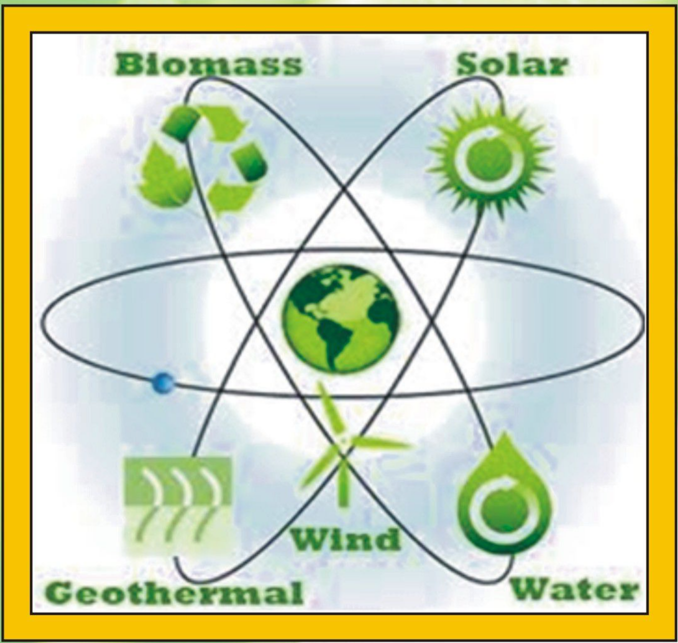
Compendium of Lectures



Renewable Energy for Sustainable Agriculture and Environmental Protection

March 8-10, 2021

Organised By:

Sponsored By:

Training Programme

On

Renewable Energy for Sustainable Agriculture and Environmental Protection

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Organised by:

Department of Agri. Engineering, COA, SKRAU, Bikaner

and

Institute of Agri Business Management, SKRAU, Bikaner

Sponsored By:

National Agricultural Higher Education Project (NAHEP) - ICAR

Agri-voltaic system: PV based generation and cultivation of cash crops

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1. Introduction

The Govt. of India has set an ambitious target of achieving 100,000 MW of solar photovoltaic (PV) based power generation capacity in the country and doubling the farmer's income by the year 2022. Considering the plentiful availability of solar insolation both in terms of duration and intensity in India (5.3-7.0 kWh $m^{-2}day^{-1}$) and particularly in arid parts of India *i.e.* in Rajasthan, solar irradiations are available in abundance for almost 300 days clear sky. The average irradiance on horizontal surface in arid Rajasthan is 5.6 kWh m^{-2} day^{-1}, which can be harnessed to fulfill a part of energy needs of rural communities. 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. 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. Both these processes require land as a basic natural resource. Therefore, competition for land may arise in future for agricultural use and PV based electricity generation. There is possibility that solar PV based electricity production will be preferred over agriculture because of its higher efficiency of converting solar energy. Agri-voltaic system provides opportunity to generate electricity from farmers' field and thus can increase farmers' income.

2. Design of Agri-voltaic system

2.1 PV Module Installation

Installation of solar power plants of 1 MW capacity requires about 2 ha area. Design parameters for erecting solar panels in AVS are slightly different from that in a conventional solar power plant. At ICAR-CAZRI, Jodhpur, India a AV systems of 105 kW capacity has been established with three experimental designs in three separate blocks. The size of the experimental farm was 68 m × 68 m and the size of the each block is 28 m × 28 m. This AVS was established with five designs in three separate blocks- i) one row PV array with full density ($ORPVA_{FD}$), ii) one row PV array with half density ($ORPVA_{HD}$), iii) two row PV array with full density of lower row and half density of upper row ($TRPVA_{FD-HD}$), iv) three row PV array with full density of bottom and middle row and half density of top row ($ThRPVA_{FD-FD-HD}$) v) three row PV array with full density of bottom row and half density of middle and top row ($ThRPVA_{FD-HD-HD}$). 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 (Fig.1). In all these three blocks, two different designs were followed: few arrays with gap in between PV modules and few arrays covered fully with PV module which allows receiving different amount of intercepted solar irradiation on ground surface, which is required for crop cultivation in between PV arrays and also below PV panel areas. The shading from the PV module varied according to the time of year and height of the crops planted between the module rows. Solar PV modules were installed on fixed MS iron angle structure facing perpendicular to south and inclination of 26° at both the sites (Fig. 2).

