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Techno-economic evaluation of different agri-voltaic designs for the hot arid ecosystem India

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ABSTRACT

The rising trend of solar PV generation from ground based installations has led to competition for land between agriculture and PV generation. The solution to this challenge lies in the agri-voltaic system (AVS). The AVS systems allows agricultural activities on land while provides opportunity for PV generation and thus returns additional income from land. Therefore, the Governments of many countries e.g. Japan, France, USA, South Korea, and China have already introduced policies for installation of AVS on agricultural land. Following this trend, policy to install AVS in farmers field has also been launched in India under the national level scheme called *KUSUM* (*Kisan Urja Suraksha evam Utthan Mahaabhiyan*) targeting for energy security and upliftment campaign for farmers. Under the scheme, subsidy is gurranted for installation of PV power plants in farmers field with a capacity between 0.5 and 2 MW_p and on-grid net metering connection of the PV power plant. After announcement of the scheme, there has been increasing interests for installation of AVS by farmers, however, limited knowledge on techno-economic performance of the system, field scale installations of it has been hindered. In the present study, techno-economic analysis of different designs of AVS systems (105 kW_p) established at ICAR-Central Arid Zone Research Institute has been evaluated with several combinations of rainfed and irrigated crops. Field performance of the AVS system of 105 kW_p has been used to extrapolate cost and returns for 520 kW_p system, which lies in the range of KUSUM target. Five AVS designs were considered in the study: extrapolated into 520 kWp AVS and compared theoretically with the price and returns of a photo-voltaic ground-mounted (PV-GM) plant the same capacity. Among five designs of PV arrays in the AVS, the one-row full density photovoltaic array with irrigated brinjal recorded the highest combined net returns of PV + crop components followed by rainfed snap melon. Based on the highest returns per hectare basis, the economic analysis of AVS design for rainfed and irrigated crops is compared to PV-GM. The higher values of life cycle benefit (LCB) could lead to higher net present worth (NPW) of AVS over PV-GM. The higher values of internal rate of return (IRR) in AVS lead to quicker repayment of investment cost as indicated by the pay-back period (PBP), which is shorter by 0.5 and 1.14 years in AVS one row PV array in rainfed and irrigated as compared to PV-GM (8.61 years). Moreover, the one row PV array with irrigated had the lowest Levelized cost of electricity generation (LCOE) (INR 3.17 kWh^{-1}), which is much lower than the prevailing electricity tariff (INR 5.0 kWh^{-1}). Hence, it is inferred that crop production can be very economical for an AVS. AVS technology shows flexibility up to 6% escalation in cost with no escalation in returns, as is indicated by sensitivity analysis. One row full density with irrigated is found the best system based on sensitivity analysis and economic feasibility. The economic analysis of AVS designs in this study is similar to the cost of other PV systems worldwide. Therefore, all PV systems analyzed represent a relatively safe investment.

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Nomenclature

AVS	Agri-voltaic system
PV	Photo-voltaic
kWp	kilowatt-peak
MW	Megawatt
PV-GM	Photo-voltaic-ground mounted
AVS-1	One row PV array with 100% PV density
AVS-2	one row PV array with 50% PV density
AVS-3	Two row PV array with 100% PV density at bottom row and 60% density at top row
AVS-4	Three row PV array with 100% PV density at bottom two rows and 60% PV density at top row
AVS-5	Three row PV array with 100% PV density at bottom row and 60% PV density at top two rows
KUSUM	Kisan Urja Surksha Utthan Mahaabhiyan
LCC	life cycle cost
LCB	life cycle benefit
NPW	net present worth
IRR	internal rate of return
A	annuity
PBP	pay-back period
LCOE	levelized cost of electricity
INR	Indian rupee
kWh	kilowatt hours
km	kilometer
REPP	Renewable energy-based power plants
GW	gigawatt
ha	hectare
mm	millimeter
h	hours
m^2	square meter
m	meter
FYM	farmyard manure
N	nitrogen
P	phosphorous
K	potassium
kg	kilogram
P_i	initial investment of PV plant(INR)
P_w (O&M)	Present worth of operational and maintenance expenses including replacement costs for damaged components (INR)
n	life of the project (year)
SV	salvage value of the system at the end of the life (INR)
R	Revenue as annual returns (INR) obtained from crop cultivation in AVS
M	annual generation of electricity (kWh)
ET	electricity tariff (INR/kWh)
d	annual degradation in generation
e	annual escalation in cost (in fraction)
i	discount rate (in fraction)
UPBP	Upper payback period
LPBP	Lower payback period
q	Quintal
IS	Interrow space
BPA	Below Panel area

1. Introduction

Sustained economic growth of developing countries like India puts enormous pressure on its energy resources, and it is likely to grow in future. Presently, India's energy system is sustaining mainly through coal, petroleum oil, and biomass. At present, India is the fourth-largest energy consumer globally [1] and the third-highest consumer of crude oil, accounting for 4.1% of the world's consumption in 2017 [2]. However, India's per capita energy consumption is around one-third of the world's average [1]. Therefore, despite rapid growth, domestic energy production could not meet the energy demand in India.

Consequently, India imports around 40% of its primary energy [1]. The increasing gap between domestic production and consumption of oil demand is likely to rise by 74% by 2040 [3]. The increase in demand for energy, especially electricity, shows supply-side variability in terms of an increasing share of renewable energy and demand-side variability in domestic consumption with increasing living standards and urbanization. Moreover, on the environmental front, India is the third-largest emitter of CO2 globally, despite low per capita emissions [1]. The international assessments indicate that India's energy choices will directly affect the well-being of its growing population and will indirectly impact the rest of the world through energy markets and the flow of technology and capital.

Power production from fossil fuels has detrimental effects on the environment considering fossil fuel-induced global climate change and air pollution. The increasing costs of fossil fuels and spiraling consumption of energy resources will be the decisive factors for the usage of renewable energy in the future. In the last decade, electricity generation from renewable energy has taken conventional fossil fuels in many countries. Among the renewable energy sources, solar energy is very convenient for electricity generation. Because of Government interventions and incentives, photo-voltaic (PV) usage has been rapidly increasing since the last three decades worldwide [4].

Moreover, the usage of PV for electricity generation has been encouraged due to its high modularity, no need for movability, and low maintenance cost. Another advantage of using PV is that its price decreases with increased usage due to economies of scale [5]. Therefore, many studies projected rapid cost reduction with the broader usage of PV systems in the future. Furthermore, considering the importance of price analysis for energy marketing, several studies examined potential cost factors for PV panels [6].

India registered the second-highest growth in the renewable energy sector after China in the world [1]. Solar PV and wind account for more than three-quarters of the capacity additions. India's power generation from renewable energy sources (10.3 billion units) is 9.11% of total power generation (113.2 billion units). Among renewable sources, solar power accounts for 36.3%. Presently, India has a renewable energy potential of 131 GW (GW) in 2019 to reach 275 GW by 2027 [2].

In arid parts of India, solar irradiations are available in abundance 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 around 6.0 kWh m^{-2} day^{-1} [7]. Looking to these potentials, the Government of India has set ambitious targets of achieving 100,000 MW of solar PV-based power generation capacity and doubling the farmer's income by the year 2022 [8]. Recently, the Ministry of New and Renewable Energy, Government of India, has formulated a scheme *KUSUM* (*Kisan Urja Suraksha evam Utthan Mahaabhiyan*) targeting energy security and upliftment of farmers. Under the scheme, financial subsidy to the developers (individuals or organizations) and on-grid net metering can be extended to the solar power plants of capacity between 500 kW_p to 2 MW_p [9]. Moreover, solar or other renewable energy-based power plants (REPP) must be installed within a 5-km (km) radius of the power sub-stations. Such solar power plants near these sub-stations may be developed, preferably by farmers, by utilizing their barren and uncultivable land. Cultivable land may also be used if the solar plants are set up on stilts where crops can be grown below. If the farmers/group cannot arrange the equity required for setting up the REPP, they can develop the REPP through developer(s). In such a case, the landowner will get lease rent as mutually agreed between the parties. Although in Rajasthan, there is a lot of uncultivable/barren lands are there. However, the requirement of grid connectivity within a five km radius is not possible in far-flung areas. Besides, due to aeolian dust deposits in the desert area, frequent washing of PV modules is required which compel for ground mounted installations of PV modules instead of stilt mounting. Hence there are prospects of installation of solar power plants on the ground on cultivable lands. The reduction in solar efficiency due to dust on PV panels is approximately 29.76% for cleaned modules [10].

Solar PV generation is a land-intensive venture, and it needs around 2 ha (ha) of land per MW of power generation. Ground-mounted photovoltaics have become the cheapest source of power generation worldwide and represent a growing PV marketplace share [11]. However, the spatial aspect of PV_{GM} implementation and the loss of cropland have hardly been discussed in detail. Land, the principal supplier of food, fresh water, and many other ecological resources, is the basis for human livelihood. However, with socio-economic upliftment, especially in the most populous world, and due to soil degradation, croplands are projected to decrease globally between 50 and 650 million ha by 2100 [12].

