Agri-volatic system and PM-KUSUM scheme: Doubling Energy Harvest and Income for Indian Farmers

International Workshop

6th Best Practices Study Tour and International Workshop on Agri PV Plants, RE Grid Integration and Green Hydrogen

Dr. Surendra Poonia
Principal Scientist, ICAR-Central Arid Zone Research Institute
Jodhpur, Rajasthan 342003
Email: Surendra.poonia@icar.gov.in / poonia.surendra@gmail.com

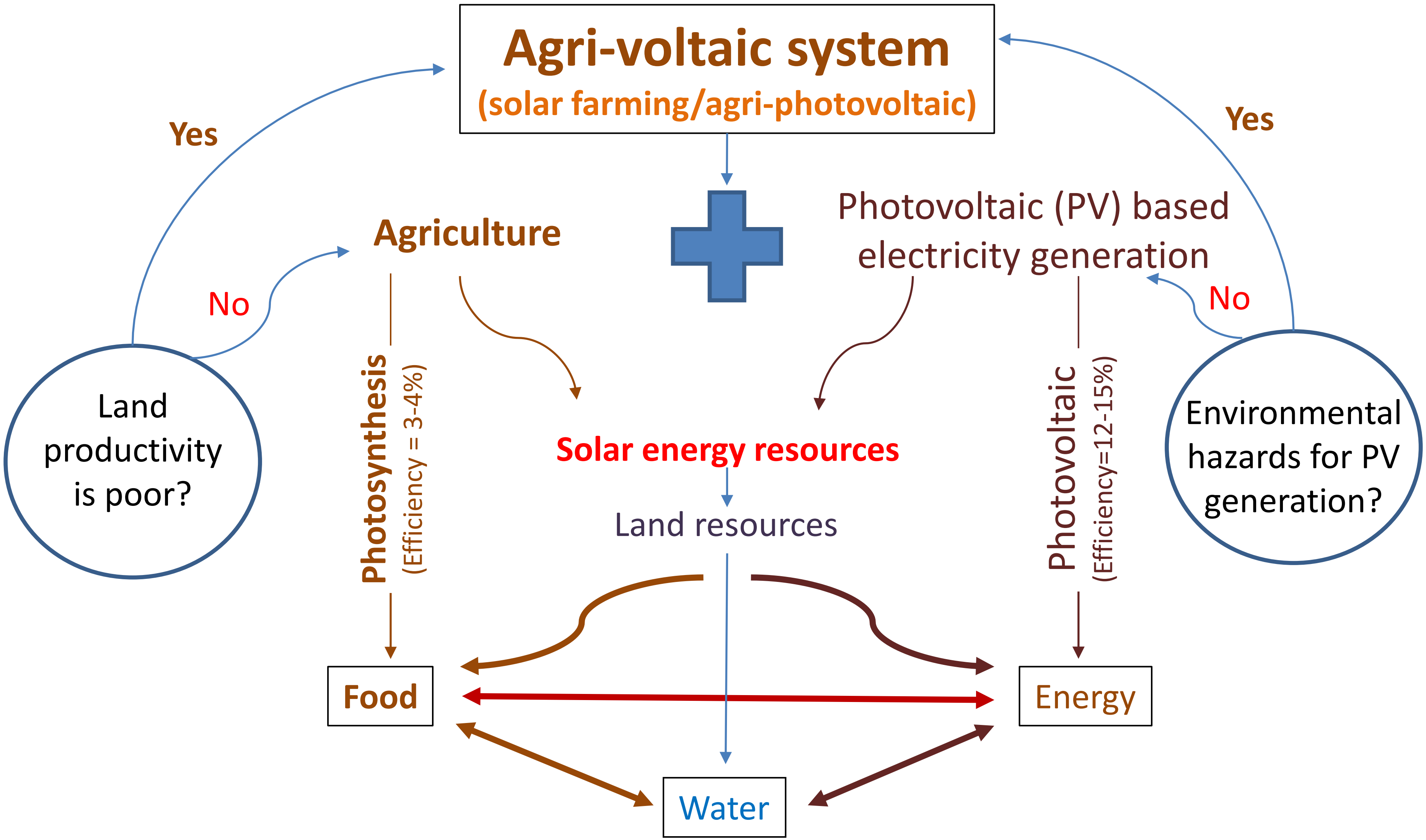
Background hypotheses

- The Govt. of India has set an ambitious target of achieving **175GW of solar photovoltaic (PV) based power generation capacity in the country and doubling the farmer's income by the year 2022**, which has been further revised with **450 GW by 2030.**

- Further, 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.**

- Considering the plentiful availability of solar insolation both in terms of duration and intensity in India and particularly in arid Rajasthan (5.3-7.0 kWh $m^{-2}day^{-1}$), **agri-voltaic system, which is an integration of PV generation and crop production, has the potential to achieve the above said two targets by 2022**.

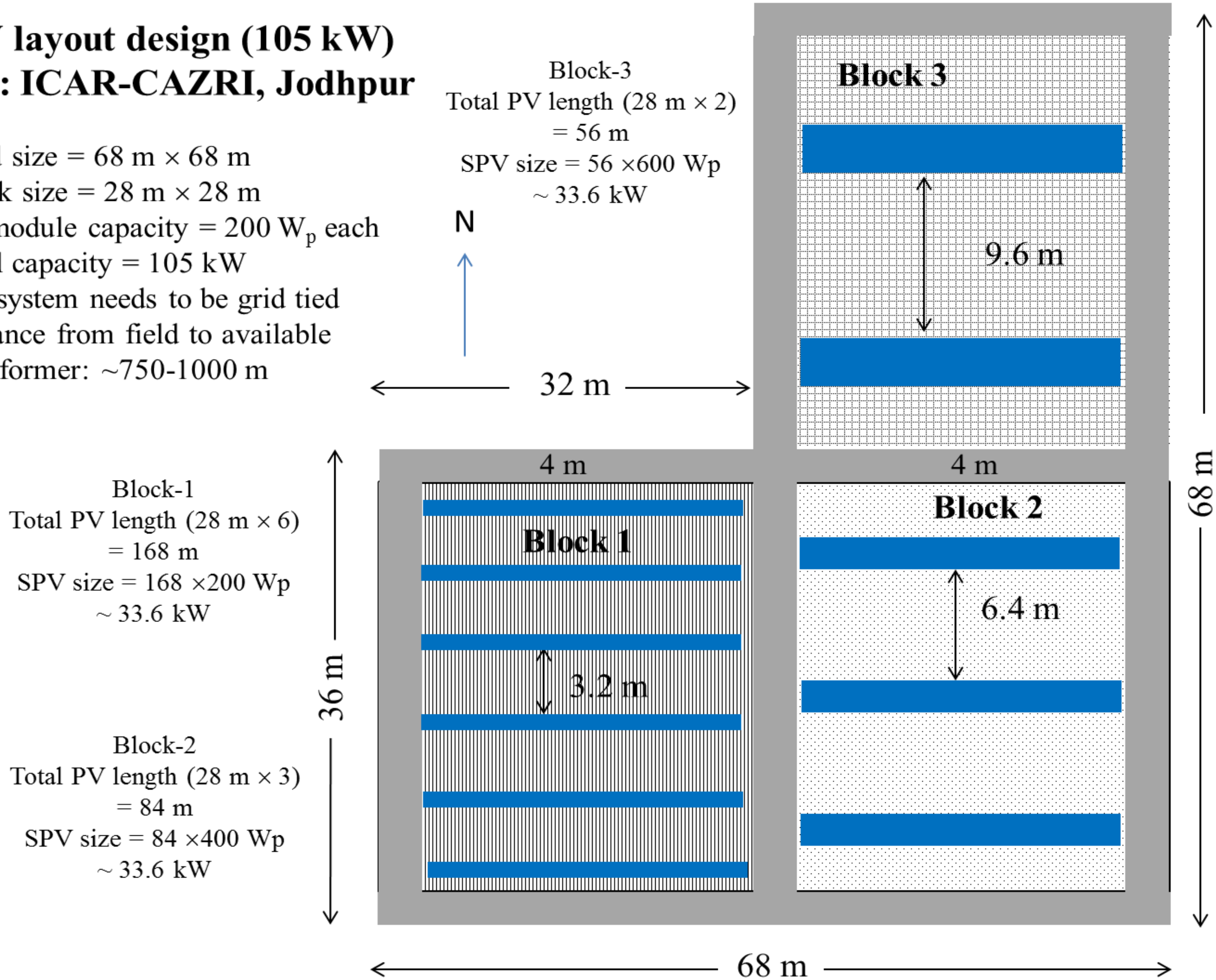
- Food is the basic need for survival of human being. Therefore, it is thought of **producing both simultaneously from a single land unit through agri-voltaic system**.
- **Agri-voltaic system** produces **food and also generates renewable energy** from a single land unit.
- The concept of integrating both food production and energy generation on a single land unit has been evolved in recent times due to ever increasing demands for the land resources.
- Production of food occurs by conversion of **solar energy to food through photosynthetic process** whereas PV based energy generation occurs through conversion of **solar energy to electric energy through photovoltaic process.**
- Agriculture sector has great scope in meeting this **renewable energy target of the country through two major ways.**



