REVIEW ARTICLE

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Reforming Agriculture Using Advanced Renewable Energy Alternatives

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Abstract

Use of advance farming techniques in recent years aided agriculture sector to cope up with the increasing demands of food and other products. Moreover, these new interventions added additional support to fossil fuels and also maintain clean environment especially in terms of reduction of carbon di oxide. Intervention of renewable energy in agriculture processes such as solar dryer, water heater, irrigation etc. improves the efficiency and energy yield. Integration of greenhouse integrated semitransparent photo voltaic thermal (GiSPVT) system with air/water collectors and Earth Air Heat Exchangers (EAHE) has become privilege to the farmers as it can increase/decrease the temperature inside the greenhouse to maintain the ambient temperature during harsh climate conditions. Further, integration of GiSPVT with precision agriculture (PA) has become important factor in sustainable agricultural which adapts a strategy for advanced data analysis, communication and information techniques in the decision-making process like application of water, fertilizer, pesticide, seed, fuel, labor, etc. and not only helps to increase yield but also reducing water and aided to reduce environmental impacts.

Keywords: Traditional farming, green house integrated semitransparent photo voltaic system, precision farming, renewable energy, sustainable agriculture.

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Introduction

Renewable energy has started playing a vital role for aiding in grid power, providing access to the energy, reduces fossil fuels consumption and helping India to pursue low carbon emission mission. India has set a goal of increasing country's share renewable energy based electric capacity to 40% by 2030[1]. For ensuring a sustainable future and addressing the adverse effects of climate change, especially global warming, developing countries seeking to opt to renewable energy. Solar power is one of the most versatile forms of energy with boundless potential, if tapped in a optimize way. It may become boon for agricultural sector, saving precious water resources, reducing dependency on the grid and even becoming an additional revenue stream for farmers. The demand for agricultural products has increased significantly to cater growing population. Use of solar energy is now adopted to meet increased energy demands [2]. Energy is required at various stages of agriculture sector including irrigation, water pumping, lighting, pesticides spray, and various types of machinery such as tractors, etc. Integration of solar energy technologies into agriculture offers numerous benefits such as sustainable energy generation, cost savings, improved environmental sustainability, and enhanced agricultural productivity [3]. Continued research and technological advancements will further refine this practice, making it an even more attractive option for farmers and contributing to a greener future.

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Solar agriculture refers to the use of solar energy at various agricultural activities. It involves harnessing solar power to meet the energy needs of farming operations such as irrigation, livestock management, crop processing etc [5]. Solar energy can be utilized in a crop processing and post-harvest operations. Solar dryers can be employed to remove moisture from harvested crops, improving their shelf life and reducing post-harvest losses [6]. Solar-powered milling machines, threshers and other agricultural processing equipment can also be used to enhance efficiency and to reduce the adverse environmental impact. Solar powered

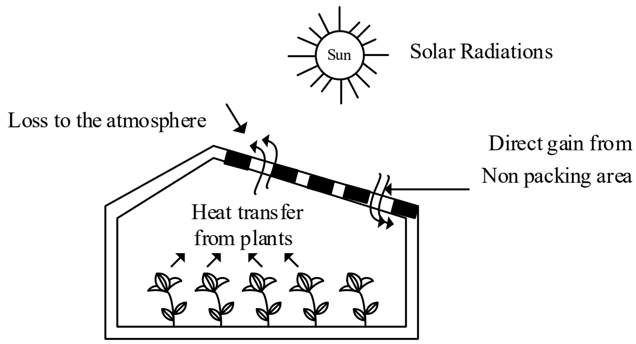

Fig. 1: Green House Integrated Photovoltaic System

systems can be integrated with sensors, remote monitoring devices and automation technologies in precision agriculture (PA). This allows farmers to remotely monitor moisture of soil, temperature and other parameters to optimize irrigation and resource management. Use of solar powered sensors and autonomous drones can help farmers to make data-driven decisions and improve overall farm productivity. Solar energy integration in agriculture is particularly valuable in off-grid or remote areas where access to grid is difficult. By harnessing solar energy, farmers can overcome the challenges associated with power availability and reduce dependency on expensive and polluting diesel generators. This promotes agricultural development, improves livelihoods and contributes to rural electrification. Moreover, solar panels have a long lifespan and require minimal maintenance resulting in reduced operational costs over time. Additionally, government incentives, tax credits and grants are often available to support the adoption of solar energy in agriculture, making it financially viable for farmers. Thus, solar energy can supply many farm energy requirements.

