Agri-Voltaic System for Climate Smart Agriculture and Clean Energy Generation

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ABSTRACT

Production of food grain through photosynthesis process requires land as basic resources. Similarly, conversion of solar energy to electrical energy through photovoltaic process also requires land for its installation. 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 higher efficiency of photovoltaic process (~15%) than photosynthetic process (~3%) specifically in those areas where solar irradiation is available in plenty however, land productivity potential is low. Substantial focus on renewable energy based electricity generation in future with solar PV as a dominating contributor throughout the world may further aggravate the situation. However, 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-photovoltaic system. Agri-photovoltaic system is defined as crop production and photovoltaic based electricity generation from a single land unit. The rainwater harvesting system from top surface of PV modules in agri-photovoltaic system has the capability to provide water for cleaning purpose and supplemental irrigation to crops in agri-voltaic system. Moreover, the agri-voltaic system helps in clean energy generation from cultivable area and thus may be a potential tool to mitigate the adverse effect of climate change. In this paper, technical details of agri-voltaic system along with its potential to produce crop, generate energy and harvest rain water is discussed.

Keywords : Agri-voltaic system; Solar farming; Renewable energy in agriculture; Collocation of solar and agriculture

Introduction

In order to keep pace with the development there is rise in energy use in every sphere of life and also in agriculture but it has adverse effects on greenhouse gas emissions due to burning of fast depleting fossil fuels. In this context, we need to harness and use more renewable forms of energy, especially solar energy that is plentiful on most part of the country. In agricultural sector, energy is directly used for pumping irrigation water, operating different mechanized farm implements/tools and post-harvest

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processing of foods. With the advancement of food production system from agrarian to a futuristic technology-driven system, there has been rapid increase in energy use in agriculture. Share of agricultural sector in total energy consumption is about 7-8% and further increase in energy use from its present value of 1.6 kW ha^{-1} to 2.5 kW ha^{-1} is expected to meet the production target of next 20 years. Therefore, solar energy driven agriculture may be the most viable option for future agriculture especially in the context of climate change. Different possible options of solar energy driven agriculture are solar pumping system for providing irrigation to crops, solar PV driven farm tools and implements e.g. solar PV sprayer, solar PV duster etc, solar thermal devices for processing and value addition of agricultural produces and even the novel concept of agri-voltaic system in which crop production and electricity generation can be done together. In this manuscript, we discuss the concept of agri-voltaic system, its technical details and potential benefits in the context of climate change.

National solar energy mission

In India, national solar mission was launched in November 2009 with a target of 4000 MW grid and 1000 MW off-grid electricity generation from solar energy by the end of phase II (2013-2017), whereas these targets are 1,00,000 MW and 2000 MW, respectively by 2022. (Table 1). The on-grid targets have been fulfilled by installation of large scale solar PV plant both on lands and roof tops. For installation of solar PV plants on ground surface, waste lands or solar parks are generally allocated @ 2 ha MW^{-1}. Recently, there has been growing interest to install solar PV plants on private lands and farmer's field where local grid networks are available. For installation of solar PV system on roof tops, solar energy corporation of India (SECI) has formulated a model through which purchase power agreement (PPA) will be signed between renewable energy service company (RESCO) and owner of the roof top. Under RESCO model, the company will invest for solar PV installation and its maintenance whereas owner will provide roof top. The PV generated electricity will be supplied to local grid through bidirectional energy meter or net metre at a tariff fixed by SECI through tendering process. The electricity tariff for sale of PV generated electricity varies across states of India e.g. in Rajasthan it is Rs 3.19/kWh whereas in West Bengal it is Rs 3.62/kWh. Maximum amount of tariff was fixed in Bihar which is Rs 4.95/kWh. Under off-grid target of 2000 MW, isolated mini grids in villages and solar PV pumping systems have been installed in the country.

Status of solar energy use in agriculture

About 14.8% of energy generation in India is met through renewable sources e.g. wind, solar, biomass etc. whereas coal is till the main source contributing about 60% of total generation. During last few years, renewable installed cumulative capacity has been increased from 24914 MW in 2011-12 to 50,068.37 MW by the end of December 2016 with an annual growth rate of 17.8%. By the end of December 2016, wind energy installation shares 57% of total renewable energy installations (28700.44 MW) whereas solar PV installation shares 18% (9012.66

MW).Rajasthan and Gujarat share ~58% of the total solar power installed capacity in the country, whereas these two states shares 29.2% of total wind installed capacity. Tamilnadu and Maharastra dominate the total wind installation in our country by sharing 52% of total installed capacity.