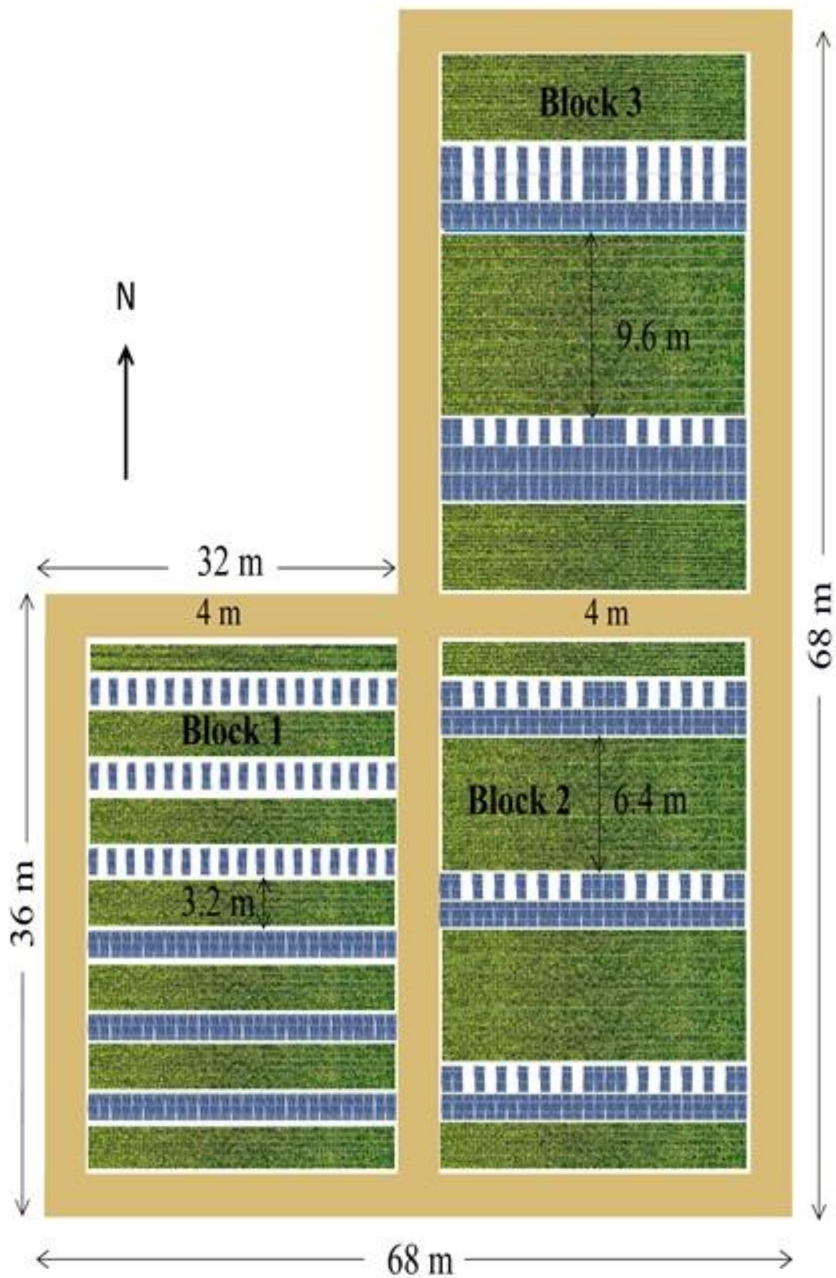
Agri-voltaic system
(solar farming/agri-photovoltaic)
Yes
Yes
Agriculture
Photovoltaic (PV) based electricity generation
No
No
Land productivity is poor?
Environmental hazards for PV generation?
Photosynthesis
(Efficiency = 3-4%)
Photovoltaic
(Efficiency=12-15%)
Solar energy resources
Land resources
Food
Energy
Water

SPV layout design (105 kW)
Place: ICAR-CAZRI, Jodhpur

- Field size = 68 m × 68 m
- Block size = 28 m × 28 m
- PV module capacity = 200 W_p each
- Total capacity = 105 kW
- The system needs to be grid tied
- Distance from field to available transformer: ~750-1000 m



