Applications of Agro PhotoVoltaic System Around the world and in India, For Power Generation and Superior Crop Production

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***Abstract*:- The growing demand and need for energy, needs sustainable and renewable sources. This is important as it will help create a sustained energy supply without increasing pollution. A way to appease this demand is by using agro photovoltaic systems. Agri Photovoltaic system is a method of combining agricultural land with a solar energy plant for production of both crops and energy. This method has recently gained popularity and in this research paper, which uses data from previous research, experiments and case studies around the world and in India to give an insight on the Agro photovoltaic system, its benefits, the technology behind it, its implementations and future prospects involved in industries like agriculture and energy production.**

Keywords : Agriculture, Photovoltaics, Solar Energy

1: INTRODUCTION TO AGRO PHOTOVOLTAIC SYSTEM

Agro Photovoltaic System is a technique to maximize the utility of a land by combining crop production and using solar panels on the same land. It is considered to be a method that could help create renewable energy while simultaneously growing crops.[1]

1.1 Agro Photovoltaic System in the world

Globally Agri Voltaics are becoming more and more popular, because not only they replace the shade giving panels for plants, but also generate electricity which if not commercialised can be used to run the farms on it's own. Also, a major factor of agri voltaic systems being preferred over conventional photovoltaics is efficiency. Agri photovoltaics not only increase the efficiency of solar panels, but also the land, as it has been seen that amid conventional solar farms, certain crops can be grown that help with the flow of water and prevent the land from becoming barren.[2]

1.1.1 Energy scenario using Agro Photovoltaic System in China

China currently produces 205.2 GW of energy by photovoltaics on solar farms and employs crops like goji berry, broccoli and shallot for agri voltaic systems. China initially used this method to combat desertification but is now employing it for sustainable renewable energy production as well as increasing crop yield.[3]

1.1.2 Energy scenario using Agro Photovoltaic System in Japan

Japan currently produces approximately 40 GW of energy by photovoltaics, by various solar farms and a few solar power plants. Recently, a 480 MW power plant for agri voltaics has started being built which stretches as far as 800 hectares of land. Japan employs crops like peanuts, yams, eggplants, cucumbers, tomatoes, taros and cabbages for agri voltaic systems.[5]

1.1.3 Energy scenario using Agro Photovoltaic System in the USA

The USA currently produces approximately 80 GW of energy by using photovoltaics. However, due to its lack of proper restriction on what is agri voltaics, it can be seen that USA considers solar farms with commercial purpose beehives, solar panel powered livestock farms, and some conventional agro photovoltaic systems using crops like alfalfa, lettuce, spinach, beans, kale etc.. [3]It should be noted, the USA is one of the only countries that focuses on improving the efficiency of solar panels by placing them on fields of crops that generate a cool environment around them, most typically green leafy vegetables.[4]

1.2 Energy scenario using Agro Photovoltaic System in India

India currently produces approximately 50 GW of energy by photovoltaics. In India, solar plants with a capacity of 1059.64 MW have the capability to absorb 1,600,000 tonnes of CO_2/year and create 10,000 tonnes of agricultural produce, which could employ 2000 people.[8] India employs crops like bottle gourd,lady finger, watermelon and spices like ginger, turmeric and chili for agri voltaic systems.[1]

1.2.1 MNRE is the Ministry of New and Renewable Energy which went under an agreement with the Government of Malaysia [10] and Netherlands [25] to encourage and promote employment of Agro Photovoltaics, by spreading awareness and doing collaborative research with the involved parties.

1.2.2 Ministry of Agriculture recently inaugurated an Agri-Voltaic System at CARZI (Central Arid Zone Research Institute), located in Jodhpur.[9] This also has a provision for installation of an Agri-voltaic system in farmers' fields with a capacity ranging from 500 KW to 2 MW.

