allowing crops to grow beneath them while utilizing sunlight that spreads between the rows of panels. - An improved version of the agrivoltaic system, called the Even-lighting Agrivoltaic System (EAS), has been designed to provide more uniform and adequate light to crops. - The EAS includes a grooved glass plate that enhances light distribution, improving crop growth and yield compared to traditional methods. - Additionally, supplementary LED lamps can be integrated into the EAS to extend the light exposure for crops, further enhancing their growth and nutritional quality. - The implementation of photovoltaics not only supports crop production but also allows farmers to generate clean energy, which can be used for agricultural purposes or sold for additional income.	- Photovoltaics (PV) implementations in agriculture, specifically through agrivoltaic systems, allow for the simultaneous generation of electricity and crop production on the same land. - This dual use of land helps to resolve competition between food production and energy generation. - Agrivoltaic systems can enhance agricultural productivity by providing a more favorable light environment for crops, which can lead to improved crop yield and quality. - The Even-lighting Agrivoltaic System (EAS) specifically addresses the issue of uneven and low irradiance, resulting in faster crop growth and yields that are similar or better than those grown in natural conditions. - The implementation of photovoltaics can also provide farmers with a source of clean energy for agricultural production or an additional income stream through electricity sales. - The comprehensive economic benefits of EAS have been shown to significantly outweigh installation and maintenance costs, potentially increasing farmers' income by an average of 5.14 times. - Overall, photovoltaics in agrivoltaic systems contribute to increased economic value and productivity per unit of land, supporting sustainable agricultural practices.
17	2019	Axel Weselek, Andrea Ehmann, Sabine Zikeli, Iris Lewandowski, Stephan Schindele, Petra Högy [41]	- The farm is located near Lake Constance in southern Germany. - Additional APV projects have been implemented in Santiago de Chile, Chile, and Chiba Prefecture, Japan. - Various commercial APV projects have also been realized in North Italy.	- The farm utilizes bifacial PV modules, which can capture light from both sides and utilize reflected radiation. - The PV panels are mounted on stilts with a vertical clearance of 5 meters to optimize light distribution for both photovoltaic and photosynthetic yield. - The system incorporates fixed PV panels oriented in a south-west direction with a tilt angle of 20 degrees. - There is also mention of mobile PV modules that enable solar tracking, which maximizes photovoltaic yield and improves light availability for crop growth.	- Photovoltaics are implemented on the farm by mounting solar panels on stilts, allowing for a vertical clearance of 5 meters to accommodate agricultural machinery. - The PV panels are oriented in a south-west direction with a tilt angle of 20 degrees, and a row spacing of 6.3 meters is maintained to ensure sufficient light reaches the crops. - The system utilizes bifacial PV modules, which can capture light from both sides, enhancing energy yield. - The implementation includes adjustments to the mounting structure to meet the requirements of agricultural operations, ensuring that the distance between pillars is suitable for planting and machinery access. - The farm's operation aims for energy self-sufficiency, with the potential to produce excess energy for nearby areas.	- The implementation of photovoltaics (PV) systems can lead to a reduction in solar radiation by about one third underneath the panels, which may result in declining crop yields. - PV systems can increase land productivity by up to 70% through the combined production of energy and crops. - In arid climates, PV systems can provide additional shading, which may improve water productivity and benefit crop production. - The economic value of farming can be enhanced through the generation of additional income from energy production, contributing to decentralized, off-grid electrification in rural areas. - PV installations can alter microclimatic conditions, affecting factors such as air and soil temperature, which in turn can influence crop cultivation and yields. - The presence of PV panels may reduce water evaporation and transpiration, potentially improving water use efficiency in dry climates. - The integration of PV systems can lead to changes in agricultural practices and field management, requiring adjustments to accommodate agricultural machinery.
18	2019	Rehan Younas, Hassan Imran, Muhammad Hussnain Riaz, Nauman Zafar Butt [42]	- The agrivoltaic farm discussed in the research paper is located in Lahore, with coordinates 31.520N, 74.358E.	- The farm implements east/west (E/W) faced vertical bifacial photovoltaic (PV) panels. - It also compares the performance of these vertical bifacial panels to standard fixed tilt north/south (N/S) faced PV structures. - The research indicates that E/W vertical bifacial panels provide better spatial homogeneity for daily sunlight distribution and higher land productivity compared to N/S faced fixed tilt panels.	- Photovoltaics are implemented in the agrivoltaic farm through the use of east/west (E/W) faced vertical bifacial panel structures. - This design is chosen to provide better spatial homogeneity for daily sunlight distribution compared to standard north/south (N/S) faced fixed tilt panels. - The implementation allows for optimized solar panel coverage, which helps prevent excessive thermal stress on crops, thereby increasing crop yield and lowering water usage. - The system can be modeled to assess PV energy and crop yield under varying densities of PV arrays and shade tolerances for crops. - The E/W vertical bifacial panels can enhance land productivity by approximately 5% compared to N/S faced fixed tilt panels when the PV array density is slightly lower than that of a standard solar farm. - The design also offers high resilience to soiling losses, making it suitable for agrivoltaic applications.	- The implementation of photovoltaics (PV) technology in agrivoltaic systems can lead to dual land productivity, fulfilling growing food and energy demands. - It can optimize solar panel coverage in hot and arid climates, which helps prevent excessive thermal stress on crops, thereby increasing crop yield and lowering water usage. - The use of east/west (E/W) faced vertical bifacial panels can provide better spatial homogeneity for daily sunlight distribution compared to north/south (N/S) faced fixed tilt panels, enhancing suitability for monoculture cropping. - E/W vertical bifacial panels can achieve approximately 5% better land productivity than N/S faced fixed tilt panels when the PV array density is slightly lower than that of a standard solar farm. - These panels exhibit high resilience to soiling (dust accumulation) losses, indicating their potential advantages for agrivoltaic applications.

