AgriVoltaics World Conference 2022
Technical Aspects
https://doi.org/10.52825/agripv.v1i.601

Published: 06 Feb. 2024

Evaluation of Agrivoltaic System in Thar Desert of India

Surendra Poonia[1][https://orcid.org/0000-0001-5732-0580], and Priyabrata Santra[1][https://orcid.org/0000-0002-8127-282X]

[1] ICAR-Central Arid Zone Research Institute, Jodhpur – 342 003, India

Abstract. The demand for food and energy is increasing fast, and their security has become the prime issue in mainly developing countries like India. Agri-voltaic system has been proposed as a hybrid system, combining photovoltaic with agriculture simultaneously on the same land to capture solar energy for both energy generation and food production. The present study examined the performance of the 100 kWp agri-voltaic systems at ICAR-CAZRI, Jodhpur. Average PV generation from the 100 kWp AVS attached to the grid through a bi-directional energy meter or net meter has been about 342 kWh day^{-1}. The average yield of mung bean, moth bean, and cluster bean in inter-row spaces between the panels in the two-row and three-row PV array was 1155, 670, and 2008 kg.ha^{-1}, respectively. Thus, there were 4.6%, 8.6%, and 11.8% reductions in the yield of mung bean, moth bean, and cluster bean, respectively, in inter-row spaces between the panels compared to control. During Rabi (Irrigated) 2021-22, the yield of chickpea, cumin, and isabgol (2490, 1000, and 700 kg ha^{-1}, respectively) were lower in interspaces of the AVS than control (2670, 1120, and 760 kg ha^{-1}, respectively). AVS resulted in a 6.6, 10.3, and 7.8% yield reduction of chickpea, cumin, and isabgol, respectively, compared to control. The AVS shows the maximum IRR (20.38%), whereas PV-GM has the lowest (19.42%) at the prevailing bank loan interest rate of 12%. The PBP estimated 7.47 years for AVS with irrigated crops and 8.11 years for AVS with rain-fed crops, whereas it was 8.61 years PV-GM. The lower value of the discounted PBP, the quicker the repayment of the investment cost. Therefore, the highest LCOE (INR 3.45 kWh^{-1}) based on the break-even electricity tariff is estimated in PV-GM, and the lowest LCOE is computed in AVS (INR 3.17 kWh^{-1}).

Keywords: Agri-Voltaic System (AVS), PV-Based Electricity Generation, Crop Production, Photosynthetically Active Radiation (PAR)

Introduction

In arid western parts of India in Rajasthan, solar irradiations are abundant for almost 300 days of clear sky. The average irradiance on a horizontal surface in arid Rajasthan is 5.6 kWh m^{-2} day^{-1}, and at Jodhpur, it is 6.0 kWh m^{-2} day^{-1} [1], which can be harnessed to fulfill a part of the energy needs of rural communities. A similar amount of solar irradiation is available in other countries in tropical and subtropical regions of the world. About 120 countries lying on the solar belt of the world have launched the International Solar Alliance (ISA) to boost solar energy in developing countries during UN Climate Change Conference in Paris held in November 2015. The prime objective of the ISA is to produce renewable solar energy to reduce global warming. India is leading the alliance with its headquarters in New Delhi, India. Apart from this international goal, India has its own national goal of installing 175 GW of renewable energy by 2022, which has been further revised with a target of 450 GW by 2030. In addition, the Govt of India has committed to a 100% renewable power system target by 2050 and a net-zero carbon emission target by 2070, declared at COP 26 climate meeting in Glasgow in November 2021. To meet this long-term goal of renewable energy installations, an agri-voltaic (AV) system is considered a potential option for co-productive utilization of agricultural land for food production and photovoltaic (PV) generation. Solar PV generation is a land-intensive venture, and it needs around two hectares of land per megawatt of power generation, and so is the case with crop production. The concept of AVS was first proposed by Goetzberger and Zastrow [2], and was later successfully studied experimentally by Dupraz *et al.* [3] and Marrou *et al.* [4]. During the last 3-4 years, there has been growing interest in utilizing the potential of AVS in different parts of the world [5-17]. Combining PV generation and agricultural production together in AVS has led to improvement of land productivity by about 40-70% [3, 18, 24]. Further, AVS system has also been found to be environmentally friendly; therefore, it may be considered a suitable option for mitigating climate change effects, specifically in drylands [6, 12]. Schindele *et al.* [19] reported that the LCOE for agri-voltaic farms is 38% higher than that of an ordinary, ground-mounted solar PV installation, the respective values being US$0.0992/kWh and US$ 0.0721/kWh. Agostini *et al.* [20] found that the initial cost of an agri-voltaic system is returned in nine years while, in the case of ground- and roof-mounted solar, the periods are eight and six years, respectively. Techno-economic analysis revealed that the agri-voltaic system had the lowest Levelized cost of electricity generation (LCOE) (Rs 3.17 kWh^{-1}), which is much lower than the prevailing electricity tariff (INR 5.0 kWh^{-1}) [17]. A recent study conducted by the Indo-German Energy Forum Support Office (IGEF-SO) and the National Solar Energy Federation of India advocates for the promotion of Agri-voltaic systems (AVS) in the agricultural sector under component-A of the Kisan Urja Suraksha evam Uthaan Mahabhiyaan (KUSUM) scheme [21]. This investigation focuses on evaluating the performance of stilt-mounted photovoltaic (PV) panels with a capacity of 100 kW, which were installed in a one-acre plot at the ICAR-Central Arid Zone Research Institute in Jodhpur, Rajasthan, India. The assessment pertains to the impact of AVS on both crop production and electricity generation within the arid ecological context of India.

