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REVIEW ARTICLE

Smart Shift from Photovoltaic to Agrivoltaic System for Land-Use Footprint

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Abstract

The fossil fuel sources are highly supportive for boosting a country's economy but have destructive bearings like spatially exhaustive, global warming, atmospheric greenhouse gas pollution, acid rain and ecosystem destroyer. The problems caused by hydrocarbon sources can only be ameliorated by renewable energy sources like solar, aeolian or geothermal, especially solar energy. Solar energy shall be the prime source of energy in future but demands a huge quantum of land for installations. Simultaneous energy generation and underneath selective agriculture adaptation is novice research. This is an innovative venture of energy generation nexus with food production so that the burden of the land requirement is diminished. The agrivoltaic is considered suitable to the areas in the tropics with resilient irradiation and comparatively less productive arable lands for plant cultivation. The system can also harvest rainwater and biomass from the installed solar panels, a source for irrigation to the plants underneath, clean solar panels, and enhance production. The developing country, India ranks 2nd globally in agricultural products. More than 50% of the Indian workforce depends on it and contributed about 20% to the country's GDP. The country's ambition is to implement more agrivoltaic systems in the vast arid lands. Parallel to contemporary energy rates, an agrivoltaic farmer can supply the consumers @5 INR/kWh and sell the agricultural harvest. Overall, the power generation, water accumulated for irrigation, and crop production ratio can be optimized by installing a techno-ecological agrivoltaic system in the farmers' land.

Introduction:

Globally, it is estimated that about 1 billion people are deprived of electricity, and 2.5 billion people are still in queue to have access to sustainable domestic cooking and heating by electricity (World Bank, 2020). According to the 15th report of Sustainable Development Goals (SDG), out of a total of 7.7 billion in the globe, 2.6 billion people have their livelihood quenched from native agriculture as a source. The model results indicate that energy consumption will be increased by almost 55% by 2050 (IRENA, 2019; RISE, 2020; SDG, 2020). SDG indicator 2.4.1, indicates "Sustainable Agriculture" with three main goals such as environmental health, economic profitability, and social equity. For the development of a country, the greatest challenge is to access reliable energy, food and water in a particular area and also to fulfil the requirement of SDG 7, recommended in the United Nations Conference (SDG, 2020). Intergovernmental Panel on Climate Change (IPCC), has reported about 60% of Green House Gas (GHG) emitted from the energy sector. At present only about 17% of energy use is met from renewable energy and predicted to surge up the generation to 85% by 2050 to mitigate the harsh impact of climate changes (IPCC, 2020; WEO, 2020; WB, 2020). With the growth of the middle class in India and China, there will be a combined demand for the above parameters. Growing demand for sustainable power productions (especially solar) will improve land use and add values to the economic and social necessity of the human race (ESMAP, 2019; GOI, 2021). About 70 nations claim excellent status for their solar PV installations, and

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their average output per day surpasses 4.5 kWh per installed kW capacity (GOI, 2021; Dinesh & Pearce, 2016; Movellan, 2013).

The limitation to the arable land, rampant population growth and surging demand for more land leads to a new horizon of land use, space constraint, socio-economic and ecologic conflicts. Extensive researches explored an innovation agriphotovoltaic (APV) or agrivoltaic system (AVS) where the agricultural land is dually used for rising crops and solar installations for mutual benefits (Santra *et al.*, 2017; Shemkus, 2019). The innovation and implementation of AVS projects were demonstrated by countries such as Japan, 2004 (Othman *et al.*, 2018), USA, 2008 (Fraunhofer, 2018; Xue et al.,2017), Malaysia, 2014 (Dinesh& Pearce, 2016; Malu et al., 2017), Germany, 2015 (Park, 2019), China, 2016 (GoI, 2021), and India, 2017 (GoI, 2019), and South Korea, 2019 (Hemalatha, 2020), as presented in Table-2.