Because of the projected cropland availability limitation in the future, the rising demand for ground-mounted PV installations will lead to increased land-use competition. The land utilization issue for future food and energy needs has been discussed recently in several literatures [13]. For future energy needs, PV systems seem to have enormous potential. However, implementation requires a large amount of land, i.e., @ 2.0 ha MW^{-1}. Hence, for meeting the national solar mission target of 60 GW PV-based electricity generation by 2022 in India, the land requirement will be around 1.2 lakh ha or 1200 km^2. One solution for minimizing the land grabbing is through the dual use of agricultural land in agro photo-voltaic (AVS), first proposed by Goetzberger and Zastrow [14]. Integrating food production and energy generation through the agri-photovoltaic (AVS) system has evolved recently, considering increasing land resources and energy demands, especially electricity. Agrivoltaics (AV) is an emerging approach of harvesting solar energy both in terms of electricity and food in a given land area that can maximize the land productivity with additional benefits including reduced irrigation water requirement, increased crop productivity, reduced degradation of agricultural land with other socio-economic benefits to farmers [15]. With the increasing international AVS market development, the scientific community has paid growing attention to AVS, and different aspects of AVS systems have recently been published [16]. Several studies discussed the techno-ecological aspects of AVS [17,18] and AVS research on geographical elements [19]. Studies also cover the agricultural productivity of different crops grown in combination with AVS [20–22], soil hydrological aspects [23], socio-economic and political considerations of AVS [24,25]. Other studies covered the economic analysis of different utility-scale grid-connected solar PV power plants [26,27].

In this study, experimental data on crop production and electricity generation in 105 kW_p AVS of ICAR-CAZRI Jodhpur, India was analyzed and further extrapolated to a 520 kW_p AVS to make it relevant for KUSUM scheme of Government of India. In this study, the economic analysis is carried out for cost and revenue in all possible combinations of AVS design and crops grown to select the highest revenue-generating design for rainfed and irrigated situations. In addition, economic analysis of the highest revenue-generating designs has been carried out compared to a hypothesized PV-GM of the same capacity.

When designing an AVS, a compromise should be made between electricity and crop production per unit area basis, between the PV and crop components. This compromise could be found by exploring different designs of panel arrangement and growing various possible crops. The panel density may also be reduced to allow more irradiation to reach the crop layer. Besides, if the gain in crop yields due to panel density reduction may not compensate for electricity foregone per unit area basis, the former component should be on priority.

Several studies demonstrate that growing crops within the AVS system has a limited impact on yields of the high-value crops [15,28]. Therefore, farmers can diversify and stabilize their income through the colocation of PV-based electricity generation and agriculture crops. Given the land requirement for PV plants, no previous analyses attempted the PV panels arrangement in a design that produces maximum revenue per unit of land. Reports on economic analyses of such utility-scale AVS designs are also limited. Therefore, in contrast to previous AVS studies, different PV arrangements have been explored for maximum electricity per unit area in the present study. Besides, in all the PV arrangement designs, returns through crop production in all possible combinations were hypothetically upscaled on the cultivable area of each 520 kW_p AVS for maximum revenue contribution. Therefore, the most economical and efficient AVS designs were selected based on maximum revenue per unit area.

Further, the detailed economic analysis of such selected designs is attempted to generate vital information on the financial performance of a utility-scale AVS system. Such information will be helpful for developers, finance bodies, and Government for extending subsidies. The economic analysis provided the needed parameters for deciding the future investments into the AVS under the general Government policy for financing the utility-scale PV generation owned and operated by farmers in arid regions. We apply and introduce the economic analysis methods to measure the techno-economic quality of an intended AVS project within an AVS permitting process. We thereby provide a decision support tool for policymakers to design public policies to promote and disseminate the AVS.

2. Materials and methods

2.1. Study area

2.1.1. Location and geography

An AVS system has been installed on research farm of ICAR-Central Arid Zone Research Institute, Jodhpur (26°18′N and 73°04′E) in Jodhpur district of State of Rajasthan in the Thar Desert of India [29]. The field of the experimental site is nearly flat, and the soil is loamy sand. The location experiences average wind speed from 9 to 13 km h^{-1}, average temperatures in the range of 4.0–42.0 °C, and annual rainfall of 379 mm, mainly in the monsoon season from July to September.

2.1.2. Solar energy potential of the region

The measured data of global solar radiation, sunshine duration, and temperature are generally needed to calculate a selected region's solar PV electricity potential [30]. The average radiation on a horizontal surface in India is 5.6 kWh m^{-2} day^{-1}. The solar resource map of India shows that arid western India receives the maximum

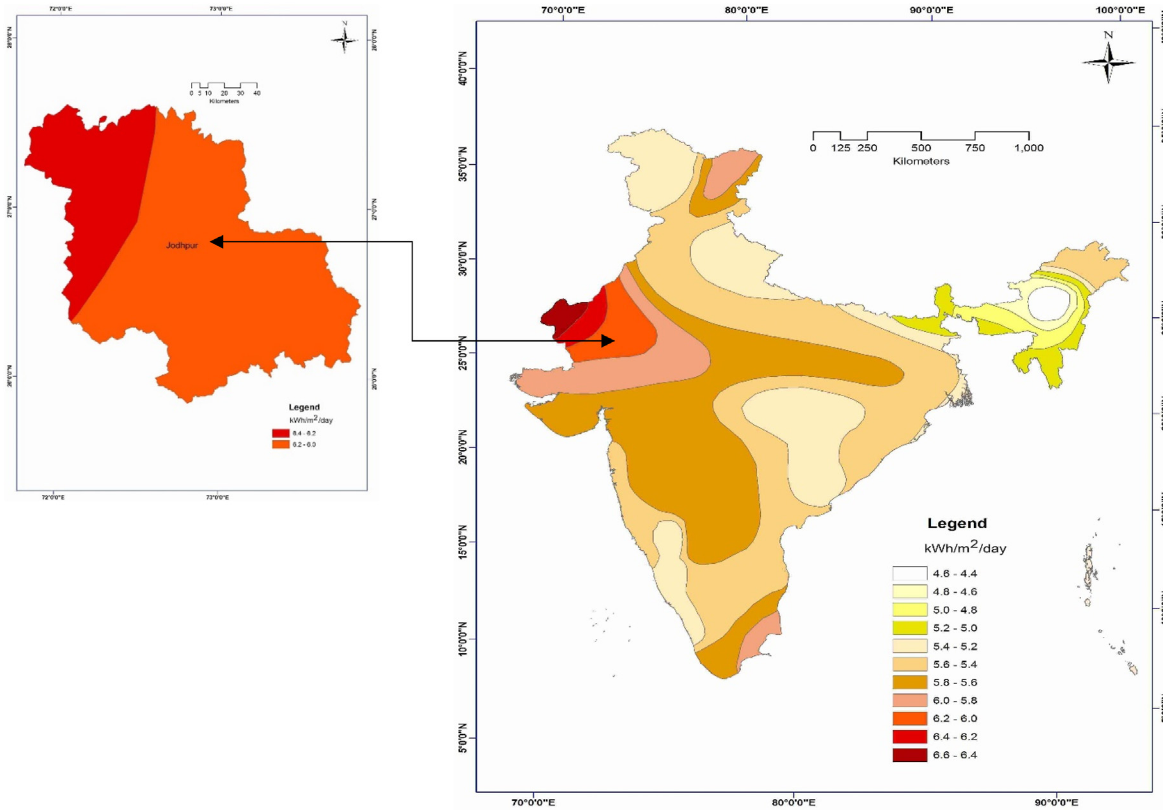

Fig. 1. Annual solar energy capacity and location of Jodhpur in India.

amount of solar radiation. In contrast, a significant portion of India (~140 million ha) receives solar radiation in the range of 5.0–5.5 kWh m^{-2} day^{-1} (Fig. 1). At Jodhpur, India, which lies in the arid western part of the country, the average solar radiation is 6.11 kWh m^{-2} day^{-1}. The highest amount of irradiation at Jodhpur was received during May (7.10 kWh $m^{-2}day^{-1}$), whereas the lowest amount of irradiation is received during December (3.85 kWh $m^{-2}day^{-1}$) (Fig. 2a and b). Moreover, at Jodhpur, around 300 days in a year are measured as cloud-free clear sunny days [7]. Therefore, the yearly average solar radiation is 6.0 kWh m^{-2} day^{-1}, and the annual total radiation duration is approximately 2640 h, sufficient for solar applications. Hence, the Jodhpur region of the country has a considerable solar energy potential in terms of sunshine duration for PV-based electricity generation.

2.2. Basic requirement of solar PV based electricity generation

The solar PV modules are arranged to form an array to provide the specific power at a specified voltage and current. The different rows of solar polycrystalline silicon PV modules of 260 W_p capacity are arranged in vertical alignment. The length of PV arrays varies with the number of PV modules connected in series. Solar PV panels are installed at an inclination angle equal to the location's latitude to harness optimum solar radiation throughout the year.

