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CURRENT TRENDS OF SOLAR PV ENERGY AS A RENEWABLE ENERGY SOURCE FOR AGRICULTURAL UTILITY IN THE PEOPLE'S REPUBLIC OF CHINA

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ABSTRACT

China is at the forefront of integrating solar PV energy into agriculture as a sustainable and efficient power source. Current trends demonstrate that solar PV technology added over 10 GW of solar capacity to benefit over 2 million citizens by 2020 for irrigation, automation, and smart agricultural operations. Farmers gain from this transition by lowering operating costs, increasing agricultural yields, and encouraging environmental sustainability. Government incentives and programs that promote energy independence and rural development drive this tendency even further. Solar PV energy is quickly transforming China's agricultural future, allowing a greener, more resilient, and commercially viable sector and increasing per-capita income by approximately 7 % to 8 %. By the end of 2018, a total of 15.44 million kW of photovoltaic poverty alleviation had been allocated nationwide to 2.24 million homes. Combining photovoltaic technology with agricultural activities results in increased yield per unit of farmed land, with values ranging from 20 to 60 % higher, depending on crop variety. However, a few papers provide a detailed summary of current developments. This review is presented to bridge the gap between recorded literature and technical advances in the field of solar PV-powered technologies in agriculture. This essay delves deeper into the technological developments and real-world examples that show how Chinese agriculture might move toward a more sustainable and energy-efficient future. This research illuminates the existing trends, opportunities, and suggestions for this dramatic transition.

KEYWORDS: *P.R. China; Socioeconomic impact; Machinery; Sustainability; Agrivoltaic; Poverty alleviation*

1. INTRODUCTION

In an age marked by climate change concerns and rising energy needs, the incorporation of renewable energy sources into diverse industries is not just an economic requirement but also an environmental necessity (Azarpour et al., 2022). Agriculture is a critical component of food security and economic stability; from 2013 to 2016, the photovoltaic (PV) poverty alleviation pilot project increased per-capita disposable income in a county by around 7 to 8 % (Zhang et al., 2020). China, frequently regarded as the world's agricultural superpower, confronts a twofold difficulty in the twenty-first century: maintaining vigorous agricultural output to fulfil the requirements of a growing population while reducing the environmental implications of traditional farming techniques (Manna et al., 2021). Solar energy appears to be a potential answer for addressing both of these issues at the same time (Shakeel et al., 2023). Solar (PV) systems are quickly becoming a part of the agricultural landscape: at the end of 2018, a total of 15.44 million kW of solar poverty alleviation had been distributed nationwide, with 2.24 million poor families recorded as producing both clean power and food (Zhang et al., 2020).

Several variables are driving the usage of solar energy in Chinese agriculture (Lobaccaro et al., 2019). First and foremost, solar energy is a sustainable option that matches China's promises to cut greenhouse gas emissions and battle air pollution (Razzaq et al., 2023). Furthermore, in rural areas of the country where many agricultural activities are concentrated, crop-produced power consumption reached 102.2 billion kWh and accounted for 1.9 percent of overall energy consumption in 2021, a 3.4 percentage point decline from 2000 (Tang et al., 2023). Solar-powered farm machinery and irrigation systems provide a decentralized energy option that has the potential to increase production in these areas (Razzaq et al., 2023). In recent years, China's solar energy sector has seen amazing technological improvements (Lobaccaro et al., 2019). Solar panels with high efficiency, energy storage technology, and sophisticated management systems have made solar power a more realistic and cost-effective option for farmers, with prices in China ranging from $3,800 to $3,800 per kilowatt (Fagiolari et al., 2022). Solar trackers can increase the performance of photovoltaic panels by up to 40 %. Single-axis systems improve efficiency by 25 % to 30 %, while dual-axis trackers improve efficiency by 5 % to 10 %, resulting in increased solar energy output (Kanwal et al., 2023).

China's dedication to renewable energy is reflected in a slew of laws, incentives, and subsidies geared at encouraging solar usage in agriculture (Rahman et al., 2022). Farmers have been

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encouraged to engage in solar infrastructure via feed-in tariffs, tax breaks, and financial incentives for grid-connected solar installations. These governmental initiatives have aided not just the growth of the solar sector, but also rural electrification and economic development (Azarpour et al., 2022). A plethora of rules, incentives, and subsidies aimed at increasing solar usage in agriculture indicate China's commitment to renewable energy (Muhammed & Tekbiyik-Ersoy, 2020). Feed-in tariffs, tax rebates, and financial incentives for grid-connected solar systems have encouraged farmers to invest in solar technology (Guo et al., 2020). These government measures have supported not just solar industry expansion, but also rural electricity and economic development.

As China seeks to modernise its agriculture business while reducing its carbon footprint, solar energy has emerged as a symbol of optimism and success. This manuscript gives an outline of the current trends and motivations driving the integration of solar energy into agricultural mechanisation systems in China. This paper delves deeper into the technological developments and real-world examples that show how Chinese agriculture might move toward a more sustainable and energy-efficient future. Finally, this article illuminates the existing trends, possibilities, and suggestions for this dramatic transition.

2. Methodology- Revision of Published Literature

Applying the "all databases" showed published manuscripts in the area of solar energy in agriculture. 4,095 manuscripts on solar energy in agriculture have been published from 2000 to 2020, and 2,544 have been published in the last 5 years. 62 % of the manuscripts were published in the last 5 years. Furthermore, 4,395 manuscripts have been published in the "Web of Science (WoS) core collection" within the same period. 2,564 of which have been published in the last 5 years, making up 58.34 % of all published research on the said topic. As illustrated in Fig. 1 below, this indicates a sharp incline in the advancement of the sector and hence growth in solar technologies.