Solar PV modules can be installed in agricultural field for simultaneous generation of electricity and production of food from same piece of land through agro-voltaic system in order to contribute in the national target of 100 GW on-grid PV generations by the year 2022. The detailed concept of agri-voltaic system is described later.Off-grid target of 2000 MW may also be achieved by installing solar PV pumping system. Currently, in most of the States in India, solar PV pumping system of 3 HP and 5 HP capacities have been started to use for irrigation purpose. These solar pumps have the capacity to withdraw groundwater from about 75 m depth using either AC or DC submersible pumps. Only limitation of the solar pump is that it can only be operated during day time when solar irradiation is available and thus cannot be used during cloudy days or when sun is off. By the end of December 2016, 1,00,521 solar PV pumping systems have been installed in the country. Again, a major portion of it (~37% of the total number of installations) has been installed in Rajasthan. Similarly, the target of installing 20 million m^2 solar thermal collector area by the end of 2022 can be achieved through propagating solar thermal devices e.g. solar driers, solar cookers, solar water heater etc. for post-harvest processing of agricultural produces. Till December 2016, 12 million m^2 solar thermal collectors have been installed in the country.

Concept of agri-voltaic system

Food and energy are two basic requirements for human civilization. Production of food grain through photosynthesis process requires land as basic resources. Similarly, conversion of solar energy to electrical energy through photovoltaic process also requires land for its installation. 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 higher efficiency of photovoltaic process (~15%) than photosynthetic process (~3%) specifically in those areas where solar irradiation is available in plenty however, land productivity potential is low. Substantial focus on renewable energy based electricity generation in future with solar PV as a dominating contributor throughout the world may further aggravate the situation. However, 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 (Dupraz et al., 2011; Ravi et al., 2016; Santra et al., 2017). Agri-voltaic system is defined as crop production and photovoltaic based electricity generation from a single land unit. The interspaces area of about 3 m to 9 m in between two PV arrays in agrivoltaic system as well as the areas below PV modules are utilized for growing suitable crops preferably short height, low water requiring and having certain degree of shade tolerance. In arid western Rajasthan, suitable crops for interspace area may be mung bean (*Vigna radiata*), moth bean (*Vigna aconitifolia*) and clusterbean (*Cyamopsis tetragonoloba*) during kharif season whereas cumin (*Cuminum cyminum*), isabgul (*Plantago ovata*), and chick pea (*Cicer arietinum*) during rabi season. Apart from these arable crops, medicinal plants e.g. gwarpatha (*Aloe vera*),sonamukhi (*Cassia angustifolia*) and sankhpuspi (*Convolvulus pluricaulis*) may be grown in interspace area. Areas below PV modules may be used to grow vegetables and spices e.g. turmeric, cucurbitaceous crops, brinjal, leafy vegetables etc. The electricity generated from PV modules in agrivoltaic system may be directly supplied to local grid through net metering 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 agrivoltaic 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 agrivoltaic system covering 1 ha area is about 3.75-4 lakh litre at Jodhpur.

Technical details of agri-voltaic system developed at ICAR-CAZRI Jodhpur

Keeping in mind the importance of agri-voltaic system in future, 105 kW and 25 kW capacity such system has been designed and installed at ICAR-Central Arid Zone Research Institute Jodhpur and its regional research station at Bhuj, respectively. At Jodhpur, Agri-voltaic system is installed with three experimental designs in three separate blocks, each of 36 m x 36 m area. These are (i) PV arrays of one row PV module and 3 m interspaces between arrays (ii) PV arrays of two row PV modules and 6 m interspaces between arrays and (iii) PV arrays of three row PV modules and 9 m interspaces between arrays.Solar PV modules were installed on fixed MS iron angle structure facing perpendicular to south and inclination of 26° to receive maximum amount of radiation.PV modules are installed in three different designs however with similar capacity and same size of land area e.g. 35 kW capacity in an area of 32 m x 32 m area. Thus the land requirement for installation was maintained 34 W m^{-2} for all three separate blocks. Thus, in 1 ha land area 340 kW capacity agri-voltaic system can be installed or in 1 acre of land 136 kW can be installed.The interspace areas and below PV module areas in agri-voltaic system available for cultivation of crops are 49% and 24% of the total block area, respectively.