In this paper, various technological advances renewable energy based systems have been presented and discussed. These modern techniques not only provide favorable conditions but also increase the yield. Introduction of GiSPVT and PA have advanced the agriculture industry to a new level.

Intervention of Solar Energy in Agriculture

Intervention of solar energy in agriculture offers numerous benefits, including increased productivity, sustainability and resilience to climate change, while also providing economic opportunities for farmers and rural communities. Top of Form Following are some applications of solar energy technologies in agriculture.

Green House Integrated Semi-Transparent Photovoltaic System (GiSPVT)

GiSPVT system is one of the widely adopted techniques in farming and fish production and have a great impact on agriculture, society as well as on economy. This system combines the benefits of solar PV and solar thermal technologies within a greenhouse structure. It is a hybrid system and generates both electricity and thermal energy using solar radiation ensuring self-sustainability [7-8]. This electrical energy is used to power various devices within the greenhouse, such as fans, pumps or lighting systems etc. Excess electrical energy can be stored in the energy storing devices for the later use.

Fig. 1 represents the GiSPVT system. It consists of green house and semitransparent solar modules. Solar modules are placed on the roof of the green house facing towards south direction to capture most solar radiation to be used as direct gain inside greenhouse through non packing area of PV module for thermal heating [9]. The energy balance equations of the GiSPVT system are modeled to assess the performance of the system. The equation has developed from a modified Hottel-Whillier-Bliss (HWB) equation [10].

Energy balance equation for the south facing PV roof is expressed as

Total solar radiations absorbed by solar cell = Energy converted into electrical + Thermal energy lost from solar cell to atmosphere+ Thermal energy lost from the bottom of solar cell to the room

Energy balance equation for room air of green house is expressed as

Thermal energy gain from solar cell+ Thermal energy gain from water = Thermal energy loss from room through all sides walls to the atmosphere.

Energy balance equation for the plants within the system is expressed as.

Thermal energy transferred from underground to the water+ Thermal radiations transferred through wall to the water pond+ Thermal energy transferred through the non-packing area= Rate of thermal energy into pond + Thermal energy transferred to room air.

Fig. 2 and Fig. 3 gives the variation of ambient temperature of New Delhi on hourly basis and on monthly basis. The performance and efficiency of Greenhouse Integrated Photovoltaic Thermal (GIPVT) systems are significantly influenced by local climatic conditions, particularly solar intensity and ambient temperature. In regions where ambient temperatures can exceed 40°C, these factors play a crucial role in optimizing system design and operation. These factors also impact on both the electrical and thermal efficiencies of the system, which are crucial for optimizing energy production and maintaining suitable greenhouse conditions.

Impact of Solar Intensity

When solar radiation increases, more energy is available to be transformed into heat and electricity. Under optimal solar radiation conditions, photovoltaic thermal (PV/T) systems can have a maximum thermal efficiency of 23.3%. Furthermore, Concentrating Photovoltaic Thermal (CPVT) systems can achieve overall efficiencies of up to 91% by effectively utilizing both electrical and thermal outputs.

Impact of Ambient Temperature

As ambient temperatures rise, the temperature of photovoltaic (PV) cells also increases. This elevation can lead to a decrease

