Combining solar panels with plants for sustainable energy and food production: state of the art

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ABSTRACT

The need for alternative energy sources becomes extensive because of the escalating cost of fossil fuels. The goal of this paper is to examine the effectiveness of combining photovoltaics and agriculture for better yield. Photovoltaic (PV) solar plants will compete with farms for available land. In this study, the methodologies are discussed how it is possible to maximize land utilization by placing solar arrays and food crops on the same plot of land. The term is proposed "agrivoltaic system" to describe this setup. Conventional solutions (discrimination of agricultural and energy extracting) were compared to two agrivoltaic schemes with varying density of PV arrays using land equivalent ratios. We utilized a crop model to simulate the amount of sunlight reaching the crop from an array of solar panels and to speculate on the yield reduction that would result from the partial shading. These early findings suggest that agrivoltaic systems may be highly effective; the two densities of PV panels were anticipated to boost worldwide land production by 73%. One possible explanation for the success of these hybrid systems is the presence of facilitation mechanisms analogous to those seen in agroforestry. At the end it is suggested that in places where arable land is rare, new solar plants may find it beneficial to produce both power and food.

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1. INTRODUCTION

Maintaining and enhancing energy and food production security are crucial to bolstering resilience in the face of a changing and uncertain environment. Conventional land use theory, which contends that solar photovoltaic (PV) installations and agricultural food production are inherently at odds with one another, acts as a brake on these initiatives. This either/or treatise influences countless policy and rules regarding energy management methods, allowing the positioning of grand-scale nonconventional power plant, despite the fact that some farmlands have accepted renewable energy generation to aid in their work [1]. At the same time, we may need a more comprehensive approach to address the requirement for more adequate food generation in different fields, with an aim to minimize the use of water. Beyond the confines of traditional methods of resource management, nexus thinking and research explore the interconnected webs of water, energy, and food systems [2].

The worldwide stability of our agricultural systems is threatened by the anticipated variation in atmospheric conditions. Due to our overreliance on irrigation, we are growing food that is not adapted to dry land climates in dryland climates, and projections of climate change suggest that rain-fed agricultural areas may shift northward in the next decades. In the United States alone, water constraint was a primary factor in the transformation of over 20,000 acres of farmland into sites for renewable energy production which happened in just one-year 2018 [3]. This was because of the fact that agriculture became unprofitable owing to water scarcity. Additionally, this dryness is predicted to last till the end of the 19th and 20th century [4]–[6].

Trommsdorff *et al.* [4] stated that the applicability and influence of agrivoltaics on agricultural production have been poorly studied. The effects of agrivoltaic systems on crop output due to changes in local microclimate are discussed. Their research indicates that crop yields under agrivoltaic systems can be predicted to decrease as a result of a drop in solar radiation; however, the extent to which this will occur is still unclear due to a lack of data on the impact of microclimatic heterogeneities on crop yields. This suggests that agrivoltaic systems may play an important role in the energy-food-water network by improving the agricultural field's flexibility to atmospheric variation [7]–[9].

Amaducci *et al.* [10] presents the evolution of agrivoltaics. REM TEC S.r.l. came up with a novel concept of agrivoltaic system they call agrovoltaico. It's the first commercial system developed and manufactured on a wide scale to simultaneously grow field crops and generate electricity from PV panels. The idea originated in 2004, and the first three plants (generating a combined 6.7 MW) were constructed in the Po Valley in northern Italy between 2011 and 2012, covering an area of roughly 35 hectares. In order to enhance electricity production and improve flexibility under extreme weather events, the agrovoltaico scheme makes use of arrays constructed of silicon PV cells that can adjust their angle of tilt in response to the movement of the sun and weather changes. The PV mounting structures are made so that normal farming equipment can be used freely beneath them, and crop shading is kept to a minimum. So far, we have not been able to locate a comprehensive environmental and economic analysis of an agrivoltaic plant in the existing literature. This study intends to fill that void by conducting a life cycle assessment (LCA) of the agrovoltaico system and comparing it to both conventional and renewable energy resources [11], [12].

