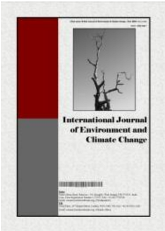

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A Review of Agri-Voltaic System in India: Opportunities and Constraints

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rising trend of solar PV generation from ground-based installations has led to competition for land between agriculture and PV generation. The solution to this challenge lies in the agri-voltaic system (AVS). However, many of them encounter difficulties as a result of their reliance on unreliable farming techniques. The difficulties can sometimes become so overwhelming that they commit suicide. Furthermore, India is densely populated, and its population is continually growing, necessitating the government's growth in GDP and energy supply to keep pace. This article examines Agrivoltaics, or the integration of solar farming with agriculture, as a Climate-Smart Agriculture (CSA) option for Indian farmers. Similarly, the paper presents opportunities and constraints to agrivoltaics in India.

Keywords: Agri-voltaic; solar energy; climate smart agriculture; rural income.

1. INTRODUCTION

"Sustained economic growth of developing countries like India puts enormous pressure on its energy resources, and it is likely to grow in future. Presently, India's energy system is sustaining mainly through coal, petroleum oil, and biomass. At present, India is the fourth-largest energy consumer globally" [1] and "the third-highest consumer of crude oil, accounting for 4.1% of the world's consumption in 2017" [2]. However, "India's per capita energy consumption

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is around one-third of the world's average" [1]. Therefore, despite rapid growth, domestic energy production could not meet the energy demand in India. Power production from fossil fuels has detrimental effects on the environment considering fossil fuel-induced global climate change and air pollution. The increasing costs of fossil fuels and spiralling consumption of energy resources will be the decisive factors for the usage of renewable energy in the future. In the last decade, electricity generation from renewable energy has taken conventional fossil fuels in many countries. Among the renewable energy sources, solar energy is very convenient for electricity generation.

"Because of Government interventions and incentives, photo-voltaic (PV) usage has been rapidly increasing since the last three decades worldwide" [3]. "India registered the second-highest growth in the renewable energy sector after China in the world" [1]. "Solar PV and wind account for more than three-quarters of the capacity additions. India's power generation from renewable energy sources (10.3 billion units) is 9.11% of total power generation (113.2 billion units). Among renewable sources, solar power accounts for 36.3%. Presently, India has a renewable energy potential of 131 GW (GW) in 2019 to reach 275 GW by 2027" [2]. "dance for almost 300 days of clear sky. The average irradiance on a horizontal surface in arid Rajasthan is 5.6 kWh m^{-2} day^{-1}, and at Jodhpur, it is around 6.0 kWh m^{-2} day^{-1}" [4]. "Looking to these potentials, the Government of India has set ambitious targets of achieving 100,000 MW of solar PV-based power generation capacity and doubling the farmer's income by the year 2022" [5]. "Recently, the Ministry of New and Renewable Energy, Government of India, has formulated a scheme KUSUM (Kisan Urja Suraksha evam Utthan Maha-abhiyan) targeting energy security and upliftment of farmers. Under the scheme, financial subsidy to the developers (individuals or organizations) and on-grid net metering can be extended to the solar power plants of capacity between 500 kWp to 2 MWp" [6]. "Moreover, solar or other renewable energy based power plants (REPP) must be installed within a 5-km (km) radius of the power sub-stations. Such solar power plants near these sub-stations may be developed, preferably by farmers, by utilizing their barren and uncultivable land. Cultivable land may also be used if the solar plants are set up on stilts where crops can be grown below. If the farmers/group cannot arrange the equity required for setting up the REPP, they can develop the REPP through developer(s). In such a case, the landowner will get lease rent as mutually agreed between the parties. Although in Rajasthan, there is a lot of uncultivable/barren lands are there. However, the requirement of grid connectivity within a five km radius is not possible in far-flung areas. Besides, due to aeolian dust deposits in the desert area, frequent washing of PV modules is required which compel for ground mounted installations of PV modules instead of stilt mounting. Hence there are prospects of installation of solar power plants on the ground on cultivable lands. The reduction in solar efficiency due to dust on PV panels is approximately 29.76% for cleaned modules" [7].

"Solar PV generation is a land-intensive venture, and it needs around 2 ha of land per MW of power generation. Ground-mounted photovoltaics have become the cheapest source of power generation worldwide and represent a growing PV marketplace share" [8]. However, "the spatial aspect of PVGM implementation and the loss of cropland have hardly been discussed in detail. Land, the principal supplier of food, fresh water, and many other ecological resources, is the basis for human livelihood. However, with socio-economic upliftment, especially in the most populous world, and due to soil degradation, croplands are projected to decrease globally between 50 and 650 million ha by 2100" [9]. Based on the literature reviews, different factors affecting agrivoltaics in India are classified as opportunities and constraints separately.