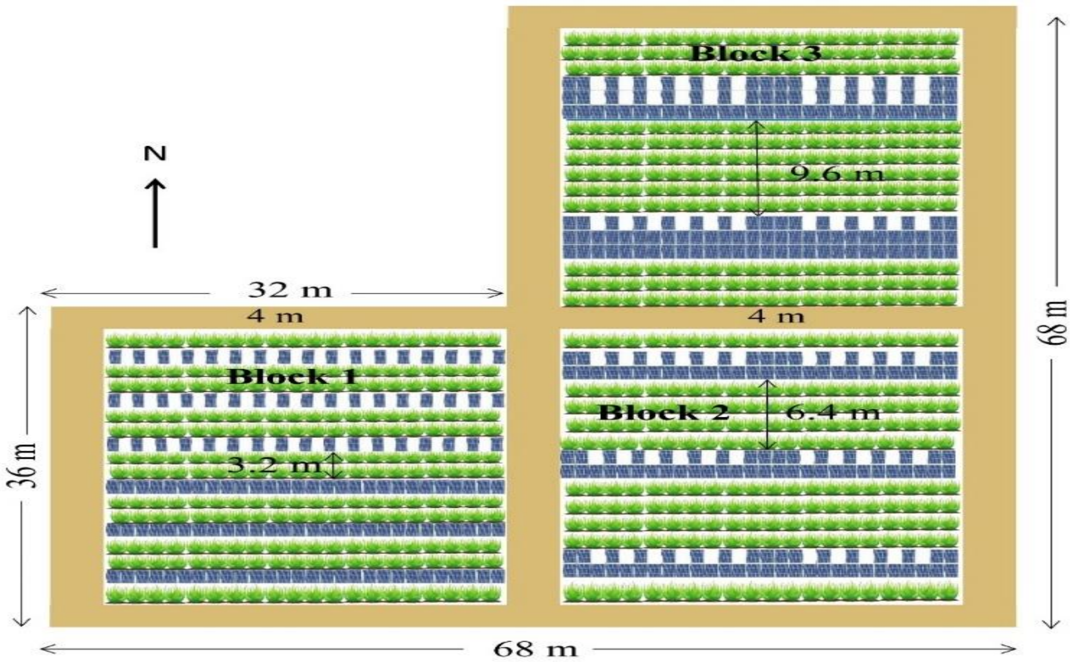

Figure 1: Schematic design of PV module installations for AVS

2.2 Crop production in agri-voltaic system

In the present AV system, the PV modules created shade on ground surface on leeward side as per the movement of sun. To avoid the shade of one PV array on the next array, a separation distance between two arrays is maintained. This interspaces area between two PV arrays was utilized to grow suitable crops. Moreover, area below the PV module was also used to grow crops since PV modules are fixed over mounting structure at a certain height from ground surface. However, growing crops in between the arrays of PV modules requires selection of suitable crops which have certain degree of shade tolerance and shorter in height to avoid shade on PV panels. The shaded portion at interspaces area varies from morning to evening as per zenith angle and azimuth angle of Sun's position. Available amount of solar irradiation both under direct (open sun) and diffused conditions governs plant growth because the amount of photosynthetically active radiation (PAR) is different under both these conditions. Height of crops is a key parameter for selection of crops for AVS because high crops may create shade on PV modules and thus reduce the PV generation. Therefore, crops with low height (preferably shorter than 50 cm) which can tolerate certain degree of shade and require less amount of water are most suitable for AVS in arid ecosystem. Following crops are chosen to grow in agri-voltaic system. Under rainfed situation, moong bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*), and cluster bean (*Cyamopsis tetragonoloba*) have been selected as arable crop, whereas under irrigated situation during *Rabi* season isabgol (*Plantago ovata*), cumin (*Cuminum cyminum*) and chickpea (*Cicer arietinum*) have been selected. Apart from these arable crops, medicinal plant, e.g. *Aloe vera* and *Solanum melongena* (brinjal) have been selected as perennial *Spinacia oleracea* (spinach) and snapmelon (*Cucumis melo* L. Momordica group) as vegetables crop as annual components. For cultivation in areas below PV modules, aromatic grasses viz. *Cymbopogan citrates* (lemon grass) and *Cymbopogan martini* (palmarosa) have been selected. These crops are expected to modify the microclimates below PV modules and thus help in optimum PV generation in arid ecosystem. Moreover, the coverage of crops on soil surface in between PV arrays will also check the erosion of soil by wind action and thus will reduce the dust load on PV module. A field view of different *kharif* and *rabi* crops grown in the AVS is shown in Fig. 2-4.