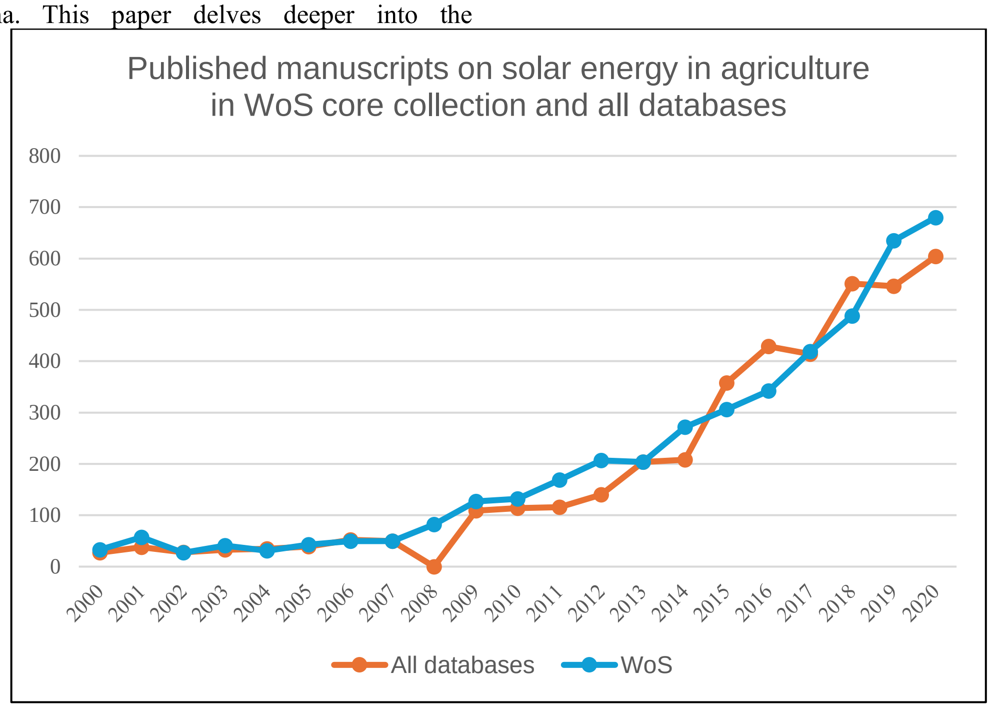

Fig. 1 Published manuscripts on solar energy in agriculture in "WoS core collection" (WoS core collection, 2023) and "all databases" (All databases, 2023). Retrieved on October 4, 2023.

Fig. 2 shows the increment in research on the area of solar energy in China. 51,313 manuscripts on solar energy in agriculture have been published in the "WoS core collection" from the year 2000 to 2020. 32,248 have been published in the last 5 years making up 62.85 % of the manuscripts published in the last two decades. Also, applying "all databases" showed that 4,188 manuscripts on solar energy in agriculture have been published from the year 2000 to 2020. 2,456 have been published, making up 58.6 % of the manuscripts published in the last 5 years.

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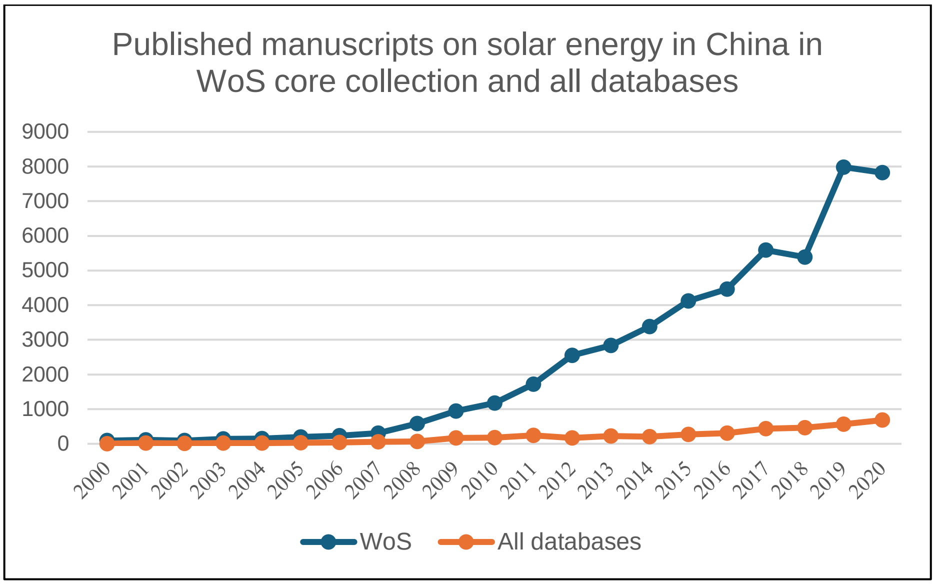

Fig. 2 Published manuscripts on solar energy in China in "WoS core collection" and "all databases" (WoS core collection & All databases, 2023). Retrieved on October 4, 2023.

Finally, 262 manuscripts on solar energy in agricultural mechanization in China have been published in the "WoS core collection" from year 2000 to 2005. 204 have been published in the last 5 years making up 78 % of the manuscripts published in the last two decades. Also, applying "all databases", the databases showed 137 manuscripts on solar energy in agricultural mechanization in China have been published from the year 2005 to 2020. 98 have been published, making up 71.5 % of the manuscripts published in the last 5 years. Fig. 3 illustrates the increment in research on the area of solar energy in agricultural mechanization in China.