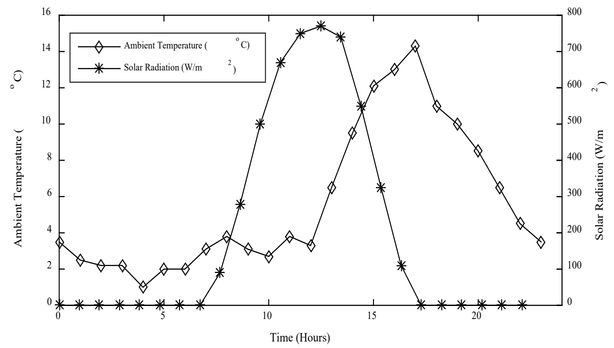

Fig. 2A: Variation of Ambient Temperature and Solar intensity on hourly basis

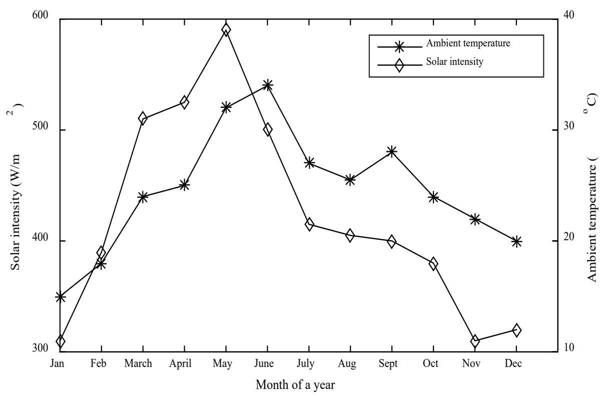

Fig. 2B: Variation of Ambient Temperature and Solar intensity on Monthly basis

in electrical efficiency due to the negative temperature coefficient of PV materials. For instance, studies have shown that for every 1°C increase in temperature above the standard operating temperature, the power output of PV modules decreases by approximately 0.4–0.5%.

In regions,where ambient temperatures frequently exceed 40°C during peak summer months, PV modules can experience significant temperature increases. For example, if a module's temperature rises to 60°C, this could result in a power loss of approximately 14% compared to its rated capacity. This temperature-induced efficiency drop is a critical factor to consider when designing and installing PV systems in hot climates.

To mitigate these effects, selecting PV modules with lower temperature coefficients is advisable. For instance, heterojunction (HJT) and copper indium gallium selenide (CIGS) technologies typically exhibit temperature coefficients below -0.3%/°C, offering better performance in high-temperature environments compared to traditional monocrystalline silicon modules, which have coefficients around -0.4% to -0.5%/°C.

Additionally, implementing design strategies such as optimizing panel orientation, incorporating ventilation systems, and using reflective materials can help reduce the operating temperature of PV modules, thereby enhancing their efficiency and longevity.

GiSPVT with Air/Water Collectors

In extremely cold climatic regions like Leh, Ladakh and Kashmir, it is difficult to maintain the adequate temperature for crop cultivation and fisheries during severe winter session. For improved electrical power generation, photovoltaic (PV) modules GiSPVT are integrated with flat plate Air/water collectors (FPC). It has been proved that the extraction of thermal energy, generated at the rear of the photo voltaic thermal (PVT) system, by flowing air/fluid at the same, increases the electrical efficiency of the PVT system by considerable amount [11]. Integration of GiSPVT with with flat plate Air/water collectors (FPC) enhances the overall efficiency and thermal exergy of the system [8]. In addition to this, inside temperature of the overall system can be stringently controlled to achieve the desired environment to enhance the production during harsh climatic conditions. Fig.2 shows the GiSPVT system integrated with Air/Water collector.

In this design of active GiSPVT system additional thermal collectors are added. There are made of semitransparent photovoltaic (SPV) module placed over blackened absorber which is insulated from aback of absorber to reduce thermal losses from backside. The outlet of first SPVT air collector is allowed to enter the second SPVT air collector for further heating and it goes up to N^{th} SPVT air collector. Such SPVT air collectors will be referred as N-SPVT air collector connected in series and it will be one panel of SPVT air collector [12].

GiSPVT with Earth Air Heat Exchanger (EAHE)

In Northern India, the atmospheric temperature as well as the temperature within the greenhouse increases to an undesirable level both during the summer period and even during clear days of the winter. During summer temperatures inside the greenhouse rises beyond 45° and during winter it drops up to 6° [1]. This destabilization of temperature between day and night, between the summer and winter, has a adverse effect on the growth and quality of crops grown in greenhouses. Among the various activities carried out for protected cultivation, heating and cooling a greenhouse uses the large amount of energy. Since the earth has enormous thermal energy storage capacity, scientists are now focusing on using the ground as a heat source or heat sink for passive heating and cooling systems.[13] with the help of buried tubes. In this system the tubes are buried at a depth where