Design of PV module installations for AVS

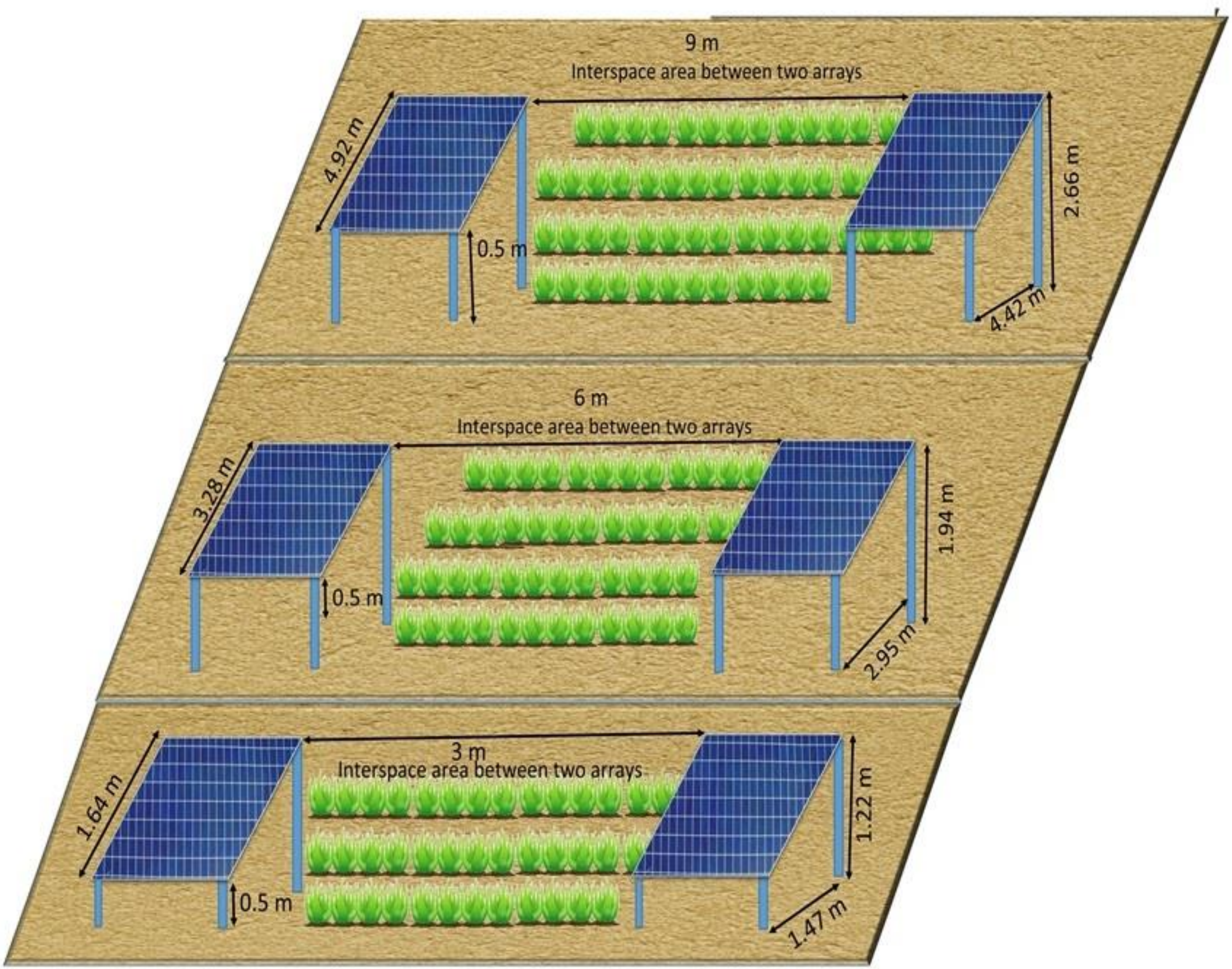


- **Size of the experimental farm: 68 m × 68 m**
- **Size of the each block is 28 m × 28 m.**

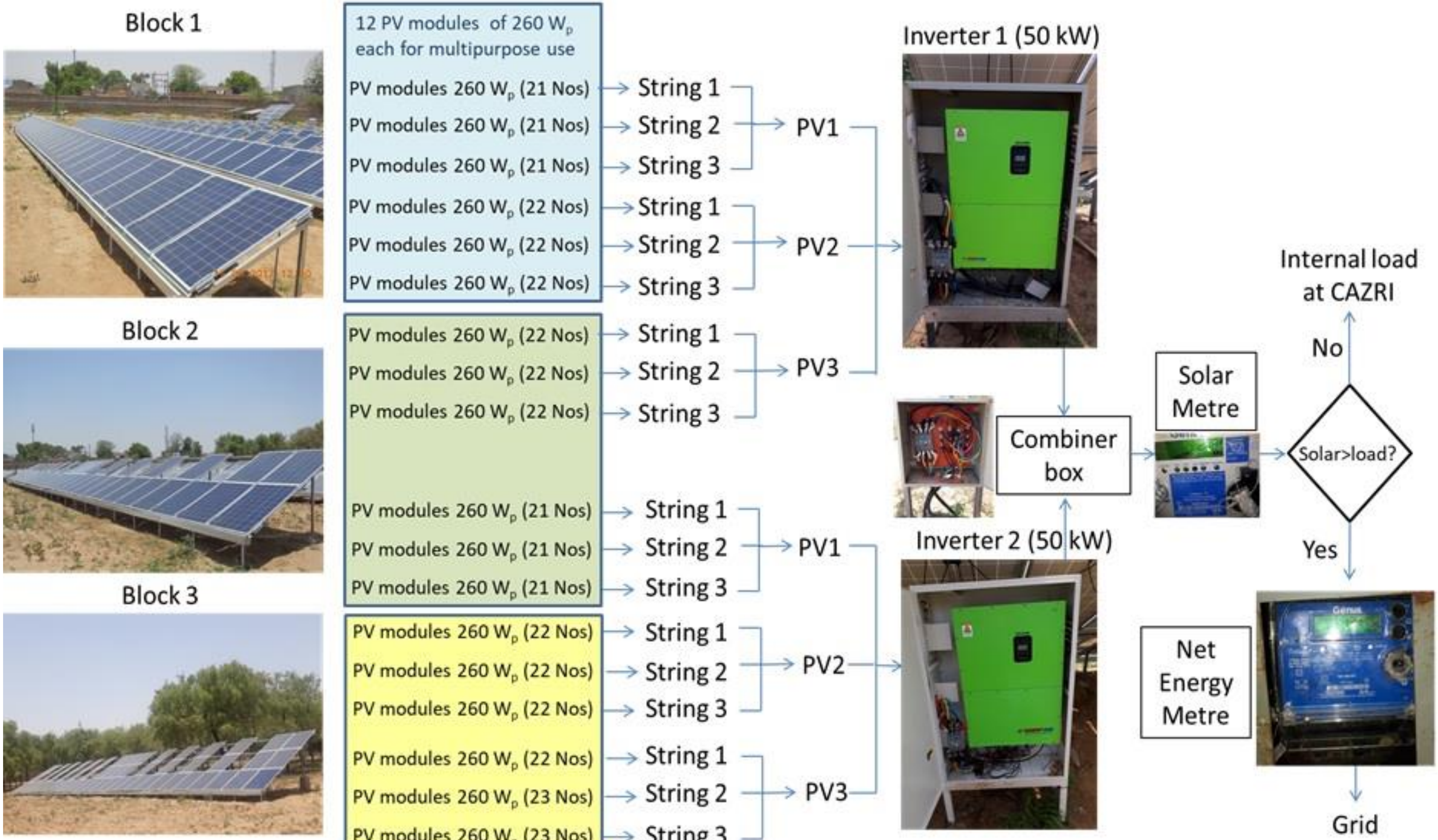
This AVS was established with five designs in three separate blocks-

- **One row PV array with full density**
- **One row PV array with half density**
- **Two row PV array with full density of lower row and half density of upper row**
- **Three row PV array with full density of bottom and middle row and half density of top row**
- **Three row PV array with full density of bottom row and half density of middle and top row**
- The full density (FD) and half density (HD) of PV plates in rows were kept to regulate amount of intercepted solar radiation on ground surface, which is required for crop production in interspaces between PV arrays.
- To avoid shade effect on PV panel on leeward side an inter-row spacing of 3.2, 6.4 and 9.6 m was maintained in ORPVA, TRPVA and ThRPVA, respectively in the North-South direction