Crops with low height preferably less than 50 cm and which tolerates certain degree of shade and require less amount of water are selected for agri-voltaic system. *Vigna radiata* (moong bean), *Vigna aconitifolia* (moth bean) and *Cyamopsis tetragonoloba* (clusterbean) can be grown in agri-voltaic system during kharif season whereas *Plantago ovata* (isabgool), *Cuminum cyminum* (cumin), *Eruca sativa* (taramira) and *Cicer arietinum* (chickpea) can be grown during rabi season(Fig. 1).Medicinal plants e.g. *Aloe vera*, *Cassia angustifolia* (sonamukhi) and *Convolvulus pluricaulis* (sankpuspi) may also be grown in agri-voltaic system (Fig. 1).

Potential crops below panel areas of agri-voltaic system are *Capsicum annum* (chilli), *Brassica oleracea* var. capitata (cabbage), *Allium cepa* Linn. (onion), *Allium sativum* (garlic), *Vigna unguiculata* (Linn.) Walp. (cowpea), *Citrullus lunatus* (Thunb.) Matsumara & Nakai ('matira'), *Cucurbita pepo* Linn.('kakri'), *Cucumis callosus* (Rottl.) Cong. ('kachri') can be grown.Water harvesting system to collect rainwater from top surface of PV module and to store it in an underground water storage tank has been designed and developed with 105 kW agri-voltaic system. The system has a potential to harvest about 1.5 lakh litre of water from top surface of PV modules in a year at Jodhpur.

Agri-voltaic system and solar devices in climate change mitigation PV based electricity generation is the clean energy generation since it does not contribute to greenhouse gas (GHG) emission. Otherwise, CO_2 emission factor of thermal power plant based electricity generation is about 0.82 kg CO_2 kWh^{-1}. It indicates that whenever we use grid electricity, we indirectly contribute to CO_2 emission in atmosphere. It has been estimated that agri-voltaic system saves about 598.6 tons of CO_2 emission ha^{-1} $year^{-1}$. Similarly, solar PV pumping system also saves CO_2 emission in atmosphere, which otherwise have been emitted by grid connected electric pump or diesel operated pumps while in operation e.g. 1 HP solar PV pumping system saves about 615 kg CO_2 emission ha^{-1} $year^{-1}$. Solar thermal devices for water heating also saves huge amount of CO_2 emission in atmosphere e.g. solar water heater with capacity of 100 litre per day can save up to 1.5 ton of CO_2 per year depending upon the location of installation. Therefore, it is clear that use of solar energy in agriculture either through adoption of agri-voltaic system or use of solar PV pumping system for irrigation or use of solar thermal based processing and value addition of agricultural produces will lead to climate smart agriculture. Moreover, adoption of agri-voltaic system will lead to improved microclimates in agricultural field, reduction in soil moisture loss through evapotranspiration, reduction in erosion of top fertile soil, optimum use of rain water by harvesting it and recycling it etc, which ultimately reduces the risk of crop failure during aberrant weather situations.

Potential areas for Agri-voltaic system

Availability of solar irradiation makes an area potential for agri-voltaic system. In the solar resource map of India as depicted in Fig. 2, it has been observed that arid western Rajasthan and Gujarat have very good potential for agri-voltaic system since plentiful solar irradiation in terms of direct normal irradiation (DNI) is available in these areas e.g. 5.5-6.0 kWh m^{-2} day^{-1} as compared to rest portion of the country (<5.5 kWh m^{-2} day^{-1}) except Ladakh. In eastern portion of the country, comparative availability of solar irradiation is less, which is about 4-5 kWh m^{-2} day^{-1}.However, other natural resources e.g. plentiful availability of water and high soil fertility makes the region advantageous for agricultural activity. Therefore, agri-voltaic system may also be a viable option in Eastern India e.g. West Bengal, Bihar and Orissa. Water harvesting system from top surface of PV modules in the agri-photovoltaic will help in conserving rain water and to use it in crop production system and also in cleaning the PV modules. There is huge potential of rainwater harvesting from agri-voltaic system in Eastern India since annual rainfall is about >1000 mm. An estimate from Jodhpur where annual rainfall is about 350 mm, showed that about 1.5 lakh litre of rainwater can be harvested from 105 kW agrivoltaic system installed in about 1 acre land.