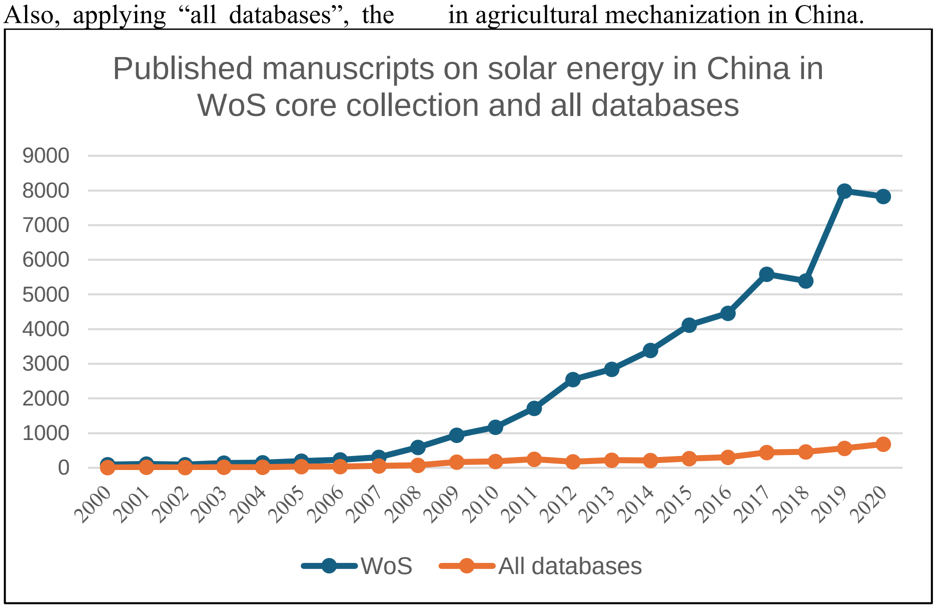

Fig. 1 Published manuscripts on solar energy in agricultural mechanization in China in "WoS core collection" and "all databases" (All databases & WoS core collection, 2023). Retrieved on October 4, 2023.

2.1 Solar energy development in agriculture in the last two decades

The last two decades have witnessed a spike in interest and investment in harnessing the power of the sun to change farming operations and address the agriculture sector's critical concerns (Azarpour et al., 2022). Solar energy development in agriculture has emerged as a major accelerator for sustainable farming, providing creative solutions to boost productivity, minimize environmental impact, and secure food security in an era of increasing energy needs and climate change concerns (Hu, 2023; Kumar et al., 2023). The growth of solar PV energy in agriculture has considerably revolutionized the industry by boosting energy efficiency, improving resource management, and lowering operational costs (Satpathy & Pamuru, 2021). Energy cost reductions and increased agricultural yields have boosted farming's economic sustainability. Technology has grown more dependable, efficient, and cost-effective (Morcilla & Enano, 2023).

By utilizing better land productivity, the integration of solar PV systems (as shown in Fig. 4 below) with agriculture production might be one of the sustainable options. This can eliminate a

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country's expanding land use competition and astounding need for energy and food. Thus, agricultural solar PV shows that by sharing the same area and light, electricity and food may be generated simultaneously. China, France, Japan, the United States, and South Korea have all enacted new regulations to boost farm solar PV since 2014. By 2020, almost 2200 farm solar PV systems with 2.8 GWp capacity will have been deployed globally (Ghosh, 2023). As a result, agricultural solar PV technology contributes to achieving sustainable development goals by reducing rivalry between land used for energy and land used for food.

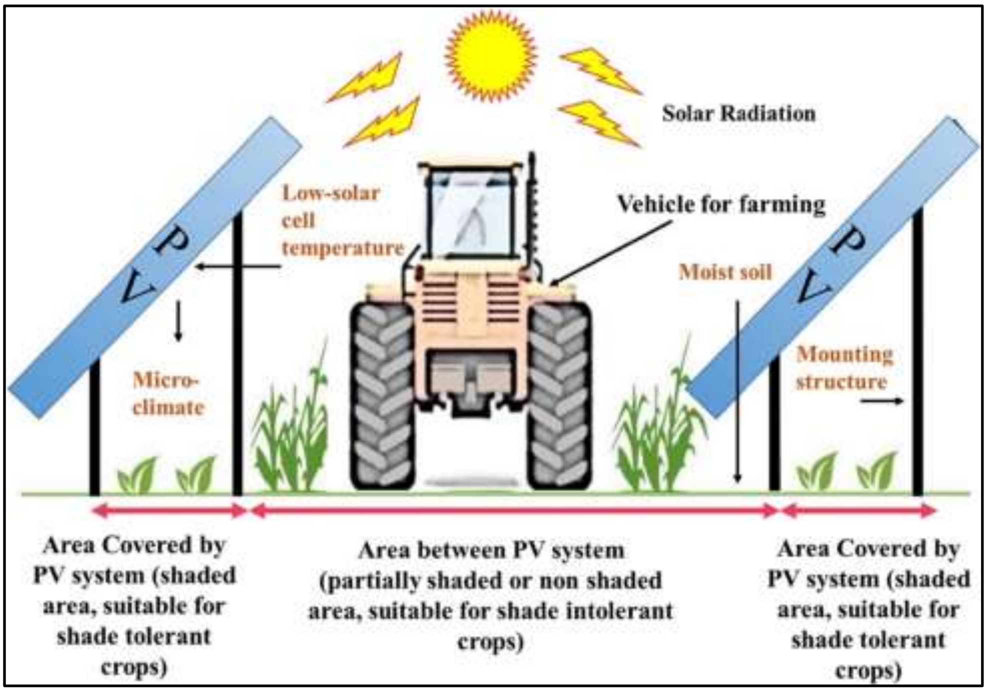

Fig. 2 Schematic of an agricultural solar PV system with room between panels for farming and equipment to move between rows (Ghosh, 2023). Reproduced with permission under the terms of Creative Commons CC-BY license.