Layout design of 105 kW agri-voltaic system



Schematic diagram of the PV generation in agri-voltaic system



Aerial view of 105 kW Agri-voltaic system

Selected crops for Kharif and rabi season

PV array	Kharif season		PV array	*Rabi season*	
	Below panel	Interspaces		Below panel	Interspaces
One row PV arrays			**One row PV arrays**		
1. FD* (3)	• Control	Aloe vera	1. FD* (3)	• Control	Aloe vera
2. HD* (3)	• Brinjal	Brinjal	2. HD* (3)	• Brinjal	Brinjal
	• Aloe vera	Snap melon		• Aloe vera	Spinach
Two row PV array			**Two row PV array**		
FD-HD (3)	• Control	Mung bean	FD-HD (3)	• Control	Gram
	• Lemon grass	Moth bean		• Lemon grass	Cumin
	• Palma rosa	Cluster bean		• Palma rosa	Isabgol
Three row PV array			**Three row PV array**		
1. FD-HD-HD(1)	• Lemon grass	Mung bean	1. FD-HD-HD(1)	• Lemon grass	Cumin
2. FD-FD-HD (1)	• Palma rosa	Moth bean	2. FD-FD-HD (1)	• Palma rosa	Isabgol
*FD- Full density; HD- Half Density			*FD- Full density; HD- Half Density		

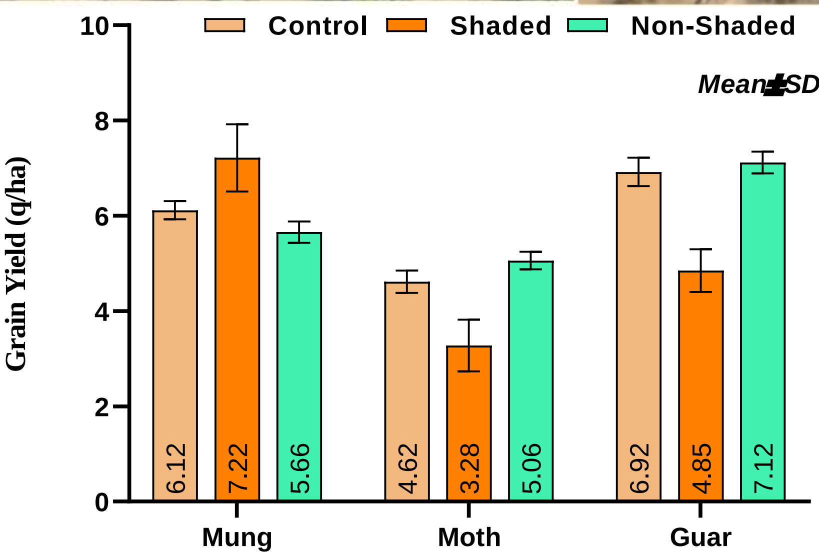
Field view of *kharif* and rabi crops grown in AV system

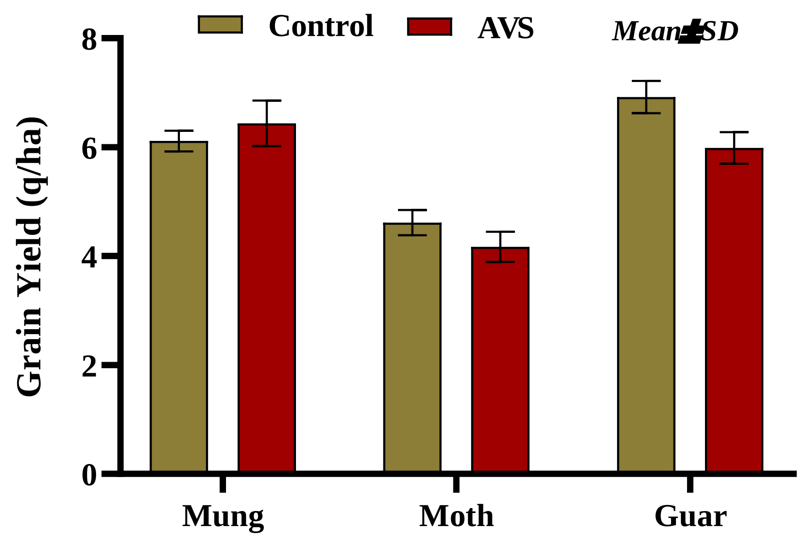
Performance of *Kharif* crops in agri-voltaic system-2020

Moong bean

Moth bean

Cluster bean





Moong bean yielded higher in shaded areas while the moth bean and cluster bean produced 54.2 and 46.6% lesser yield under shaded area as compared to non-shaded area

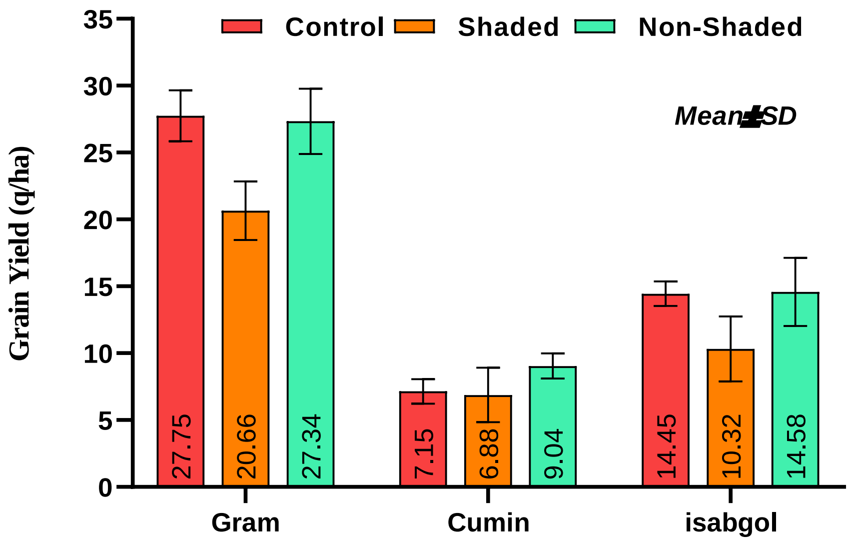
AVS resulted in +5.2, -9.7 and -13.5% yield influence on moong bean, moth bean and cluster bean, respectively as compared to control

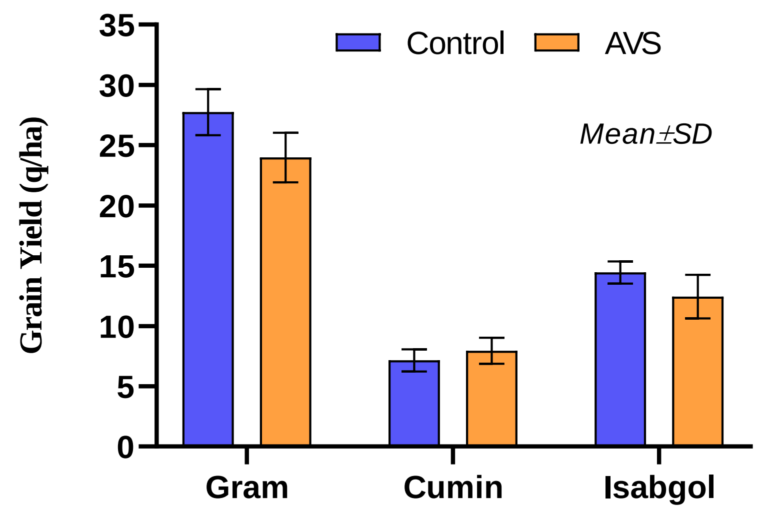
Performance of *Rabi* crops in agri-voltaic system-2020

Gram

Cumin

Isabgol





Gram, cumin and isabgol recorded 24.2, 23.6 and 29.4% yield reduction under shaded area over non-shaded area

AVS resulted in -15.7, +10.03 and -15.9% yield influence on gram, cumin and isabgol, respectively as compared to control

Performance of vegetables crops in interspace area of single-row PV block

Brinjal

Aloe vera

Snap melon

- Yield of brinjal was higher in interspaces area (1375 kg ha^{-1}) than below panel areas (512 kg ha^{-1}) and control plots (1097 kg ha^{-1}).

