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Studying the Factors Affecting Performance of an Agri-voltaic Plant under 185kWp Conventional Ground Mounted Solar Photovoltaic Power plant in Gurugram, Haryana

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A B S T R A C T

Agri-voltaic is dual use of land for farming and solar photovoltaic electricity generation thereby increasing productivity of the land. The objective of this paper is to study the feasibility of creating an Agri-voltaic plant under a 185kWp ground mounted solar power plant located in Amity University Haryana near the Aravali Mountain range. The study provides detailed information about the method adapted to convert the wasteland into arable land and presents the feasibility of creating such plants under solar power plant. The study highlights the technical, environmental, social and political challenges associated with this technology and provides possible solutions.

The experimental study showed that converting a conventional solar power plant to Argi-voltaic plant requires proper tilling of barren land on which it is commissioned. Regional plants and some medicinal plants grew well. Wildlife posed threat to the farm and plants like bitter gourd, spinach and coriander could not grow as were eaten away by birds. An average of 718.9 kWh of energy was generated uniformly. Potential barriers for societal diffusion of APV are lack of regulatory policies addressing the land use issues, taxation and subsidies for APV and lack of technical & economical knowledge among stakeholders which requires immediate attention.

1. Introduction

As the world's population grows, so does the world's demand for energy. The generation of clean and alternative energy is emerging as a solution to the world's energy demands. Not only energy but the need for more food is also increasing due to the rapid increase in the population, and so is the requirement for more space to grow food. Both energy and food situations can be easily tackled by using the same piece of land for both proposes, i.e., combining Agriculture and Renewable Energy production and

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this technology is known as Agri voltaic. APV directly addresses the sustainable development goals for clean energy and sustainable cities and communities [1].

1.1 Defining Agri-voltaic

About four decades ago in 1982, Goetzberger and Zastrow [2] proposed the idea of Agri-photovoltaics. These systems combine agricultural activities and solar energy generation on the same site with the objective of reducing energy and food crisis [3] Agri- photovoltaics is defined as the dual use of the same land area for electricity and agricultural production, including aquaculture [4] and is considered as a Climate-Smart Agriculture option for Indian farmers [5]. As per the way agrivoltaics is conceived in Japan, the basic difference between a solar PV power plant and Agrivoltaics lies on its objective. Solar PV power plants are designed to optimes its energy output. On the other hand, APVs are designed to optimize its agricultural output [6]. The APV mandate of France talks about maintaining the qualitative and quantitative agricultural yield whilst promising no reduction in revenue from the agricultural activity [7]. Solar PV plus animal farming is also seen as a profitable business model having reports showing enormous profits from selling meat/ animal produce [8, 9] and PV power.