Materials and methods

PV Module Installation

This investigation utilized the 100 kWp capacity ground-mounted and fixed-tilt solar photovoltaic (PV) system located at ICAR-CAZRI, Jodhpur, Rajasthan, India, for a comprehensive techno-economic assessment. The PV system spanned an area of 4624 m² and featured polycrystalline silicon solar PV modules (dimensions: 0.992□1.640 m) arranged in the East-West direction with a southward inclination at a tilt angle of 26□. The system comprised five distinct designs denoted as AVS-1 to AVS-5, each implemented in separate blocks. AVS-1 entailed a single-row PV array with 100% PV density, AVS-2 featured a single-row PV array with 50% PV density, AVS-3 incorporated a double-row PV array with 100% PV density in the bottom row and 60% density in the top row, AVS-4 included a triple-row PV array with 100% PV density in the bottom two rows and 60% PV density in the top row, and AVS-5 comprised a triple-row PV array with 100% PV density in the bottom row and 60% PV density in the top two rows. The allocation of full (100%) and half (60%) PV density in rows was implemented to regulate solar radiation interception on the ground surface, essential for crop production in the interspaces between PV arrays. To mitigate shading effects on leeward PV panels, inter-row spacing of 3.2, 6.4, and 9.6 m was maintained in one, two, and three-row PV arrays, respectively, in the North-South direction. Each block measured 28 m □ 28 m, with the total area covered by PV panels and interspaces accounting for 24%, 49%, and 73% of the total area in one, two, and three-row PV arrays, respectively. Refer to Fig. 1 for a detailed depiction of the various modules comprising the AVS setup employed in this investigation [16-17].

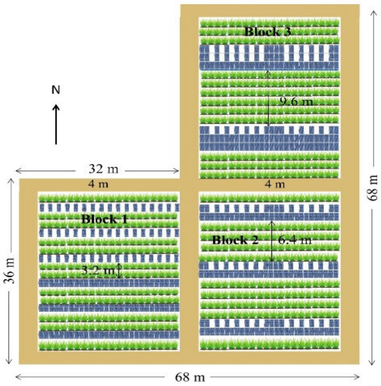

Fig. 1. Schematic design of PV module installations for AVS

Cropping options

In the prevailing solar photovoltaic (PV) system, the shading effect of PV modules on the ground surface, particularly on the leeward side relative to the sun's trajectory, necessitates a designated separation distance between adjacent arrays. This inter-array space is effectively utilized for cultivating specific crops, contingent upon their shade tolerance and limited height to prevent shading on the PV panels. The crop height emerges as a critical parameter in crop selection for AgriVoltaics (AVS), as taller crops have the potential to cast shadows on PV modules, thereby diminishing photovoltaic energy generation. Consequently, crops characterized by a diminutive stature (preferably below 50 cm), adept shade endurance, and low water requirements prove most suitable for AVS implementation in arid ecosystems.