2. OPPORTUNITIES

2.1 Increased Demand of Solar Energy

Agrivoltaics' acceptance and success will raise public knowledge about the advantages of converting to renewable energy. This was regarded as a key impediment to the acceptance of solar as a viable energy generation option [10,11,12]. Other areas where solar energy can be used, such as residential homes and buildings, business structures, cars, portable electronic gadgets, and many others, will be fueled by public awareness. Furthermore, improved local understanding of solar energy would increase demand and pressure the government to strengthen local manufacturers so that solar panels can be manufactured locally. With its Make in India campaign, the Indian government has already demonstrated its commitment to domestic manufacturing. As a result, boosting the local solar industry is a good fit for the company's current objective.

2.2 Increase in Locally Manufactured Solar Panels

"The supply chains were interrupted as a result of COVID-19, giving India the opportunity to boost indigenous manufacturing for energy security and to avoid future uncertainty" [13]. The likelihood of widespread adoption of agrivoltaics will be one of the catalysts for local solar system manufacturers and policymakers to nurture a self-reliant local supply chain. Such momentum could result in a surge in demand for solar panels, resulting in an increase in the number of solar panel production units. This, in turn, will eventually generate employment opportunities for the local community. All of these will lower the cost of solar systems in the United States. As a result, if the supply chain is disrupted as a result of the epidemic, local production may become more appealing than before.

2.3 Decrease in Greenhouse Gas Emissions

"India is the world's third-largest emitter of greenhouse gases" [9]. "The biggest contributors to greenhouse emissions are electricity, agriculture, and manufacturing/construction. Additional electricity can be created using agrivoltaics, reducing the need on coal-fired power plants. Methane gas produced by livestock such as cows, buffaloes, and others adds to greenhouse gas emissions in agriculture" [14].

2.4 Generation of Rural Income

"Farmers in India employed inconsistent farming practises, making it difficult for many to make a living in this industry. As a result, India has seen an alarming increase in farmer suicides in recent decades. A low rate of return from agriculture, a high cost of production, poverty, indebtedness, unsecured loans, insufficient irrigation, and many other factors are among the key causes" [15,16,17,18]. "Agriculture is fraught with uncertainty since it takes a long time for farmers to see a return on their efforts. Many variables, such as flooding, drought, cyclones, or attacks from animals, birds, and insects, could affect the harvest and hence their prospects for returns on investments between sowing and selling the crop. They supplement their agricultural revenue by selling animal products such as milk, eggs, and meat. Agrivoltaics, in a similar vein, provides an extra source of revenue. Farmers can sell extra electricity generated by a grid-tied solar panel to utility companies. In the Vidarbha area of India, a grid-tied solar panel with a capacity of 100 MW put on 6 acres of farmland earned an annual income of $27,655. Similarly, in Pennsylvania, agrivoltaics-based rabbit farming systems provided additional profits ranging from $7623–$15,247 per year to $8678–$17,358 per year [19]. Even with uncertain farm revenue mixed with market instability, agrivoltaics provides an economically viable option that is attainable" [20], according to a Malaysian study. With the inclusion of better water management for irrigation, a feasibility study in Maharashtra determined that agrivoltaics of 50 MW had the ability to reduce poverty [21].

2.5 Water Conservation in Agrivoltaics

"Solar panels boosted the water conversation by 328 percent, according to a recent agrivoltaics study conducted on six acres of agriculture on the Oregon State University, Corvallis campus. Solar panels acted as a barrier to water evaporation, resulting in water conservation. The same can be shown in a study carried out in Montpellier, France" [22]. "Water balance increased by 10–30% in an agrivoltaics system when the light intensity was 50–70% of full sun radiation, according to this study" [22]. "In lettuce farming, another modelling study conducted in the same city of France revealed a 20% reduction in water irrigation. The combination of tilting-angle solar panels with the farm results in irrigation water conservation" [23]. Similarly, [23] shows that agrivoltaics can save a large amount of water in places with above-average temperatures and disproportionate solar energy. Water evaporation from agrivoltaics will be significantly reduced in India, where the majority of the landmass receives warm weather throughout the year.