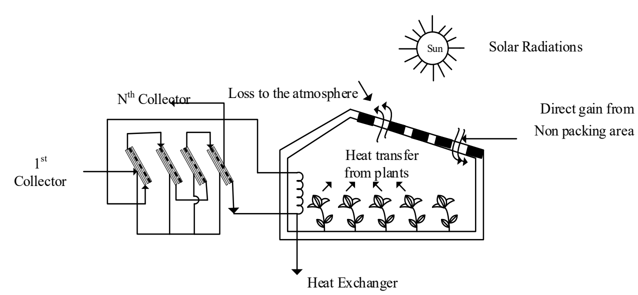

Fig. 2C: GiSPVT system integrated with Air/Water Collector

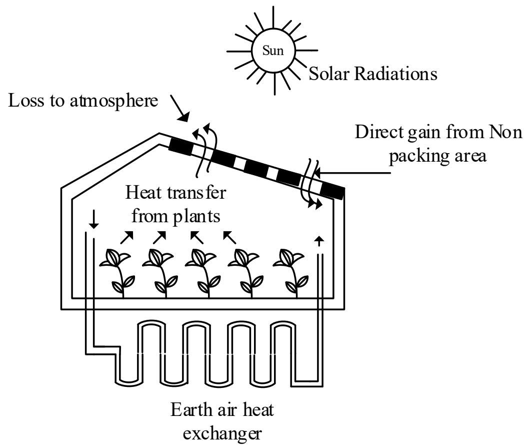

Fig. 3: GiSPVT system integrated with EAHE

the soil temperature is almost consistent throughout the year, it exploits heat transfer between the earth, the tubes, and the air passing through the tubes. When air enters the enclosed space, it experiences space conditioning because it is heated in the winter and cooled in the summer as it traverses the length of the tube.An earth air heat exchanger system has, therefore, the potential of being used throughout the year [14-15]. Fig.3 shows the GiSPVT system integrated with EAHE

Other Application of Solar Energy in Agricultural Process

Solar Dryer

One of the applications of thermal energy generated by GiSPVT is solar dryer. It is employed for drying crops, fruits, and vegetables for storage. There are two varieties of solar dryers: direct and indirect. In direct solar dryers, the material to be dried is spread out over a sizable field and exposed to the sun. An insulated box with a black absorption surface coated inside, an air inlet and outlet, and either single- or double-glazed glass make up an indirect sun dryer. Solar dryer operates on the principle of differential densities. The cold air enters through the lower input air hole, and the opposite wall's upper side receives the output air. Sunlight coming through the glazing keeps the inner environment warm, which dehydrates the substance. The cold air takes the hot air enriched with moisture content from the box and, because of the difference in the density the air is ventilated through the hot air outlet [16-17]. Fig.4 shows the solar dryer.

Space and Water Heating

Operations involving livestock and diaries frequently necessitate significant heating of air and water. In order to improve the growth as well as health of the animals. To obtain adequate temperature and better air quality, modern pig and poultry farms are reared in enclosed buildings. These establishments must routinely replenish indoor air to get rid of dust, moisture and harmful gasses [18].

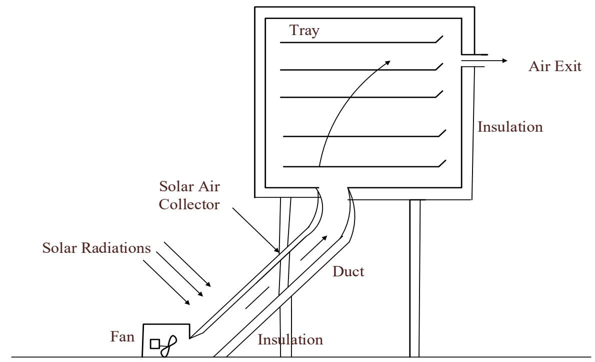

Fig. 4: Solar Dryer

Water Pumping

In areas without an existing power line, solar water pumping systems might be the most economical choice for water pumping. In the extreme summer months, when they are most required, simple photovoltaic power systems operate pumps straight from the sun. Because the water is pumped to fields or stored in tanks and used during the day, batteries are typically not required. Batteries, inverters, and tracking mounts that follow the sun are possible components of larger pumping systems. [19-20]. These systems are very cost-effective for remote farm animal water supply, small irrigation systems and pond aeration. The cost and size of a solar water pumping system depend on the quality of solar radiations available at the site, the pumping depth, the water demand, and system purchase and installation costs.

Solar Mower

Various farmers use solar-powered mowers to trim crops or grasses in the same way as conventional mowers do. Solar energy outperforms diesel-powered mowers, which are detrimental to the environment. Solar lawn cutters have a solar panel that charges the battery, as well as electric circuits, DC motors, blades and three wheels [21].

Solar Tractors

Tractors may be found on almost every farm and are considered important agricultural equipment. Tractors are typically powered by diesel or gas; however, some scientists and researchers have installed solar panels on the tops of tractors to allow these panels to get the most sunshine, allowing these hefty tractors to operate on solar power. The combination of solar panels and lithium batteries is revolutionizing the agricultural industry. These tractors may be powered directly or indirectly by solar energy; some tractors operate on lithium batteries, which are charged by solar panels; others are equipped with solar panels on the top, which can either drive the tractor or charge the batteries while it is running [22].