Economics of Agri-voltaic system

The installation cost for agri-voltaic system is comprised of PV module installation and construction of rainwater harvesting system. Generally, the cost for installation of 1 MW plant in 2 ha area is about Rs 5 crores. PV modules of agri-voltaic system at ICAR-CAZRI Jodhpur has been installed at a price rate of Rs 49.84 per W_p, thus the cost of installation was Rs 52,33,200 and Rs 12,46,000/- respectively for 105 kW system at Jodhpur and 25 kW system at Bhuj, respectively. The cost for constructing rain water collector channels, laying out of the PVC conveyor pipes below ground, water harvesting tank of 1 lakh litre capacity, drip irrigation system, and cleaning system of PV modules was about Rs 10 lakhs. Therefore, the total cost for installation of 105 kW agri-voltaic system at Jodhpur was about Rs 62 lakhs.At Jodhpur, effective solar irradiation to generate electricity is available for an average of 4-5 hours in a day. Thus, 105 kW agri-voltaic system in Jodhpur will generate at least 420 kWh unit of electricity per day and 25 kW system at Bhuj will generate 100 kWh unit of electricity per day. The income from selling of PV generated electricity will be about Rs 7,60,000/- per year and Rs 1,80,000/- per year from 125 kW and 25 kW agri-voltaic system at Jodhpur and Bhuj, respectively (Electricity tariff considered: Rs 5 per kWh). Apart from these income from electricity, about Rs25,000/- additional income per acre per year can be generated from crop yield at arid situations of Jodhpur. The income from crop yield may be increased by introducing suitable cash crops at other locations in India where water and soil fertility is not limiting. Considering the discount rate and interest rate, the break-even period of the system is roughly calculated as 8-9 years whereas the life cycle of the system is 25 years.

Conclusion

The major potential benefit of agri-voltaic system is the increased income from farm land by selling of PV generated electricity as well as from crop yield and thus contributes to doubling the farm income. Other benefit includes utilization of harvested rain water resources for crop cultivation as well as for cleaning of PV modules, improving the land equivalent ratio, reduction of GHG emission, improvement of microclimates for optimum PV generation and crop production etc. Therefore, agri-voltaic system has a great scope in Indian agriculture by providing food-energy-water security and thus may be good option for climate smart agriculture in future.

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Table 1: National solar mission targets

Sl. No.	Application segment	Target for Phase I (2010-13)	Target for Phase II (2013-17)	Target for Phase III (2017-22)
1.	Grid connected solar power generation	1,100 MW	4,000 MW	1,00,000 MW
2.	Off-grid solar applications	200 MW	1,000 MW	2,000 MW
3.	Solar thermal collectors	7 million sq. m.	15 million sq. m.	20 million sq. m.
4.	Solar lighting systems	5 million	10 million	20 million

Source : Ministry of Renewable Energy Sources, Govt. of India

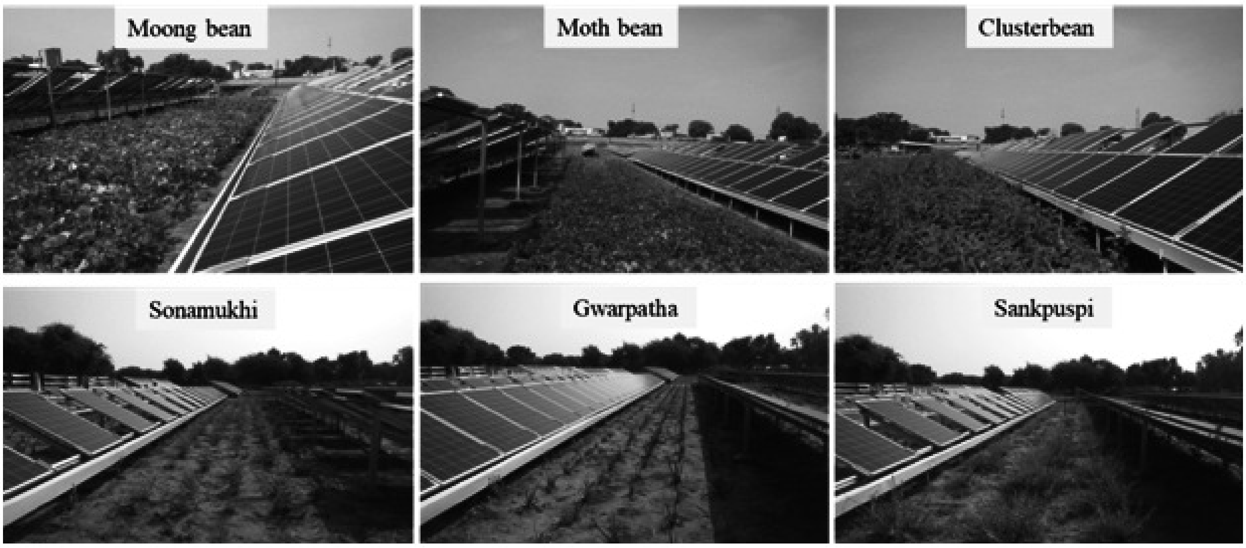

Fig. 1: Crops at interspace area of 105 kW agri-voltaic system at ICAR-Central Arid Zone Research Institute