3. CONSTRAINTS

3.1 Intensive Cost of Solar Panels

When combined with social and economic infrastructure development, solar-based electricity generation has the ability to provide rural electrification and economic growth [24]. The cheap maintenance costs of these renewable energy sources make them excellent for rural electrification [25]. The high capital and installation costs of solar-based electricity generation, on the other hand, are one of the barriers to widespread adoption [24–26]. Local production is one approach to bring down the high cost of solar panels. The interest rate on solar system manufacturers' and end-users' loans is quite high. Furthermore, the cost of utilities for local manufacturing firms in India is relatively high. As a result, the cost of producing solar systems in India is higher than in other Asian countries. Furthermore, Khare et al. recognised reliance on imported wafers for solar cell manufacture, high capital costs, a lack of technical knowledge, and competition from neighbouring nations like China and Taiwan as some of the problems that keep solar cell costs high [27]. As a result, until the cost of solar panels is reduced, persuading farmers to include solar farming into their agricultural land and reap the benefits would be a difficult task.

3.2 Need of Social Awareness and Apprehension of Failure

In the farming community, there is a general lack of knowledge regarding agrivoltaics. Maintaining and operating a solar power plant, like any other career, demands specialised knowledge and training. Experts are unwilling to go to rural India to train the indigenous populace unless they are compensated well [28]. Because of a lack of information, agrivoltaics may not be implemented, leaving the potential benefits of this technology unrealized. As a result, there is a need to educate the farming community on how to properly deploy agrivoltaics. However, simply teaching farmers may not be sufficient. In Uttar Pradesh, India, a semi-structured survey was undertaken in 700 families [29]. It was discovered that simply boosting awareness of solar technology and providing renewable energy subsidies is insufficient to achieve widespread adoption of clean energy [29]. According to the same study, government efforts and advertisements in print and electronic media are insufficient to boost solar energy awareness [29]. Rather, word of mouth, experiential learning, and village-level awareness activities are preferred by many households [29]. Farmers who switched to agrivoltaics, according to [30], presented the positive elements of employing this technology as a result of getting a consistent income and a sustainable agriculture production when interviewed. Having such farmers scattered across India's rural areas will successfully spread agrivoltaic awareness. By piloting select projects and giving them first-hand exposure to the agrivoltaics concept, the GOI should take determined steps to produce such technology-champion-farmers. Furthermore, in the farming community, as in any other business community, there is a fear of failure. Fear is one of the flaws that prevents widespread adoption of the agrivoltaics strategy, and it necessitates government agencies developing novel ways to educate farmers and so assist them in making educated decisions, reducing the fear of failure.

3.3 Solar System Degradation

Solar systems are subjected to natural components such temperature, wind speed, dust collection, irradiance, humidity, and physical stress, all of which reduce their production capability [31]. Solar systems degrade at a rate of 0.5 percent every year, according to NREL studies. With a solar system's life period ranging from 20 to 25 years, the degradation rate suggests that ageing solar systems will provide less than 90% of the electricity produced in year 1 [32]. Over a ten-year period, a study of solar panels utilised in India yielded alarming results. The research was carried out on solar systems using panels manufactured in accordance with International Electrotechnical Commission (IEC) standards, specifically IEC61215 standards. Despite the fact that the panels were built to IEC standards, they were harmed in various ways. The study discovered that panel performance deteriorated from 8% for the best performing panels to 28% for the worst performing panels. The study ascribed the improved performance to precisely constructed panels, the use of high-quality raw materials, and other production quality control techniques [33]. As a result, we can fairly assume that the GOI should provide stringent quality control in the manufacturing of solar systems to overcome this problem.

3.4 Theft of Solar Panel

According to [34,35], India ranks 53rd out of 117 countries in the world crime index in 2016. Theft is one of the crimes that mostly affects India's rural areas, and it has been scientifically proven to be considerably triggered by weather and trade shocks [36]. Another element that contributes to an increase in crime in rural India is poverty [52]. Solar panels are vulnerable to theft because they are installed in the open and have a high value. The effectiveness of solar-based mini-grid deployment for electrifying rural Chhattisgarh, India, was investigated in a study

[37]. The solar mini-grid successfully electrified the eight project sites selected in the two districts of Raipur and Korba in Chattisgarh, according to the report. The study discovered two issues: mortgaging solar panels when the user was under financial difficulty, and theft, which defeated the objective of deployment [37]. Solar panels were utilised for irrigation at Moamba, Mozambique, where the same problems were reported [38]. As a result, the theft of solar panels could be a deciding factor in whether or not other people directly involved in agriculture adopt the technology. As a result, a technique to prevent the theft of solar panels must be developed. One of the options in agrivoltaics for preventing theft was to install solar panels at elevation [39]. In the event of a break-in, the stolen solar panels should be tracked so that the perpetrators can be apprehended and punished. In addition, financial outlets or safety nets for rural farmers to use in the event of solar panel theft must be developed. A solar panel insurance policy, for example, can compensate a farmer in the event of theft, allowing them to avoid financial hardship.

