Indian Farming **68**(09): 108–111; September 2018

Agri-voltaic system

to enhance land productivity and income

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Agri-voltaic system showed 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 Photovoltaic modules. The harvested rainwater can be used for cleaning of deposited dust on Photovoltaic modules and to provide supplemental irrigation to crops. The agri-voltaic system can be connected to grid through net metering system to supply te Photovoltaic generated electricity and earn an income of ₹ 7.5 lakh acre/year. Otherwise, the off-grid agri-voltaic system can be used to operate solar Photovoltaic pumping system in farmers' field. Apart from income by selling the Photovoltaic generated electricity, farmers can also earn income from crop production. Overall, the land equivalent ratio can be improved by installation of agri-voltaic system in farmers' field.

Key words: Agri-voltaic system, Crop cultivation, PV generation, Rainwater harvesting, Solar farming

AGRICULTURE sector consumes about 7 to 8% of total energy consumption of India. Pumping of irrigation water, use of machineries for different farm operations, processing and value addition of farm produces etc. are the major activities consuming energy in agriculture sector. With the mechanization, groundwater irrigation and protected cultivation of food production system from agrarian to a futuristic technology-driven system, there was rapid increase in energy use in agriculture. It is estimated that energy use in agriculture needs to be increased from 1.6 to 2.5 kW/ha to meet the production target of next 20 years. The rise in energy use has led to increase in burning of fossil fuels, which emits greenhouse gasses and thus contributes to climate change and increased frequency of extreme weather events. In this context, there is need to harness and use more renewable forms of energy from solar, wind and biomass sources, all of which are plentiful in the country.

However, among renewable sources, photovoltic-based electricity generation has gained more interest than others and for this purpose agricultural lands are used for its installations. Food and energy are two basic requirements for human civilization. Therefore, competition for land may arise in future for agricultural use and Photovoltic-based electricity generation. There is possibility that solar photovoltic-based electricity production will be preferred over agriculture because of higher efficiency of photo-voltaic process (~15%) than photosynthetic process (~3%) specifically in those areas where solar irradiation is available in plenty however, land productivity potential is low. But food is the basic need for survival of human beings. Therefore, it is thought of producing both simultaneously from a single land unit through agri-voltaic system.

Agri-voltaic system produces food and generates photovoltic-based electric energy from a single land unit. Both the processes of photosynthesis for food production and photovoltaic for electricity generation require solar irradiation and land resources as basic resources. Therefore, in agri-voltaic system, crops are cultivated in between PV arrays and below photovoltic installations for simultaneous generation of food and energy.

Crop production in agri-voltaic system

Solar photovoltic modules when installed in field, a space between two rows of photovoltic array needs to be kept blank so as to avoid shades of one photovoltic array on another. The interspace area is generally kept as 6 m between two photovoltic arrays when two rows of photovoltic modules are adjusted in an array and ground clearance of photovoltic module is kept as 0.5 m. Similar to this design criteria, the interspace area is of 3 m and 9 m width strip when the photovoltic array is consisted of one row and three rows photovoltic

Fig. 1. *Isabgol* crop in interspace area of agri-voltaic system

Fig. 2. *Aloe vera* crop in interspace area of agri-voltaic system

Fig. 3. Cultivation of spinach below photovoltic module in agri-voltaic system

module, respectively. Therefore, the interspace area between photovoltic arrays is used for cultivation of crops. However, crops should be selected in such a way that it should not affect the photovoltic generation by creating shade on photovoltic module. Moreover, low water requirement and certain degree of shade tolerance of crops may be additional requirements while selecting crops for agri-voltaic system. About 49% area of agri-voltaic system is available as interspace area for cultivation of crops. Apart from interspace area, the area below Photovoltic module can also be utilized to grow suitable crops.

In arid western Rajasthan and Gujarat, suitable crops for interspace area may be moong bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*) and cluster bean (*Cyamopsis tetragonoloba*) during *kharif* whereas cumin (*Cuminum cyminum*), *isabgol* (*Plantago ovata*), and chickpea (*Cicer arietinum*) during *rabi*. Apart from these arable crops, medicinal plants e.g. *guar patha* (*Aloe vera*), *sonamukhi* (*Cassia angustifolia*) and *sankhpuspi* (*Convolvulus pluricaulis*) may be grown in interspace area. Examples of growing *isabgol* and *aloe vera* in interspace area of agri-voltaic system are shown in Fig 1 and 2.

Areas below photovoltic modules may be used to grow vegetables and spices e.g. onion, garlic, turmeric, cucurbitaceous crops, leafy vegetables etc. Examples of growing onion and spinach below photovoltic module are shown in Fig. 3.