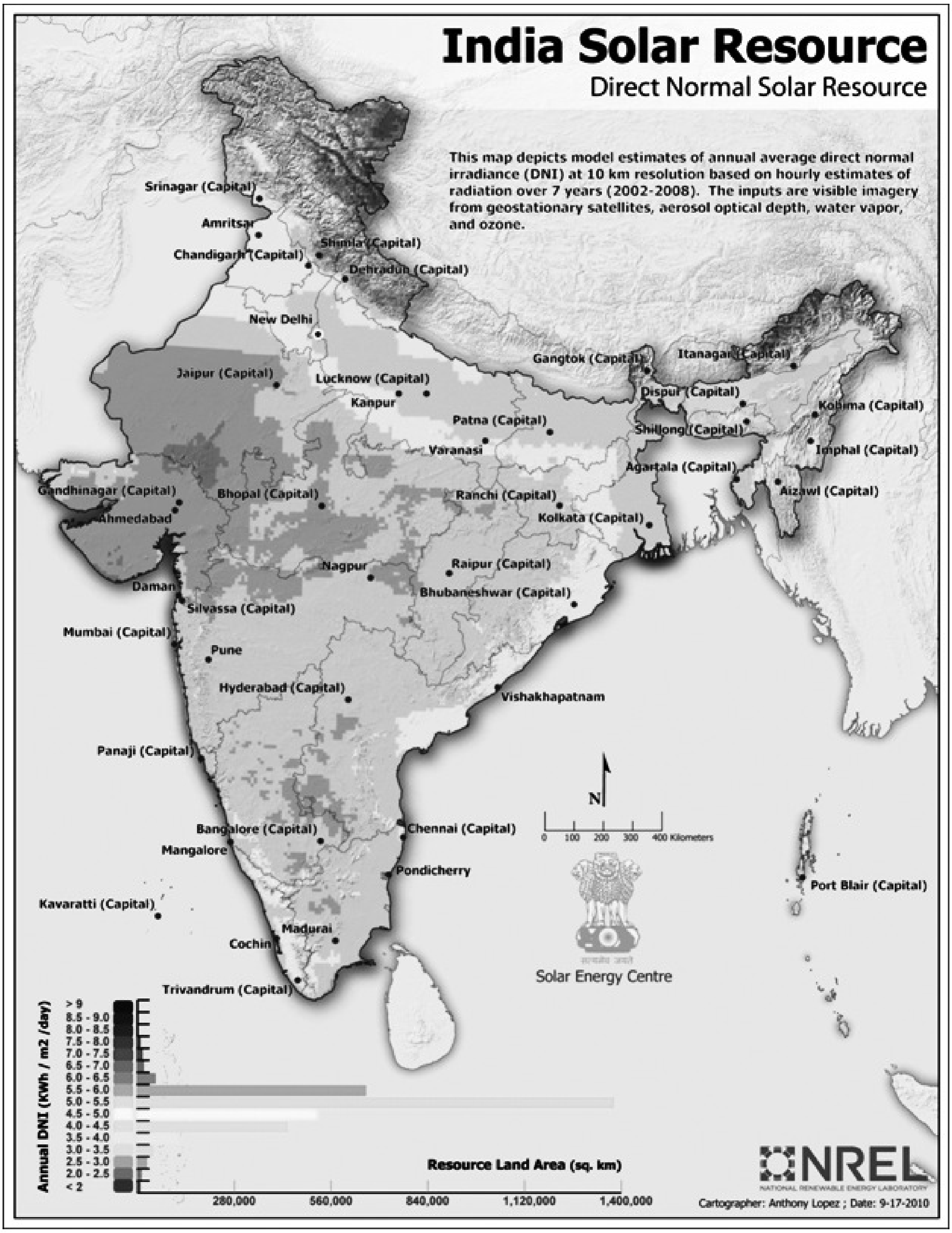

Fig. 2 : Availability of solar irradiation in India

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