2.2 Solar photovoltaic (PV) technology in agriculture

PV technology, as a rapidly increasing renewable-based approach, can provide a promising choice for sustainably powering agricultural activities. PV technology can meet both heat and power demands in agriculture, with the latter being accomplished through the use of photovoltaic-thermal (PVT) systems (Gorjian et al., 2021). Distributed PV systems are preferable in protected cultivation systems such as greenhouses or growth rooms, as well as small-scale remote access farms, but large-scale centralized PV power plants are more practical (both technically and economically) in big farms. Multiple studies have been undertaken to assess the integration of PV technology with agricultural chores that are broadly classed as traditional and contemporary (Alami et al., 2022). The integration of PV technology with electric farm tractors and agricultural robotics is based on a taxonomy of current tasks, which is detailed below. PV can power irrigation water pumps, which is especially useful in distant or off-grid settings. This provides cost-effective and environmentally beneficial alternatives to diesel-powered pumps, maintaining a steady supply of water for crops (Radovanović, 2023; Sayed et al., 2023).

Solar dryers employ PV technology to efficiently decrease moisture content in harvested crops, reducing spoiling and improving yield quality. Solar PV powers an electric fence, which protects crops and animals from predators and theft. These self-sustaining systems are both affordable and dependable (Suresh et al., 2023). Farmers may make educated decisions to enhance yields and optimize resource usage. Solar PV generates power for greenhouse heating, cooling, and ventilation, extending the growing season and guaranteeing ideal crop cultivation conditions. Solar-powered refrigeration devices keep perishable commodities fresh by maintaining the necessary temperature and humidity conditions, avoiding post-harvest losses (Benyezza et al., 2023). Solar energy drives electric tractors and agricultural vehicles, reducing dependency on fossil fuels and pollutants (Yap et al., 2022). Solar PV technology can filter water for crops as well as cattle, guaranteeing a safe and dependable water supply. Farmers may create additional revenue by selling excess power back to the grid, decreasing carbon emissions and contributing to sustainable agriculture by installing solar panels on their farms (Azarpour et al., 2022).

3. SOLAR PV ENERGY ADVANCEMENT IN CHINESE AGRICULTURE

PV generation in China currently has a 0 % share (Hu, 2023). Fortunately, the government has recognized the importance of PV generation, and some goals have been set in the strategic planning of Chinese renewable resource utilization from 2006 to 2020. According to CDIC data, the object of renewable energy development in 2020 includes 0.3 billion kW of large

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water electric power, 30 GW of wind energy, 1.8 GW of solar PV generating system, 30 GW of biology energy, 0.3 billion m^2 of solar water heater, and 15 billion litres of biology fuel. Renewable energy will account for 25 % of the total energy supply in 2050, with PV generation accounting for 5 % (Al-Mamun et al., 2023).

It is commonly known that China possesses a vast number of solar energy resources (Su et al., 2023). Chinese ancestors harnessed sun energy to insulate maize, salt, and clothes thousands of years ago. Until recently, simple applications such as solar energy streetlamps, solar water pumps, solar heaters, and solar energy chargers were employed to enhance the lives of regular people (Hu, 2023). In the last ten years, China's PV sector has grown dramatically. For example, the production of Chinese PV in 2007 was more than 1200 MW (Zou et al., 2017), with a global share of 35 %, ranking first in the world (Kumar Sahu, 2015). Various real-world applications have been employed to enhance people's daily lives (Che et al., 2022). Solar PV was critical in giving contemporary energy access to isolated populations (Urban et al., 2016). Agrivoltaics appeared as a technical innovation for solar PV application in the early 2010s (as shown by Fig. 5 below), when multiple factors merged to propel a spatial restructuring from centralized large-scale solar power plants in China's desolate west to smaller scale distributed solar PV models in China's east and south (Hu, 2023). Unlike the much-discussed solar PV poverty alleviation projects that were directly initiated and promoted by state actors for poverty alleviation, agrivoltaics has served as an important strategy to alleviate the accumulation crisis of solar capitalism, albeit with formidable state power assistance. The combination of green capitalism and local governments encouraged agrivoltaic models throughout China (Senthil Kumar et al., 2020).

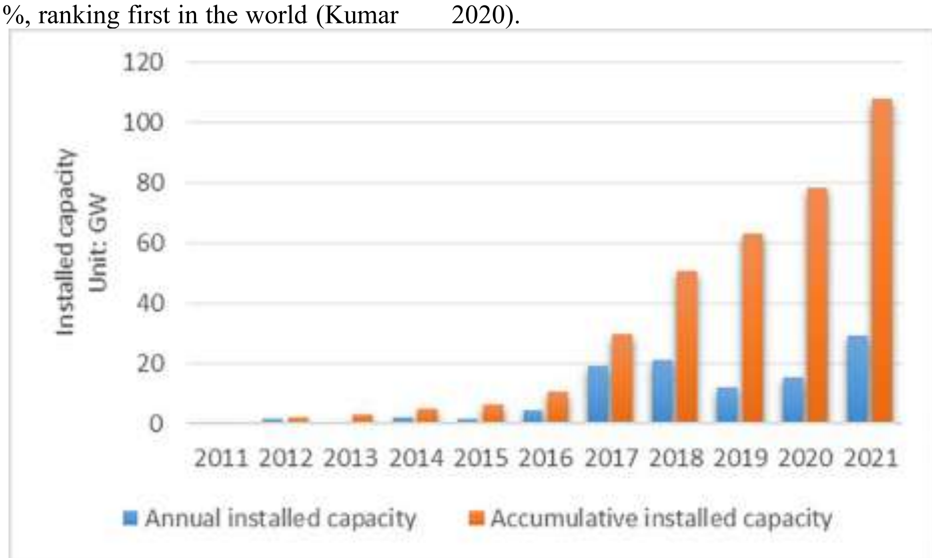

Fig. 3 The increasing trend of distributed solar PV installation capacity in China (Hu, 2023). Reproduced with permission. License number 5684141496108.