Toledo and Scognamiglio [13] conducted a representation of the effects of shadowing on agricultural yields and found that the effect varied greatly depending on the type of crop. At last, a qualitative evaluation of agrovoltaico systems potential to aid in the United Nations' Sustainable Development Goals' realization was conducted [13]. Figure 1 represents the pictorial concept of agrivoltaic.

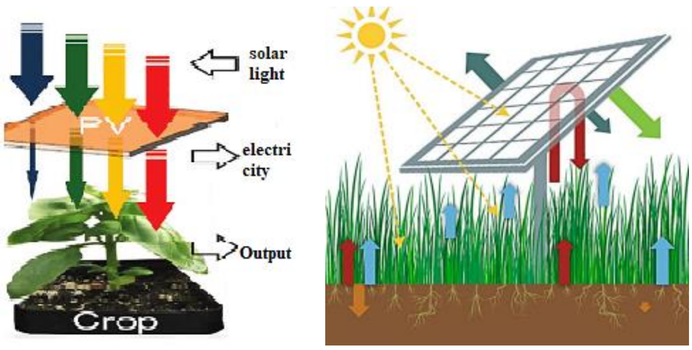

Figure 1. Agrivoltaic farming concept

2. DIFFERENT TIERS OF AGROPV CLASSIFICATION

The application of agrivoltaics can be categorized depending on the system that is carried out, the type of photovoltaic system that is being utilized, the farming techniques that are being utilized, and lastly, the adaptability of the system. Figures 2(a) and 2(b) presents cases when separately crops and PV panels are used. The productivity is 100% wheat and 100% solar electricity generation. When the same land is used for crops and PV panels the productivity of the land has been increased as reported in [14]. The land which generates 100% wheat or electricity can produce 160% as shown in Figures 2(c) and 2(d) when combined on the same land. Integrating crops and PV on the same land has proven to be an effective method for optimizing the land.

2.1. Application

There are two main types of agrivoltaic systems, “crop + PV” and “livestock + PV,” both of which are used for different purposes. The term "agrivoltaic" is typically understood to mean "crop + PV," where "agro" refers to the study of agriculture as it relates to the cultivation and utilization of plants (agronomy) and "voltaics" refers to photovoltaic technology. In contrast, the term "rangevoltaics" is short for "cattle + PV", where "range" refers to the open fields that are viewed by livestock.

(a) (b)

(c) (d)