Figure 2: Installed Agri-voltaic system at ICAR-CAZRI, Jodhpur, India

Figure 3: Field view of different Kharif and Rabi crops grown in AV system during 2019-20

Figure 4: Field view of different vegetables and aromatic grasses in AV system during 2019-20

2.3 PV based electricity generation from Agri-voltaic system

Solar PV generation and solar irradiation has been regularly monitored through SCADA (Supervisory Control and Data Acquisition) facility and automatic weather station. The installed AVS has been connected to local electricity grid through net metering system. Therefore, the generated electricity is directly sold to state electricity board at a fixed tariff which varies across different states of India. The average tariff rate of INR 5 per kWh may be considered to calculate the income from PV-generated electricity. The schematic diagram of the PV based electricity generation from the installed AVS and its supply to grid is depicted in Fig. 5. At Jodhpur, India effective solar irradiation to generate electricity is available for an average of 4–5 h in a day. Therefore, 1 kW PV system is expected to generate 4–5 kWh unit of electricity per day. Thus, 100 kW AVS in Jodhpur will generate at least 400 kWh unit of electricity in a clear sunny day. During the year 2019, month wise, highest PV generation was observed during April 2019 and average PV generation has been observed as 331 kWh month^{-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. Similarly month wise, highest PV generation was observed during April 2020 (Fig. 6). Average PV generation has been observed as 353 kWh month^{-1}. 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.

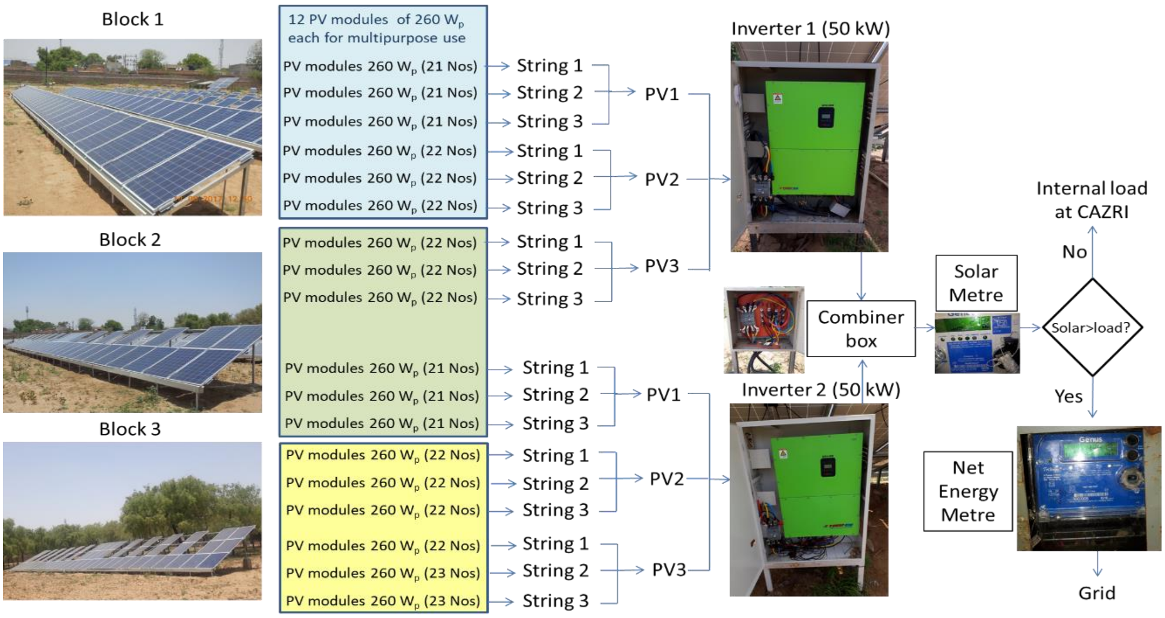

Figure 5: Schematic diagram of PV based electricity generation in AVS and its supply to local grid.