Within the AVS framework, crops such as mung bean (Vigna radiata), moth bean (Vigna aconitifolia), and cluster bean (Cyamopsis tetragonoloba) are cultivated during the Kharif season in the interspace between two PV arrays. Additionally, during the Rabi season, irrigated cultivation includes Isabgol (Plantago ovata), cumin (Cuminum cyminum), and chickpea (Cicer arietinum). Beyond conventional arable crops, perennial components such as medicinal plants like aloe (Aloe vera) and brinjal (Solanum melongena) are grown in the interspace areas of AVS-1 and AVS-2. Vegetable crops like spinach (Spinacia oleracea) and snap melon (Cucumis melo L. Momordica group) are incorporated as annual components in the AVS system. These strategically selected crops are hypothesized to induce microclimate modifications beneath the PV modules, leading to temperature reduction and consequently optimizing PV-based electricity generation. A visual depiction of various Kharif crops cultivated within the AVS is presented in Figure 2.

Fig.2. Field view of different crops grown in agri-voltaic system during *Kharif,* 2021

Photo-Voltaic-based electricity generation from AVS

Solar power generation and solar radiation are consistently observed using the SCADA (Supervisory Control and Data Acquisition) system and an automated weather station. The deployed AVS is linked to the regional power grid through a net metering mechanism, facilitating the direct sale of generated power to the state electricity board at a predetermined tariff. Consequently, the average tariff of INR 5 per kilowatt-hour can be employed for the computation of revenue derived from photovoltaic-generated electricity.

Environmental parameters monitoring

The operational efficiency of photovoltaic (PV) systems is significantly influenced by both internal and external factors, including structural characteristics, aging, radiation exposure, shading, temperature fluctuations, wind, and the accumulation of dust on PV plates. Furthermore, alterations in climatic conditions lead to variations in solar radiations and ambient temperature, consequently impacting the performance of solar PV outputs. Ambient and PV module temperatures were recorded at 10-minute intervals using a J-type thermocouple with a 32-channel data logger. Various probes were strategically positioned in shaded areas beneath the panel, subjected to full and half-density treatments, as well as at the bottom of the panel. Additionally, soil temperature at different depths was measured. Microclimatic parameters, specifically net radiation and photosynthetically active radiation (PAR), were assessed during daytime using an AVS in shaded regions beneath solar PV modules and under open-sun conditions.

Economic analysis of AVS

The economic evaluation of revenue generation from five 100 kWp capacity Agrovoltaic Systems (AVS) designs was conducted based on electricity generation and crop production data. Combinations of crops for each design were systematically computed to determine maximum returns per hectare of land for both rainfed and irrigated scenarios. Subsequently, economic analyses of the selected AVS designs, along with a reference ground-mounted PV design in the same area, were performed. The assessment involved the computation of essential economic indicators, including life cycle cost (LCC), life cycle benefit (LCB), benefit-cost ratio (BCR), net present worth (NPW), annuity (A), internal rate of return (IRR), and payback period (PBP). Additionally, levelized costs of electricity generation (LCOE) and various economic parameters were determined across multiple escalation rates and electricity tariffs, as referenced in literature [1, 17, 19].

i. *Levelized cost of PV electricity generation*

The Levelized cost calculation method calculates and compares the electricity costs per unit of electricity produced (Rs/kWh). LCOE was computed by equating the PV system's life-cycle cost (LCC) and the life cycle benefit (LCB) of the PV system [17, 19]. Where,

$$LCOE = \frac{\left(LCC - R\frac{X(1-X^n)}{(1-X)} \right)}{M.ET.\sum_{n=1}^{n=25}(1-d)^n \left(\frac{1+e}{1+i}\right)^n} ------(1)$$

ii. *Benefit-cost ratio (BCR):* The ratio of discounted benefits to the discounted values of all costs given as LCB/LCC

iii. *Net Present Worth (NPW):* The Net Present Worth (NPW) serves as an economic indicator wherein the computation of the disparity between the discounted value of benefits and discounted costs is undertaken at a specified discount rate. A positive NPW denotes a prospective viability of the project. The NPW is derived as the cumulative sum of all discounted net benefits over the project's duration, articulated as the difference between the present value of long-term benefits (LCB) and long-term costs (LCC).