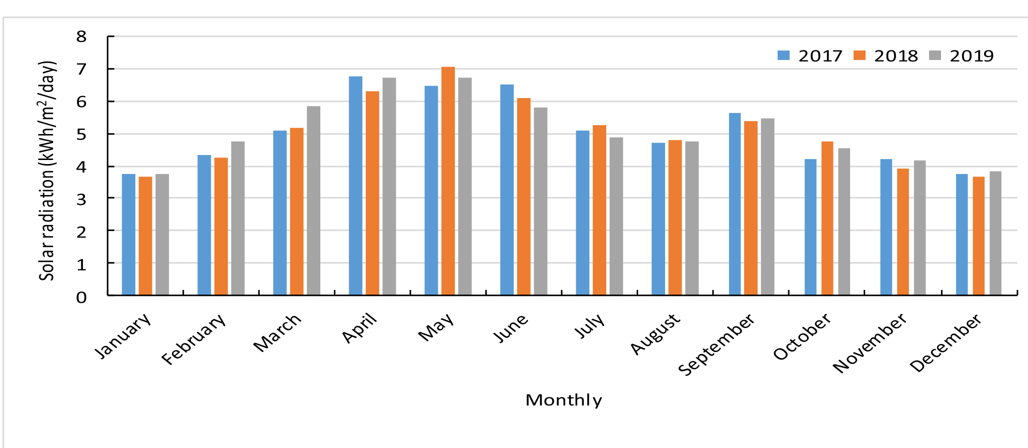

Fig. 2a. Monthly average of daily solar radiation throughout the year 2017–2019.

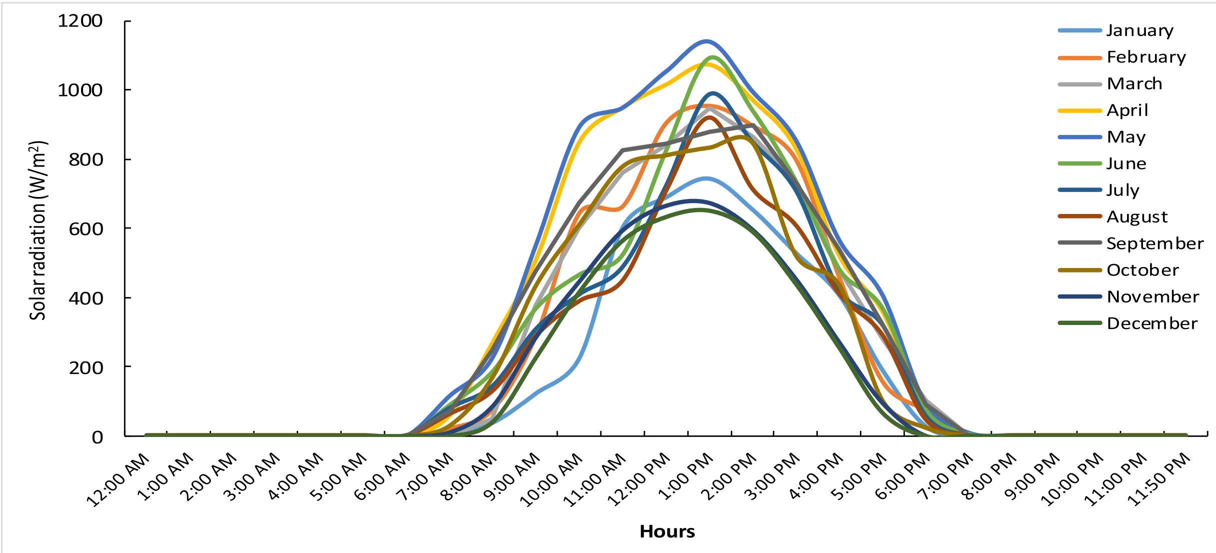

Fig. 2b. Hourly measured monthly average daily global radiation for the year 2019 at Jodhpur, India.

Provision may also be made to change the zenith and azimuth angle of solar PV panels' fixtures to harness a more significant amount of solar energy considering solar irradiance's diurnal and seasonal variation. However, the cost for installation will be higher. Ground-mounted structures will be more feasible because of PV panels' low cost and frequent washing needs in arid regions due to aeolian dust deposition. Generally, in conventional ground-mounted solar power plants, 6–12 m space between two rows of PV arrays is maintained to avoid shadow on the next row [13,29]. Considering the zenith and azimuth angle on December 22 (winter solstices) of the location, 2.96 m of spacing between PV rows was found optimum between two PV arrays [13,29]. Ground clearance of around 0.5 m has to be kept to avoid shade on crops grown between two rows of PV array on PV modules. Considering the above characteristic features of solar PV panels and their requirement for harnessing solar energy, establishing a solar PV power plant requires nearly 2.0 ha of land area/MW capacity [31].

With fixed solar panels of a given size, a fixed sloping angle towards the South and a spacing distance between two arrays must be optimized [16]. At 26°18′ N (Jodhpur, India), the optimized system has a 26° slope [13,29]. During vernal equinox and the autumnal equinox on March 22 and September 23, respectively, the shade length varies from 1 to 6 m with its minimum value during 12:00–14:00 h. When the sun lies at the top of 23.5(N) during the summer solstice, the maximum shade length will be 4 m during the morning at 8:00 h and almost negligible during noon. In a year, the maximum shade length of 6 m is observed in the morning and late afternoon hours during the winter solstice.

For designing the PV array installation in the northern hemisphere, the maximum shade length on December 22 was considered a critical parameter for deciding the separation distance between two PV arrays. It is regarded as the reference energy production system. However, in that case, the solar radiation available below the panels and interspaces may not be sufficient to ensure profitable crop production. Therefore, a reduced density (or a different sloping angle) of the panels may be required to produce a good crop. For allowing easy mechanical cultivation of the crops, inter-row spaces should be wide enough for machinery movement. Hence the multiple rows design of solar panels can be a better option for the mechanized cultivation of crops.

2.3. Design of agri-photovoltaic system

2.3.1. AVS designs

In this study, the AVS system installed at ICAR-CAZRI, Jodhpur with 105 kWp capacity was used for techno-economic evaluation. The AVS system was ground-mounted and fixed-tilt covering an area of 4624 m^2. Polycrystalline silicon solar PV modules (dimension: 0.992 × 1.640 m) were used in the AVS systems. PV modules were arranged in the East-West direction and inclined southward with a tilt angle of 26°. This AVS system was established with five designs in three separate blocks-. The AVS system consisted of five designs and these are: AVSi) AVS-1 having one row PV array with 100% PV density, (ii) AVS-2 having one row PV array with 50% PV density, iii) AVS-3 having double row PV array with 100% PV density at bottom row and 60% density at top row iv) AVS-4 having triple row PV array with 100% PV density at bottom two rows and 60% PV density at top row and (v) AVS-5 having triple row PV array with 100% PV density at bottom row and 60% PV density at top two rows. Detailed specifications of five AVS designs are given in Table 1. Different PV density in arrays were designed to allow photosynthetic photon flux density (PPFD) in interspace of PV installation area, which is essential for crop production.

Top view and side view of the five AVS designs as discussed above are shown in Figs. 3 and 4, respectively. The design parameters of the AVS designs were calculated based on the length of shade created by the PV structure on the day of winter solstice. On this day, the sun moves farthest to south in northern hemisphere and thus the shade length is generally found highest on this day. Detailed modeling of shade length as affected by solar zenith and azimuth angle may be found in Refs. [13,29]. Apart from the above said AVS system, a control plot of 252 m^2 was maintained immediately south of the AVS system plots to avoid the shadow of PV panels on the crop grown in the control plots. AVS.

2.3.2. Electric circuit diagram of AVS system

The schematic diagram of the PV-based electricity generation from the installed AVS system and its supply to the grid is depicted in Fig. 5. The installed AVS system was connected to the local electricity grid through net metering system. Therefore, the generated electricity is being directly sold to local power

Table 1
Details of 105 kW AVS system modules at CAZRI, Jodhpur, India.