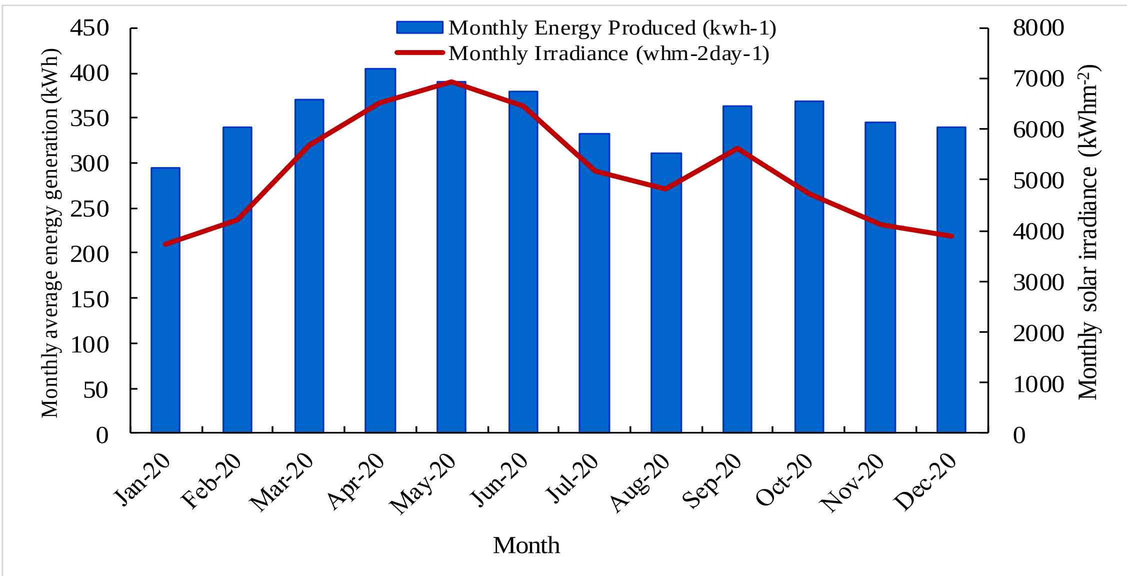

Figure 6: Solar PV generation and solar radiation in different months during the year 2020

2.4 Rainwater harvesting system in agri-voltaic system

For optimum PV generation, regular cleaning of deposited dust from PV module surface is essential and requires about 20-40 litre month^{-1} kW^{-1} of water. The rainwater harvesting system from top surface of PV modules in agri-photovoltaic system has the capability to provide water for cleaning purpose and to recycle it. Apart from cleaning, harvested rainwater may provide irrigation of about 40 mm during rabi season. Potential capacity of harvested rainwater from agri-voltaic system covering 1 ha area is about 3.75-4 lakh litre at Jodhpur. It is possible to collect and store rain water from the top surface of PV modules in AVS. Therefore, in this AVS rainwater harvesting system was also designed and developed by rectangular MS sheet as water collection channels (Fig. 7), underground water conveying PVC pipes of 4′′diameter and an underground water storage tank of 1 lakh litre capacity. Surface area of a solar PV module of 260 W capacity is 1.64 m × 0.992 m. Thus, total surface area of 105 kW capacity agri-voltaic system is about 651 m. The total quantity of water received as rain cannot be harvested from PV module surface because of splash loss, evaporation loss, etc. Therefore, a factor of 0.8 may be considered to estimate the total harvested water from rainfall amount. Again, 10% conveyance loss of the collected water to rainwater storage reservoir needs to be considered. Therefore, about 72% of annual rainfall is expected to be collected in water reservoir. Thus, about 180,000 litre of water can be harvested from 105 kW agri-voltaic system. Field observations revealed that solar PV top area harvested 93.3 m^3 of water against a rainfall of about 221.2 mm during the period from June 1- 31 July 2019 with an efficiency of 65.8%. Hence in arid region with severe challenge of water scarcity for agriculture, the agri-voltaic system is a feasible and sustainable option for meeting both food and energy demand in future.