iv. *Annuity (A):* A of a project indicates the annual average net returns and is given as,

v. *Pay Back Period (PBP):* The PBP can be determined as follows: LCB-LCC = 0 and solving for n by getting one positive NPW and one negative NPW close to NPW = 0, and by way of superimposition, we can arrive at the value of n, which is PBP; as given below.

$$PBP = UPBP - \frac{(UPBP - LPBP) \times NPW \ \ for\ UPBP}{(NPW \ \ for\ UPBP - NPW \ \ for\ LPBP)} ------(2)$$

where, UPBP = Upper payback period; LPBP = Lower payback period

vi. *Internal Rate of Return (IRR):* IRR is the rate of interest that makes life cycle benefits and costs equal. The IRR can be computed by using the following relationship

$$IRR = lower\ discount\ rate + \frac{Difference\ of\ discount\ rate\ X\ NPW\ at\ lower\ discount\ rate}{(NPW\ at\ lower\ discount\ rate - NPW\ at\ higher\ discount\ rate)} -----(3)$$

Results and discussion

The agri-voltaic system's performance was evaluated during the Kharif seasons (June-September 2021) and Rabi season (November 2021-February 2022). Cultivation of crops occurred in the interspace areas between photovoltaic (PV) arrays and the regions beneath them. The available cropping area varied based on the installation design. In our investigation, PV modules were implemented in three distinct designs, each possessing identical capacity and occupying the same land area of 32m × 32m, totaling 35 kWp capacity. Consequently, the land requirement for each installation was maintained at 34 W m-2 across the three separate blocks. Thus, a 1-hectare land area could accommodate a 340 kW capacity agri-voltaic system, while 1 acre of land could support a 136 kW installation. The interspaced and below PV module areas designated for crop cultivation constituted 49% and 24% of the total block area, respectively. The remaining portions of the blocks were preserved as pathways for implement movement and other operational purposes. The interspaced areas were strategically designated for the cultivation of major arable crops compatible with the agri-voltaic system.

Crop production potential

Field experiments conducted during the rainfed cropping season (June-September 2021) investigated the impact of shading within double row and triple row photovoltaic (PV) array modules of Agricultural Voltaic Systems (AVS) on crop production. Mung bean, moth bean, and cluster bean exhibited average yields of 1155, 670, and 2008 kg.ha-1, respectively, in the inter-row spaces between panels in both two-row and three-row PV arrays. Notably, there were reductions of 4.6%, 8.6%, and 11.8% in the yields of mung bean, moth bean, and cluster bean, respectively, in shaded inter-row spaces compared to the control. The leeward side of the panels, covering half of the inter-row spaces, resulted in lower yields for moth bean and cluster bean, while mung bean exhibited higher yields in the shaded portion than in the non-shaded area. In the subsequent Rabi season (2021-22), chickpea, cumin, and isabgol yielded 2490, 1000, and 700 kg ha-1, respectively, in AVS inter-spaces, indicating lower yields compared to control plots (2670, 1120, and 760 kg ha-1, respectively). AVS led to yield reductions of 6.6%, 10.3%, and 7.8% for chickpea, cumin, and isabgol, respectively.

In Kharif 2021-22, Aloe vera and brinjal, as perennial and seasonal vegetables, were grown in inter-row spaces of full and half-density one-row PV arrays. The yields of brinjal, Aloe vera, and snap melon were significantly lower than those in control conditions. However, no significant yield difference was observed between control and AVS in Kharif snap melon and spinach. The highest PV generation occurred in April 2021, with an average electricity generation of 342 kWh month-1. Consequently, the AV system generated an annual power output of 1,24,823 kWh, resulting in a total revenue of INR 6,24,115 in 2021.