Specifications	AVS system design				
	Single row PV array		Double row PV array	Triple row PV array	
	AVS-1	AVS-2	AVS-3	AVS-4	AVS-5
Number of array (a)	3	3	3	1	1
Number of PV modules in each array	28	17	45	73	62
Width of below panel area (m) (b)	1.47	1.47	2.94	4.41	4.41
Interspace distance (c)	3.2	3.2	6.4	9.6	9.6
Length of PV row (m)	28	28	28	28	28
Total width of each array (m) (b + c)	4.67	4.67	9.34	14.01	14.01
Total area of each array (m^2)	130.76	130.76	261.52	392.28	392.28
Below panel area in each array (m^2)	41.16	41.16	82.32	123.5	123.5
Below panel area (% of total area)	31.5	31.5	31.5	31.5	31.5
Inter space area (m^2)	89.60	89.60	179.2	268.8	268.8
Inter space area (% of total area)	68.5	68.5	68.5	68.5	68.5
Electricity generation (kWh/day)	93.90	57.0	150.93	81.60	69.32

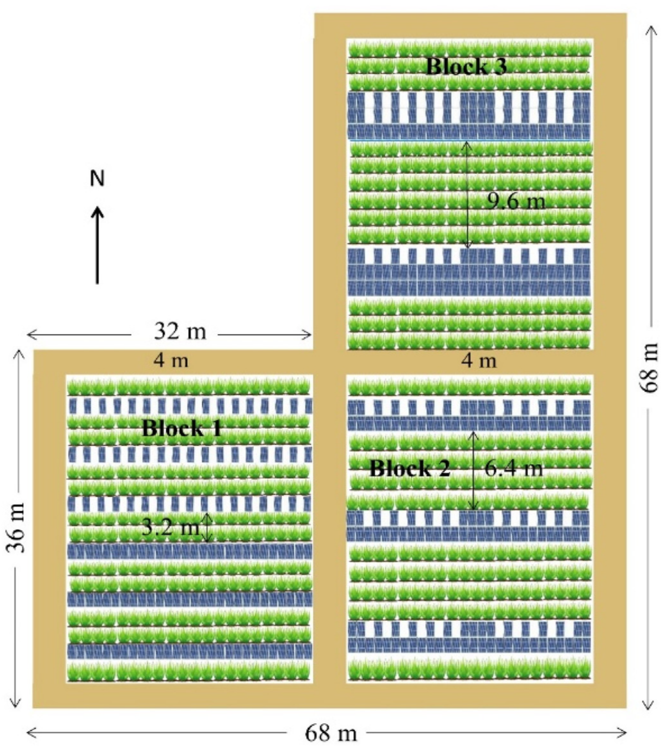

Fig. 3. Schematic design of PV module installations for AVS system.

distribution company at a fixed tariff, which varies across different states of India. In our study, an average tariff rate of Rs 5.0 kWh^{-1} was considered to calculate the income from PV-generated electricity. Solar PV generation and solar irradiation were regularly monitored through SCADA (Supervisory Control and Data Acquisition) facility (model: Wonder Share InduSoft Web Studio 8.0) and automatic weather station (model: Davis Vantage Pro 2 Wireless), respectively.

2.4. Agricultural activities in the AVS system

In the present AVS system, the interspaces of PV arrays were utilized to grow suitable crops. In the arid eco-system of Jodhpur, crops with low height (shorter than 0.5m), slightly tolerant to shade, and requiring less amount of water were selected for the AVS (Table 2). To allow simultaneous cultivation of *kharif* (rainy season) and *rabi* (winter season) crops in two and three row (Block-2 and 3) AVS designs, interspaces along the length (28 m) are divided into three equal parts, each of 8 m length keeping the inter-plot path of 2 m between the plots. In one row AVS design, only a single crop was grown in interspaces of each rpw of PV arrays (Fig. 6). For movement of field workers and washing of PV modules, 0.3 m space was left along the length of PV strings, keeping the harvestable area of 81.2, 48.8, and 74.4 m^2 of each crop in each strip in one row, two-row and three-row PV array, respectively. Different crops were evaluated in the AVS designs in various seasons spanning from July 2019 to June 2020 (Table 2). All the crops were planted/sown in lines parallel to the PV arrays in the East to West orientation. One-year-old plantings of brinjal (*Solanum melongena*) and Aloe vera were used for yield and return analysis in one row PV array.

In annual crops grown in two and three-row PV array, farmyard manure (FYM) and fertilizers were applied based on the local package of practices for respective crops. The leguminous crops Mung bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*), cluster bean (*Cyamopsis tetragonoloba*), and chickpea (*Cicer arieatinum*) were supplied with the entire quantity of fertilizers as a basal dose by drilling below the sowing depth at sowing. While in cumin (*Cuminum cyminum*) and psyllium (*Plantago ovata*), half dose of nitrogen (N) and a total amount of phosphorous (P) fertilizers were applied as basal, and the remaining dose of N was applied as top dressing twice before flowering. In *Aloe vera*, FYM was applied only initially at planting in July 2018. In brinjal, besides the initial application of compost at the time of transplanting in July 2018, compost @50 kg 100 m^{-2} was applied thrice during 2019-20 in July, November, and April besides the monthly spray of 1.0% water-soluble fertilizers (N:P:K: 19:19:19). In seasonal vegetables like snap melon and spinach, in addition to the localized compost placement (@30 kg 100 m^{-2}) just before sowing, three sprays of 1% N:P:K: 19:19:19 in each crop were applied during the entire crop cycle. Weed management in the whole cropped area was done manually, and hand hoe was used for intercultural operations.

The crops in the rainy season were grown as rainfed, whereas the winter and summer crops and perennials were raised with irrigation. For irrigated arable crops, the pre-sowing irrigation for land preparation was applied by flooding. The subsequent irrigations were applied through drip irrigation (2.0 l $dripper^{-1}$ h^{-1}), keeping laterals 45 cm apart spread along the crop rows. During the rainy season, no irrigation was applied in *Aloe vera*. In brinjal, irrigation was applied weekly during summer and fortnightly in winter and rainy seasons. For spinach in winter and snap melon in summer, irrigations were applied after every fifth day. In cumin, psyllium, and chickpea, six irrigations were applied through the

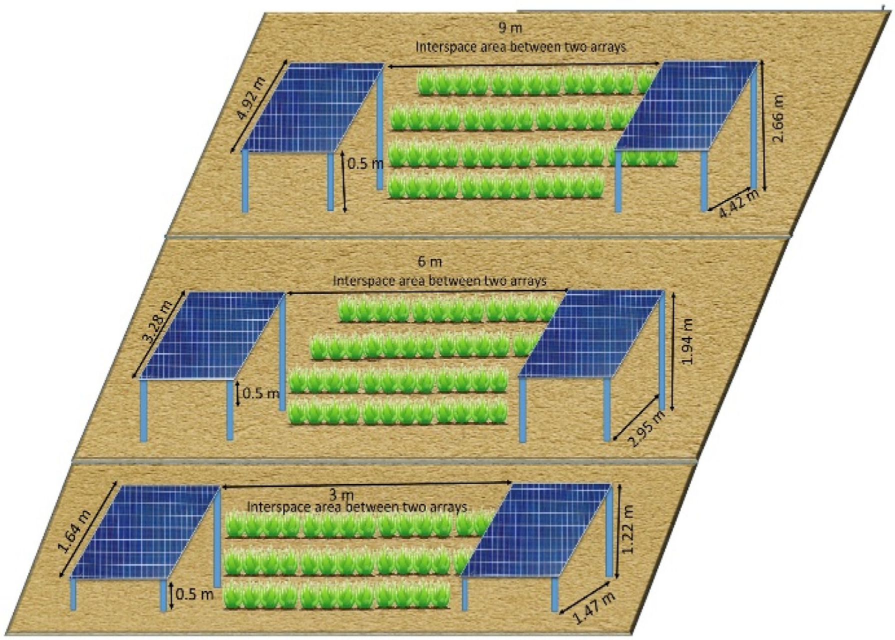

Fig. 4. The installed agri-voltaic system at ICAR-CAZRI, Jodhpur, India.

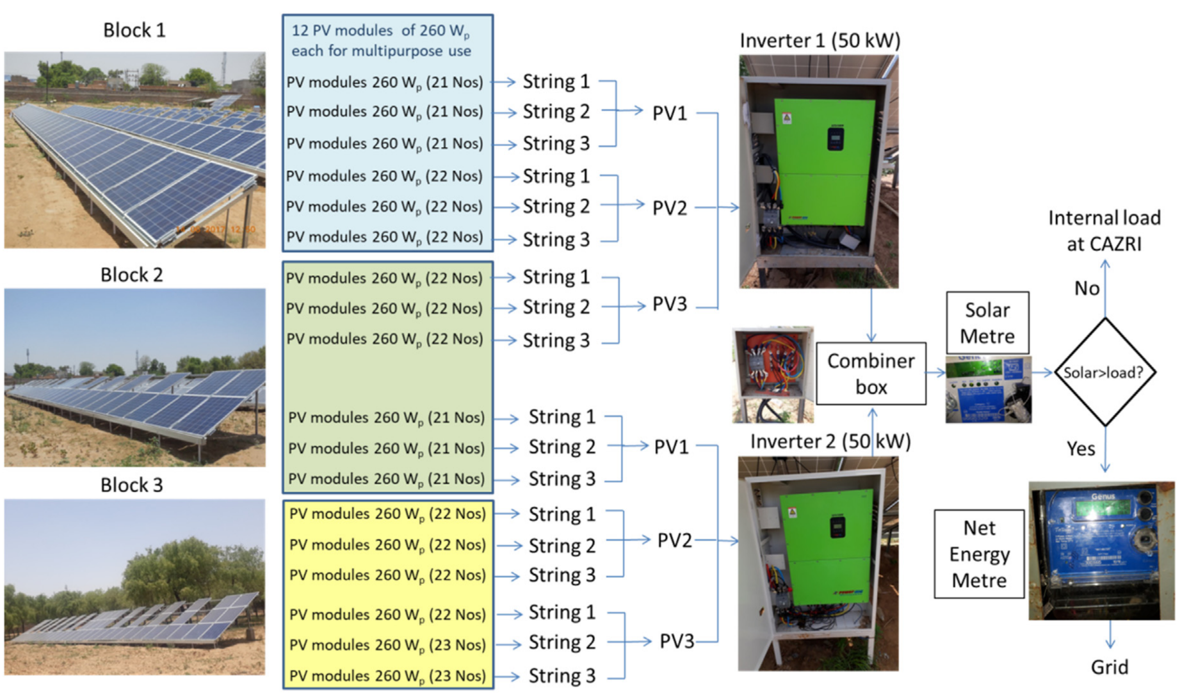

Fig. 5. Schematic diagram of PV-based electricity generation in AVS system and its supply to the local grid.

drip system. For plant protection, prophylactic pesticide sprays were done in all the crops except for *Aloe vera*.