India is a fast developing country in both agriculture and solar power production after Parish Agreement 2016. The country's solar installed capacity has been surged up generating 38.79 GW by January 2021. Almost 70% of the country's population depends on agriculture; industries are focusing on better crop production and more employability (PV Magazine, 2019). The government of India (GoI) and German are considering the APV system as a reliable production of energy, simultaneous use of food and water in a single land (Weselek *et al.*, 2019; Marrou *et al.*, 2015). In 2017, a 105 kW AVS was designed, installed, and tested for real settings as per the Indian Council of Agricultural Research (ICAR) and the Central Arid Zone Research Institute (CAZRI) (Santra *et al.*, 2018; Santra et al., 2018). Apart from 105 kW AVS, more than twenty grid-interactive AVS were implemented in India by 2020 (Malu *et al.*, 2017; Xue *et al.*, 2017; Irie *et al.*, 2019).

Some figure and facts : The agrivoltaic structure has become an unabated technological resolution for adoption in present agriculture to combat concurrent climate changes. It blends that on the same land, the suitable PV panels, proper solar radiation and the selected low height crops plantation should be managed to optimize potential utilization of the land by retaining the ecosystems (World Bank, 2020). Armin Zastrow and Adolf Goetzberger (1981) was the founder of the concept of agriculture with PV system i.e. “agriphotovoltaics (APV)” (IRENA, 2019; RISE, 2020). Various countries like China, France, Japan, USA, and Malaysia have announced policies about supportive AVS innovations and implementations by 2015. The Government of India (GoI) considers the APV installations are the most dependable energy production for water, food, and energy in a suitable plot (SDG, 2020; IPCC, 2020; WEI, 2020; World Bank, 2020; ESMAP, 2019). AVS installations of about 2200 numbers (177 GW) have been completed worldwide by

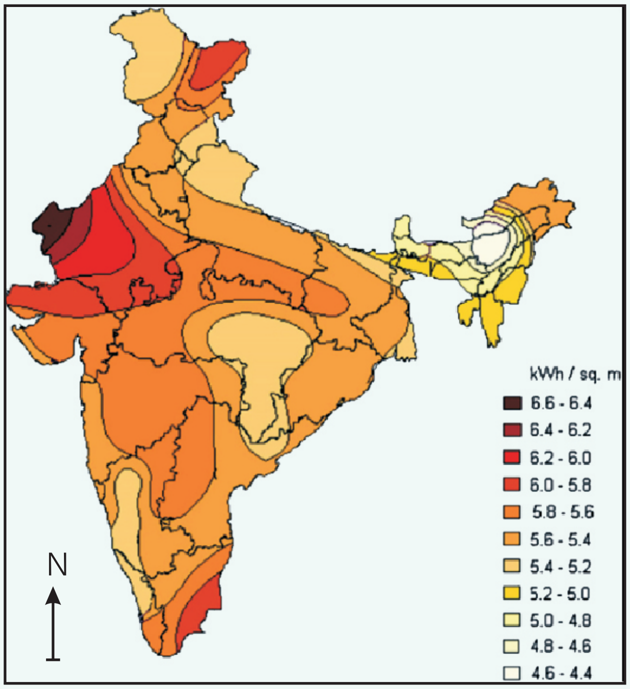

Figure-1: Irradiance map of India (ESMAP, 2019)

2014 as per International Agency's Photovoltaic Power Systems Programme (IEA-PVPS) (GoI, 2021; Dinesh& Pearce, 2016; Movellan, 2013; Santra et al., 2017). India has augmented its AVS installation capacity of about 3 GWp by January 2020 (Ministry of Power, 2021) (Shemkus, 2019; Othman et al., 2018). The solar irradiance map of India is demonstrated in Fig.-1.

The mainland of India extends between 804’ and 3706’ N latitude and $68^{o}77'$ and $97^{o}25'$ E longitude (Fraunhofer, 2018; Xue *et al.*, 2017; Malu *et al.*, 2017; Park, 2019). The solar radiation intensity in an average received in India is calculated to be 0.2 GW/km^2. India has a geographical area of 3.287 million km^2 and produces 0.6574 million GW power. Most part of India receives high intensity of solar radiation with an average of 5 kWh/ m^2/day (ESMAP, 2019; GoI, 2021; Weselek *et al.*, 2019).