3.1 Modern technologies in solar PV energy utility in Chinese agriculture

China has been a global pioneer in the adoption and implementation of contemporary solar energy technology. Significant progress has been made because of the country's commitment to clean energy and a quick increase in solar power capacity (Fazal & Rubaiee, 2023). In China, where the government has aggressively promoted the use of renewable energy sources to address energy security and environmental issues (Morcilla & Enano, 2023), solar PV energy has found several applications in agriculture. Solar PV technology has been incorporated into different parts of Chinese agriculture, providing advantages such as lower energy costs, enhanced sustainability, and increased agricultural output (Irshad et al., 2023).

3.1.1 Solar PV energy-powered Greenhouse

Solar PV systems are incorporated into greenhouses in a variety of ways to reduce energy consumption and offer a more regulated and productive environment for plant development (Ndukwu, Augustine, et al., 2023). Solar PV panels put on a greenhouse's (Fig. 6) roof or surrounding regions can provide enough electricity to run the greenhouse's different electrical systems. Lighting, ventilation fans, temperature control systems, and irrigation equipment are all included. Climate control systems powered by solar PV, such as heating, cooling, and dehumidification, aid in maintaining ideal growth conditions within the greenhouse (Reza Rouzegar et al., 2023). These technologies have the potential to be energy-efficient, reducing the greenhouse's dependency on fossil fuels or grid electricity (Atalay & Aslan, 2023). Water pumps and irrigation systems may be powered by solar PV energy, guaranteeing a steady and efficient water supply for plants. This is especially crucial in areas where water is scarce or grid energy is unstable (Duque-Dussán et al., 2023). Solar energy may be utilized to power high-efficiency LED grow lights, extending daily light exposure for plants and stimulating development, particularly in places with low sunshine or during the winter months. Solar PV systems may be used in conjunction with energy storage technologies such as batteries to store surplus energy generated during the day for usage at night or on overcast days (Gitan & Al-Kayiem, 2023). This offers a dependable power supply for the greenhouse and allows it to operate off-grid. Solar panels are installed above crop rows in greenhouses in agrivoltaic

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systems. This method maximizes land utilization by generating power while also shading plants, minimizing the need for artificial shading (Singh et al., 2021).

Temperature, humidity, and other environmental parameters within the greenhouse may be monitored remotely using solar-powered monitoring and control systems (Philip et al., 2022). This information may be utilized to make real-time changes and enhance crop management. Solar-powered greenhouses are frequently utilized for agricultural research and development. Crop development under varied conditions may be studied thanks to the controlled environment and renewable energy sources. Solar-powered greenhouses provide a sustainable and cost-effective option for year-round food production in distant or off-grid agricultural locations (Liu et al., 2010). They can help with food security and economic growth in these areas. Solar energy may be used to power hydroponic and aquaponic systems in greenhouses, which are used to produce crops without soil (Jahangir et al., 2022). These systems frequently need the use of water pumps, aeration, and temperature control, all of which may be efficiently powered by solar PV. Solar-powered greenhouses help ecologically friendly and sustainable farming methods by lowering greenhouse gas emissions, energy costs, and dependency on fossil fuels (Zukowski & Woroniak, 2023). Solar PV electricity in greenhouses may drastically lower operational costs over time, making agriculture more economically viable for farmers. Solar PV energy integration in greenhouses provides a sustainable alternative to agricultural output. It not only minimizes the carbon footprint of greenhouse operations, but it also provides a consistent and clean energy supply, adding to agricultural practices' overall sustainability and resilience (Kellogg & Reguant, 2021).

Fig. 4 Solar PV energy-powered greenhouse (Going Solar, 2018). Reproduced with permission under the terms of the Creative Commons CC-BY license.

3.1.2 Solar PV-Powered dryers for agriculture in China

Solar-powered agricultural dryers use solar energy to remove moisture from agricultural products such as grains, fruits, vegetables, and herbs (Satpathy & Pamuru, 2021). These dryers provide an ecologically responsible and cost-effective method of preserving and processing agricultural products by lowering moisture content to a level that avoids spoiling and increases crop shelf life (Barbosa et al., 2023). Solar collectors, which gather and concentrate solar energy, are installed on solar dryers (as shown in Fig. 7 below). These collectors, which can be constructed of glass, plastic, or metal, are intended to raise the temperature within the dryer (Nayanita et al., 2022). Within the solar dryer, agricultural produce is put in a drying chamber or drying trays. To allow for appropriate air circulation, the drying chamber is frequently outfitted with perforated trays or shelves. The drying chamber is circulated by a solar-powered fan or blower. The heated air drawn in by the solar collectors is directed into the chamber, where it collects moisture from the crops before being discharged, sending the moisture away. Some sun dryers have temperature and humidity control devices to guarantee that the drying process is effective and that the crops are not overheated (Ramli & Jabbar, 2022).

Solar tunnel dryers are enclosed with constructions that are long and have sun collectors on one side and a drying chamber on the other. Solar cabinet dryers, on the other hand, are smaller, box-like constructions with a solar collector on top and drying trays within (Shakeel et al., 2023). They are suited for huge quantities of produce. They are used for lesser amounts of crops and are frequently portable. Hybrid Solar Dryers are attached to greenhouses with transparent roofs and use solar collectors to dry produce (Reza Rouzegar et al., 2023). They provide regulated drying settings. Some solar dryers are intended to function in tandem with other energy sources, such as biomass or electricity, to enable continuous operation even on overcast or nighttime days (Adamsab et al., 2019). Solar-powered agricultural dryers are a long-term solution for small and large-scale farmers, helping them to better manage their harvests, decrease food waste, and access markets for dried products.

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Their implementation helps to ensure food security and sustainable agriculture practices (Gitan & Al-Kayiem, 2023).