Figure 7: Rain water harvesting system from top surface of PV module

2.5 Environmental parameters monitoring

The performance of PV systems is highly affected by internal and external factors such as the structural features, aging, radiation, shading, temperature, wind, dust load on PV plates. Any type of climatic change causes changes in the solar radiations and in the ambient temperature, hence causing changes in the solar PV output performance. The J-type thermocouple with 32 channel data logger was used to measure ambient temperature and PV module temperature at 10 minute interval. Different types of probes were set in the shade of panel at full and half density treatment, bottom of panel as well as soil temperature at different depth of the panel. During daytime, micro-climatic parameters viz. net radiation (NR) and photosynthetically active radiation (PAR) were measured in shaded areas under solar PV modules and at open sun condition in the AVS. Both NR and PAR were measured at one-hour interval from morning to evening during clear days. The NR was measured by net radiometer at crop canopy during peak summer and winter season, whereas PAR was measured by line quantum sensor at crop canopy. Deposition of dust has also a negative role on solar PV generation since it reduces the transparency of the top glass surface of solar PV module. Cleaning of PV modules is, therefore, a regular management practice to get optimum PV generation. Dust deposition of solar PV module was measured during cleaning operation in each block.

The ambient temperature varied from 2.7°C to 48.6°C. Air temperatures increase sharply from March onward and stand highest during June till pre-monsoon showers set in the area. The temperature of shade of PV panel areas vary between 3.0°C to 49.6°C with peak values as high as 50°C in June 2020. 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 2020. It has been observed that PV module temperature was always about 15-20°C higher than ambient temperature during day time and thus reduces the solar PV generation. It is to be noted here that solar PV module performs optimally at 25°C and each degree increase in temperature from this optimum value decreases the voltage output and hence negatively affect the PV generation. Diurnal variation in temperature of PV module, shade of PV panel areas and ambient temperature during a typical summer day and winter day is shown in Fig. 8.