Electricity generation from agri-voltaic system

The agri-voltaic system is capable of generating electricity from its photovoltic component as a major output. The electricity generated from the system may be directly supplied to local grid through net metering system. Otherwise, cluster of farmers can use the generated electricity for pumping irrigation water or to operate different post-harvest processing machines and equipment. The amount of photovoltic generation depends on the available solar irradiation. At western Rajasthan and Gujarat, where available solar irradiation is about 5.5-6.0 kWh m^{-2} day^{-1}, the average photovoltic generation from agri-voltaic system is about 4-5 kWh kW_p^{-1} day^{-1}. At other parts of the country, where solar irradiation is about 5 to 5.5 kWh m^{-2} day^{-1} and the number of cloudy days is about 100-150, average photovoltic generation is about 3 to 3.5 kWh kW_p^{-1} day^{-1}. Averge of photovoltic generation from a 50 kWpagri-voltaic system during winter at Jodhpur is found about 212 kk/h day^{-1}.

Rainwater harvesting system in agri-voltaic system

For optimum photovoltic generation, regular cleaning of deposited dust from top surface of photovoltic module is essential and requires about 20 to 40 litre of water $month^{-1}$ kW^{-1}. The rainwater harvesting system from top surface of photovoltic modules in agri-voltaic system was 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*. Potential capacity of harvested rainwater from agri-voltaic system covering 1 ha area is about 3.75 to 4 lakh litre at Jodhpur.

Agri-voltaic system for enhancing land productivity

Since agri-voltaic system produces both photovoltic generated electricity and crop yield from a single land unit, it improves overall land productivity. Therefore, agri-voltaic system is most suitable on those lands whose productivity potential is low or is cultivated only under rainfed situation. Additional photovoltic generation from resource poor lands increases the land productivity by several folds. Similarly, there is additional advantage of crop production in agri-voltaic system than conventional solar power plants. Although the portion of return from photovoltic generation is quite larger than the crop production in agri-voltaic system, there are several additional benefits of agri-voltaic system over conventional solar power plants. Improvement of land productivity through agri-voltaic system can be quantified through land equivalent ratio (LER), which is given below:

$$LER = \frac{\text{PV generation}_{\text{agri-voltaics}}}{\text{PV generation}_{\text{sole}}} + \frac{\text{Crop production}_{\text{agri-voltaics}}}{\text{Crop production}_{\text{sole}}}$$

LER value more than 1 indicates the improvement of land productivity whereas its value lesser than 1 indicates that integration of two components is not beneficial. Here, photovoltic generation and crop production in sole indicates the conventional solar power plants and crop production system, respectively. In conventional solar power plants, 500 kW_p photovoltic systems are generally installed in 1 ha whereas in