Solar Electric Fences

Animals such as cows, elephants, and buffaloes wreak havoc on crops and plants. Farmers employs various ways to protect their crops all around the globe. Solar-powered fence is made up of solar panels that supply electricity to the wires and whenever an animal touches the fencing.it receives an electric shock, preventing the crops from being damaged [23].

Submersible Pump

It is buried deep within the well, either up to the groundwater level or where there's a natural stream of water. The depth of the well as well as the accessible ground water level determines the pump's size and power [24].

Aquaculture or Fish Farming

Temperature regulation is crucial for the health of aquatic organisms in aquaculture ponds. Solar collectors can play an important role in maintaining optimal temperatures by providing energy for various heating or cooling systems. By integrating solar collectors into aquaculture pond systems, farmers can effectively manage water temperatures, ensuring optimal conditions for the growth and health of their aquatic organisms while also promoting sustainability and resilience in their operations.

GiSPVT with Precision Agriculture

Precision agriculture is an approach to farming that utilizes technology and data-driven methods to enhance crop production at the same time minimizing inputs such as water, fertilizer, and pesticides. It involves the use of various technologies such as satellite images, GPS, drones, sensors and data analytics to compile data regarding soil conditions, crop health, weather patterns, and other parameters affecting agricultural productivity [25-26]. This information is then used to make more precise and timely decisions regarding crop plantation, irrigation system, fertilization, pest control and harvesting. The goal of PA is to increase efficiency and productivity, reduce input costs and improve environmental sustainability [27-28]. Amalgamation of GiSPVT with PA offers a holistic approach to sustainable and efficient crop production, benefiting both farmers and the environment. Different parameters of GiSPVT system like solar cell temperature, room air temperature, crop temperature and humidity will serve as data for PA which makes the system accurate and precise for a given set of weather conditions. Moreover, energy generated by GiSPVT can be utilize to power various components of PA like sensors, climate control systems, irrigation pumps, and lighting thus reduces the dependency on the electricity and makes the system self-sustainable. Fig.5 represents the different tools used in precision agriculture.

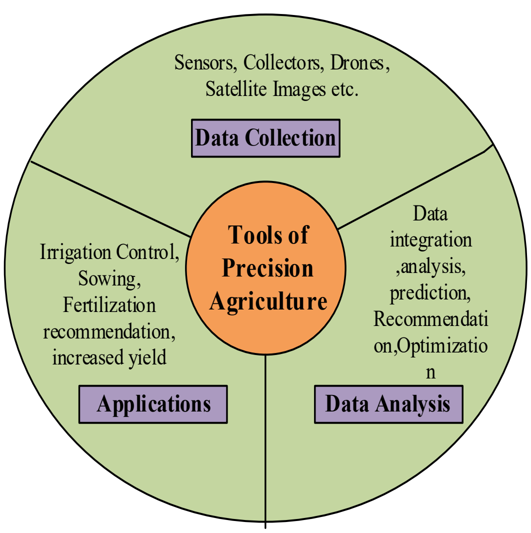

Fig. 5: Tools of Precision Agriculture

Observations

After comparing the conventional farming with modern techniques using renewable energy alternatives following observations has been recommended.

- The major problem in conventional agriculture is its dependency on climatic conditions.
- Use of GiSPVT with air/water collectors and EAHE has become an asset to the farmers as it provides the ambient temperature and protects the crops from the harsh weather conditions along with generation of electrical and thermal energy which can be used to power various devices within the greenhouse such as fans, pumps or lighting systems etc. Thus, making the system self -sustainable.
- It also reduces the emission of carbon di oxide (CO_2) in environment thus contributing towards the transition to a low-carbon economy and global efforts to combat climate change.
- Carbon credit earned by the GiSPVT system reduces cost of the system over the entire life span and allows farmers to earn extra revenue through selling their surplus of carbon credits.
- Precision farming is one of the emerging fields which utilizes technology such as GPS, sensors, and data analysis to precisely target inputs based on real-time data and spatial variability within fields, minimizing waste and optimizing resource use efficiency.
- Integration of GiSPVT with PA makes the system more precise and reliable as energy generated by GiSPVT can be used to power the components of PA thus making the system self-sustainable.

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