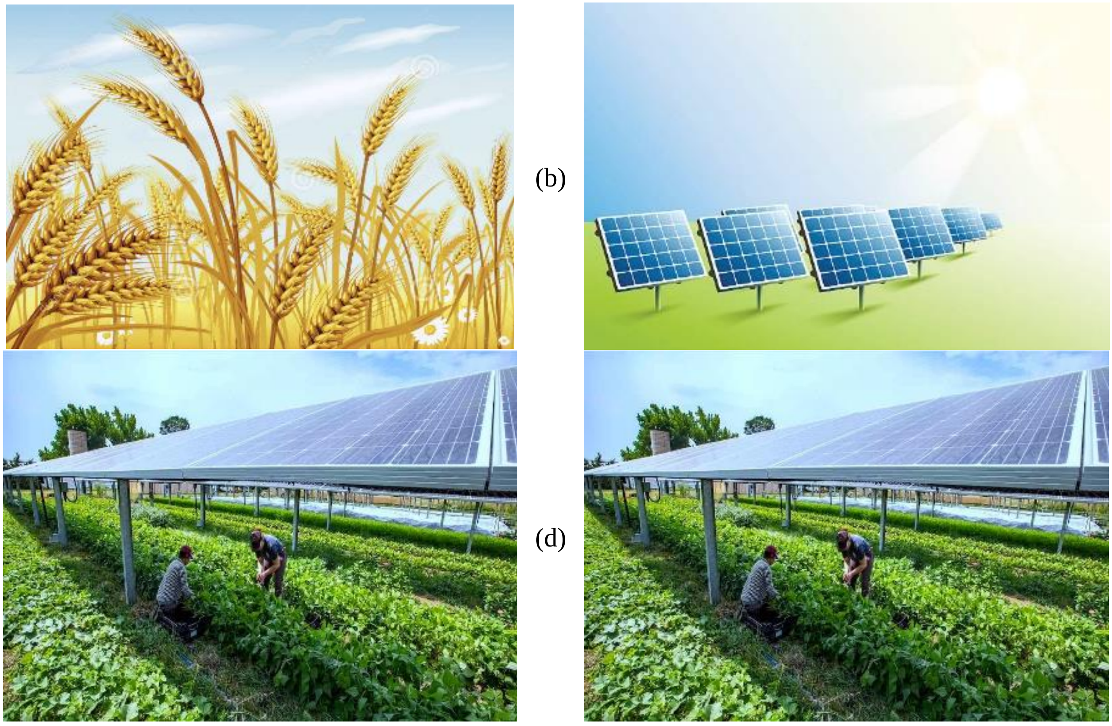

Figure 2. Combined land use on 2 hectare cropland: efficiency increases over 60% [15]: (a) land use with only crops, (b) land use with only PV panels, (c) land use with both crops and PV panel, and (d) land use with both crops and PV panel

2.2. System

As with any technology, agrivoltaics can be broken down into "open" and "closed" categories based on the system architecture. The latter are PV greenhouses, which have photovoltaic modules affixed to their ceilings. Another option is to raise the PV array off the ground, as shown in Figure 3, allowing crops to grow and cattle to move freely between the rows. Increased PV array densities are an advantage of these buildings, which in turn shields cattle and crops from excessive heat and other environmental hazards [15], [16]. The higher elevation of PV panels increases visual pollution and raises investment expenses due to stilts and additional wind reinforcements, which are two primary drawbacks of such an installation. In cases where huge dimensions of agricultural machines prevent the PV array from being spanned on stilts, spaced systems. An open rangevoltaic system, in contrast to a closed one, has the panels positioned between or above the cattle.

Figure 3. Spaced AgroPV farming [16]

2.3. Farming type

Agrivoltaic systems could also be categorized according to the methods typically used in agriculture. Farming of field crops and fruit trees both fall under this category. As part of a crop rotation system, farmers that practice field crop farming typically grow staples like wheat, potatoes, rice, and so on every year [17]. These crops typically have a poor economic value and are grown in nations where agriculture is extensively mechanized. Orchard farming, on the other hand, involves planting trees in a precise geometric row-based structure in order to produce fruit or nuts. These crops often last for multiple growing seasons and are more lucrative. They also need some way to be shielded from severe weather, such as plastic covers, hail covers, or some other method.

3. FOUNDATIONS OF AGROPV

3.1. Crop selection

Because the success of the horticulture PV strategy hinges so heavily on the crops that are chosen and their level of shade tolerance, determining which crops and farming methods are appropriate is a vital step. Therefore, plants like leaf vegetables or berries are preferable since they do well with less solar irradiation than grain crops like corn, rice, and wheat. Again, the crop selection is impacted by atmospheric conditions like sunlight, temperature, and wind speed [18].

3.2. Light management

Horticulture PV systems, in comparison to standard ground-mounted PV (GM-PV), typically have wider row spacing to allow for adequate light transmission to the ground. The percentage of farmland that is covered with photovoltaic panels, as seen from above, is typically between 20% and 40%. Many studies reported improved growth in horticulture due to support of PV system.

3.3. Mounting structure and foundation

The use of machinery is essential to the majority of farming methods. That's why most horticulture PV systems aim for a lot of space between the poles and necessitate a certain amount of vertical clearance. Full harvesters, which can reach heights of up to 5 m, are frequently used as a yardstick for vertical clearance in arable farming [19].

4. EFFECTS OF AGROPV ON AGRICULTURE

4.1. Horticulture PV system and wind

The protection from wind that the horticulture PV power station provides to the crops produced in it is a major benefit of the system. The system's supporting pillars function as windbreakers, which could mitigate soil erosion brought on by strong winds. PV system has positive impact on horticulture by breaking wind gust and saving plants from scorching sunlights.