There exist three basic forms of agrivoltaics structure which can be explored to generate energy. They are solar arrays with the provision of space for crops underneath, slanted solar array installation overlain crops land and solar array enclosed within greenhouse environment (GoI, 2019; Hemalatha, 2020). All three arrangements of agrivoltaics have numerous parameters which need to be optimized like solar energy simultaneous incidence on the panels and the crops. The two major parameters are taken in the present research of agrivoltaic system are the tilt angle of solar panels and suitable choice of the location depending on the crops, panel heights, solar irradiation and local climate (PV Magazine, 2019; Weselek *et al.*, 2019, Santra *et al.*, 2018; Amaducci, 2018). The comparison of the traditional solar power plant and agrivoltaic systems are presented in Table-1.

Table-1: Comparison between traditional solar power plants and agrivoltaic systems

#	Traditional solar plants	Agrivoltaic systems
1	Only PV	PV + Agriculture
2	Big land use footprint	Land use footprint solutions
3	Only power production	Increase power, food, water and biomass production
4	Soiling loss	Less soiling loss
5	More water consumption	Less water consumption
6	Available of micro-particles	Mitigate micro-climate climate particles
7	Output efficiency 70-80%	Efficiency increases 40-50% extra
8	Payback period 6-8 years	Payback period 4-6 years

Configuration of AVS:

Efficient configuration of AVS system helps to optimize the production of energy, food and water in the same area. The following points to be considered;

- Southerly orientation of fixed solar panels or axially rotating east-west panels
- Supportive elevation and adequate spacing between panels for requisite solar light for the crops underneath.

Generally, Solar PV panels are installed at a fixed-tilt angle equal to the latitude of the suitable location for producing maximum power at the output (Pulipaka *et al.*, 2020; Harinarayana & Vasavi, 2014).

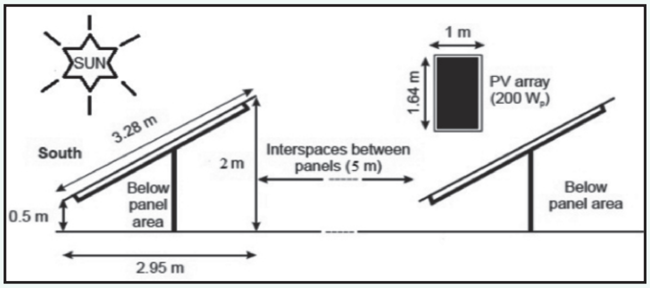

Figure-2: Basic design of agrivoltaic system

The Fig.-2 describes the basic design of solar PV panel installation in an agrivoltaic system. In general, low height mounting structure (ground clearance of 0.5 m) with suitable space between two rows (5-10 m) of solar PV arrays to escape the shadow of it on next row. The suitable crops can grow in between two rows easily (UNCCD, 2017; Campen *et al.*, 2000; Talbot *et al.*, 2014).

Fixed Solar Panels over Crops:

The simple and easy methods of installations is fixed solar panels for agriculture, (when the crops underlain or the crops within the gaps). There is a necessity to optimize structural installation arrangements for the tilting type solar panels (Miskin *et al.*, 2014; Adeh *et al.*, 2019; Nakoul, 2014; Marrou et al., 2015; Malu *et al.*, 2017).

Dynamic Agrivoltaic:

This is one of the most intricate arrangements. Uses of tracking or mobile structural installations are needed for this type of agrivoltaic system. The control of the solar panels desired to be optimized for their sitting which can increase concurrent agricultural and energy production (Xue *et al.*, 2017; Irie *et al.*, 2019; Barron-Gafford, 2019; Schindele *et al.*, 2020; Ott *et al.*, 2020).

Japan was the first nation to develop a dynamic agrivoltaic system with manually operative panels for controlling solar inputs. The position of the solar panels can only be adjusted manually by the farmers conferring to the season or stage of crop development. The manually operated system could regulate power generation along with a requirement for shading (Ketzer *et al.*, 2020; Giri *et al.*, 2020).