3.5 Lack of Proper Insurance

Extreme weather events such as earthquakes, floods, and cyclones have occurred in India over the years. Hydro-meteorological events such as floods and cyclones have caused crop damage [40–44]. Climate change, according to [40,45–47], will exacerbate such climate extremes in the future. As a result of the intense weather conditions, the solar panels planted in the farms will be damaged. As a result, suitable insurance programmes are required so that farmers may recover their investments in the event of loss caused by harsh weather. The same is true in the case of solar panel theft. Repair and reuse, according to a research published by the International Renewable Energy Agency (IRENA), is the most environmentally favourable alternative for dealing with end-of-life solar panels [48]. Farmers should obtain sufficient insurance or warranties if a flaw or defect is discovered during the early life phase of installed solar panels. They will be able to get damaged solar panels repaired or replaced in this manner. In addition, flaws such as hot-spot, double-ground, and arcs in solar panels have the potential to cause a fire danger [49–51]. As a result, insurance coverage is required for these types of catastrophes as well. Even after receiving government subsidies, more than 90% of farmers did not cover a single crop, according to a situation assessment survey conducted in 2013 [52]. This emphasises the importance of educating the farming community in order to mitigate the hazards of farming and its consequences. As a result, having an insurance policy for both the crop and the solar panels is crucial for integrating solar panels with agriculture.

4. DISCUSSION AND CONCLUSION

Solar PV is expanding at a fast rate of roughly 30% to 40% across all renewable energy fields. [53]. In 2009, annual global solar PV energy production surpassed 10 GW, up from 2 GW in 2006. Many governments are concentrating on free natural resource availability, mature technology with long-term reliability as critical components in achieving renewable and sustainable energy generation. The environmental challenges associated with the installation and operation of big solar plants have been systematically investigated, with 32 positive benefits identified across land use intensity, human health and wellbeing, plant and animal life, geohydrological resources, and climate change [54]. Electricity generating is a capital-intensive industry that is unevenly distributed throughout the country. Electricity cannot be stored in a situation where demand and supply must be matched to fulfil the country's continuously expanding demand for optimal and quick growth [55].

The cost of solar panels has been steadily decreasing over the previous decade [56]. Many advancements resulted in considerable gains in performance. Recent advances in solar cell manufacturing techniques have raised the efficiency of silicon-based solar cells to 29.4 percent [57], up from 25 percent in 2011 [57]. Similarly, more expensive multi-junction solar cells have a 43.4 percent efficiency [58]. Switch embedded solar panels outperformed traditional solar panels in partial shadowing conditions, according to a recent study [59]. In agrivoltaics, such enhanced solar panels will make them even more efficient under shifting illumination circumstances. At the same time, advancements in sun-tracking technologies [60,61] and MPPT [62–63] may make agrivoltaics even more appealing than before. As a result of advances in solar cell manufacturing techniques, sun-tracking technology, and MPPT algorithms, the electricity generation capacity of agri-voltaics will rise in the future under variable lighting situations. Farmers will be able to earn more money as a result of this. As a result, agrivoltaics is a fantastic strategy that India should follow.

Farmers in rural India are already under financial strain, so expecting them to assume financial duties and risks by installing solar panels is unrealistic. Policymakers should adopt rules that allow local power providers to work with farmers to install solar panels in order to overcome financial barriers. Local utility providers will be able to work with farmers in this way, allowing the latter to incur less risks by transferring only those hazards that the farmers can manage.

Due to high subsidies offered to farmers, distribution losses due to remoteness, and energy theft, utility firms supplying electricity to rural portions of India are often in bad financial shape [64]. As a result, they frequently see no benefit in delivering reliable electricity to India's rural areas. In most cases, having a local power plant in rural areas reduces distribution losses. Land acquisition laws, on the other hand, make it very hard for utility corporations to develop such power facilities. These kinds of initiatives can be made possible by having a provision for public-private partnerships, in which utility companies and the government pay financing for the purchase and installation of solar panels on farmland. Utility firms will gain access to farmland in exchange for permission to develop solar-powered power plants to cut distribution losses. Farmers will receive a portion of the profit earned by power production as well as a monthly leasing payment for equipping their farmland with solar panels. Farmers have benefited from loan forgiveness initiatives established by the Indian federal and state governments over the years [64-69]. Instead, taxpayer money would be better spent sponsoring projects that help farmers become more sustainable by collaborating with utility providers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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