4.2. Soil moisture and lower evapotranspiration

Soil moisture readings taken in the summertime revealed that the soil surrounding some crops had up to 9.4% more water than the soil in the control region, making for optimal growing situations [20], [21]. The shade by PV panels helps to limit evaporation from the soil which eventually helps the soil to retain more moisture. Higher moisture content is beneficial for some micro-organisms and some specific crops. Soil moisture contributes significantly to atmospheric water vapour through the process of evapotranspiration (ET), which entails both plant transpiration and bare soil evaporation. Depending on the geography, ET can be responsible for returning as much as 60% of the water on the continent to the air.

4.3. Land losses due to dual land use

Actual mounting structure coverage in typical horticulture PV systems is less than 1% of land. Therefore, about 99% of the land may be used if it is manually cultivated [22]. Even if land machines are used and the direction of work is in straight lines, there would still be strips of land between the poles that could account for as much as 10% of the total area. These stripes take up about 8% of the area at the Fraunhofer ISE research horticulture PV system [23]–[25].

With the addition of a rainwater collection and storage system, AVS infrastructures can become more self-sufficient. Thus, the AVS's rain-water gathering system has also undergone study and development. Figure 4 depicts the standard layout for a rainwater harvesting system, which includes a network of collection channels, a network of underground PVC pipes, and a storage tank with a typical capacity of 1,000,000 liters. Aside from irrigating the crops, this stored water can also be used to wash away any dust that has settled atop the PV panels.

Figure 4. Rain water harvesting system on AgroPV [23]–[25]

5. PERFORMANCE INDICATORS

The purpose of this work is to offer seven key performance measures (KPIs) that may be employed to more accurately compare and benchmark different types of agrivoltaic systems. The parameters like ground coverage ratio, energy and agricultural yield, land equivalent ratio, and economic indicators are considered. Table 1 provides a summary of these performance measures.

Table 1. Summary of perfomance indicators

Parameters	Mathematical representation	Salient features
Ground coverage ratio (GCR)	$GCR=A_{PV}/A_{Ground}$ $A_{PV=}$ Surface area of PV panels A_{Ground}= Area of cultivated ground surface	Detrimental variable in agrivoltaic design High GCR value implies high energy yield, low crop yield
Energy and agricultural yield (Y_{EL}, Y_{AG})	$Y_{EL}=\frac{AnnualEnergy\ (MWh)}{unitland(ha)}$	Y_{EL} depends on solar insolation, module efficiency
Land equivalent ratio (LER)	$YAG=\frac{Yield\ (kg)}{Unitlandarea\ (ha)}$ $LER=\frac{E\ (YAgri.AV)}{E\ (YAgri.N)}+\frac{Yel.AV}{Yel.N}$ AV- Agrivoltaic N- Normal cultivation	LER value>1 increases productivity of land Combination of agriculture and PV leads to increased spatial efficiency
Economic indicators: price performance ratio	$PPR=\frac{P}{Pb}$ P= Cost of agroPV structure Pb= Cost of ground mounted PV structure	Extra cost mainly depends upon levelized cost of energy (LCOE) PPR>1 is not considered reasonable where as PPR=1 is economically reasonable

5.1. Energy and agricultural revenue

The annual electrical energy production expressed as a multiple of land area in ha is referred to as the energy yield Yel, [MWh/ha]. It is important to include the (normalized) performance indicator because the energy yield is affected by various local factors such as solar irradiation, module efficiency, temperature and the impact of the microclimate, and cable losses. Since the modules in an agroPV system will be spaced further apart, the length of the cables connecting them will be greater, leading to higher cable losses. Collecting the harvest, a farm's total output (in Y_{AG}) is a function of its total acreage. Both kilograms per hectare (for instance, dry crop matter in agrivoltaics) and liters per hectare (for instance, water use) are acceptable units of measure.

5.2. Agricultural quality

The quality of crops could be improved with the help of PV modules, which could shield them from damaging hail, heavy rain, and sunburn. Positive effects on other quality dimensions have also been observed. Given the intractable nature of quantifying quality, it's essential to account for the crop's market value while assessing its impact. The effect of the PV panels on the water balance is an essential metric for agrivoltaics, particularly in (semi-)arid regions.

5.3. Human comfort

Farmers and other land workers should take frequent rests in the shade on days with high solar intensity to prevent sunburn and other health problems. Reduced radiation and more readily available shade are also benefits of the modules' design. As a result, the farmer will experience less heat exhaustion as he works the soil. The wet bulb globe temperature (WBGT) in Kelvin is a measure of the cultivators' ease of mind.