Solar PV-powered dryers are rapidly being utilized in China to dry agricultural products effectively and sustainably at a solar radiation intensity of 759.53W/m^2, the mass flow rate of air was 0.023 kg/s, and the solar dryer's thermal efficiency at 2.59 %., lowering post-harvest losses, boosting crop quality, and minimizing environmental impact (Verma et al., 2023). Dryers powered by solar PV are utilized for drying grains such as rice, wheat, corn, and soybeans. This is critical for decreasing moisture and avoiding spoiling. Solar dryers are used to preserve the nutritious content of fruits, vegetables, and herbs while also increasing their shelf life and are used to efficiently dry herbs and medicinal plants in China, which has a strong heritage of herbal medicine. In the fish processing sector, solar PV-powered dryers are used to dry and preserve fish and seafood products (Fazal & Rubaiee, 2023). The Chinese government has launched several initiatives and regulations to promote the use of solar PV-powered dryers, particularly in rural and agricultural areas. These projects frequently include financial incentives, subsidies, and assistance with technology transfer and training. Solar greenhouses are intended to be both drying facilities and agricultural-producing areas (Hu, 2023). These buildings are outfitted with solar panels and drying racks, allowing farmers to make better use of their land. Some solar dryers in China are hybrid systems that combine solar PV technology with other energy sources like biomass or biogas to enable constant operation even during overcast or rainy months. Solar dryers in China are available in a variety of configurations, including tunnel dryers, cabinet dryers, and greenhouse dryers (Suresh et al., 2023). The sort of drier used is determined by the crops and the climate.

Owing to China's dedication to renewable energy and sustainable agriculture, solar PV-powered dryers have become a significant tool for conserving and processing agricultural goods while decreasing environmental impact and boosting food security (Wanyama et al., 2023). According to market projections, the worldwide solar dryer market was valued at USD 3.5 billion in 2023 and is expected to rise at a compound annual growth rate (CAGR) of 10.6 % from 2023 to 2031. In 2023, the hybrid type category accounted for 42 % of the market and is predicted to retain its dominance during the forecast period. The Asia-Pacific region dominated the market in 2023, accounting for 38 % of the total, and is predicted to expand at the quickest pace of 12.4 % from 2023 to 2031 (Saini et al., 2023).

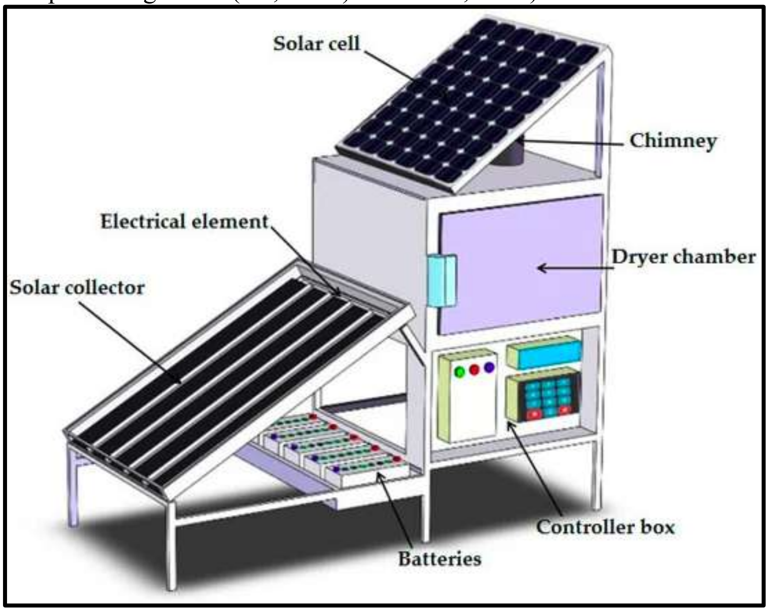

Fig. 5 Solar PV-Powered dryer for drying rosemary (Rosmarinus officinalis L.) leaves (Karami et al., 2021). Reproduced with permission under the terms of the Creative Commons CC-BY license.

3.1.3 Solar PV-Powered Irrigation System

Solar PV-powered irrigation systems have grown in popularity in China as part of the country's attempts to boost agricultural output, water resource management, and sustainability. China's vast agricultural industry, along with the country's dedication to renewable energy and environmental goals, has produced an opportune atmosphere for the development of solar PV-powered irrigation systems (Grant et al., 2022). The Chinese government has implemented several laws and measures to encourage the implementation of solar PV-powered irrigation systems. These include financial incentives, subsidies, and initiatives to encourage farmers to switch to solar-powered irrigation water pumps. Such initiatives include the "Photovoltaic Poverty Alleviation Program" and the "Solar Greenhouses" program. Irrigation systems powered by solar PV (as shown in Fig. 8 below) are frequently integrated into traditional farming methods (Sani Theo, 2023). Solar panels are used to power water pumps in agricultural areas or along the margins of irrigation ponds. This integration maximises land usage since the panels may offer shade for crops or fishponds (Liang, 2010). A study examined the effects of solar irradiance, panel temperature, and component efficiency on the dependability and performance of photovoltaic water pumping systems (PVWPS) under real-world operating conditions. Experiments were carried out on a 10 hp PVWPS in Bani Salamah, Al-Qanater-Giza Governorate, Egypt, between

December 2020 and June 2021, at latitude 30.3° N, longitude 30.8° E, and 19 m above sea level. The irradiance values at noon in December, March, and June were 755.7, 792.7, and 805.7 W/m^2, respectively. Furthermore, the irradiance has a significant impact on the pump flow rate, with 129, 164.1, and 181.8 m3/day pumped during the day, respectively. The temperatures in the panels rose to 35.7 °C, 39.9 °C, and 44 °C, respectively. When the temperature rises by one degree Celsius, efficiency decreases by 0.48 %. The average efficiency of photovoltaic solar panels was highest in March (13.8 %) and lowest in December (13 %) (Ahmed et al., 2023).