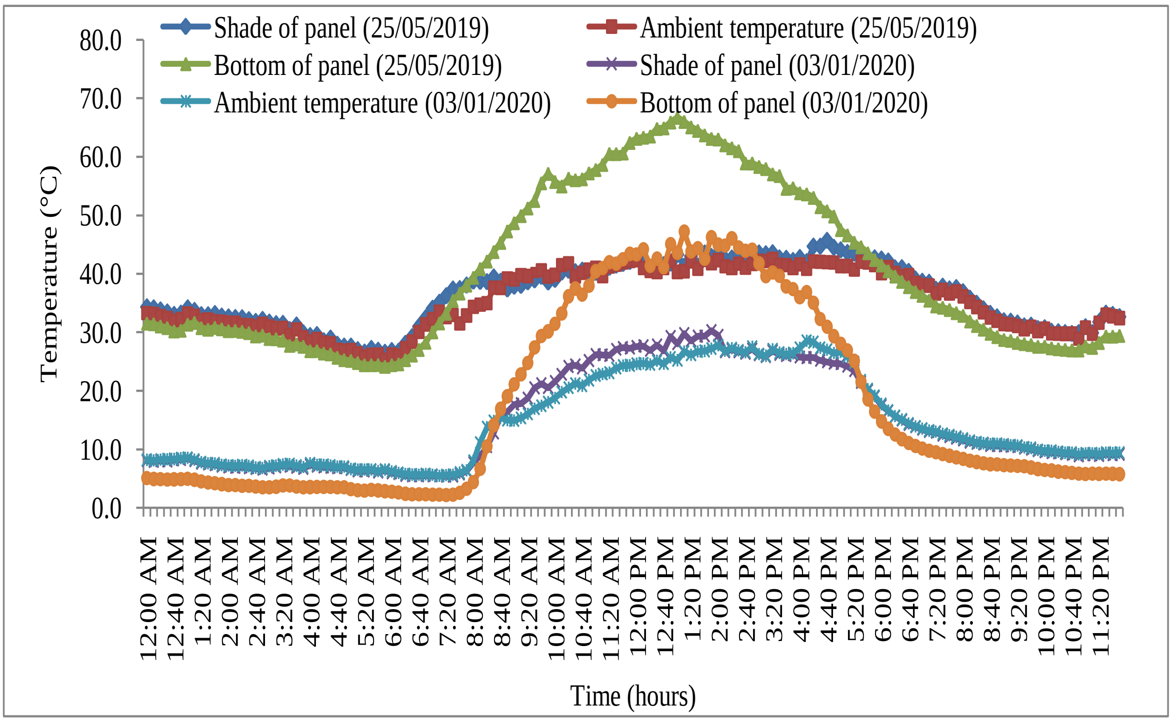

Figure 8: Variation in temperature of solar PV module and the ambient condition during summer and winter season in the Agri-voltaic system

2.6 Dust deposition on solar PV module

Deposition of dust has also a negative role on solar PV generation since it reduces the transparency of the top glass surface of solar PV module. Cleaning of PV modules is therefore a regular management practice to get optimum PV generation. Cleaning with water soaked wiper once in a week during summer months and once in a fortnight during winter months has been followed. Dust load on the PV module was observed slightly higher in block 2 with double-row PV array than block-3 with triple-row PV array and single-row PV array. Average dust load on PV module was quantified as 1.98 g m^{-2}, 2.35 g m^{-2} and 2.17 g m^{-2} respectively in single-row, double-row and triple-row PV array in the agri-voltaic system.

3. Potential areas for establishing agri-voltaic system in India

The agri-voltaic system has very good potential in those portions of the country where solar irradiation is available in plenty. Arid western Rajasthan and Gujarat receives higher amount of solar irradiation (5.3-6.0 kWh m^{-2} day^{-1}) as compared to rest portion of the country (<5.5 kWh m^{-2} day^{-1}) except Ladakh (Fig. 9). Apart from western India, southern tip of India covering Tamilnadu and Kerala also receives considerable amount of solar irradiation and thus there is scope of installation of agri-voltaic system in the region.