5.4. Economic indicators

The benefits of agrivoltaics are not limited to those mentioned above. Agrophotovoltaics needs to be cost-effective to become mainstream. The price performance ratio (PPR) presented in Table 1 in equation can be used to determine whether or not the agrivoltaic project is economically viable. In this case, 'p' represents the yearly premium above the prince of a ground-mounted PV system that would be incurred by implementing an agrivoltaic system. The levelized cost of energy (LCOE) for agrivoltaics and ground-mounted PV are the primary determinants of this supplementary expense. In this context, performed benefits (Pb) refer to the annual revenue generated by the protection of agricultural land and the sale of its products. This Pb should include the quality aspects as was mentioned earlier.

5.5. Outlook and future application opportunities

The APV systems are still in their infancy in terms of research and use in real-world circumstances. Still there is room for enormous technical advances by combining new technologies and refining those already deployed. It is possible to conduct in-depth research into the use of spectrally selective PV technologies in agrivoltaic systems, with a focus on meeting the unique needs of the crops being grown.

6. DISCUSSION

The aim of this paper is to discuss the benefits of combining photovoltaics with agriculture. The listed benefits for agriculture are soil moisture and lower evapotranspiration, rainwater harvesting, energy and agricultural revenue. The PV system gets benefited as the panel temperature remains lower due to cooling effect generated from the crop under the panels. Older solar panels that aren't designed for recycling may be better suited for reuse in autonomous vehicles. Table 2 depicts the estimates of AV advantages. Small vertical-axis wind turbines and conversion to biogas can be considered by AV concept designers to make power output less intermittent.

Table 2. The concluding estimates of AV advantages

	Agriculture		PV		
	Yield	Income increase	Electricity income share	Infrastructure sharing savings	Total benefits
Horticulture	-30….+60%	-30….+75%	50…….90%	0…….10%	60..…1000%
Livestock	0....…+50%	0……+50%	0..…….80%	0…….80%	50..…4000%
Water use					10……..30%
Growth stimuli					50……500%
On-site process					30……300%
GHG emission					10….….50%
Robotics & IoT					30...…100%
Old PV utilities					50...….200%

6.1. Effects on the environment

Agrivoltaic systems are gaining popularity around the world as a way to provide renewable energy with minimum impact on resources, especially land use. There is no data on the economic or environmental viability of agrivoltaic systems because most research has only considered performance simulations or prototypes. When first introduced, the agrivoltaic system's environmental performances were not only inferior to those of ground-mounted structures, but also to those of coal electricity due to the vast concrete basements and large poles used to assurance their stability during harsh environmental conditions. Instead, agrivoltaic systems outperform the Italian electricity mix in every environmental effect category except for the reduction of mineral and metal resources because to their use of tensile structures. PV systems are still infrastructure intensive in comparison to fossil-based systems, although tensile structures allow for a significant decrease in resource use.

6.2. Economics

Since the LCOE of agrovoltaico schemes and GM-PV are quite close, the additional electrical generation helps to offset the greater costs of supporting structures and installation, and BOP. The location and configuration of PV structures, as well as the prevailing conditions in the electricity market, affect the systems' potential profits and losses. While the manufacturer-defined and commodity-price-based (steel and PV panels) capital costs are likely to be comparable across regions, the installation and maintenance labor costs, as well as the cost of the land, may vary greatly depending on the region. However, their impact on the overall price tag is minimal. Instead, the incentives and energy rates unique to the PV power market have a significant bearing on earnings. The amount of sunlight available is also important for financial reasons. While there is always some degree of uncertainty in any economic evaluation, we feel confident in the results we offer here because they are based on actual data from a currently active project in Italy's Po Valley.