1.3 Objectives of this paper include but are not limited to understanding:

- Application of Agro Photovoltaic System in India
- Optimizing design parameters for construction of agri voltaics
- Economics involved in a project
- Suitability of cropping pattern

2: REVIEW OF LITERATURE

2.1 Review of literature of Worldwide studies and research

2.1.1 The relationship between electricity generation and farming is studied in a case report by Jaiyoung Cho, Sung Min Park, A Reum Park, On Chan Lee, Geemoon Nam, and In-Ho Ra for the enhancement of solar applications in agricultural. Their research found that crops (in this case, grapes) cultivated under solar plants were of superior quality, being heavier and containing more sugar than grapes grown under normal conditions. In addition, during the five months that grape growth was observed, 55 MWh was produced, resulting in a profit of $5551. Their research proved that using solar power systems as a crop cultivation environment allows agriculture and renewable energy to coexist.[6]

2.2.2 The potential of the Agrivoltaic system in Turkey is discussed in a paper by Atl Emre Coşgun. According to the report, if Turkey used solar panels at full efficiency, 75 percent of the country's current electricity consumption could be met. [7]

2.2 Review of literature of Indian studies and research

2.2.1P. Santra, R.K. Singh, H. M. Meena, R. N Kumawat, D Mishra, D. Jain, and O. P. Yadav address how the agri voltaic system created at Central Arid Research Institute will aid in land growth and sustainability in a report released by Central Arid Research Institute, Jodhpur(Rajasthan)[8]. According to the study, 49 percent of the land may be used to grow crops such as mingbean, mothbean, cumin, and chickpea. Other low-growing plants and crops, such as aloe vera and sankhpuspi, require less water, making them suited for the Agri-Voltaic System. Rainwater can be harvested at a rate of 150,000 litres per acre, and the stored water can be utilised to complement crop irrigation. Finally, energy generation might generate Rs. 700,000 per acre in annual revenue, boosting rural jobs and income.

2.2.2 According to an article published in Journal of Solar Engineering [9] by Beena Patel, Bharat Gami, Vipul Baria, and Akash Patel, agri-voltaics systems can be recruited in such a manner that they adopt a water and land use paradigm for producing energy and food on the same land. This would aid policymakers in improving agricultural practises and solar project developers' recommendations. This strategy would also bring entrepreneurship and jobs to rural areas where food and energy could be produced on the same land, according to the research, due to a lack of land in metropolitan areas for agriculture and energy production. The authors suggest that in order to make efficient use of land and natural resources, crops should be chosen in accordance with climatic conditions, agricultural potential, and natural resource availability in order to facilitate local or regional policies for agricultural practises under solar power.

3: Technology Behind Agro PhotoVoltaic System

3.1 APV is a game-changer and a critical component. It has ushered in a new era of industrial innovation. It may be used for both solar power generation and agriculture on the same piece of land. It is a natural approach to provide environmentally friendly and long-lasting power for agricultural uses. It is environmentally friendly since it emits far less carbon emissions than traditional energy producing methods.

3.2 A big area is required to supply global energy demands with renewable energy utilising solar cells. There is a lot of area utilised for crop farming in India. Many groups are working on this project to determine the true values of how agricultural photovoltaic systems effect output and how they might boost total revenue earned for farmers. Amity University also established programmes to obtain actual data rather than theoretical data. CAZRI in Jodhpur is also conducting similar studies. Using agricultural land to generate green power and food is a huge step forward. It will solve the energy issue and produce food, but the efficiency of production will be diminished by a certain proportion. However, it can be compensated for by using electricity saved for agricultural reasons. Agriculture practises may evolve in order to increase yield while also creating green energy. It is possible to pick crops that require little or no sunshine.

3.3 The technical features of APV systems are constantly improving, and they differ for different countries and localities [22]. PV modules are put at an inclination angle corresponding to the area's latitude in APV systems. Separation between two PV modules is critical to avoid panels shading other panels. Panels are placed at an appropriate height above the ground. Different types of crops can be grown in the gap between two panels. However, crop selection is critical since certain crops require an excessive quantity of sunshine. To reduce production loss, one should pick a crop that requires the least amount of sunshine. Crop height should be taken into account as well, because if it is higher than PV modules, it might block sunlight from reaching the modules. For the interim space between two panels, the sun's movement must also be taken into account. Furthermore, since water can be collected from the top of PV panels, rain harvesting is increasingly being used. Around 49% of the area might be used to grow crops and generate green power at the same time [22]. According to several studies, it will improve farmer earnings by 1500 percent.