Implementation of solar PV-powered irrigation systems in China offers multiple advantages, such as a decrease in dependence on fossil fuels and grid electricity, resulting in fewer expenses for operation for farmers, higher energy effectiveness and dependability of water pumps, ensuring consistent water supply for crops, enhanced water resource management through remote monitoring and control of irrigation systems, and reduced environmental impact by lowering greenhouse gas emissions (Hoppmann et al., 2013; Sovacool, 2022). Yu et al. (2018) investigated the temporal and spatial distribution of cassava; discussed the potential and distribution of solar energy for irrigation; and finally considered the main factors influencing the feasibility of using a solar water pumping system to irrigate cassava. Solar water pumping was found to be suitable for irrigating a theoretical total of 718,500 ha of cassava, with the results currently applicable to a region of 623,000 ha (Yu et al., 2018). Solar PV irrigation is especially useful in distant and off-grid agricultural areas where access to grid electricity is limited. These systems offer farmers a dependable and sustainable water source, therefore promoting food security and economic growth. China has undertaken several large-scale solar irrigation projects, particularly in areas with strong sun radiation (Ndukwu, Akpan, et al., 2023). These projects might include large-scale solar panel installations, efficient water pumping systems, and cutting-edge monitoring and control technologies. Significant advances in solar PV technology have been made in China, including the creation of highly efficient solar panels and high-quality solar water pumping systems. These technical advancements have increased solar irrigation systems' overall effectiveness and dependability. The implementation of solar PV-powered irrigation coincides with China's aim to lower air pollution and tackle climate change (Che et al., 2022). These solutions assist in minimizing agriculture's environmental effects, resulting in cleaner air and a more sustainable farming industry. While solar PV-powered irrigation systems have various benefits, problems in China may include upfront expenditures for small-scale farmers, system dependability and maintenance in harsh weather conditions, and guaranteeing sufficient technical training and support for users (Verma et al., 2023). China's continued efforts to encourage the use of solar PV-powered irrigation systems are consistent with the country's overall aims of transitioning to clean and renewable energy sources, improving agricultural practices, and lowering the environmental effect of agriculture. These systems are critical to the country's agricultural production and water resource management (Che et al., 2022).

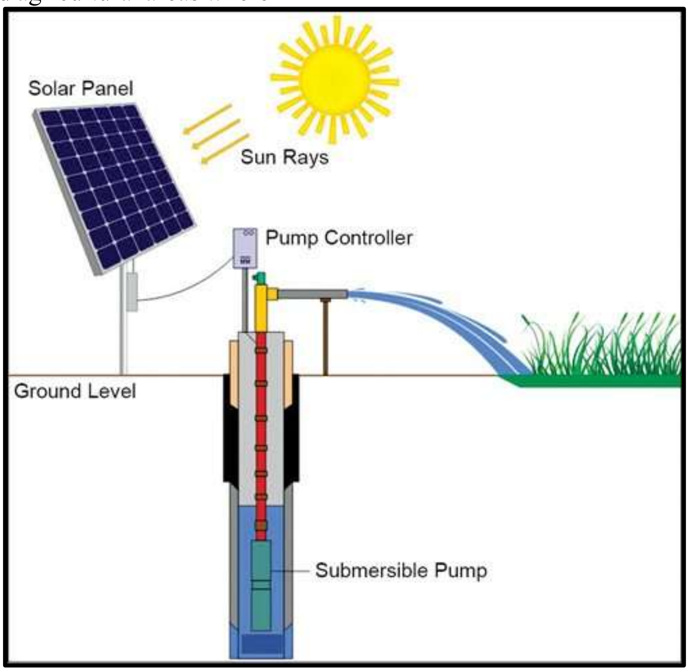

Fig. 6 Irrigation systems powered by solar PV (Sani Theo, 2023). Reproduced with permission under the terms of the Creative Commons CC-BY license.

3.1.4 Solar PV-powered Cameras and Sensors in China

In China, solar PV-powered cameras and sensors (as shown in Fig. 9 below) are widely employed for a variety of applications such as surveillance, environmental monitoring, and agricultural, and smart cities (Gorjian et al., 2020). These gadgets are outfitted with solar panels and energy storage technologies, allowing them to function autonomously by utilising solar energy (Das et al., 2022). Crop growth and health are monitored using solar-powered cameras and sensors. They give real-time data on elements like as temperature, humidity, soil moisture, and light levels, allowing farmers to make smart irrigation, fertilisation, and pest management decisions (Das et al., 2022). Pests and illnesses on crops may be detected using solar-powered cameras equipped with image recognition technology. Early diagnosis enables tailored treatments and lowers the use of pesticides. Solar-powered sensors are used to collect data on environmental factors such as temperature, humidity, and wind speed. This data is used to monitor microclimates and determine the appropriateness of a certain area for certain crops. Soil pH, nutrient levels, and moisture content may all be measured using solar-powered sensors. This information is critical for improving soil quality and nitrogen management. Solar-powered weather stations outfitted with a variety of sensors give real-time weather data for accurate forecasts and irrigation scheduling. Solar-powered cameras are used in agriculture to monitor livestock and ensure animal welfare. In irrigation systems, solar-powered sensors are used to improve water utilisation (Chand et al., 2021). They monitor soil moisture levels and adjust irrigation based on crop requirements and weather conditions.