7. CONCLUSION

Since expanding renewable capacity is hampered by increasing population density, preserving agriculture while enriching nonconventional energy output is a crucial part of addressing forthcoming energy demands. Depending on local climate, agrophotovoltaics (AgroPV) offers a wide range of options for attaining a long-term, environmentally friendly answer to the problem of how to combine energy production with food production. By allowing for the generation of both energy and food at the same time, APV increases value by providing economic benefits to farmers and the possibility of synergistic effects. In hot, arid climates, adopting crops that can thrive in the shade can increase productivity and protect against the damaging effects of the sun. It has been observed that compared to conventional full-light agriculture, agrivoltaic systems may boost and stabilize maize yield. The results of this study support the viability of agrivoltaic systems from both an economic and ecological perspective. The tensile structure used in agrivoltaic systems allows them to achieve environmental results that are on par with those of ground-mounted solar systems, and they outperform the Italian electricity mix in every impact category except for mineral and metal resource use.

REFERENCES

[1] M. E. Ya'acob, N. F. Othman, M. Buda, E. Jani, and A. S. Mat Su, "Field assessment on agrivoltaic misai kucing techno-economical approach in solar farming," in *2021 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, Dec. 2021, pp. 1–6, doi: 10.1109/ICECET52533.2021.9698511.

[2] G. S. Kuaban *et al.*, "Smart sustainable agrivoltaics systems: The future of sustainable agricultural technology (agri-tech) and green energy," in *2023 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Jul. 2023, pp. 1–6, doi: 10.1109/ICECCME57830.2023.10253215.

[3] H. Abdulmouti, A. Bourezg, and R. Ranjan, "Exploring the applicability of agrivoltaic system in UAE and its merits," in *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, Feb. 2023, pp. 1–6, doi: 10.1109/ASET56582.2023.10180741.

[4] M. Trommsdorff *et al.*, "Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany," *Renewable and Sustainable Energy Reviews*, vol. 140, p. 110694, Apr. 2021, doi: 10.1016/j.rser.2020.110694.

[5] M. A. Z. Abidin, M. N. Mahyuddin, and M. A. A. M. Zainuri, "Performance evaluation of solar tracking system towards crop-light demands in agrivoltaic systems," in *2023 IEEE International Conference on Agrosystem Engineering, Technology & Applications (AGRETA)*, Sep. 2023, pp. 74–79, doi: 10.1109/AGRETA57740.2023.10262512.

[6] M. S. Ahmed and M. R. Khan, "Assessing agrivoltaics: Crops under solar panels, or solar panels over crops?," in *2023 IEEE Region 10 Symposium (TENSYMP)*, Sep. 2023, pp. 1–4, doi: 10.1109/TENSYMP55890.2023.10223638.

[7] S. Panda *et al.*, "A review on advanced cooling techniques for photovoltaic panel," *Materials Today: Proceedings*, vol. 62, no. 12, pp. 6799–6803, 2022, doi: 10.1016/j.matpr.2022.04.925.

[8] M. A. Z. Abidin, M. N. Mahyuddin, and M. A. A. M. Zainuri, "Optimal efficient energy production by PV module tilt-orientation prediction without compromising crop-light demands in agrivoltaic systems," *IEEE Access*, vol. 11, pp. 71557–71572, 2023, doi: 10.1109/ACCESS.2023.3293850.

[9] H. Alam, M. A. Alam, and N. Z. Butt, "Techno economic modeling for agrivoltaics: Can agrivoltaics be more profitable than ground mounted PV?," *IEEE Journal of Photovoltaics*, vol. 13, no. 1, pp. 174–186, Jan. 2023, doi: 10.1109/JPHOTOV.2022.3215087.

[10] S. Amaducci, X. Yin, and M. Colauzzi, "Agrivoltaic systems to optimise land use for electric energy production," *Applied Energy*, vol. 220, pp. 545–561, Jun. 2018, doi: 10.1016/j.apenergy.2018.03.081.

[11] F. D'Alessandro, F. Sevagian, A. R. Massulli, F. Nardecchia, and L. Pompei, "Smart cities and communities: A case study of agrovoltaic systems applied to an italian urban periphery," in *2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)*, Jun. 2023, pp. 1–6, doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194641.

[12] Y. Oktarina, Z. Nawawi, B. Y. Suprapto, and T. Dewi, "Digitized smart solar powered agriculture implementation in Palembang, South Sumatra," in *2023 10th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, Sep. 2023, pp. 60–65, doi: 10.1109/EECSI59885.2023.10295805.