4: SOFTWARE USED FOR DESIGN OF AGRO PHOTOVOLTAIC CELLS

4.1 Agro photovoltaic cells have a different design than regular photovoltaic cells, as can be observed. In PV, the angle is chosen based on the amount of energy that will be generated, but in APV, we must consider the amount of sunlight necessary for agricultural operations when choosing the angle of APV modules [15]. It entails a variety of design changes based on the local climate, which will differ for various places. As a result, there is a wide range of software available for mathematical modelling of photovoltaic cells. The following are some examples:

4.1.1 Quite Universal Circuit Simulator (QUCS) – It's a modelling programme that's available for free. The current and voltage curves for solar cells are adjusted using a generic diode. Additionally, this programme may be used to depict the characteristic curves. QUCS is a multiplatform programme that runs on both Windows and Linux [24].

4.1.2 PVGIS Estimation Utility- It's fantastic software for figuring out how a planned PV system would interact with the sun based on its location. With this knowledge, you can estimate the cell's power output. Knowing the expected power output, you may fine-tune your cell accordingly [24].

4.1.3 SMA Sunny Design- SMA is the world's top PV inverter and monitoring system company. This programme is available for free download and is a highly strong PV calculator. It simply needs a few basic location data to create comprehensive results. This programme also aids cable computations, reducing power losses [24].

4.2 Some recent Developments in design of Agro-Photovoltaic System:

4.2.1 New Tracker design- Spanish company Axial Structural has introduced a new type of tracker for agrivoltaic installations. The product can be optimized to various ground conditions and gradients, and is programmable to change light and shade for different crops in different climates. Axial's agri voltaics solution can be used for sloping terrains, and accommodate crops with different light requirements being planted beneath one installation (grapevine, fruit trees and vegetables, for example). The system can adapt to very steep slopes and land dimensions. Modules can be installed at a height of up to 6.79 meters, allowing heavy farming machinery to pass underneath. The tracker supports up to 96 modules per motor, and rows of up to 32 modules, split into four groups of eight panels each [20].

4.2.2 Germany publishes new guidelines to develop agri voltaics- Germany's Fraunhofer Institute for Solar Energy Systems ISE has recently published a new set of guidelines on agri voltaics, providing latest information on the technology, its potential and the current state of development. For some crop types, the elevated(height) PV mounting structure can even lead to an increase in yield, as shown by research projects such as APV-RESOLA. One of the current projects being researched by Fraunhofer Institute for Solar Energy Systems ISE is the APV-MaGa project, which targets the presentation and analysis of the potential of agri voltaics for Mali and The Gambia. It aims to prove the technical and economic viability of an integrated triple(three different uses) land-use system in order to contribute to a more ecological and socio-economic sustainable development within the West African context [19].

5: CASE STUDIES CARRIED OUT :

5.1 Case studies around the world:

5.1.1 Analysis of the Rice Yield under an Agrivoltaic System: In a case study in Japan, they discovered that the shadowed zone from PV module installation was roughly 27-39 percent, affecting rice output by only 20%. Around 285 million MWh per year might be generated by these cells. This diagram depicts the potential of agrivoltaic systems for effective land use and the creation of sustainable and clean energy [18].

5.1.2 Economic Feasibility of Agrivoltaic Systems in Food-Energy Nexus Context: A case study farm size of 0.15 hectare has been chosen as a reference farm in a hamlet in Niger, West Africa, for modelling and a case study. All four agricultural scenarios are taken into account. Rain-fed, irrigated with diesel-powered pumps, irrigated with solar pumps, and the APV system are all options. The APV system is examined further in two scenarios: advantages to investors and benefits to both investors and farmers. The results are presented using a variety of economic measures, including gross margin, farm profit, benefit-cost ratio, and net present value (NPV). The solar-powered irrigation system's economic indicators were all positive, but the diesel-powered irrigation systems were all negative. In addition, to irrigate the chosen reference farm, the diesel system will produce around 4000 kg CO_2 per year. For two occurrences of shading-induced yield loss, the land equivalent ratio (LER) was found to be 1.33 and 1.13, respectively [17].