1.2 Design of APV

The traditional PV system design procedures which are majorly concerned with factors such as tilt and orientation angles to maximize power production by selecting slopes near to the latitude and orientations facing the equator does not fit well for an Agri-voltaic system. APV requires that PV structures be installed in such a way that it allows optimal agricultural development and other farming activities leading to several design changes based on local climatic conditions, crop type, energy needs, and landform. To ensure and optimize the energy output, food production, and space, a new set of design criteria needs to be developed [10]. Unlike the traditional solar PV installation where solar panels are tightly packed to maximize land utilization, in Agri voltaic the panels are installed with a larger ground clearance compatible with modern machinery for easy mobility and easy mechanical cultivation of crops. The expense of constructing a structure capable of supporting either fixed panels or trackers at that elevated height increases the budget significantly. Supporting pillars are sufficiently spaced apart to allow large machinery (such as tractors) to pass through. Solar panels can be fixed or have single-axis or dual-axis sun-tracking capability to maximize the power output from the panels and can be a grid-connected system [11]. Selection of design of Agri-voltaic depends upon the type of crops grown by farmers for example APV created using bifacial PV placed vertically, or using transparent, and semi-transparent tilted PV panels are suitable for shade-intolerant crops whereas APV under opaque PV panels are suitable for shade-tolerant crops and in places having high insolation which leads to excessive transpiration from plants. [1]. Agri voltaic systems are not restricted to only stilted solar arrays (stripes) over crops but can also be created under a conventional ground mounted solar PV plant. Low height mounting structures reduces the cost compared to a stilted Agri-voltaic and the microclimate which is generated beneath the solar modules provides an opportunity for multiple cropping based on the light and height requirements of the plant. As a result, the area beneath modules can be used to grow shade-tolerant plants, especially in hot, arid conditions. Some studies have been conducted in this regard in India [12] and Malaysia where testing on few species like java tea, aloe vera, spinach, coriander leaves were performed, which achieved higher crop yields for herbal plants whilst also reducing the module temperature increasing the annual energy production up to 2.8 percent [10]. Solar panels offer a buffering effect to plants facing extreme climatic conditions and with right design can provide micro-climatic conditions favourable for its growth [13]. To increase the crop output, it is suggested to have a lower density of solar panels [14] and install it at a height of 3 feet to ensure that solar radiation reaches the ground approximately uniformly. Sarr et al. [15] reported that crop yield and energy generation from solar PV can be maximized by optimally choosing mounting height and spacing between solar PV arrays. There are many ground-based initiatives with creative design developed in the field of Agri voltaic. A company named the Next2Sun developed a concept of vertical installations with bifacial PV modules facing east and west and leaving a space of approximately 10m between the rows for agricultural purpose [16].

1.3 Crop selection

Al Mamun et al. [17] have classified different crops under the category of sun loving plants (like rice, cabbage, turnip corn, tomato, pumpkin, watermelon and cucumber), plants that grow under full shaded light (like Alfalfa, arugula, Asian greens, broccoli, cassava, chard, collard greens, hog peanuts, kale, kohlrabi, lettuce, mustard greens, parsley), shade tolerant crops (like scallions, sorrel, spinach, sweet potatoes, taro, and yam), plants that grow under moderate light (like Beans, carrots, cauliflower, coriander, green peppers, and onions) and plants that grow under low light (like Mushroom) to study their growth under Agri-voltaic plants. Researchers reported a reduction in the yield under APV due to shading [18]. Yield of Bok Choy corn under conventional and high-density solar PV panel was reported to be 0.10 kg/m^2 and 3.23kg/m^2 respectively [19]. Yield of lettuce [20] and winter cabbage [21] under PV panels was reported to be 2.65kg/m^2 and 0.32 kg/m^2 respectively. Jiang et al [22] reported a reduction in yield of kiwi from 1.71kg/m^2 under conventional farming to be 1.66 kg/m^2 under low density solar pv panels.

The availability of solar radiation under the solar panels impacts the growth of plants. Pal et al. [23] proposed an analytical method to calculate sun's position on the sky which can be used to determine the length of the shadow cast by panels on the ground. Availability of photosynthetically active radiation (PAR) depends upon atmospheric conditions, location, time and day of the year and is essential for modelling biological growth system [24]. Since solar radiation is important for photosynthesis in plants, the vertical bifacial module installations are perfect for crops requiring high amount of solar radiation for growth [16]. On the other hand, shade tolerant plants can be grown beneath the conventional ground-mounted solar PV panels. Therefore, the correct installation can be chosen based on the type of crop that is grown in the Agri-voltaic setup [25].

1.4 Economics of APV

Harshavardhan and Joshua [20] found that there is a 30% increase in the economic output from Agri-voltaic farms which combines solar-generated power with shade-tolerant crop production compared to conventional agriculture. Farming losses can be reduced by using shade-tolerant crops which grow better in APV environment allowing crop prices to remain stable. Further the use of APV creates additional income through energy generation for farmers and improves farming profitability, and it may boost rural electrification [26]. Moreover, a dual usage of agricultural land has the potential to have a major impact on national PV output.