In the second year, ratooning was done in brinjal in July 2019, and fruits were harvested regularly from mid-September 2019 to June 2020. The *Aloe vera* was harvested thrice, once each in rainy, winter, and summer seasons, by cutting 4–5 fully grown leaves of each plant. Spinach was grown in winter from November 2019 to January 2020. In two and three-row PV arrays, crops were grown both during the rainy and winter seasons. The crops were harvested at grain maturity, and separate yields of both grain/seed and stover were recorded after threshing.

2.5. Economic analysis of AVS system

Economics of AVS designs were calculated on the upscaled capacity of 520 kWp considering the KUSUM target of solar PV installations in farmers' field. In this study, experimental data of crop yield and electricity generation of a CAZRI developed 105 kW_p AVS were extrapolated to a 520 kW_p AV system (as per Government of India policy). For all the five designs, a 520 kW_p power plant size is envisaged. Therefore, the economic viability and feasibility of a 520 kW_p AVS are analyzed to optimize design and returns that can be scaled up to 2 MW.

Table 2
Details of crops evaluated in 105 kW AVS.

Crop component	Season	Crop
One row PV array		
Perennials		Brinjal (*Solanum melongena*)
		Aloe vera
Seasonal vegetables	Rainy	Snap melon (*Cucumis melo*)
	Winter	Spinach (*Spinacia oleracea*)
	Summer	Snap melon (*Cucumis melo*)
Two-row/three-row PV array		
Arable crops	Rainy	Mung bean (*Vigna radiata*)
		Moth bean (*Vigna aconitifolia*)
		Cluster bean (*Cyamopsis tetragonoloba*)
	Winter	Cumin (*Cuminum cyminum*)
		Psyllium (*Plantago ovata*)
		Chickpea (*Cicer arietinum*)

Based on the data of electricity generation and crop production, the revenue generation from five AVS designs with 520 kW_p capacity AVS was calculated. All possible combinations of crops for the year were calculated for all the five designs. Based on the maximum returns per ha of land, one rainfed and one irrigated AVS design were selected. Further, the economic analysis of the AVS systems of selected designs was carried out with one reference ground mounted PV design in the same area. Economic analysis was done by computing the life cycle cost (LCC), life cycle benefit (LCB), benefit-cost ratio (BCR), net present worth (NPW), annuity (A), internal rate of return (IRR), and pay-back period (PBP). Levelized costs of electricity generation (LCOE) and various economic parameters were determined at multiple escalation rates and electricity tariffs. The sensitivity analysis was attempted based on escalation rates in cost and returns.

The annualized cost of drip irrigation facility and solar pump-set was taken by considering their life as 25 years. For field preparation, the cost of diesel consumption was taken into account, presuming tractor availability with the farmer. For perennial crops like brinjal and *Aloe vera*, the annualized cost of the establishment was taken by considering crop life as two and five years, respectively. Hence, the annualized cost of establishment, diesel cost for field preparation, annualized cost of irrigation, and the cost of inputs used for different crops were taken for the cost of cultivation. For calculating returns, the marketable product of other crops like the fruits of brinjal and snap melon; leaves of *Aloe vera* and spinach; and seed/grain and stover of arable crops were used after multiplying with the market price. The seeds/grains of all the arable crops and stover of leguminous crops like mungbean, moth bean, cluster bean, and chickpea with fodder utility were used to calculate the returns.

2.5.1. Life cycle cost (LCC)

Life cycle cost (LCC) is the sum of all the costs associated with a system over its lifetime in terms of money value at the present instant of time by considering the time value of money [32,33].

$$LCC = P_i + annual \cos t \ (O\&M)\frac{X(1-X^n)}{1-X} - SV \ X^{-n} + P_w \ (IRC) \tag{1}$$

where, P_i is the initial investment cost of AVS plant, annual cost (O&M) is the present worth of operational and maintenance expenses including replacement costs for damaged components, n is the life of the project (year), SV is the salvage value of the system at the end of the life.

2.5.2. Life cycle benefits (LCB)

The LCB can be given as,

$$LCB = R\frac{X(1-X^n)}{(1-X)} + M.ET.\sum_{n=1}^{n=25}(1-d)^n\left(\frac{1+e}{1+i}\right)^n \tag{2}$$

where,

R = Revenue as annual returns (INR) obtained from crop cultivation in AVS; M is the annual generation of electricity (kWh), ET is the electricity tariff (INR/kWh), d = annual degradation in generation (0.01) and X is given as,

$$X = \frac{1+e}{1+i}$$

where,

e = annual escalation in cost (in fraction) (0.02) and
i = discount rate (in fraction) (0.12)

2.5.3. Levelized cost of PV electricity generation

The Levelized cost calculation method calculates and compares the electricity costs per unit of electricity produced (INR/kWh). In

a b

Fig. 6. Field view of different *Kharif* crops grown in the AVS system a) Whole AVS system consisting of single row at left, double row at right and triple row at the back b) Single row PV array during *Kharif*, 2019.

practice, this method is the current cost comparison criterion for a different design of electric power plant systems [34–37]. LCOE was computed by equating the life-cycle cost (LCC) of the PV system and the life cycle benefit (LCB) of the PV system. Where,

$$LCOE = \frac{\left(LCC - R\frac{X(1-X^n)}{(1-X)}\right)}{M.ET.\sum_{n=1}^{n=25}(1-d)^n\left(\frac{1+e}{1+i}\right)^n} \tag{3}$$

$$IRR = lower\ discount\ rate + \frac{Difference\ of\ discount\ rate\ X\ NPW\ at\ lower\ discount\ rate}{(NPW\ at\ lower\ discount\ rate\ -\ NPW\ at\ higher\ discount\ rate\ )} \tag{6}$$

2.5.4. Economic attributes

Following economic attributes were calculated.

i. *Benefit-cost ratio (BCR):* The ratio of discounted benefits to the discounted values of all costs given as LCB/LCC
ii. *Net Present Worth (NPW):* The NPW is an economic indicator in which the value of discounted benefits minus discounted cost is calculated at the given discount rate. Positive NPW represents an indicator of a potentially feasible project [32,37]. NPW is the sum of all discounted net benefits throughout the project given as LCB-LCC
iii. *Annuity (A):* A of a project indicates the annual average net returns and given as,

$$A = \frac{NPW}{\sum_{t\,=\,1\ to\ 10}\left(\frac{1+e}{1+i}\right)n} \tag{4}$$

iv. *Pay Back Period (PBP):* The pay-back period (PBP), which is an essential economic parameter, is considered in this study. The PBP is the period between the beginning of a project and the net benefits return the cost of capital investments (value of n for LCB - LCC = 0). Economically, the project investment may be unacceptable when the PBP presents a higher value (long pay-back periods). Simple PBP does not incorporate the time value of money; moreover, assumptions on discount or interest rates are not required. The shorter the PBP, the better is the investment. It is well known that the PBP value should be far less than the life of the PV project. The PBP can be determined as following: 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.

$$PBP = UPBP - \frac{(UPBP - LPBP)\ \times\ NPW\ for\ UPBP}{(NPW\ for\ UPBP\ \ - NPW\ for\ LPBP)} \tag{5}$$

It can also be written as;

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

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

v. *Internal Rate of Return (IRR)* is the rate of interest, which makes life cycle benefits and life cycle costs equal [37–39]. It is calculated by subtracting the LCC from LCB and equating it to zero (LCB - LCC = 0). IRR is used to evaluate the future performance of the investment compared to other projects of different sizes or a required benchmark rate of return. If the IRR is greater than the discount rate, it is viable; otherwise, it should be rejected. In general, the higher the IRR, the more desirable it is to undertake the project [36]. The IRR can be computed by using the following relationship