5.1.3 Agrivoltaic system: a possible synergy between agriculture and solar energy: In Montpellier, France, a demonstrator with various experimental arrangements was developed to investigate the influence of a fixed and dynamic solution on the crops under the panels. With a Land Equivalent Ratio larger than 1, the effect of shadow on lettuces appears to be beneficial. The crop species most adapted to the agrivoltaic system are selected in order to expand the experiment to additional crops. Shade tolerance and climate change sensitivity are important factors to consider when choosing crops that will benefit the most from the installation of PV panels. According to the SWOT analysis, agrivoltaic systems can be used to maximise land usage and adapt crops to climate change [16].

5.2 Case studies in India:

5.2.1 Potential of agri photovoltaics to contribute to socio-economic sustainability: In Maharashtra, India, a case study was conducted. This document outlines the conclusions of a feasibility study undertaken by Fraunhofer ISE in Maharashtra in 2018/2019 on a 50 MWp agro photovoltaic project, with an emphasis on social effect and economic

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viability. According to the studies, an agro photovoltaic system looks to be economically viable, with a levelized cost of electricity (LCOE) of INR 2.02 (EUR 0.0243), which already includes costs for water management, rainfall collection, water storage, and irrigation [13].

5.2.2 Agrovoltaics in India- From Indo-German Energy Forum- It is a summary of operational programmes and policies that are relevant. It primarily focuses on how much electricity solar power produces currently, as well as the Indian government's aim for 2022 and the many plans implemented to meet that goal. It also focuses on LCOE (Levelized Cost Of Energy) [14].

5.2.3 Agrivoltaic potential on grape farms in India- It concentrates on the economic value of grape farms that deploy the suggested agrivoltaic systems, which might rise by more than 15 times over conventional farming while keeping the same grape yield. If this dual use of land is applied across the country, it has the potential to generate over 16000 GWh of power, enough to cover the energy needs of more than 15 million people. Agrivoltaics based on grapes can also be used in rural regions to provide community electrification [12].

5.3 Industries working on Agri Photovoltaic Systems (APVS):

5.3.1 French PV companies set up agri photovoltaics association- Sun'Agri, REM Tec, Kilowattsol, and Altergie Développement et Râcines have joined forces to establish France Agrivoltaisme, the world's first agrivoltaics trade organisation. Furthermore, the French environmental regulator Ademe has attempted to define agro photovoltaics and has established implementation standards. The association's goal is to promote agro photovoltaics by focusing on solutions that have a significant agricultural impact. Its goal is to represent the industry and define and defend the opinions of its members [21].

5.3.2 Largest agrivoltaic research project in Colorado- Solar FlexRack, a branch of Northern States Metals, revealed today that it provided a solution for Jack's Solar Garden, a 1.2-MW solar farm in Boulder County, Colorado, and the country's biggest agrivoltaic research project. Namasté Solar planned and built the solar project. This project, in collaboration with the National Renewable Energy Laboratory (NREL), Colorado State University, and the University of Arizona, will investigate the best ways to grow wildflowers, pasture and prairie grasses, pollinator habitats, and crops like carrots, onions, tomatoes, and squash, which will all be grown this season beneath and around the solar array [23].

6.AUTHORS AND AFFILIATIONS

1. Ujjwal Dehlan: Introduction, Review of literature, Conclusion of the study.
2. Sukhdeep Singh Gill: Technology behind Agro Photovoltaic, Software used for design optimization, case studies carried out.
3. Dr. Janardhan Prasad Kesari: Topic, Conceptualization, Styling, Format,

7: CONCLUSION

Looking at the case studies, research papers and other data, we have the following conclusions:

I. Agri photovoltaic systems can help in increasing the yield of crops.
II. APVS helps in extending the agricultural land.
III. More rainwater harvesting can be done optimally that directly helps for irrigation of crops.
IV. Less water is required by crops for maintaining a cooler temperature.
V. APVS can successfully protect crops against UV-B damage.
VI. APVS can increase rural employment through energy production and increase in usable agricultural land.
VII. APVS can help in covering almost 50-75% of energy requirements of many countries.

FUTURE RECOMMENDATIONS :

APVS is a promising technology and can definitely aid in overcoming our heavy dependency on fossil fuels and reduce carbon production in our environment. Although we (the authors) could not do any experiments on Agri Photovoltaic Systems, we expect and are open for further research to be done on the subject by agricultural universities and technological universities. So that the competence of the technology increases and the method of combining solar energy production and agriculture production becomes mainstream.

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