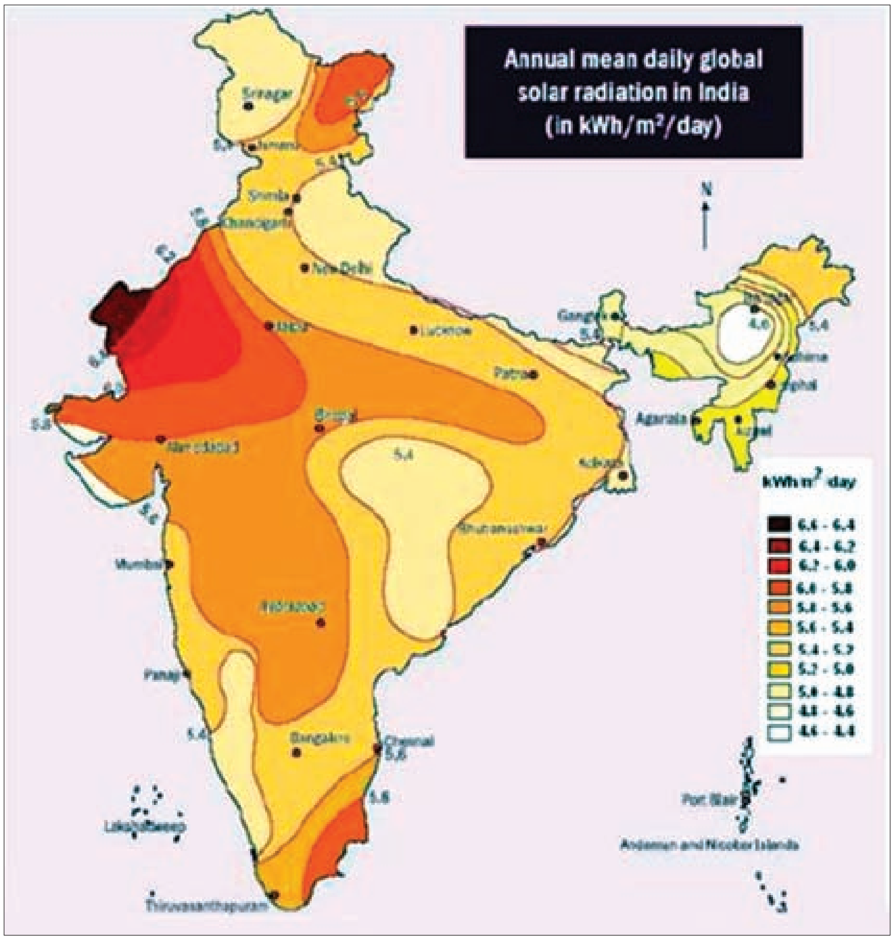

Fig. 4. Availability of solar irradiation in India

agri-voltaic system same capacity photovoltaic systems are installed. Difference between conventional solar power plant and agri-voltaic system is that both interspace area and below panel area are cultivated with suitable crops in agri-voltaic system, which is otherwise left fallow in conventional solar power plant. It was calculated that maximum 49% and 24% area in an agri-voltaic system can be cultivated with crops as interspace area and below panel area. From initial field experiments it was found that there was slight decrease (~10-15%) in crop yield due to shade of photovoltaic module on crops. Therefore, the crop yield in agri-voltaic system is considered as 85% of crop yield under sole condition. Under such situation, LER value is calculated as 1.42, if only interspace area is used for crop cultivation and as 1.62, if both interspace and below panel area is cultivated. To avoid the loss of crop yield due to effect of shade, sometimes a gap between two solar photovoltaic modules maybe kept in photovoltaic array. It will lead to decrease in photovoltaic capacity of the agri-voltaic system. If the photovoltaic capacity is reduced by one-third the LER value will be 1.09, if only interspace area is used for crop cultivation and will be 1.29, if both interspace and below panel area is cultivated.