1.5 Benefits of APV system

Agri-voltaic can provide numerous benefits like rural electrification, crops protection from intense radiation [27], reduced irrigation water usage, increased revenue, higher crop yields in case of shade tolerant crops and lower GHG emissions [28]. Semi-arid and dry locations are considered as the best suited place for Agri-voltaic system [29]. The intense radiation leads to reduction of moisture from the soil and hence planting crops underneath the solar panel helps in protecting the plant from direct radiation and water losses. Also, water that is used for cleaning solar panels can also be used for irrigation [30]. Othman et al. [31] conducted a detailed study to examine the impact of growing crops underneath a solar panel on its temperature. They have reported that crops through evapotranspiration help in reducing the temperature of solar panels which is a major concern for solar developers as it affects the efficiency of the system. On the other hand, it was observed that solar panels provide necessary shade to minimize evapotranspiration and thereby reduces crop hydric stress, particularly in locations with strong sun exposure [12].

The Agri voltaic technology of combining food and energy generation has numerous advantages like increased land efficiency or better land utilization while providing an optimal coordination between energy, food and environmental security [13]. Controlling the microclimate inside a solar greenhouse could result in year-round cultivation and reduce threats from extreme weather conditions [32].

1.6 Shortfalls

It also has a few drawbacks like i) APV systems are difficult to install because of their constraints related to energy generation, agriculture produce, local economy, and on-site stakeholders, ii) it is more expensive than conventional ground-mounted PV systems, iii) selection of crops is a crucial factor for APV, otherwise the yield of crops will be very low, and last but not the least iv) absence of proper policy related to APV also leads to low acceptance of the technology [25, 33]. Therefore, a more comprehensive understanding of technological and economic factors, as well as agricultural difficulties, is required for APV Systems. Moreover, the variables influencing public acceptance of the technology needs to be investigated [34]. As reported by Ghosh [1] there is a huge requirement of sharing dialogue between policymakers and economists to promote the growth of APV in the country. Research related to successful growth of mainstream crops like paddy, wheat under APV for Indian conditions are very few which hinders the societal diffusion of innovation. A rich data pertaining to successful growth of all types of crops and their economic analysis will help farmers adapt the technology [35].

Ghosh [1] pointed out the lack of knowledge about APV among its stakeholders as one of the reasons for low adaptation of the technology by the community. Gölz and Larisch [36] carried out a social impact analysis of Agri-PV in fruit growing region to understand the public perception of Agri-PV among fruit growers in Germany. In India, regulations related to land use for solar projects requires change of status from agricultural to non-agricultural land [37]. A need arises for creating a separate legal provision for land use permissions for agrivoltaics [35]. Also, in India agricultural income is exempted from taxation. Farmers have a major concern related to tax on income generated from agrivoltaics [35]. In Japan, income generated from agrivoltaics plant is exempted from taxation [6].

1.7 Research gap

As per the record available there are now sixteen operational agri-voltaic plants in India as shown in fig 1 scaling from 1 MW agri-voltaic plant at GPCIL Amrol Gujrat to 7 kW at Junagadh Agricultural University. Commonly three types of Agri-photovoltaic plants [38] namely interspace farming, farming below the solar panels installed at conventional structure heights and farming below elevated structure are considered in India.

Figure 1. Agri-voltaic plants in India.
(https://buff.ly/3tNHxsc)

Some developers have also grown flowering plants underneath rooftop solar PV power plants. The agrivoltaics plants developed in India are on agricultural land for research purpose or are developed by solar developers. The available literature on Indian Agri-voltaic plant majorly focuses on the different designs of Agri-voltaic plants, economic analysis, engineering, procurement and construction requirement, operations and maintenance requirements for the system.

There is no literature reporting the step-by-step process for creating an agrivoltaics plant under a conventional solar power plant. Neither it provides any information about the soil conditions under a conventional solar power plant and how to deal with the problems related to infertile land, low humidity content of soil and wildlife threats that may occur during the project timeline and its impact on the project.