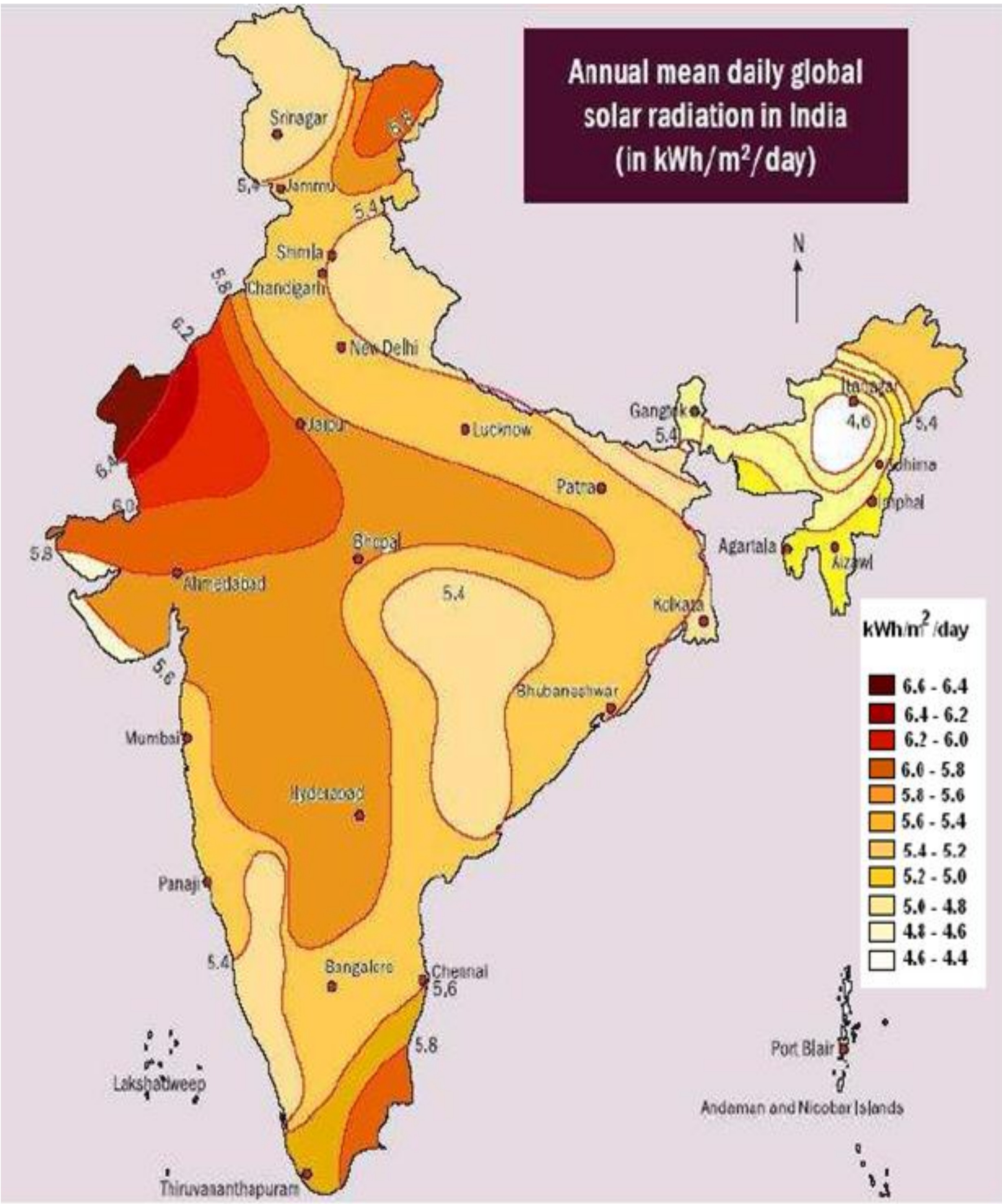

Figure 9: Availability of solar irradiation in India

Among twelve districts of western Rajasthan, availability of solar irradiation is high in Jaisalmer, Barmer and Jodhpur (>5.7 kWh m^{-2} day^{-1}) whereas comparatively low in Ganganagar, Hanumangarh, Churu and Jhunjhunu (5.3-5.5 kWh m^{-2} day^{-1}). In arid Gujarat, the Kachch district has vast potential to harness solar energy. In contrast to it, low availability of water in these arid districts is a limiting factor to achieve potential crop yield. Therefore, water harvesting system from top surface of PV modules in the agri-voltaic will help in conserving rain water and to use it in crop production system and also in cleaning the PV modules.

4. Possible way to install agri-voltaic system in farmer's field?

Initial investment for establishment of agri-voltaic system is about Rs 250 lakhs for 1 ha. High cost of investment is a major hindrance for its adoption in farmers' field. Therefore, policy supports and guidelines are necessary for establishment of agri-voltaic system in farmers' field. Very recently Ministry of New and Renewable Energy (MNRE), Govt. of India has taken a plan under '*Kisan Urja Surksha Utthan Mahaabhiyan* (KUSUM)' yojana. Under component-A of KUSUM scheme, a total of 10 GW of decentralized ground mounted grid connected solar power plants are planned with an individual plant size ranging from 500 kW to 2 MW. Considering the potential of the technology such plant can increase the income of farmers by simultaneously generating electricity and growing cash crops.

5. Conclusion:

Agri-voltaic system has been shown as a potential option to grow crops and generate renewable energy from a single land unit. The system is best suitable for those areas where solar irradiation is available in plenty and land productivity potential is comparatively low. Additional advantage of agri-voltaic system is its ability to harvest rainwater from the top of PV modules. The harvested rainwater can be used for cleaning of deposited dust on PV modules and to provide supplemental irrigation to crops. The agri-voltaic system can be connected to grid through net metering system to supply the PV generated electricity and earn an income of Rs 7.5 lakhs acre^{-1} year^{-1}. Otherwise, the off-grid agri-voltaic system can be used to operate solar PV pumping system in farmers' field. Apart from income by selling the PV generated electricity, farmers can also earn income from crop production. Overall, the land equivalent ration can be improved by installation of agri-voltaic system in farmers' field.