Considering Fig.-2 and features, the installation of a solar power plant requires a large amount of land around 3.5 acres or 1.42 hectare for a 1 MW plant. Design parameters for the installation of solar panels in AVS are a little different from those in a conventional solar power plant (Gaikwad & Sharma, 2018; Sharpe *et al.*, 2020; Pandey *et al.*, 2018; Proctor *et al.*, 2021; Teo & Go, 2021). Solar PV panels should be installed on fixed or dynamic iron or GI angle structure facing perpendicular to the south with specified tilt angle (Giri & Mishra, 2017; Trommsdorff *et al.*, 2021; IBEF, 2020), as demonstrated in Figure 2. Installation of such systems in farmers' land may raise extra income from the sale of electricity and crop production. This has been predicted that 350 to 700 kW capacity systems may be established in 3.5 acres or 1.42 hectare cropped land (Weselek *et al.*, 2019; Ketzer *et al.*, 2020; Younas *et al.*, 2019). In April 2016, the first experimental design of the AVS system commissioned with a capacity of a 1 MW power plant at Amrol, Gujarat (Kalita *et al.*, 2019; City Air New, 2018; Czaloun, 2017; SolAgra, 2019). The solar panels are installed on a mounting structure at a height of 3 meters. Tilting of panels is carried out manually and the adjustment period is within a gap of 2 months. These plant structures differing inter-module (0.05 m or 5 cm) and inter-array gaps (4 m or 400 cm) for studying the bearings of various shading patterns during crop growth (Pulipaka *et al.*, 2020; Proctor *et al.*, 2021; Omar *et al.*, 2014).

PV-based Electricity Generation from AVS:

At Amrol, average solar irradiation and sunny hour available is 6 kWh/day and 7 to 8 hour/day. It is assessed that a 1 kW PV system can generate 7-8 kWh/day. The installed AVS has been connected to the local grid to sell electricity with a tariff rate of INR 3.44/kWh in 2019 (Santra *et al.*, 2018; Bano & Rao, 2016). The schematic diagram of the PV based electricity generation from the installed AVS is described in Fig.-3.

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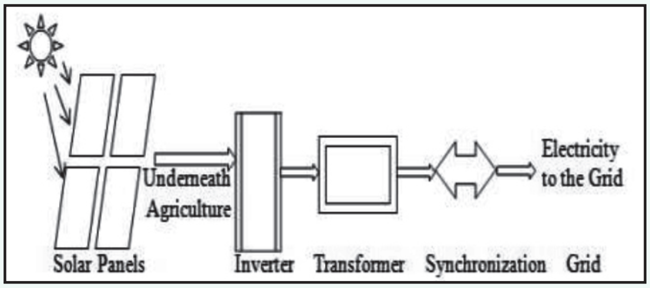

Figure-3: Schematic diagram of power generation in agrivoltaic system

Crop Production in AVS:

In practice, SPV panels are needed to be tilted by an angle of ±5° or ±10° (depending on latitude) in AVS to the ground. Thus, the shade of PV panel is spawned on the sheltered sideways on the ground in accordance with the sun movement during daytime (Kumar & Sudhakar, 2015; Hariri *et al*., 2020; Giri, 2019; Suman & Ahamad, 2018). The gap area amidst two PV arrays (suitable 5-10 m) is utilized to grow appropriate low height crops. The availability of PAR (Photosynthetically active radiation) on the shielded ground was assessed considerably which is lowered by 84.5 to 127 mmol/cm²/sec in comparison to open sun values of 243-1296 mmol/cm²/sec at ICAR-CAZRI, Jodhpur (Santra *et al*., 2018; Saddique *et al*., 2019). More than 40 crops were tested in this AVS such as moth bean (*Vigna aconitifolia*), mung bean (*Vigna radiata*), and cluster bean (*Cyamopsis tetragonoloba*). Besides these rain-fed Kharif produces, limited pharmaceutical plants have been cultivated such as Aloe Vera saplings, sonamukhi (*Cassia angustifolia*) and eggplant (*Solanum melongena*) (Santra *et al*., 2018; Sekiyama & Nagashima, 2019; Al-agele *et al*., 2021), as demonstrated in Fig.-4. Vegetable crops can also be cultivated below the panels. It is observed that suitable crops or plant cultivation is predictable to modify the micro-climates and also reducing the temperature. Thus, AVS can optimize both electricity and food production in the same land (Santra *et al*., 2018; Awan *et al*., 2020; Menon & Yokohama, 2020).