Keeping the research gaps in mind associated with Argi-voltaic plants in India, the present study focuses on performing a feasibility study of converting part of a 185kWp conventional ground mounted solar PV plant located in Amity University Haryana in the Aravalli Mountain range into an Agri-voltaic plant. The solar farm is built on a non-agricultural land area which was never cultivated and is a home for many wild species and insects. The study reports the steps taken to prepare the site for cultivation, methodology adapted for selection of crops, detecting moisture content of the soil, analyse the plant growth and agricultural output, solar PV output from the plant, and finally discusses the opportunities and challenges faced in creating the Agri-voltaic plant.

2. Steps Taken for Creating Agri-voltaic Plant under the Conventional Ground Mounted Solar PV Plant

2.1 Site Description and Site Preparation

At Amity University Haryana (AUH) an Agri-voltaic plant has been developed over an area of 200m^2 covering part of a 185kWp ground mounted solar PV power plant. Fig 2 shows the bird eye view of the site where the Agri-voltaic plant was created at AUH. The land on which the solar plant is installed is covered with wild grasses, stones and had never been cultivated before.

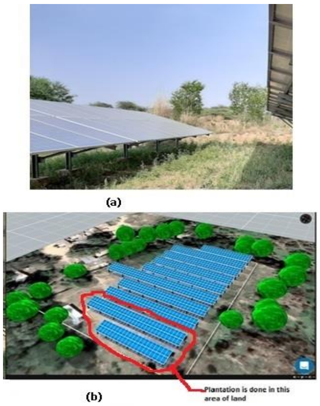

Figure 2. a) Site before cultivation. B) 3D Bird eye view of the site in The Solar Labs Software [12]

Study Soil Type: Sample of the soil from the site was collected and tested for soil type by determining the coefficient of curvature applying sieve analysis and moisture content using oven drying method [39] in the Soil Testing laboratory at AUH. It was found that the soil is a well graded soil as shown in fig 3 having a moisture content of 16.67% which was low. Soil texture indicates relative content of particles of various sizes and provides information about its capacity to hold water and air and the rate at which water can enter and move through the soil.

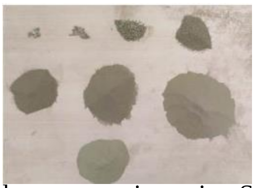

Figure 3. Soil texture testing using Sieve Analysis

Conventional Technique to increase moisture content of soil: Having done with the soil testing, the first step was to prepare the land for farming by removing the stones and weeding the whole land area and then leveling the land for cultivation purposes. The moisture content of soil was detected low in soil test. Thus, farmers were consulted, and a low-cost solution was adopted to deal with the problem by creating continuous contour trench in the site. It stops water from flowing downhill and helps in percolating water into the soil below. This technique helped in retaining moisture content of the soil as shown in fig 4 below. The soil was mixed with compost to increase the mineral content of the soil and was regularly irrigated for a week before sowing seeds. Seeds were sown either on the edges of the contour or in the trench.

Figure 4. Continuous contour trench created to reduce water loss and increase moisture content of soil: An important step for land preparation for cultivation

2.2 Plantation

The entire process of cultivation started in the month of March - April 2022 after seeking approval from solar developers and AUH administration. Farmers suggested to grow seasonal plants like coriander, spinach, cucumber, ridge gourd, pumpkin, bitter gourd, legume, bottle gourd, Indian squash, bottle gourd round and lady finger in the Argi-voltaic plant which grows well in the state of Haryana during this period. Seeds of these plants were sown on 18th April in the inter row spacing of the panels as well as underneath the panels in the contour trench. Seedlings of medicinal plants like Tulsi, lemon grass, Aloe-Vera, snake plants were also planted in this area. The area was irrigated every day in the morning at 8.30AM and the trenches were filled with water to keep the soil moist for the rest of the day.

The seeds germinated within two weeks and the seedlings started to grow as shown in fig 5. The growth of the plants was recorded at an interval of one week during the test period.

Figure 5. Growth of Seedlings after one week of sprouting

3. Identifying the factors affecting performance of Agri-voltaic farm

To analyze the performance of the newly created agri-voltaic plant, the following analysis was carried out:

3.1 Shadow analysis

Availability of solar radiation on the ground level has a great impact on the growth of plants.