Environmental parameter observations, including ambient temperature, temperature under the shade of the panel, temperature at the bottom of the panel, and soil temperature at depths of 10 cm, 20 cm, and 30 cm, were recorded at ten-minute intervals throughout the study period (Jan-Dec 2021) under AVS. Ambient temperature fluctuated between 3.4°C and 48.1°C. The temperature of PV panel shaded areas varied from 4.9°C to 49.7°C, reaching peak values of 50°C in May 2021. During summer days, the average temperature of the PV module reached 61-66°C, while in winter, it reached up to 42-46°C, with peak values of 69°C in May 2021. Notably, the PV module temperature consistently remained 15-19°C higher than ambient temperature during the daytime, resulting in reduced solar PV generation. Throughout the year, discernible differences in microclimate were observed due to the presence of PV arrays.

Availability of photosynthetically active radiation

During the Rabi season, photosynthetically active radiation (PAR) and net radiation were quantified in the Agrovoltaic System (AVS) at two-hour intervals between 8:00 and 16:00 hours, while for the Kharif season, measurements were conducted at three-hour intervals from 9:00 to 15:00 hours. In cumin crops, the PAR values in shaded interspaced areas were 486 and 465 µmol $m^{-2}s^{-1}$ for two and three-row photovoltaic (PV) arrays, respectively. This represented reductions of 42% and 44% compared to the control PAR level of 836 µmol $m^{-2}s^{-1}$. Isabgol and chickpea exhibited PAR reductions of 54% and 47% in two-row arrays and 32% and 59% in three-row arrays, respectively. Examining net radiation in the shaded areas of cumin, the values between two-row (108 $W.m^{-2}$) and three-row (119 $W.m^{-2}$) PV arrays showed reductions of 46% and 41%, respectively, relative to the control (201 $W.m^{-2}$). Isabgol displayed net radiation reductions of 75% and 60% in two-row and three-row PV arrays, respectively, with values of 48 and 78 $W.m^{-2}$ compared to the control (194 $W.m^{-2}$). In chickpea, net radiation reductions of 66% and 60% were observed in two-row and three-row PV arrays, respectively. For mung bean, the PAR reductions in the shaded interspaced area were 7% between two-row (1151 µmol $m^{-2}s^{-1}$) and three-row (392 µmol $m^{-2}s^{-1}$) PV arrays compared to the control (1233 µmol $m^{-2}s^{-1}$). The peak photosynthetic photon flux density (PPFD) values occurred typically between 12:00 and 13:00, ranging from 1206 µmol $m^{-2}s^{-1}$ in December to 1970 µmol $m^{-2}s^{-1}$ in May. Consequently, the availability of PPFD in Jodhpur was found to be conducive for meeting the photosynthetic requirements essential for optimal plant growth and yield [16].

Economics of AVS

The economic evaluation of five distinct designs, each with a 105 kWp Agro-Photovoltaic System (AVS), was conducted in comparison to a reference ground-mounted PV plant. Returns per unit area were analyzed for all designs, considering different crop combinations and electricity generation. The daily average PV generation for each design was determined: AVS-1 (93.90 kWh/day), AVS-2 (57.0 kWh/day), AVS-3 (150.93 kWh/day), AVS-4 (81.60 kWh/day), and AVS-5 (69.32 kWh/day). The annual electricity generation of the 105 kWp AVS was 1,65,254 kWh, resulting in a capacity of 4.3 kWh/day/kW and a total electricity revenue of INR 8,26,270. The most economically viable design, AVS-1 with one row of PV panels, was selected for further analysis. For rainfed conditions, the combination of AVS-1 with snap melon (INR 784851 ha-1 annum), and for irrigated conditions, AVS-1 with brinjal (INR 836465 ha-1 annum) showed the highest returns per hectare. Economic evaluations, including Levelized Cost of Electricity (LCOE), Life Cycle Cost (LCC), Land Cost Benefit (LCB), Benefit-Cost Ratio (BCR), Net Present Worth (NPW), annuity (A), Internal Rate of Return (IRR), and Payback Period (PBP), were conducted for AVS-1 in both rainfed and irrigated scenarios. AVS-1-Irrigated exhibited the highest IRR (20.38%), outperforming PV-GM with the lowest IRR (19.42%) at a 12% bank loan interest rate. The Payback Period was estimated at 7.47 years for AVS-1-Irrigated and 8.11 years for AVS-1-Rainfed, compared to 8.61 years for PV-GM. The Levelized Cost of Electricity was highest in PV-GM (INR 3.45 kWh-1) based on break-even electricity tariff, while AVS-1-Irrigated had the lowest LCOE (INR 3.17 kWh-1) (Table 1).