3. Results and discussions

Economic analysis of the 105 kW_p AVS of all the five designs fetching the highest returns per unit area was compared with reference ground mounted PV plant. The 105 kW_p AVS was established in the year 2018 and in the first year of the project, It was observed that the per day average PV generation from the AVS-1 was 93.90, in AVS-2: 57.0, in AVS-3: 150.93, in AVS-4: 81.60, and AVS-5: 69.32 kWh/day (Table 1). As a result, the annual total electricity generation by the AV system was 1,65,254 kWh, leading to 4.3 kWh/day/kW capacity, and the total electricity revenue was INR Rs. 8,26,270 of the 105 kW_p AVS. Based on this experimental observation, the same annual generation was extrapolated to a 520 kW AVS (as per Government of India policy) was used for economic evaluation considering 1% yearly degradation of solar PV modules. In addition to electricity generation, observations on crop productivity (Tables 4 and 5) were also extrapolated and considered in economic evaluation. For all the five designs of three blocks, a 520 kW power plant size is envisaged. Therefore, the economic viability and feasibility of a 520 kW AVS are analyzed to optimize design and returns that can be scaled up to 2 MW. Different design specifications adopted in the trial show that an AVS of 520 kW_p in each design is envisaged considering crop production feasibility between PV panels (Fig. 7). The technical details of the different AVS designs for 520 kW_p PV plants are given in Table 3. Based on the estimated average electricity generation in the whole year (@to4.3 kWh/day/kW capacity), total electricity generation (816000 kWh), and electricity revenues (INR 4080000) of different AVS designs are calculated as presented in Tabel 3. First, the yield of crops raised in different designs of the trial AVS is recorded and converted into quintal (q) per ha (Table 4). Then, based on the sale price of the economic produce, net returns (INR ha^{-1}) of different crops were obtained (Table 5).

Based on the area available for cultivation in each design of 520 kW_p, capacity, the returns of different crops in all the AVS designs are calculated in all possible combinations. Further, the total returns of the AVS for all possible crop combinations are obtained by adding the returns of crops and electricity in different designs of 520 kW_p capacity. Finally, for assessing the relative efficiency of different AVS, the crop + PV electricity combinations of maximum returns (INR ha^{-1}) each for rainfed and irrigated situations were selected for further economic analysis.

AVS-1 is found to produce maximum electricity returns as it accommodates the highest number of PV panels per unit area (Fig. 7). Therefore, based on the highest returns per ha, AVS-1 with

Table 3
Technical details and electricity yield assumptions of different AVS system designs for 520 kW_p PV plant.

S. No.	Particulars	AVS-1	AVS-2	AVS-3	AVS-4	AVS-5
1	Number of rows (a)	20	40	10	5	5
2	Number of PV plates	2000	2000	2000	2000	2000
3	Width of below panel area (m) (b)	1.47	1.47	2.94	4.41	4.41
4	Interspace area between PV arrays (c)	3.2	3.2	6.4	9.6	9.6
5	Net length (m)	100	96	132	159	198
6	Net width (m)	90.2	183.6	87	60.4	60.4
7	Net Area covered by PV arrays (m^2)	9020	17626	11484	9612	11969
8	Buffer area (m^2)[a]	1789	3174	2217	2014	1977
9	Gross area (m^2)	10809	20800	13701	11625	13946
10	Interspace (m^2)	6080	11981	7603	6106	7603
11	Below panel area (m^2) (calculated)	2940	5645	3881	3506	4366
12	Below panel area (m^2) (Actual)[b]	2340	4493	3485	3267	4069
13	Total area for cultivation (m^2)	9020	17626	11484	9612	11969
14	Interspace area % of net area	67.4	68.0	66.2	63.5	63.5
15	PV power generation capacity (kWp) (@0.26kWp/PV panel)	520	520	520	520	520
16	Total generation (kWh) (@4.3 kWh/day)[c]	816000	816000	816000	816000	816000
17	Total revenue (INR) (@ INR 5/kWh)	4080000	4080000	4080000	4080000	4080000

[a] In one row PV array, 2m along the length in North and South and 3m along the width in East and west.
[a] In two and three row PV array 2m along the length in North and South and 5m on the East side for machinery.
[b] 0.3m area in running width will be kept empty in all the designs.
[c] kwh/m^2 monthly average of the whole year.

Table 4
Average economic yield and sale price of various crops raised in different AVS system designs.

Crop		Yield (q ha^{-1})					Sale price (INR q^{-1})
		AVS-1	AVS-2	AVS-3	AVS-4	AVS-5	
Brinjal		604	665				1200
Aloe vera* (Irrigated)	IS	1380	1409				250
	BPA	1130	1356				
Aloe vera (Rainfed)	IS	455	465				250
	BPA	373	447				
Spinach		295	303				1000
Snap melon (*Kharif*)		133	142				2000
Snap melon (summer)		82	77				3500
Mung bean	Grain			6.40	6.89	6.86	7050
	Stover			17.24	18.46	18.11	200
Moth bean	Grain			4.13	4.26	4.22	4300
	Stover			7.20	7.37	7.09	200
Cluster bean	Grain			5.95	5.96	6.11	3800
	Stover			19.21	19.87	19.09	800
Cumin				7.5	7.2	7.1	12500
Psyllium				7.4	7.1	7.3	12000
Chickpea	Grain			16.2	15.1	15.1	4500
	Stover			92.6	82.0	84.0	500

IS- Interrow space; BPA- Below Panel area.
* Aloe vera was grown both in interspaces and below panel areas.

Table 5
Net returns (INR ha^{-1}) of various crops raised in different AVS system designs.

Design		AVS-1	AVS-2	Mean	AVS-3	AVS-4	AVS-5
Brinjal		724800	798000	761400			
Aloe vera* (Irrigated)	IS	345000	352250	348625			
	BPA	282500	339000	310750			
	Total	627500	691250	659375			
Aloe vera (Rainfed)	IS	113850	116243	115046			
	BPA	93225	111870	102548			
	Total	207075	228113	217594			
Spinach		295000	303000	299000			
Snap melon (*Kharif*)		266000	284000	275000			
Snap melon (summer)		287000	269500	278250			
Mung bean[a]					48580	52238	51958
Moth bean[a]					19185	19776	19546
Cluster bean[a]					37981	38548	38476
Cumin[b]					93698	93698	89375
Psyllium[b]					88340	85560	87000
Chickpea[a]					94000	88210	87040

IS- Interrow space; BPA- Below Panel area.
[a] Total of returns of both grain and stover.
[b] Total of return of grain portion only.