[13] C. Toledo and A. Scognamiglio, "Agrivoltaic systems design and assessment: A critical review, and a descriptive model towards a sustainable landscape vision (three-dimensional agrivoltaic patterns)," *Sustainability*, vol. 13, no. 12, p. 6871, Jun. 2021, doi: 10.3390/su13126871.

[14] P. Cellier, "Peer review report 2 On 'Microclimate in agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels?,'" *Agricultural and Forest Meteorology*, vol. 201, pp. 171–172, Jan. 2015, doi: 10.1016/j.agrformet.2015.08.021.

[15] Anonymous, "Peer review report 1 On 'Microclimate in agrivoltaic systems: is crop growth rate affected in the partial shade of solar Panels?,'" *Agricultural and Forest Meteorology*, vol. 201, pp. 177–178, Jan. 2015, doi: 10.1016/j.agrformet.2015.08.020.

[16] M. Kayitare, G. A. Dalson, and A.-M. Sendegeya, "A study on the design and financial viability of solar PV plants in Rwanda," in *2023 3rd International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Jul. 2023, pp. 1–6, doi: 10.1109/ICECCME57830.2023.10252327.

[17] A. H. Pardhi, A. R. Phadke, and G. V. Lakhekar, "Assessment of microclimatic alteration and their impact using crop level data through experimental prototype of agro photovoltaic system," in *2023 3rd Asian Conference on Innovation in Technology (ASIANCON)*, Aug. 2023, pp. 1–7, doi: 10.1109/ASIANCON58793.2023.10270004.

[18] S. Panda, B. Panda, C. Jena, L. Nanda, and A. Pradhan, "Investigating the similarities and differences between front and back surface cooling for PV panels," *Materials Today: Proceedings*, vol. 74, pp. 358–363, 2023, doi: 10.1016/j.matpr.2022.08.424.

[19] B. Willockx, C. Lavaert, and J. Cappelle, "Development of a quick-scan webtool to facilitate agrivoltaic system design," in *2022 International Conference on Renewable Energies and Smart Technologies (REST)*, Jul. 2022, pp. 1–5, doi: 10.1109/REST54687.2022.10022628.

[20] H. Wang, H. J. Williams, X. Bu, and K. Max Zhang, "A combined shading and radiation simulation tool for defining agrivoltaic systems," in *2022 IEEE 49th Photovoltaics Specialists Conference (PVSC)*, Jun. 2022, pp. 0384–0386, doi: 10.1109/PVSC48317.2022.9938795.

[21] S. Gorjian *et al.*, "Progress and challenges of crop production and electricity generation in agrivoltaic systems using semi-transparent photovoltaic technology," *Renewable and Sustainable Energy Reviews*, vol. 158, p. 112126, Apr. 2022, doi: 10.1016/j.rser.2022.112126.
[22] G. A. Barron-Gafford *et al.*, "Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands," *Nature Sustainability*, vol. 2, no. 9, pp. 848–855, Sep. 2019, doi: 10.1038/s41893-019-0364-5.
[23] P. M. Jansson, M. G. Newberry, and S. M. Myers, "Agrivoltaics using Bi-Facial PVs for permaculture in utility-scale projects," in *2022 IEEE 49th Photovoltaics Specialists Conference (PVSC)*, Jun. 2022, pp. 0330–0332, doi: 10.1109/PVSC48317.2022.9938476.
[24] K. Ahmad, Y. Wijayanti, A. Subandriya, T. Setyorini, S. Mukhid, and R. Budi Prasetyo, "The agrivoltaic system development in Baron Technopark, Yogyakarta, Indonesia," in *2022 5th Asia Conference on Energy and Electrical Engineering (ACEEE)*, Jul. 2022, pp. 147–151, doi: 10.1109/ACEEE56193.2022.9851860.
[25] A. Pradhan, B. Panda, and S. Mohapatra, "Performance analysis of proposed MPPT method with the conventional methods," in *2020 IEEE International Symposium on Sustainable Energy, Signal Processing and Cyber Security (iSSSC)*, Dec. 2020, pp. 1–5, doi: 10.1109/iSSSC50941.2020.9358820.

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