No	year	authors	Place	Photovoltaics Technology	Photovoltaics Implementation	Photovoltaics Impacts
19	2018	Noor Farhani Othman, A. S. Mat Su, M. E. Ya'acob [43]	- The Agrivoltaic pilot project mentioned in the context is set up at Universiti Putra Malaysia.	- The photovoltaic technology implemented in the farm includes solar photovoltaic (PV) systems. - The specific configuration mentioned is a 1 kWp PV array consisting of 7 strings. - The solar PV arrays are ground-mounted and designed with fixed structures. - The PV system converts light energy from the sun into electricity, utilizing various materials such as crystalline, multi-crystalline, polycrystalline, microcrystalline, and amorphous types.	- Photovoltaics (PV) is implemented in the farm through ground-mounted arrays, which are fixed structures that support the solar panels. - The integration of PV systems with agriculture is referred to as Agrivoltaic (AV) systems, allowing for dual production of energy and food on the same land. - The AV system is designed to optimize the yield by considering appropriate plant characteristics such as crop height, sustainability, water requirements, and shading tolerance. - A pilot project in Malaysia, specifically at Universiti Putra Malaysia, has been established, integrating Java Tea as a high-value herbal crop under the PV array. - The PV array covers an area of 1 acre, with specific spacing considerations to ensure proper growth of crops beneath the solar panels. - The implementation aims to create a suitable environment for crops while generating clean energy, thus promoting a sustainable agricultural practice.	- Photovoltaic (PV) implementations contribute to clean energy generation, reducing reliance on fossil fuels and lowering carbon emissions. - The integration of PV systems with agricultural practices, known as Agrivoltaic (AV) systems, optimizes land use by allowing dual production of energy and food. - PV installations can address land scarcity issues by utilizing vacant spaces under solar panels for crop cultivation. - The design and installation of large-scale solar PV farms can enhance ecological performance and provide additional monetary benefits to operators. - The adaptation of PV technology supports the development of a green economy, promoting sustainable practices and improving social equity. - PV systems can lead to increased crop production compared to conventional farming methods, enhancing agricultural efficiency. - The economic viability of PV projects can be assessed through simulations, indicating potential positive cash returns and payback periods for investments.
20	2016	Harshavardhan Dinesh, Joshua M. Pearce [44]	- The agrivoltaic farm is located in Kansas City, U.S.	- The agrivoltaic farm utilizes Trinia Solar TSM300-P14A PV modules for its photovoltaic technology. - The PV modules can be mounted in two configurations: ground mounted and stilt mounted. - The ground mounted configuration consists of PV arrays mounted 1 meter above ground with a spacing of 6 meters. - The stilt mounted configuration has PV modules mounted at a height of 4 meters above the ground, allowing for agricultural activities underneath.	- Photovoltaics are implemented in agrivoltaic systems through various mounting configurations, including ground-mounted and stilt-mounted PV modules. - In the ground-mounted configuration, PV arrays are installed 1 meter above ground with a spacing of 6 meters to allow for the passage of industrial-sized harvesters and standard farming equipment. - The stilt-mounted configuration involves PV modules elevated at a height of 4 meters, allowing agricultural activities to occur underneath without interference. - The optimal mounting configuration is determined based on local solar irradiation data to maximize solar energy capture while minimizing shading effects on crops. - The PV system's performance is modeled using PVSyst, which considers factors such as tilt angle, conversion efficiency, and row spacing. - The integration of PV modules into agricultural land not only generates electricity but also provides benefits such as reduced water evaporation and soil erosion, enhancing overall farm productivity.	- Photovoltaics (PV) systems can significantly increase economic value when integrated with agriculture, as demonstrated by agrivoltaic systems that show over a 30% increase in value compared to conventional agriculture. - The implementation of PV systems can lead to a substantial increase in national PV power production, with potential increases of over 40 to 70 GW from specific crops like lettuce. - PV systems can alleviate water evaporation during dry seasons, resulting in water savings of 14-29%, which is beneficial in drought-prone areas. - The shading provided by PV modules can help reduce soil erosion and moisture evaporation, contributing to improved soil health. - Agrivoltaic systems can serve as a standalone power source for irrigation and pumping schemes, enhancing food security in areas with limited electricity access. - The dual use of land for both energy and food production can mitigate land competition issues, ensuring that food prices remain stable while meeting energy demands.

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