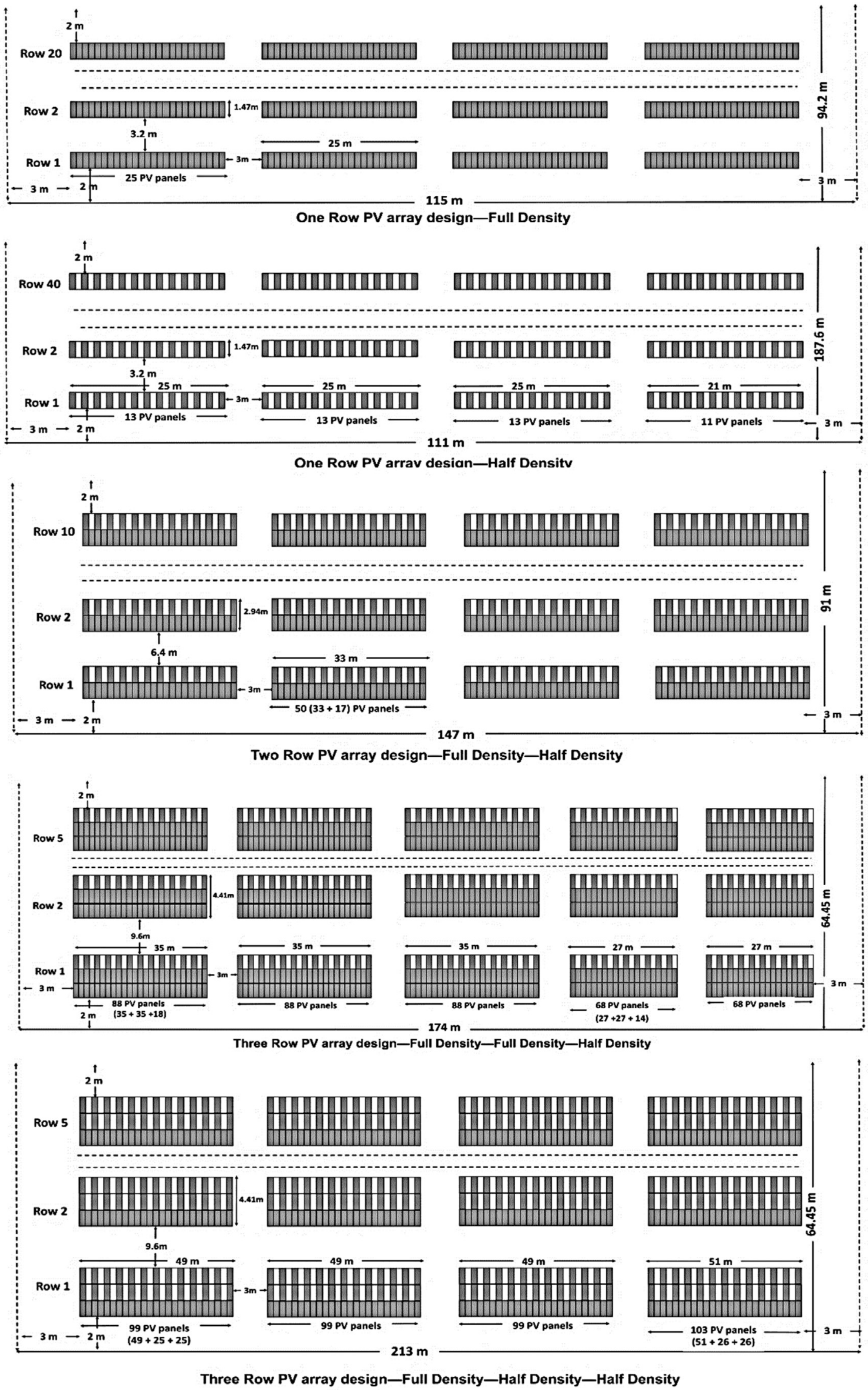

Fig. 7. Hypothetical sketch of 520 kW_p AVS system in different designs.

Table 6
Input parameters for LCC and LCB (INR) of the 520 kW_p PV system.

S. No.	Parameters	Sub-parameter	Unit	PV-GM	AVS -1 Rainfed	AVS-1- Irrigated
1	Initial investment of PV plant (P_i)	Cost of PV plant		20800000	20800000	20800000
		Cost of water tank (50,000 lit.)	INR	350000	350000	350000
		Life cycle cost of solar PV pumping system (1 Hp)	INR	32999	32999	32999
		Life cycle cost of drip irrigation system[a]	INR	–	–	272116
		Total	INR	21182999	21182999	21455115
2	Operational and maintenance expenses (P_w O&M)	Labour cost/annum (1 @15000/month)	INR	180000	180000	180000
		Cost of crop operations and inputs/annum[b]	INR	–	14470	35365
		Miscellaneous expenses/annum	INR	28000	28000	28000
		Total	INR	208000	194470	215365
3	Salvage value of PV plant at the end of the life(P_wSV) (@ 5% of P_i)		INR	1040000	1040000	1040000
4	Present worth of inverter replacement cost (P_w IRC) (life = 13 years)		INR	688954	688954	688954
5	Annual generation of electricity (M)		(kWh)	816000	816000	816000
6	Electricity tariff (ET)		(INR/kWh)	5.0	5.0	5.0
7	Annual returns (R)		INR	4080000		

PVC pipes for 1.0 ha and drip laterals for 0.6 ha.
[b] Operations and inputs cost of *Kharif* snap melon (rainfed) and brinjal (irrigated).

Table 7
Economic attributes of different AVS designs with rainfed and irrigated condition.

Attributes	PV-GM	AVS-1-Rainfed	AVS-1-Irrigated
LCC (INR)	23888870	24022220	24486897
LCB (INR)	34580038	36070465	38641168
BCR	1.45	1.50	1.58
NPW (INR)	10691168	12048245	14154271
Annuity (INR)	1160111	1307369	1535897
IRR (%)	19.42	19.98	20.38
PBP (Years)	8.61	8.11	7.47
LCOE (INR/kWh)	3.45	3.33	3.17

Table 8
Values of NPW at various discount rates (INR).

Discount Rate (i)	PV-GM	AVS-1-Rainfed	AVS-1-Irrigated
12%	10691168	12048245	14154271
20%	−1314661	−548095	−524596
22%	−3259362	−2569883	−1630151

Table 9
Values of NPW at various stages of project life.

Years (n)	PV-GM	AVS-1-Rainfed	AVS-1-Irrigated
n = 6	−4196837	−3551788	−2693520
n = 8	−747043	44206	1158677
n = 10	2052199	2964708	4291673

snap melon (INR 3924256 ha^{-1} annum) for rainfed and AVS-1 with brinjal (INR 4182328 ha^{-1} annum) for the irrigated situation were selected for further economic analysis.

Economic analysis of AVS-1-rainfed and AVS-1-irrigated was carried out with a hypothetical ground-mounted full density one-row photo-voltaic array plant (PV-GM) by computing their Levelized costs of electricity (LCOE), life cycle cost (LCC), life cycle benefit (LCB), benefit-cost ratio (BCR), net present worth (NPW), annuity (A), internal rate of return (IRR) and pay-back period (PBP) for assessing the economic viability.

The initial investment (P_i) of an AVS includes the cost of PV plant, the cost of a water tank to be used for irrigation and panel washing, cost of drip irrigation system, and water pumping system with escalation rate (2%) and discount rate (12%) are considered. The operation and maintenance expenses (P_wO&M) included the labor cost of maintaining and washing the PV panels. No additional labor cost is added for crop production as the human resources deputed for maintaining the PV plant are sufficient to raise crops in the AVS. For calculating LCB, combined annual return from the crops and electricity generation, taking the electricity tariff as INR 5.0 kWh^{-1}, was considered as per a previous study [31]. The data of input parameters given in Table 6 are used for determining LCC and LCB.

Table 7 presents economic parameters of AVS-1-rainfed with snap melon and AVS-1-irrigated with brinjal in addition to that for PV-GM. LCC and LCB are computed as per Eqs. (1) and (2) at 12% interest rate and 2% inflation rate by considering the life of PV system as 25 years. Data in Table 7 show that the LCC and LCB of AVS are higher than PV-GM. The added cost of irrigation facilities, and crop production in the AVS makes the differences. The higher values of BCR in the AVS compared to PV-GM indicates that the ratio of added returns to added cost has been more than unity. Comparison of BCR between rainfed and irrigated AVS also shows that the annual returns of the irrigated crop (brinjal) cover the annualized cost of the irrigation facility. The results of this economic analysis are similar to the cost of PV systems currently built in the world [37].

NPW is the difference between the present worth of LCB and LCC. A positive value of NPW indicates the economic viability of a project. Here a positive NPW proves the acceptance of the PV project and economic efficiency of the selected design. It is evident from Table 8 that for all three PV systems, NPW is positive at one discount rate and negative at the other discount rate. Values of NPW at various stages of project life are presented in Table 9. It is evident from Table 9 that the value of NPW decreases with a decrease in the project life. The annuity (Eq. (4)) values of the PV systems that present the net annual average returns of a project also follow the trends of NPW.

The IRR was determined by using Eq. (6) and presented in Table 7. The PV project development would be acceptable if the IRR is equal to or higher than the required borrowing rate. The AVS-1-Irrigated shows the maximum IRR (20.38%), whereas PV-GM has the lowest IRR (19.42%) at the prevailing bank loan interest rate of 12%. Fig. 8 (a,b,c) also displays IRR considering the relation between NPW and discount rates. By putting the values of NPW as zero in the equations, IRR is calculated, i.e., and the line cuts the Y-axis (NPW = 0) at a particular value of discount rate, which is IRR. These findings are in contradiction to the lower values of IRR (13%) for a 500 kW_p AVS system as compared to PV-GM (14%) estimated in

Italy [37]. It is due to fact that, in the present study PV-GM and AVS evaluated were of the same capacity and covered equal areas.

Similarly, the values of the PBP of three PV systems under evaluation were computed using Eq. (5) and presented in Table 7. The PBP estimated 7.47 years for AVS-1- Irrigated and 8.11 years for AVS-1- Rainfed, whereas it was 8.61 years PV-GM. The lower the value of the discounted PBP, the quicker the repayment of investment cost. Lower PBP for the irrigated condition means that return accrued from irrigated crops was much higher than rainfed farming (Table 5). Fig. 9 (a,b,c) also displays PBP considering the relation between NPW and project life. By putting the values of NPW as zero in the equations, PBP is calculated, i.e.; the point where the line cuts the Y-axis (NPW = 0) at a particular stage of project life, which is PBP. This figure clearly shows that AVS-1- Irrigated with the lowest PBP (7.47) was found most economical option. The PBP was 6.27 years, and the mean value of the IRR was 10.36% for the 1 MW AVS system in Osmaniye, Turkey [32].

Fig. 10 presents the values of NPW for various escalation rates in cost and return components. As per Fig. 10, the escalation rate of e (0,6) can provide a positive NPW value, which indicates that the technology can sustain even when the escalation in cost is 6% with no escalation in return. It shows that the technology has much flexibility and can bear the fluctuation in cost components. As per Fig. 10, AVS-1-Irrigated is found most sustainable based on sensitivity analysis.