Table 1. Economic attributes of different AVS designs with rainfed and irrigated condition

Attributes	PV-GM	AVS-1-Rainfed	AVS-1-Irrigated
LCC (INR)	4777774	4804444	4897379
LCB (INR)	6916008	7214093	7728234
BCR	1.45	1.50	1.58
NPW (INR)	2138234	2409649	2830854
Annuity (INR)	232022	261474	307179
IRR (%)	19.42	19.98	20.38
PBP (Years)	8.61	8.11	7.47
LCOE (INR /kWh)	3.45	3.33	3.17

Source: (17)

Data availability statement

NA

Underlying and related material

No

Author contributions

Surendra Poonia: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing original draft, Writing review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Priyabrata Santra: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing review & editing, Visualization, Supervision.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

NA.

Acknowledgement

Authors express their sincere thanks to Director, ICAR-CAZRI, Jodhpur for providing necessary financial support to carry out the present study.

References

[1]. S. Poonia, S., A.K. Singh, D. Jain, “Performance evaluation of phase change material (PCM) based hybrid photovoltaic/thermal solar dryer for drying arid fruits”, Materials Today: Proceedings 52P3, 1064-1070, (2022a), https://doi.org/10.1016/j.matpr.2021.11.058.

[2]. A. Goetzberger, A. Zastrow, A., “On the coexistence of solar energy conversion and plant cultivation” International Journal of Solar Energy, 1(1), 55-69, (1982).

[3]. C. Dupraz, H. Marrou, G. Talbot, L. Dufour, A. Nogier, Y. Ferard, “Combining solar photovoltaic panels and food crops for optimising land use: towards new agrivoltaic schemes”, Renewable energy, 36 (10), 2725–2732, (2011), https://doi.org/10.1016/j.renene.2011.03.005.

[4]. H. Marrou, L. Guilioni, L. Dufour, C. Dupraz, J. Wéry, “Microclimate under agrivoltaic systems: Is crop growth rate affected in the partial shade of solar panels?”, Agricultural and Forest Meteorology, 177, 117–132 (2013), https://doi.org/10.1016/j.agrformet.2013.04.012 .

[5]. S. Amaducci, X. Yin, M. Colauzzi, "Agrivoltaic systems to optimise land use for electric energy production", Applied energy, 220, 545–561, (2018), https://doi.org/10.1016/j.apenergy.2018.03.081.

[6]. G. A. Barron-Gafford, M. A. Pavao-Zuckerman, R. L. Minor, L. F. Sutter, I. Barnett-Moreno, D. T. Blackett, M. Thompson, K. Dimond, A. K. Gerlak, G. P. Nabhan, J.E. Macknick, "Agrivoltaics provide mutual benefits across the food–energy–water nexus in drylands", Nature Sustainability, 2(9), 848-855, (2019), https://doi.org/10.1038/s41893-019-0364-5.

[7]. H. Dinesh, J. M. Pearce, "The potential of agrivoltaic systems", Renewable and Sustainable Energy Reviews, 54, 299–308, (2016), http://doi:10.1016/j.rser.2015.10.024.

[8]. Y. Elamri, B. Cheviron, J.-M. Lopez, C. Dejean, G. Belaud, "Water budget and crop modelling for agrivoltaic systems: Application to irrigated lettuces", Agricultural Water Management, 208, 440–453, (2018) https://doi.org/10.1016/j.agwat.2018.07.001.