Potential areas for establishing agri-voltaic system in India

The agri-voltaic system has very good potential in those portions of

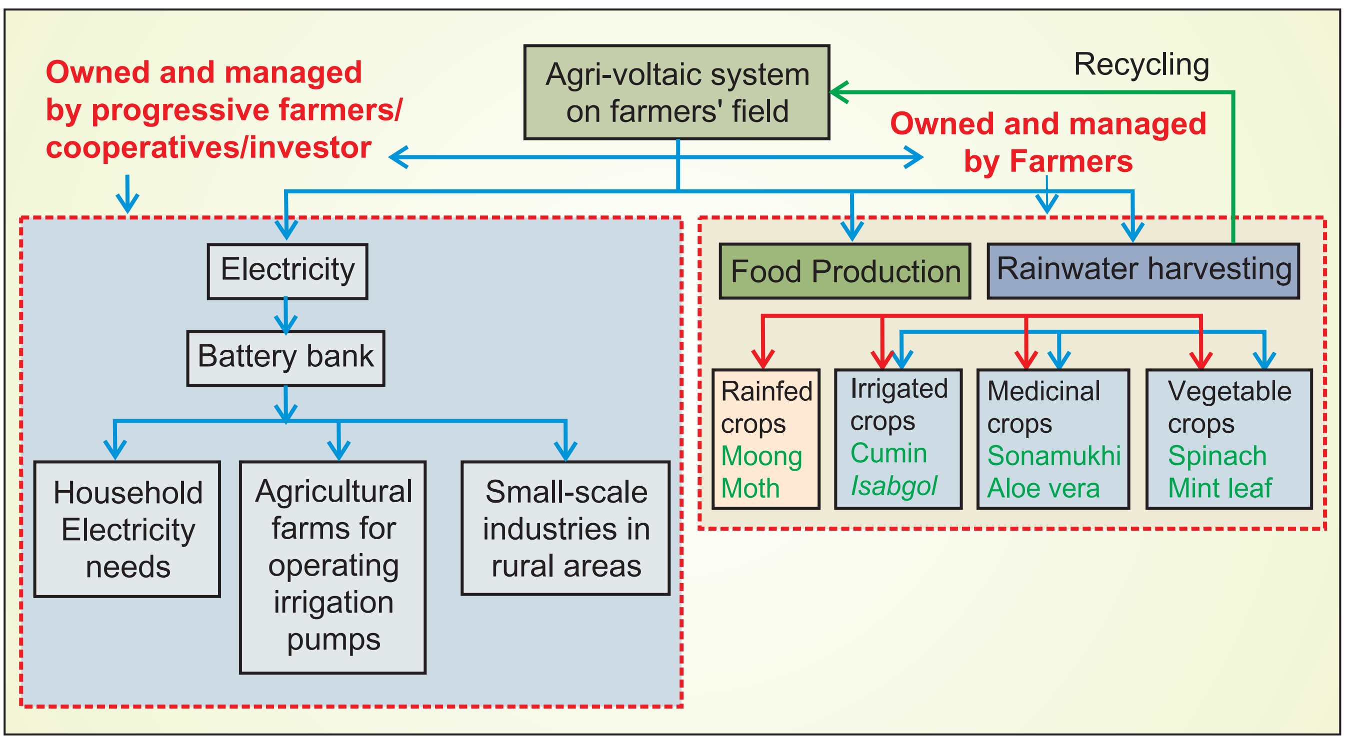

Fig. 5. Functionality of RESCO model for establishing agri-voltaic system in farmers' field

the country where solar irradiation is available in plenty. Arid western Rajasthan and Gujarat receives higher amount of solar irradiation (5.3 to 6.0 kWh m^{-2} day^{-1}) than rest portion of the country (<5.5 kWh m^{-2} day^{-1}) except Ladakh (Fig. 4). Apart from western India, southern tip of India covering Tamil Nadu and Kerala also receives considerable amount of solar irradiation and thus there is scope of installation of agri-voltaic system in the region. Among 12 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. On the contrary, 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 photovoltic modules in the agri-voltaic system will help in conserving rain water and to use it in crop production system and also in cleaning the photovoltic modules.

Possible way to install agri-voltaic system in farmers' field?

Initial investment for establishment of agri-voltaic system is about ₹ 250 lakh 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. Renewable energy service company (RESCO) may be identified for installation and management of agri-voltaic system in farmers' field similar to RESCO rooftop model. The functionality of the RESCO model for agri-voltaic system is presented in Fig. 5.

Apart from RESCO model, the scheme '*Kisan Urja Suraksha evam Utthan Mahabhiyan* (KUSUM)' is launched by Ministry of New and Renewable Energy, Government of India, which also focuses on installation of solar photovoltic modules and solar photovoltic pumping system combining to a total of 10 GW solar photovoltic installations in farmers' field with a Government support of about ₹ 50,000 crore.

Following policy interventions may be required to establish agri-voltaic system in farmers' field.

- Loaning through banking sector for installment of agri-voltaic system need to be initiated.
- Capital investment on agri-voltaic system is quite high and therefore subsidy may be introduced to promote such system.
- Grid network should be made available to remote locations and farmers' field so that generated electricity can easily be sold to grid.
- Land use policy need to be developed so that leasing of land for installation of agri-voltaic system be easy.

Agri-voltaic system for enhancing farmers' income

The agri-voltaic system may bring huge opportunity to dryland farmers since rainfed based crop production is risky because of uncertainty and scarcity of rainfall. Initial investment to install 500 kW_p capacity agri-voltaic system in 1 ha is about ₹ 2,50,00,000. Annual income from selling of Photovoltic generated electricity is about ₹ 22,96,800 per year with a decrease of 1% per year. It is to be noted here that average Photovoltic generation per kW_p agri-voltaic system is considered as 4.5 kWh and number of effective days for Photovoltic generation in a year is 320 days. Average tariff rate is assumed as ₹ 3.19 kWh^{-1}, which is the prevalent tariffrate for solar roof top system in Rajasthan. Additional income of ₹ 50,000 to 60,000/ha can be generated from crop yield in the agri-voltaic system. As compared to the income from Photovoltic generated electricity, income from agricultural activity is quite less but it has several environmental and societal benefits. Few environmental benefits of agri-voltaic system are mentioned below:

- Increased income from farm land
- Recycling of harvested rainwater for cleaning photovoltic modules and irrigating crops (1.5 lakh litre/acre and can provide 40 mm irrigation in 1 acre (0.404 ha) land)
- Improvement in microclimate for crop cultivation and optimum photovoltic generation
- Reduction in soil erosion by wind
- Reduction in dust load on photovoltic panel
- Improvement in land equivalent ratio (LER ~1.42-1.62)
- Soil moisture conservation by reducing the wind speed on ground surface
- Reduction in green house gas emission (598.6 tonnes of CO_2 savings $year^{-1}$ ha^{-1})

SUMMARY

The agri-voltaic system has huge potential in farmers' field of the country specifically in those areas where solar irradiation is available in plenty. Installation of such system will produce food as well as generate renewable-based electricity from a single land unit whereas scarce rain-water will be conserved and used efficiently. The agri-voltaic system has capacity to increase farmers' income in a fragile ecosystem. There is scope of improving the land equivalent ratio (LER) up to 1.62 by installation of agri-voltaic system.

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