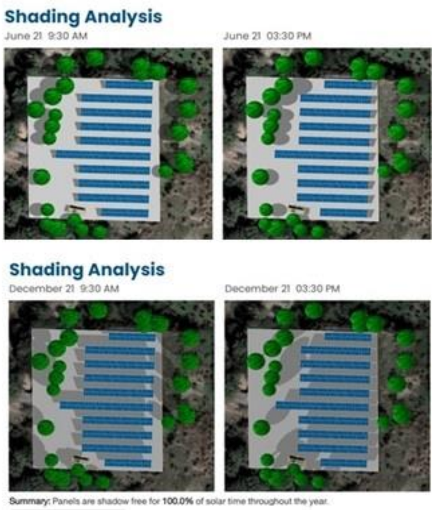

Figure 6: Shadow Analysis of the Solar power plant for summer and winter solstice [12]

Shadow analysis of the solar photovoltaic panels was conducted for the summer and winter solstice using the Solar Labs software as shown in fig 6. It was observed that during summer solstice, the space between two arrays is partially shaded over the length of the day and it receives both direct and diffuse components of solar radiation. On the other hand, during winter months, it is observed that the spacing between the two arrays are under the shadow of the panels over the entire day and hence will receive only diffuse component of radiation.

The selection of plants will depend on the availability of radiation and hence shadow analysis is important.

3.2 All Sky Photosynthetic Radiation

The shadow of solar panel will have an impact on photosynthetically active radiation (PAR) which is utilized by plants for photosynthesis and have wavelengths ranging from 400-700 nm. Ghayas [40] reported that the measured daily average PAR values for Delhi varied between 7.9 to 185.3 W/m^2 and they compared these values with CERES derived all sky PAR values.

To analyze the availability of PAR at the site during the summer and winter months, the NASA Power CERES/MERRA2 native resolution daily all sky PAR data were analyzed. Fig 7 shows the daily all sky PAR for the month of April to July which shows seasonal variation.

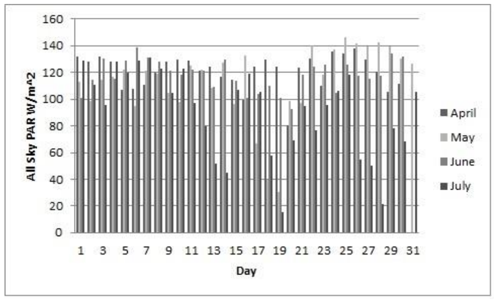

Figure 7. Variation of daily all sky Photosynthetically Active Radiation for the month of April to July 2021

The average all sky PAR values for the month of April when seeds were sown were 120.8±12.4 W/m^2 and decreased to 90.6± 31.9W/m^2 in the month of July 2021. During this time the plants received majorly direct radiation over the day but during the winter months the inter row spacing were shaded. The all-sky PAR values for the month of August were 91.2 ±31.9 W/m^2, September 83.4±22.0 W/m^2, October 86.7±17.1 W/m^2, November 58.9 ±7.1 W/m^2 and December 49.6±11.9W/m^2 as shown in fig 8.

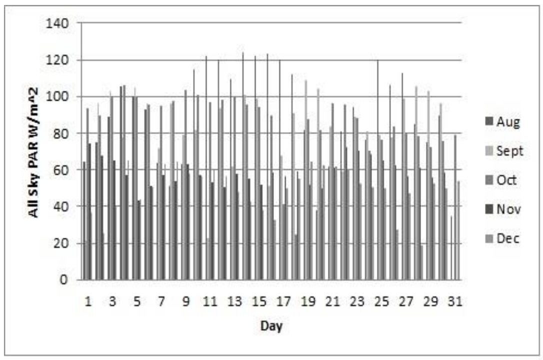

Figure 8. Variation of daily all sky Photosynthetically Active Radiation for the month of August to December 2021