[9]. D. Majumdar, M. J. Pasqualetti, "Dual use of agricultural land: Introducing 'agrivoltaics' in phoenix metropolitan statistical area, USA, Landscape and urban planning 170, 150–168, (2018), https://doi.org/10.1016/j.landurbplan.2017.10.011

[10]. P. R. Malu, U. S. Sharma, J. M. Pearce, "Agrivoltaic potential on grape farms in india", Sustainable Energy Technologies and Assessments 23, 104–110, (2017), https://doi.org/10.1016/j.seta.2017.08.004.

[11]. P. Santra, P.C. Pande, S. Kumar, D. Mishra, R.K. Singh, "Agri-voltaics or solar farming: The concept of integrating solar PV based electricity generation and crop production in a single land use system" International Journal of Renewable Energy Research, 7(2), 694-699, (2017).

[12]. P. Santra, R.K. Singh, D. Jain, O.P. Yadav, "Agri-voltaic system to increase land productivity and income" Indian Farming, 68(9), 108-111, (2018).

[13]. A. Weselek, A. Ehmann, S. Zikeli, I. Lewandowski, S. Schindele, P. Högy, "Agrophotovoltaic systems: applications, challenges, and opportunities. A review", Agronomy for Sustainable Development, 39 (4), 35, (2019), https://doi.org/10.1007/s13593-019-0581-3.

[14]. S. Poonia, P. Santra, N.K. Jat, D. Jain, H.M. Meena, "Agri-voltaic system: A novel technology for doubling the farmer's income in hot arid ecosystem of western Rajasthan, India" Indian Farmer 8(5), 351-360 (2021).

[15]. P. Santra, R. K. Singh, H. M. Meena, R. N. Kumawat, D. Mishra, D. Machiwal, D. Dayal, D. Jain, O. P. Yadav, "Agri-voltaic system for crop production and electricity generation from a single land unit", Advances in Energy Research, Springer Nature Singapore Pvt Ltd. 1, 45-56, (2020), https://doi.org/10.1007/978-981-15-2666-4_6.

[16]. P. Santra, H.M. Meena, O.P.Yadav, "Spatial and temporal variation of photosynthetic photon flux density within agrivoltaic system in hot arid region of India", Biosystems Engineering, 209, 74-93, (2021), https://doi.org/10.1016/j.biosystemseng.2021.06.017.

[17]. S. Poonia, S., N.K. Jat, P. Santra, A.K. Singh, D. Jain, H.M. Meena, "Techno-economic evaluation of different agri-voltaic designs for the hot arid ecosystem India" Renewable Energy 184, 149-163, (2022b). https://doi.org/10.1016/j.renene.2021.11.074.

[18]. B. Valle, T. Simonneau, F. Sourd, P. Pechier, P. Hamard, T. Frisson, M. Ryckewaert, A. Christophe, "Increasing the total productivity of a land by combining mobile photovoltaic panels and food crops", Applied Energy 206, 1495–507. https://doi.org/10.1016/j.apenergy.2017. 09.113.

[19]. S. Schindele, M. Trommsdorff, A. Schlaak, T. Obergfell, G. Bopp, C. Reise, C. Brauna, A. Weselekb, A. Bauerlec, P. Högyb, A. Goetzbergera, E. Weber, "Implementation of agrophotovoltaics: Techno-economic analysis of the price performance ratio and its policy implications", Applied Energy, 265, 114737. https://doi.org/10.1016/j.apenergy.2020.114737.

[20]. A. Agostini, M. Colauzzi, S. Amaducci, "Innovative agrivoltaic systems to produce sustainable energy: An economic and environmental assessment", Applied Energy, 281, 116102, (2021), https://doi.org/10.1016/j.apenergy.2020.116102.

[21]. S. Pulipaka, M. Peparthy, "Agrivoltaics in India: Overview of operational projects and relevant policies", National Solar Energy Federation of India (NSEFI): New Delhi, India;

Indo-German Energy Forum Support Office (IGEF-SO): New Delhi, India, pp.1-56, (2021).