- There was no yield differences were recorded in *Aloe vera* in interspaces and below panel areas.

- The highest fruit yield of rainfed snap melon (*Cucumis melo* L.) was recorded 34.1% higher in interspaces (111.6 kg) over control plot (83.3 kg).

Spinach

Lemon grass

Field view of *kharif* crop grown in AV system - 2021

Performance of Kharif crops in AVS-2021

Growth and yield of mung bean

Growing conditions	Days to flower	Days to maturity	Dry weight (g)/plant	No. of pods	Grain yield (q/ha)	Biomass
Control	36	62	12.3	21	11.6	36.1
2RPV-Shaded	40	67	14.6	25	12.2	40.00
3RPV-Shaded	39	65	15.1	24	11.7	38.5
2RPV-open	35	59	11.2	19	10.2	30.8
3RPV-open	36	60	11.8	22	10.8	32.5
Av. AVS	37.5	62.8	13.2	22.5	11.2	35.5
Sem	1.83	2.59	1.51	2.23	1.43	3.31
LSD (0.05)	4.6	6.5	3.8	5.6	NS	8.3

Growth and yield of moth bean

Growing conditions	Days to flower	Days to maturity	Dry weight (g)/plant	No. of pods	Grain yield (q/ha)	Biomass
Control	38.2	66	16.5	38	7.33	11.15
2RPV-Shaded	42.7	70	18.2	33	6.55	9.45
3RPV-Shaded	41.5	72	17.3	35	6.12	8.66
3RPV-open	38.6	65	15.2	40	6.92	9.45
2RPV-open	39.1	67	14.6	36	7.12	10.36
Av. AVS	40.5	68.5	16.3	36.0	6.7	9.5
Sem	1.6	2.71	2.4	2.07	2.59	3.90
LSD (0.05)	3.5	6.8	NS	5.2	6.5	9.8

Growth and yield of cluster bean

Growing conditions	Days to flower	Days to maturity	Dry wt/plant	No. of pods	Grain yield (kg/ha)	Biomass
Control	35	110	42	55	14.6	42.5
2RPV-Shaded	38	119	45	45	12.2	46.5
3RPV-Shaded	40	116	48	42	11.4	44.2
2RPV-open	32	108	38	52	13.8	40.5
3RPV-open	34	113	40	56	15.1	41.2
Av. AVS	35.8	113.2	42.6	50.0	13.4	43.0
Sem	2.53	3.32	2.87	4.22	1.80	1.59
LSD (0.05)	7.3	9.6	8.3	12.2	NS	4.6

Reduction in grain yield in mung bean, moth bean and cluster bean were 3.3, 9.7 and 8.7, respectively in AVS compared to control

Differential photo-thermal unit accumulation caused significant difference in days to flowering and maturity in all the crops under open and shaded portion of AVS inter-rows

As compared to moth bean and cluster bean; mung bean found better tolerant to shade and yielded on par to open and control

Performance of Rabi and Kharif crops in AVS-2022

Yield (q/ha) of Kharif crops under AVS

	Mung bean		Moth bean		Cluster bean	
	Grain	Biomass	Grain	Biomass	Grain	Biomass
Control	12.10	45.11	7.33	11.15	23.5	74.91
2RPV-Shaded	10.91	43.08	6.55	9.45	18.4	64.08
3RPV-Shaded	10.20	40.15	6.12	8.66	17.7	62.84
2RPV-open	11.83	48.56	6.92	9.45	21.2	67.17
3RPV-open	12.71	45.05	7.12	10.36	23.0	68.02
Av. AVS	11.55	44.39	6.7	9.5	20.8	67.40
%± AVS	-4.58	-1.59	-8.59	-14.80	-11.81	-10.02
SE(m)±	0.415	2.147	2.59	3.9	0.82	2.547
CD (p=0.05)	1.324	NS	6.5	9.8	2.616	NS

Yield (q/ha) of Rabi crops under AVS

	Chickpea		Cumin		Isabgol	
	Grain	Biomass	Grain	Biomass	Grain	Biomass
Control	26.7	114.7	11.2	22.6	7.6	42.8
2RPV-Shaded	21.8	104.0	8.9	19.0	5.9	38.2
3RPV-Shaded	22.0	102.7	9.3	18.2	6.6	39.8
2RPV-open	27.8	112.7	10.1	24.5	7.3	41.7
3RPV-open	26.5	109.6	9.9	23.4	7.6	42.0
Av. AVS	24.9	108.7	10.0	21.5	7.0	40.9
%± AVS	-6.6	-5.2	-10.3	-4.9	-7.8	-4.4
SE(m)±	1.0	2.7	0.6	0.9	0.3	0.8
CD (p=0.05)	3.3	NS	NS	2.9	1.0	2.6

Differential photo-thermal unit accumulation caused significant difference in days to flowering and maturity in all the crops under open and shaded portion of AVS inter-rows

Reduction in grain yield in mung bean, moth bean and cluster bean were 4.6, 8.6 and 11.8, respectively in AVS compared to control

Reduction in grain yield in chickpea, cumin and isabgol was 6.6, 10.3 and 7.8, respectively in AVS compared to control

Growing cucurbits on ground

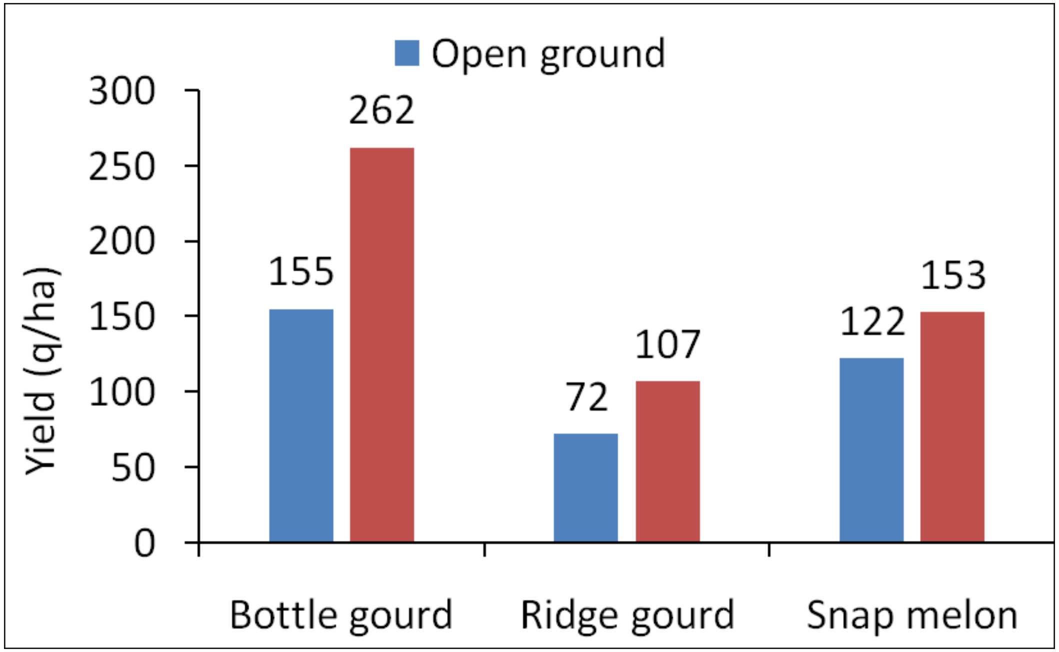
Cucurbits on bower system made of GI wire mesh