3.3 Selection of Plant and studying its growth

Fifteen varieties of plants were planted under the panels and in the inter row spacing between the panels. The height, width, area of canopy, leaf area was measured at an interval of one week during the first phase of plantation in the month of April. The variance in the growth of plants under the panels and in inter row spacing were studied. It was observed that during the summer months there was no difference in the average height of thirteen different varieties of plants for which analysis of variance was conducted (refer Table 1). The plants grew equally well under the panels and in the interrow spacing as all plants received direct solar radiation for major part of the day and the shadow cast by panels helped in reducing the adverse effect of sunlight.

Table 1. Analysis of variance for the growth of thirteen different plants grown under the shade of panel and interrow spacing.

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*
Sample	86.8	1	86.8	1.4	0.2
Columns	455.6	12	38.0	0.6	0.8
Interaction	186.2	12	15.5	0.3	1.0
Within	6264.6	104	60.2		
Total	6993.1	129			

Ladyfinger, Bottle gourd, Cucumber, Tulsi, Snake plant, Lemon grass grew well in this region.

Figure 9. Growth of plants in the Agri-voltaic plant after one month of plantation

Seedlings of spinach, coriander leaves, bitter gourd and legume were eaten up by peacocks and other animals, thereby affecting its growth.

During winter months seeds/seedlings of seasonal vegetables like carrot, radish, brinjal, potato was sown as suggested by farmers from their experience of growing crops in this region. Due to shading under the panel and in the inter row spacing, very few seeds germinated. Brinjal plants survived the extreme weather conditions and bear fruit. Other plants did not grow. The reduced availability of PAR during the winter months hindered the growth of the plants under the solar panels. This is a matter of concern reported by researchers from Sri Lanka and emphasized on the inadequate availability of data regarding plants that can be grown under the solar panels [43].

3.4 Estimation of Chlorophyll Content by Arnon Method

Attempt was made to study the impact of shading caused by solar panels on photosynthesis during the summer months. Two leaves were taken, one each from a plant which grew in the open sunlight and another which grew under panel for the study.

The chlorophyll content of lady finger plant (fig 10) was estimated using Arnon method [41] to see the variance of the same in plants planted under the panel and that planted in the inter row spacing.

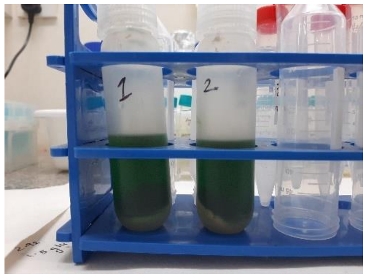

Figure 10. Chlorophyll extracted from the two leaf samples of lady finger plants, one grown under direct sunlight, and another grown under the panel

A known amount of leaf tissue 1g was suspended in 20 mL of 80% acetone, mixed well and kept at 4°C in dark for 4 hours. Supernatant was withdrawn after centrifugation (5000 rpm) and absorbance was recorded at 663 and 645nm in UV-Vis Spectrophotometer.

Chlorophyll concentration was estimated following the Arnon's equations as follows:

Chlorophyll a (µg/mL) = 12.7(A663) − 2.69 (A645)

Chlorophyll b (µg/mL) = 22.9(A645) − 4.68 (A663)

Total chlorophyll (µg/mL) = 20.2(A645) + 8.02 (A663).

It was observed from fig 11 and Table 2 that total chlorophyll content of sample 2 (plants in inter row spacing) is greater than that of sample 1(plant under the panel). Although chlorophyll a content in both the samples were found to be almost same. The findings supported the field observations. The plants grew equally well under the panel and in the interrow spacing between the panel. However, some plants which grew under the open sun showed stress marks due to increased evaporation of water from leaves during the summer months.