The LCOE of the three PV systems is given in Table 7. The highest LCOE (INR 3.45 kWh^{-1}) based on break-even electricity tariff is estimated in PV-GM and the lowest LCOE is computed in AVS-1-Irrigated (INR 3.17 kWh^{-1}). The contribution of crop component in total revenue brings down the LCOE values in AVS, which are much lower than the market electricity tariff (INR 5.0 kWh^{-1}). Therefore, it is inferred that crop cultivation, either rainfed or irrigated, can be very economical for an AVS. The trends of LCOE observed in this analysis are in contradiction to other AVS in the world. For Germany's 520 kWh^{-1} AVS, the estimated LCOE was € 0.0828 kWh^{-1} while it was € 0.0603 kWh^{-1} for PV_{GM} [34]. Similarly, the LCOE was € 0.0895 kWh^{-1} for a 500 kWh^{-1} AVS system and € 0.0847 kWh^{-1} for a PV_{GM} system built-in Italy [37].

This study finds AVS-1 is the most suitable AVS design considering the land use economy and the economic parameters. Furthermore, adopting the AVS in AVS-1 both in rainfed and irrigated situations favors the economical parameters of AVS compared to PV-GM. Hence in arid regions, based on the availability of irrigation water, AVS-1was found the most feasible and economical design to enhance and stabilize farm income, assured return from agriculture, and climate change adaptation.

4. Conclusions

Optimizing the agri-voltaic system (AVS) for simultaneous electricity generation and food production from the same land unit can lead to better land utilization. The findings of this study suggest that among the various AVS designs evaluated, full density one row PV array (AVS-1) produced maximum electricity and crop produce, ensuring maximum monetary returns per unit land area. Additional returns provided by crops in AVS systems, with meager cost addition, resulted in favorable economic parameters of AVS systems compared to PV-GM. The added returns of crop production in AVS systems led to a lower pay-back period and Levelized cost of electricity generation over PV-GM. The AVS systems also show resilience to future escalation in cost up to 6% and no escalation in return (e,6). These economic parameters indicate quicker repayment of investment cost and low cost of electricity generation in AVS systems with stability due to returns of crop component. Furthermore, the study finds the AVS systems of full density one row PV array in rainfed and irrigated situations economical. These findings will pave the way for the feasibility of AV systems even in the fertile land of the arid region with minimum LCOE (INR 3.17 kWh^{-1}).

The present study's findings on the economic feasibility will encourage the farmers and entrepreneurs to install solar PV plants in fertile land. However, this study has some limitations. The various economic parameters were calculated based on the estimates of extrapolation of the results of a small-scale study. Despite this, it is strongly felt that this work is valuable, especially for assessing the economic feasibility of the AVS and selection of

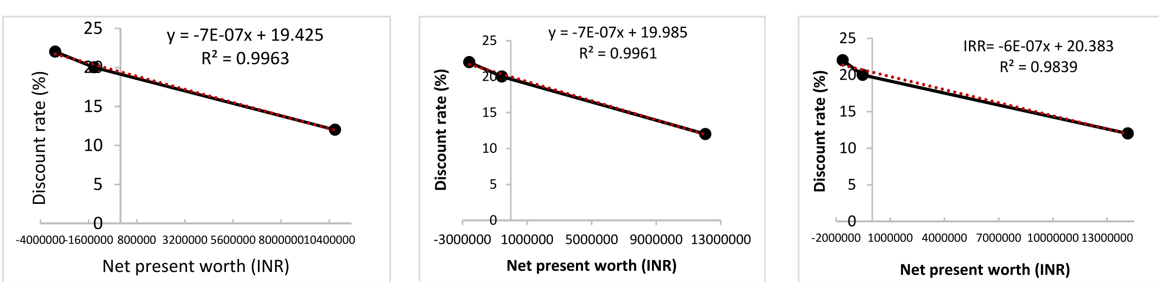

Fig. 8. Relationship between the discount rate and net present worth for a) PV-GM; b) AVS-1-Rainfed and c) AVS-1-Irrigated designs.

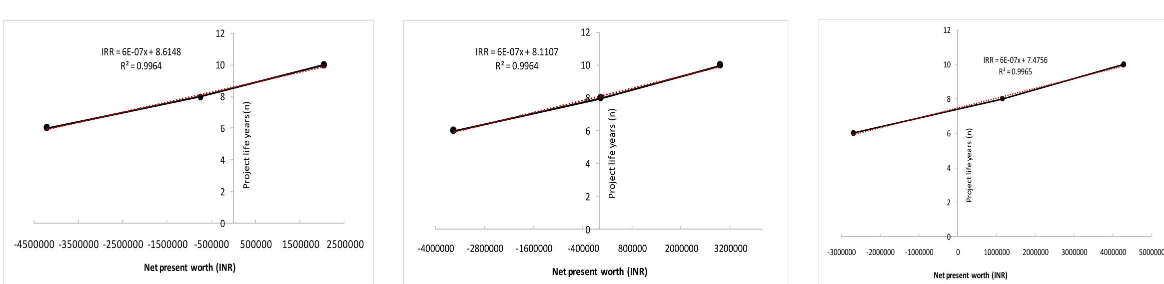

Fig. 9. Relationship between project life and net present worth for a) PV-GM; b) AVS-1-Rainfed, and c) AVS-1-Irrigated designs.

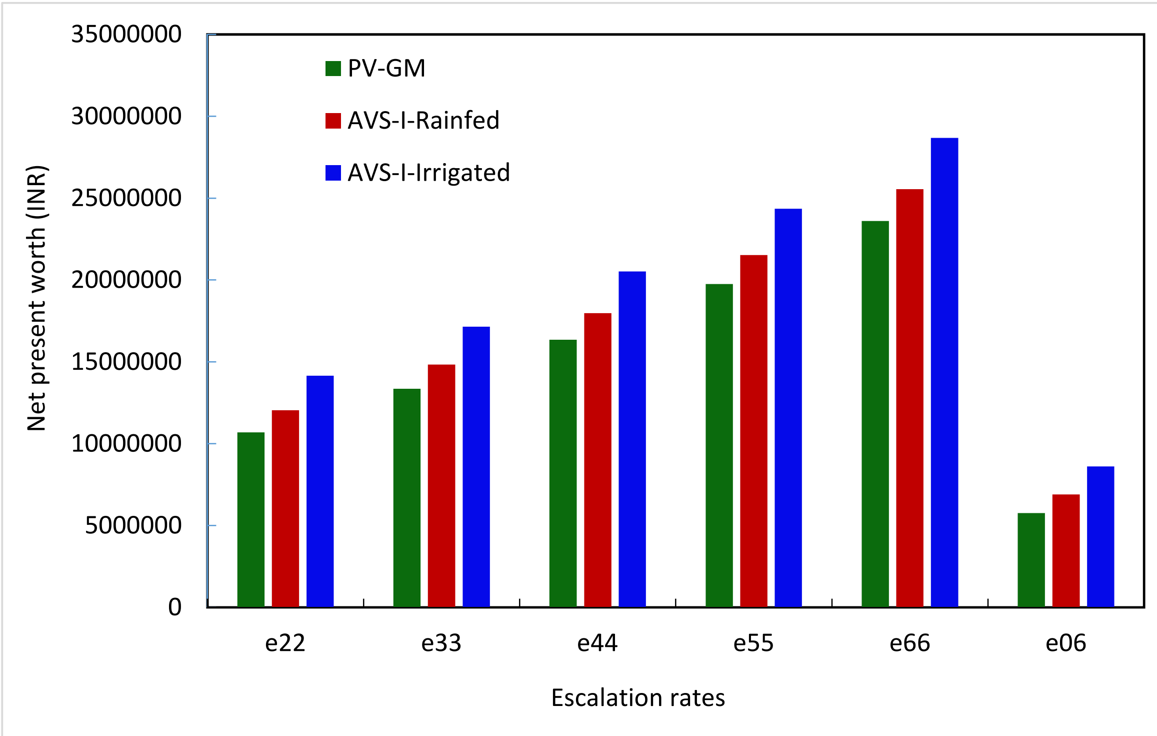

Fig. 10. Net present worth (NPW) at various escalation rates of cost and returns for different AVS designs.

snapmelon as rainfed and brinjal as irrigated crop for arid regions. Furthermore, if the crops and practices are explicitly optimized, AVS can stabilize the yield of rainfed crops by reducing evapotranspiration and soil temperature in arid conditions. Compared to PV-GM in AVS, the crops in the inter-row spacing moderated the micro-climate there by reducing the temperature which helps electricity generation.

CRediT authorship contribution statement

Surendra Poonia: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **N.K. Jat:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Priyabrata Santra:** Conceptualization, Methodology, Software, Validation, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **A.K. Singh:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing. **Dilip Jain:** Software, Resources, Writing – original draft, Visualization, Supervision, Project administration, Funding acquisition. **H.M. Meena:** Validation, Formal analysis, Investigation, Data curation, Writing – review & editing, Visualization.

Declaration of competing interest

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.renene.2021.11.074.

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