Bottle gourd in bower system

Fig. 5. Vegetables grown in double-row PV array of AVS

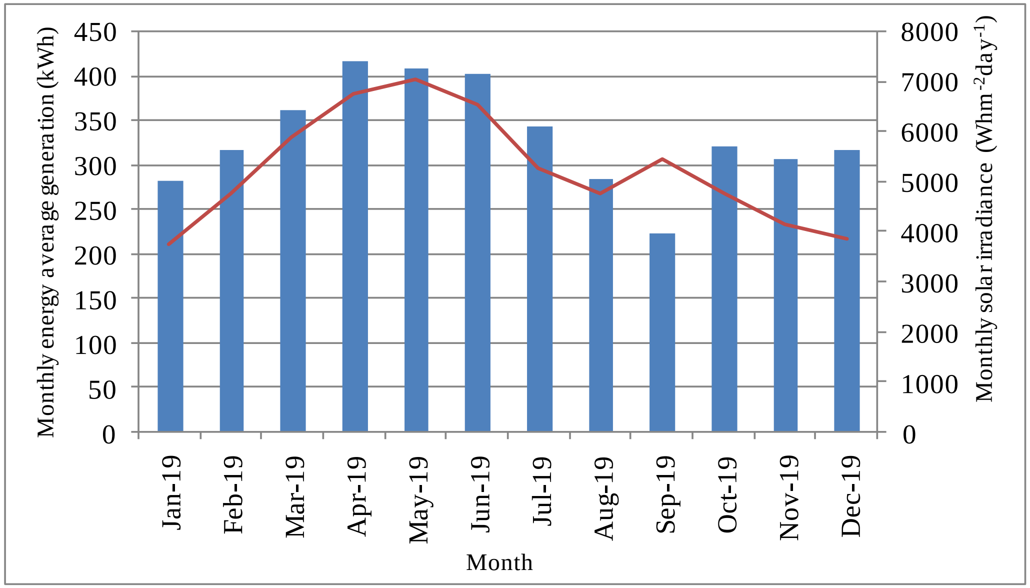
Economic yield of trailing vegetables in open ground and bower system cultivation

In double-row PV array of AVS, trailing vegetables *viz.*, **bottle gourd, ridge gourd and snap melon** were grown during Kharif 2022 in bower system on the leeward side of PV panels. Results show that as **compared to open ground, the cultivation of these trailing vegetables in bower system resulted in 69.0, 48.6 and 25.4% increase in economic yield of bottle gourd, ridge gourd and snap melon.**



PV generation in Agri-voltaic system

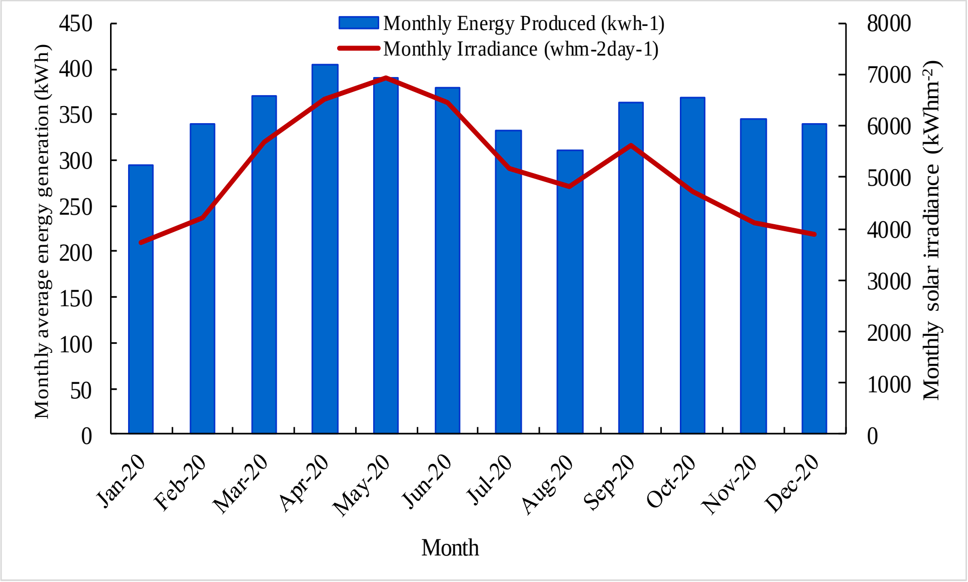
Average PV generation = 331 kWh day^{-1}



- Solar PV generation and solar insolation have been regularly monitored through supervisory control and data acquisition (SCADA) facility and automatic weather station.

Average PV generation = 353 kWh day^{-1}

- The annual power output generated by AV system was 1,20,779 kWh and the total revenue generated was Rs. 6,03,895 during the year 2019.
- The annual power output generated by AV system was 1,29,266 kWh and the total revenue generated was Rs. 6,46,330 during the year 2020.



Power output (kWh) of agri-voltaic PV modules from January-December 2019.

Month	kWh per day	kWh per month	kWh per m^2	Revenue per m^2 (Rs.)	Revenue (Rs.)
Jan-19	280	8680	7.4	36.90	43400.0
Feb-19	316	8848	7.5	37.62	44240.0
Mar-19	360	11160	9.5	47.45	55800.0
Apr-19	415	12450	10.6	52.93	62250.0
May-19	408	12648	10.8	53.78	63240.0
Jun-19	401	12030	10.2	51.15	60150.0
Jul-19	343	10633	9.0	45.21	53165.0
Aug-19	284	8804	7.5	37.43	44020.0
Sep-19	222	6660	5.7	28.32	33300.0
Oct-19	320	9920	8.4	42.18	49600.0
Nov-19	305	9150	7.8	38.90	45750.0
Dec-19	316	9796	8.3	41.65	48980.0
Total		120779	102.7	514.0	603895

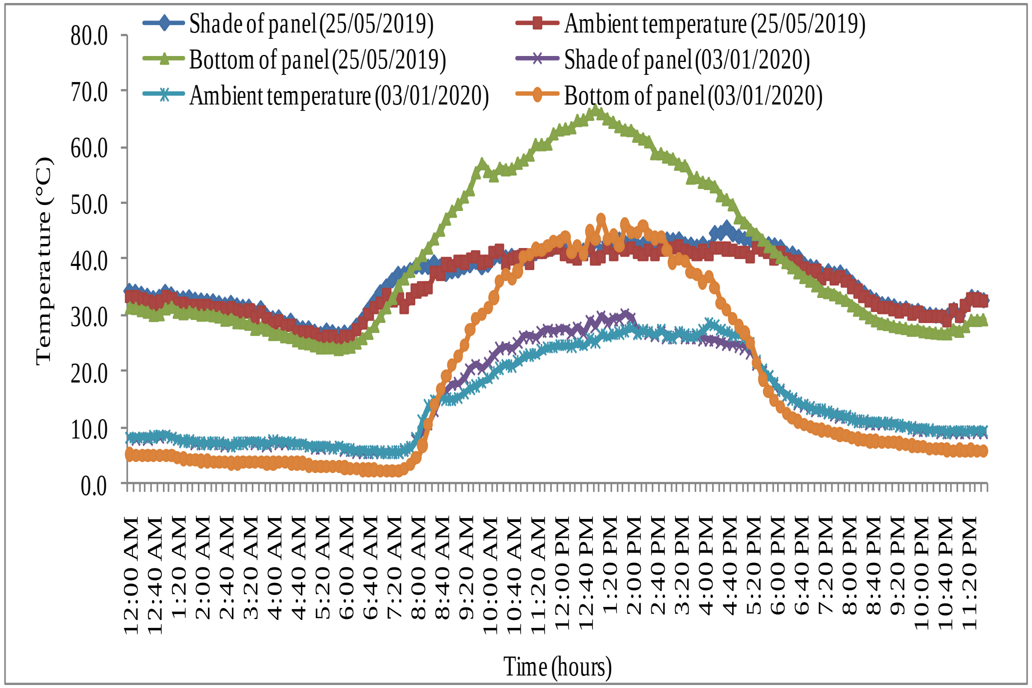
Temperature of solar PV module, ambient and soil