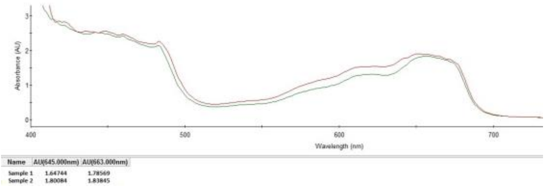

Figure 11. Absorbance vs. wavelength plot for the two samples of chlorophyll

Table 2. Estimation of chlorophyll a, b and total chlorophyll of the two samples

Sample	AU 645 nm	AU 663 nm	Chlorophyll a (µg/mL)	Chlorophyll b (µg/mL)	Total Chlorophyll (µg/mL)
I	1.64744	1.78569	18.247	29.369	47.600
II	1.80084	1.83845	18.504	32.635	51.121

3.5 Studying Flowering and Fruit bearing of plant

Hybrid seeds were used for plantation which showed fruits within a month of plantation. The first yield of lady finger accounted to 50g and thereafter there was a uniform yield of approximately 3kg per day. Bottle gourd showed a very good yield and produced at least 4-5 fruits daily amounting to 5-8 kg.

Figure 12. Legume plant growth after one month of plantation and its produce after being eaten away by animals and birds

Fig 12a shows the growth of legume plant after one month of plantation on 19th May. Fig 12c shows the condition of these plants on 2nd June after the first attack of blue bucks in the field. These plants had been a favourite food for peacocks, rabbits and other small birds which lives in this region. After being eaten away by animals and birds these plants produced fruits in small quantity on 22nd June as shown in the fig 12b. These plants were found to survive even after the animal attacks. And hence can be graded as a plant suitable for growing in agro-voltaic plant in this region of Haryana.

Cucumber plants also grew well and bear fruit within a month, but ridge gourd did not bear any fruit although the plant grew well. Spinach, coriander, pumpkin, and bitter gourd could not survive the animal attack and hence needs to be grown under proper protection from birds and animals in this region.

Plantation was done during the month of September when potato, brinjal, radish and carrots seeds were sown. Only brinjal plant grew but the other seeds did not germinate due to the lack of insolation and extreme weather condition.

3.6 Effect on Dust Accumulation and Solar PV Output

The energy generation from the solar PV plant was recorded daily and it is observed that on an average 718.9 kWh is generated over the period from April to October 2022. Although not much difference is observed in the energy generation before and after the plantation but visually it was seen that panels under which plants were grown accumulated less dust. As a result, the energy output from the solar PV plant was uniform whereas that that before the plantation showed dip fall in energy generation which may be attributed to dust accumulation on the solar panels as seen in fig 13.

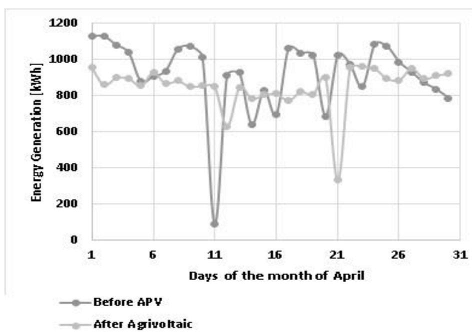

Figure 13. Energy generation from solar PV plant before and after plantation under the panels

3.7 Threats from Wildlife

The Agri-voltaic site was visited by different variety of birds, butterflies, insects and small animals (like ants, rabbits, porcupines, rats, snakes) mainly for food and shelter.

Figure 14. Wildlife threats- plants grazed by blue bucks

Some of these posed a major threat to plants and for people visiting the site for farming. Some of these were useful for the pollination but few of them were a threat for the plants growth as they would eat away the seedlings and the tender leaves of the plants. Animals like blue bucks, boars and peacocks were found to be a major threat in this area as they would destroy the entire farm and would attack the farm at regular interval leading to a complete loss of crop produce as shown in fig 14. Venomous snakes are also found in this area and can cause threats to life of people working in these farms. A local insecticide, "Fortex" as suggested by the farmers was sprinkled along the boundary of the site to keep the snakes and other wild animals away.