Figure-4(a,b): Crop (Aloe vera and eggplant) cultivation in agrivoltaic system (Source: ICAR-CAZRI)

Rainwater Harvesting in AVS:

This is also possible to collect and store precipitations from the PV panel surfaces in AVS. Therefore, a rainwater harvesting system in the developed 1 MW AVS has also been planned and installed (Pascaris *et al*., 2020; Adeh *et al*., 2019). The system for water harvesting sources consists of conical Mild Steel (MS) sheet for water collection, and underground water conveying Polyvinyl Chloride (PVC) pipes of 8-inch dia is connected to the storage system. Total water consumption in the storage tank is about 200000 litres/MWp/year capacity (GoI, 2021; Santra *et al*., 2018; Weselek *et al*., 2021). This will be used in the cultivation of crops. Thus, the farmer can optimize their cultivation and socio-economic in the same land, as demonstrated in Fig.-5.

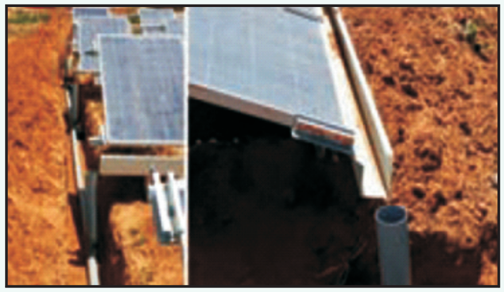

Figure-5: Rainwater harvesting system in agrivoltaic system (Santra *et al*., 2018)

Discussion:

The limitation to the arable land, rampant population growth and surging demand for more land leads to a new horizon of land use, space constraint, socio-economic and ecologic conflicts. Extensive researches explored an innovation agriphotovoltaic (APV) or agrivoltaic system (AVS) where the agriculture land is dually used for rising crops and solar installations for mutual benefits. The additional advantage of agriculture with PV installations in arid areas shall reduce GHG emission and dust elimination of the panels and conserve soil moisture simultaneously (Patel *et al*., 2018; Majumdar & Pasqualetti, 2017 Elamri *et al*., 2018). The innovation and implementation of AVS projects were demonstrated by many countries, as presented in Table-2.

The AVS application will likely to be affect crop cultivation and agricultural yield. It is pertinent to account for its impact on the technological features, and operating processes in ground controls, and the simultaneous impact of AVS during changing microclimatic conditions. The consequences of crop cultivation are discussed in the present study.

Agriculture is possible below (≈24%) and within interspace (≈49%) areas of agriphotovoltaic area and simultaneous harvesting of rainwater can be done for the crops to be cultivated. Researches reveal that some specific crops that grow in arid areas can be possible such as cumin, isabgol, grapes, chickpea, and some varieties of beans such as cluster bean, mungbean, and moth bean (Santra *et al*., 2018).

Table-2: Global agrivoltaic innovation and implementation scenarios

#	Country Name	Implemented on	Capacity
1	Japan	2004	49.9 kW
2	Austria	2007	20 kW
3	USA	2008	3 MW
4	Denmark	2014	33 kW
5	Malaysia	2014	1 MW
6	Germany	2015	194.4 kW
7	China	2016	500 kW
8	India	2017	1 MW
9	Croatia	2017	500 kW
10	South Korea	2019	1 MW

Expected drawbacks include the very high cost of installation ,the safety of the agriculture workers ,and complexity in the management of power amalgamated with agriculture , cost allocation and sharing of the benefit .There is a chance of affecting the neighbouring farmers in AVS installations (Harinarayana & Vasavi , 2014).

The PV energy generation involves the end -user than orthodox grid supply system ,the role of farmers and the end -users do not get their proper share so the fixation of ownership is a difficult tax and the programme may fail during field implementation (Campen *et al* .,2000).

Conclusion:

With fixed land, exponential population hike, modernization with more energy requirement need can be substituted by the twofold use of land in AVS systems. Hence, there is vast scope for techno-social and optimization in energy, food and water productions, as it's still in its primary stages. India has the future prospect and multiple options for this type agrivoltaic system for the vast arid lands of Punjab, Rajasthan, Gujarat, and Haryana. A suitable implementation of agrivoltaic systems leads to better income for the farmer's, efficiency increases to 40-50% extra and the payback period of the solar plant will be reduced to half. Even the mountainous hills of Odisha can be tried with AVS installations. Verities of area-specific crops and multiple installations photovoltaic trees (higher altitude) and arrays need to be verified in test fields and the effects need to be monitored. However, there will be several techno-economic, environmental and social challenges faced in sustainable development that would be addressed in future. There is a great future for the AVS .

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