- **Ambient temperature: 2.7°C to 48.6°C.**

- **Shade of PV panel areas: 3.0°C to 49.6°C with peak values as high as 50°C in June 2019.**

- **During summer days: Average temperature of PV module reached up to 60-65°C whereas during winter season it reached up to 40-45°C with peak values 71°C during June 2019.**

- **From January to December, soil temperature under different depths of the PV arrays was significantly cooler (up to 4.4°C daily average) compared to the recorded data of meteorological observatory, CAZRI, Jodhpur.**



Variation in temperature of solar PV module and the ambient condition during summer and winter season in the agri-voltaic system

Variability of microclimatic parameters during 2019

Months	Ambient temp. (°C)	Shade of panel (°C)	Bottom of panel (°C)	Soil temp. 10 cm depth (°C)	Soil temp. 20 cm depth (°C)	Soil temp. 30 cm depth (°C)
Jan.2019	4.6-35.1	4.9-34.2	1.7-53.5	10.7-26.1	13.3-24.5	14.1-24.2
Feb 2019	2.7-36.3	3.0-35.6	0.3-56.5	11.0-29.7	14.9-23.7	15.1-23.2
March 2019	10.2-44.6	10.4-44.7	7.5-65.9	15.7-31.4	19.8-32.4	19.9-23.6
April 2019	16.8-46.9	17.0-47.8	14.9-70.8	24.5-34.0	26.0-35.1	30.8-36.2
May 2019	18.9-46.7	19.5-48.5	19.9-68.2	24.5-47.1	27.5-37.7	28.5-39.3
June 2019	23.1-48.6	23.6-50.0	24.1-70.9	28.1-38.1	30.6-39.8	31.2-47.5
July 2019	22.0-46.2	23.1-46.4	23.2-67.1	26.8-45.8	29.1-40.5	29.4-42.6
Aug. 2019	23.7-40.6	24.3-41.7	24.2-52.8	25.5-42.0	27.5-36.8	31.5-35.5
Sept 2019	23.4-43.5	23.3-44.0	22.2-68.8	25.1-40.8	27.4-38.4	28.3-36.6
Oct. 2019	13.7-43.1	13.6-44.4	10.8-66.4	21.5-41.3	25.0-37.9	27.3-35.5
Nov. 2019	8.5-38.7	8.3-40.8	5.0-60.8	14.4-33.0	17.5-32.6	20.2-29.1

Rainwater harvesting in agri-voltaic system

System features

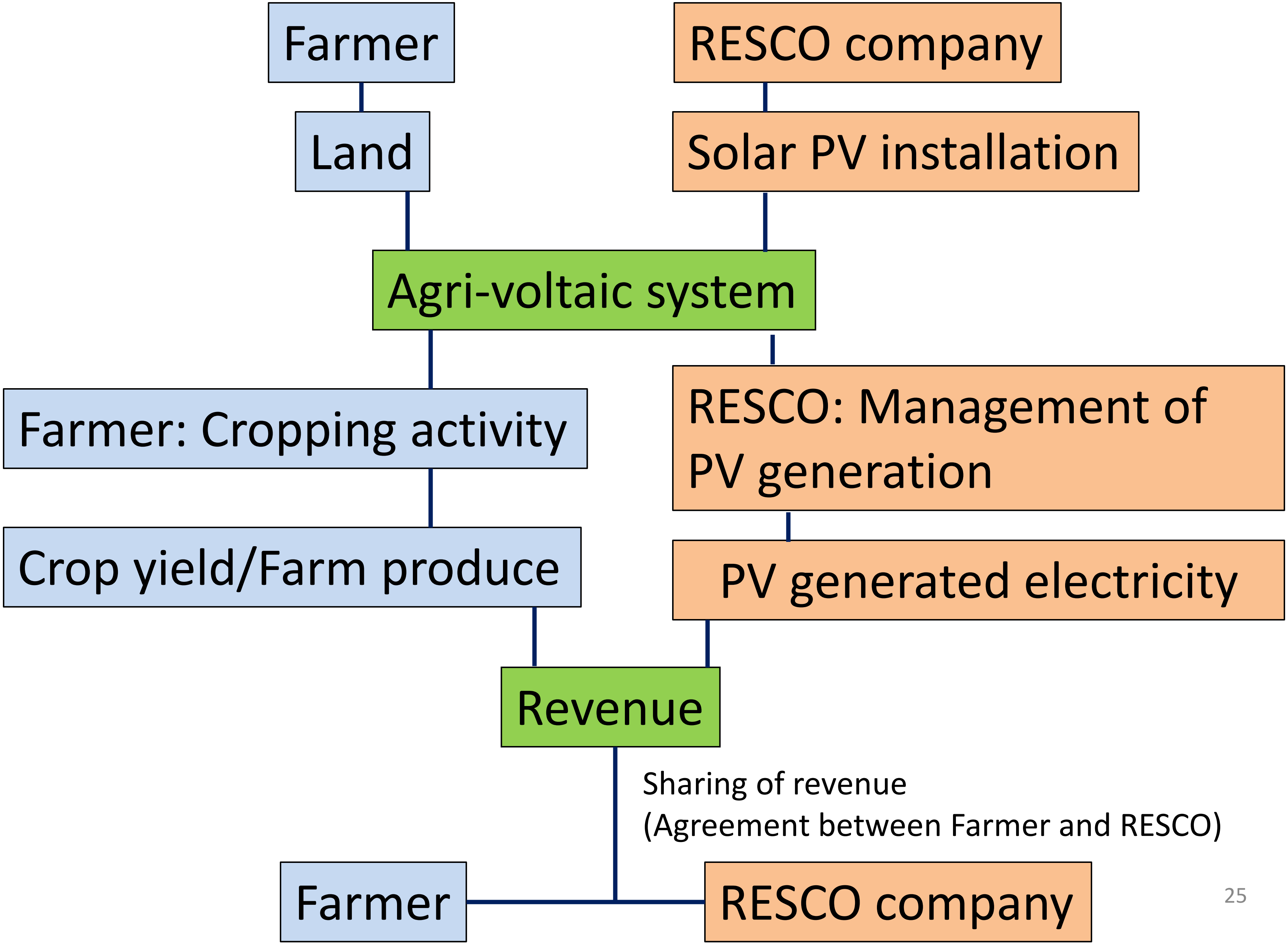
- Surface area of a solar PV module of 260 W_p capacity is 1.64 m × 0.992 m.
- Thus, total surface area of 105 kW capacity agri-voltaic system is about **651 m^2.**
- Rectangular shaped water collector channels made of MS sheet was fixed with about 2° slope at the edge of each PV array, which were connected to underground conveying PVC pipes of 4″ diameter.
- Rainwater storage tank capacity = **1 lakh litre**
- Stored water will be recycled for cleaning and can provide 40 mm irrigation in about 1 acre land