3.7.1 Diseases

It was observed that some of the cucumber plants had white lines on their leaves which are the eggs of flies as shown in fig 15. When these eggs hatch, the larva from these eggs feed on the same leaf on which they were born and leaves white lines from the dead tissues left behind. These leaf minors can drop off from the leaves into the soil and reproduce. These do not kill the plant, but they will reduce the hardiness and lower the productivity of the plant and destroy the nutrient base of the plant.

Figure 15. Plant Diseases caused by insects which reduce plants growth

Insecticides mixed with water were sprinkled on the plants to get rid of the insects.

4. Conclusions

In this research, an Agri-voltaic plant was constructed under a conventional ground mounted solar PV plant in the Aravalli Mountain range. The feasibility of such project is studied to identify the major challenges and opportunities. A pointwise conclusion for each of the findings are presented below:

- *Effective site preparation technique:* The conventional ground mounted solar PV plant is installed on a barren land which was not suitable for farming. Preparing the site to make it suitable for farming by adding compost to the soil to increase its mineral content, regular irrigation and by creating contour trench for reducing water loss was seen as an essential step for making the land suitable for farming.
- *Selection criteria for plants*: Relying on the traditional farming knowledge in selection of crops did not go well especially for the winter months because of poor insolation under the panels. It is recommended to select crops based on the PAR availability under the panels especially for the winter months when whole area is under shadow for major part of the day. Future work in this direction is planned to create a database to map crops with the available PAR to make it easier for stakeholders to identify the crops that will grow well in Agri-voltaic plant.

- *Identified Environmental risks*: Wildlife in this area posed a major threat to the Agri-voltaic plant. Peacocks, boar, porcupine and small birds would eat away the seedlings and hamper the growth of plants. Grazing of plants by blue bucks at regular interval destroyed the entire plantation. This can be overcome by fencing the site and using nets to prevent the birds and animals to spoil the crops. The site under study was infested with insects which also harmed the plants causing diseases. Poisonous snakes are also a regular visitor at the site which can cause harm to people working in the farm. Insecticides was used to keep the insects away and Fortex was sprinkled at the site boundary to keep the snakes and other wild animals away.
- *Identified Social and policy risks:* The Agri-voltaic plant was created with the help of farmers from the local villages. These farmers had no prior knowledge about Agri-voltaic but after working in the Agri-voltaic farm found it beneficial for them. But were concerned about the tax they must pay in case they opt for setting up Agri-voltaic plant in their farming land. It is observed that lack of awareness of stakeholders is one of the factors that is affecting societal diffusion of the innovation. At the same time having insufficient regulatory clarity for Agri-voltaic in the current policy framework is also a major concern among farmers. However, Government of India has initiated programs to promote Agri-voltaic in India under the KUSUM scheme [42]. The scheme allows setting up of solar photovoltaic plants on stilts setup over the cultivable land where crops can be grown below the stilts while power generated from the plants can be sold to electricity distribution companies.
- *Opportunities*: Agri-voltaic plants are eco-friendly and serves as a home for small birds and butterflies which helps in pollination. It is observed that growing plants under solar PV panels help in reducing dust accumulation on the panels and helps in keeping the panels relatively cool resulting in increased energy output from solar plant. A proper selection of crops would result in increasing the agricultural productivity of the land by guaranteeing revenue from both farming and solar PV power generation.

Based on the study, it can be concluded that Agri-voltaic can been considered as a technology for increasing the revenue of farmers and solar developers. Creating awareness of the technology among the stakeholders, providing policy support and technical knowledge may lead to potential adaptation of the technology by stakeholders in India that promises better utilization of the land and increased revenue to the developers. The present study will serve as a guideline for creating Agri-voltaic plant under conventional ground mounted solar PV power plants in Haryana.

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Nomenclature

Au	Absorbance unit
A663	Absorbance of light of wavelength 663 nm (Au)
A645	Absorbance of light of wavelength 645 nm (Au)
Df	Degree of freedom
F	F test value
MS	Mean square
PAR	Photosynthetically active radiation (W/m^2)
PV	Photovoltaic
SS	Sum of squares

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