Efficiency of the system

- **Rainfall from 1 June to 31 July 2019 = 221.2 mm**
- **Efficiency of the system = 65.8%.**
- **Total harvested rainwater = 93,300 litre**

Land requirement: 1 ha for 500 kW agri-voltaic system
Income from electricity generation: Rs 20-25 lakhs y^{-1}
Additional income from crop component: Rs 0.5-0.6 lakhs y^{-1}

Agri-voltaic system in Farmer's field-Possible ways



Benefits of Agri-voltaic system

- Increased income from farm land
- Recycling of harvested rainwater for cleaning PV modules and irrigating crops (1.5 lakh litre per acre and can provide 40 mm irrigation in 1 acre land)
- Improvement in microclimate for crop cultivation and optimum PV generation
- Reduction in soil erosion by wind
- Reduction in dust load on PV panel
- Improvement in land equivalent ratio (LER ~1.41)
- Soil moisture conservation by reducing the wind speed on ground surface
- Reduction in GHG emission (598.6 tons of CO_2 savings/year/ha)

Few perceived drawbacks

- Safety of field workers engaged in agricultural activity
- Managerial complexity: additional load on plant manager for agricultural activity
- Ownership issue: Farmer and solar power plant functionary
- Sharing of benefits in case of joint venture
- High capital investment during initial establishment

Kisan Urja Suraksha Utthaan Maha Abhiyaan (KUSUM)

The **Government has launched a new scheme for farmers** for **installation of solar pumps** and **grid connected solar power Plants**, with an objective of providing financial and water security to farmers.

The scheme consists of three components

- **Component-A: 10,000 MW of decentralized ground mounted grid connected renewable power plants of individual plant size up to 2 MW.**

- **Component-B:** Installation of **17.50 lakh standalone Solar Powered Agriculture Pumps** of individual pump capacity up to **7.5 HP.**

- **Component-C:** Solarisation of 10 Lakh grid-connected agriculture pumps of individual pump capacity up to 7.5 HP.

- All three components combined, the scheme aims to add a solar capacity of **25,750 MW by 2022**.

Features of the KUSUM Scheme

- **The Component-A and Component-C will be implemented on pilot mode** for **1000 MW capacity** and **one lakh grid connected agriculture pumps** and thereafter, will be scale-up on success of pilot run. **Component B will be implemented in full-fledged manner.**
- **Under the component A** Solar energy based power plants of capacity **500 kW to 2 MW** will be setup by individual farmers/ cooperatives/panchayats/Farmer Producer Organizations (FPO) with joint collaboration with local DISCOMs.
- The power projects under the scheme would be implemented on any land, **including agricultural lands where solar plants may be installed in stilt fashion and with adequate spacing between panel rows for ensuring that farming activity is not affected so that agri-voltaic system is a part of the KUSUM scheme.**
- State Government, can call for bids specifically only for **solar plants to be installed on stilts, especially on cultivable lands, so that the farmers continue to get the opportunity to cultivate the land, apart from enjoying lease rent.**

Benefits of the KUSUM Scheme

- The scheme will open a stable and **continuous source of income to the rural land owners for a period of 25 years by utilization of their dry/uncultivable land.**
- In case cultivated fields are chosen for setting up solar power project, the **farmers could continue to grow crops as the solar panels are to be set up above a minimum height.**
- The proposed scheme would ensure that sufficient local solar/ other renewable energy based power is available for **feeding rural load centres and agriculture pump-set loads, which require power mostly during the day time.**
- As these power plants will be located closer to the agriculture loads or to electrical substations in a decentralized manner, it will result in **reduced Transmission losses for STUs and Discoms.** Moreover, the scheme will also help the Discoms to achieve the RPO target.

Economics of 100 kW agri-voltaic system (Per ha basis)

- Different designs of AVS with options to grow crops were established in hot arid region of India.
- AVS design with single row full density PV modules recorded the highest returns with brinjal.
- LCOE (3.17 kWh^{-1}) was found lowest with the AVS design with single row full density PV modules.
- Internal rate of returns was highest in single row full density PV modules with irrigated (20.38%) as compared to PV-GM (19.42%).
- Pay back period was also lowest for irrigated AVS-1 (7.47) as compared to rainfed AVS-1 (8.11) and PV-GM (8.61) years.

Specifications	AVS system design				
	AVS-1 (one row PV full density)	AVS-2 (one row PV half density)	AVS-3 (two-row PV array)	AVS-4 (three row PV array)	AVS-5 (three row PV array)
Number of rows	3	3	3	1	1
Number of PV modules	84	51	135	73	62
Interspace distance	3.2	3.2	6.4	9.6	9.6
Net Area (m^2)	392.3	392.3	784.6	392.3	392.3
Inter space area (m^2)	268.8	268.8	537.6	268.8	268.8
% of net area	68.5	68.5	68.5	68.5	68.5
Elec. Gen. (kWh/day)	**93.90**	**57.0**	**150.93**	**81.60**	**69.32**

Attributes	PV-GM	AVS-I-Rainfed	AVS-I-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**

Projects already installed under KUSUM scheme of component-A in Rajasthan

(Installation almost completed likely to commission by February 2022)

District	Category	Approved Capacity (MW)
Alwar	3 Farmers and 1 develope	7.00
Bikaner	3 Farmers and 1 developer	3.50
Jaipur	3 Farmers and 1 GOF	5.50
Barmer	3 Developers and 1 farmer	6.00
Jodhpur	2 Farmers	3.00
Ganganagar	3 Farmers	4.00
Churu	3 Farmers	5.00
Jaisalmer	1 Farmer	1.00
Chittorgarh	1 Farmer	0.50
Jhunjhunu	1 Farmer	0.50
Tonk	1 Farmer	1.00
Kota	1 Farmer	1.50
Pali	1 Farmer	1.00
Nagaur	1 Farmer	2.00
Hanumangarh	1 Farmer	2.00
	Total (MW)	**43.5**

District-wise approved projects under KUSUM component-A in Rajasthan

District	No. of farmers/FPO/Group of farmers/developers	Offered capacity (MW)
Ajmer	6 farmers and 1 FPO	7.0
Bhilwara	6 farmers	3.5
Chittorgarh	3 farmers	3.0
Jhunjhunu	38 farmers	38.5
Nagaur	41 farmers, 1 FPO and 3 GOF	47.0
Sikar	25 farmers	22.5
Udaipur	1 farmer	0.5
Alwar	14 farmers, 2 developers and 1 FPO	23.0
Baran	4 farmers	3.0
Bharatpur	4 farmers	4.0
Bundi	2 FPO	4.0
Dausa	10 farmers	7.5
Dholpur	1 farmer	0.5
Jaipur	38 farmers and 1 GOF	35.0
Jhalawar	3 farmers and 3 FPO	5.0
Karauli	2 farmers and 1 GOF	2.0
Kota	3 farmers and 1 FPO	4.0
Sawai Madhopur	6 farmers	5.0
Tonk	10 farmers	7.5
Barmer	52 farmers and 3 developers	78.5
Bikaner	55 farmers and 15 developers	104.0
Churu	13 farmers, 7 developers and 1 FPO	42.0
Hanumangarh	2 farmers and 2 developers	8.5
Jaisalmer	16 farmers	22.0
Jalore	15 farmers	17.0
Jodhpur	57 farmers and 3 developers	87.0
Pali	18 farmers, 1 developer and 1 GOF	13.5
Sri Ganganagar	17 farmers and 1 developer	18.5
Sirohi	5 farmers	5.5
	Total (MW)	**619.0**

Thank you