The Chinese government aggressively promotes the use of solar PV-powered cameras and sensors in agriculture. They have been aggressively encouraging the use of solar PV-powered cameras and sensors in agriculture since January 2022. The use of solar-powered technology in agricultural monitoring systems is consistent with China's larger aim to modernize and increase the efficiency of its agricultural methods (Adak et al., 2022). As a result, utilities imposed PV power grid-friendly control (GFC) to provide additional flexibility for power system operations. Traditional GFC strategies have limitations in estimating real-time maximum available power, particularly when fast-moving clouds are present. In this regard, spatiotemporal (ST) PV nowcasting via a sensor network addresses the aforementioned issue. However, current ST nowcasting methods have issues such as predictor mis-selection, inconsistent nowcasting, and poor model adaptability, which make them unsuitable for GFC. This paper presents a novel ST PV power nowcasting method with predictor preselection that can be used for GFC. The proposed method allows for quick and precise predictor selection in various scenarios, as well as consistent PV nowcasts with cloud information interpolated. The proposed nowcasting method's effectiveness is tested in a real sensor network. The experimental results show that the proposed method has high robustness in a variety of weather conditions, despite using fewer training data. On cloudy days, the proposed method outperforms conventional methods by an average nRMSE and nPMAE improvement of 13.5 % and 41.3 %, respectively. It is also demonstrated how to apply the proposed nowcasting method to GFC operation. The results show that the proposed method has the potential to improve GFC performance (X. Chen et al., 2019). Solar-powered weather stations outfitted with a variety of sensors give real-time weather data for accurate forecasts and irrigation scheduling. Solar-power cameras are used in agriculture to monitor livestock and ensure animal welfare. In irrigation systems, solar-powered sensors are used to improve water utilization. They monitor soil moisture levels and adjust irrigation based on crop requirements and weather conditions.

Policies, incentives, and programs encourage the use of renewable energy technology and precision agriculture methods to increase production and sustainability (Zhang et al., 2024). Encouraging the adoption of renewable energy technologies and precision agriculture practices is a typical government approach to increasing agricultural productivity and sustainability. These regulations, incentives, and initiatives are intended to assist farmers and agricultural enterprises in implementing environmentally friendly and creative techniques. Besides, China's smart agriculture programs modernise the farming sector by utilizing solar-powered sensors and data analytics. These programs seek to boost crop yields while reducing resource use and environmental effects. Critical data and monitoring capabilities in rural and remote agricultural locations where connection to the electrical grid may be limited are provided. They contribute to closing the technology gap in these areas. Solar energy cuts operating costs for farmers by removing the requirement for grid electricity and lowering the costs associated with battery replacement (Sciences & 2022, 2022). The introduction of solar-powered sensors and cameras matches China's environmental and sustainability goals by minimizing agriculture's environmental effects. These technologies contribute to greener, more efficient farming methods by optimizing resource consumption (Millot et al., 2020). The use of solar PV-powered cameras and sensors in Chinese agriculture is part of the country's attempts to improve food security, resource efficiency, and environmental sustainability in agriculture. These technologies give useful insights and monitoring capabilities, resulting in more accurate and long-term agricultural operations.

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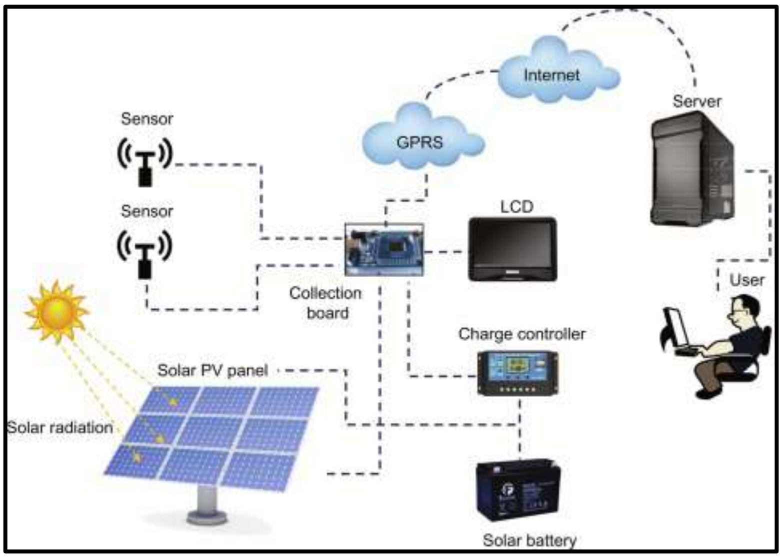

Fig. 7 Schematic illustration of solar PV systems in agricultural automation and robotics (Gorjian et al., 2020). Reproduced with permission. License number 5684151444521.

3.1.5 Solar PV energy-powered tractors/harvesters in China

Tractors (as shown in Fig. 10) and harvesters driven by solar PV electricity have grown in popularity in China as part of the country's commitment to renewable energy and sustainable agriculture. These machines are meant to use solar energy to accomplish a variety of farming activities, providing multiple advantages such as lower operating costs, environmental sustainability, and energy efficiency. In China, solar-powered tractors are harvesters outfitted with solar panels, which are commonly positioned on the roof. These panels use PV cells to turn sunlight into power. Electric motors are used in solar tractors/harvesters for propulsion as well as to power different tools and equipment (Gorjian et al., 2021). These motors are powered by the electricity generated by solar panels, allowing the tractor to do farming activities. Many solar-powered machines have battery storage devices for storing surplus power generated during sunny periods. These batteries can be used to power the tractor/harvesters in low light or at night.

In China, several solar tractors are hybrid systems. As a backup, they may be charged from the grid or other power sources, ensuring continued operation even when sunshine is scarce. Solar tractors are adaptable, and they may be used with a variety of farming accessories such as ploughs, tillers, seeders, and harvesters (Hamidinasab et al., 2023). These attachments are intended to help with various farming activities. Solar-powered tractors employ clean and sustainable solar energy, lowering carbon emissions and contributing to China's environmental sustainability. When compared to standard diesel-powered vehicles, these tractors have much reduced running expenses. They use less fuel and require less maintenance. Many solar harvesters have battery storage devices to store extra power generated by the sun. These batteries can be used to power the harvester in low light or at night. Some Chinese solar harvesters are hybrid systems, allowing them to be charged from the grid or other power sources as a backup. This ensures continued operation even when there is inadequate sunshine. Solar harvesters are outfitted with specific harvesting equipment that varies according to the crop being harvested. Reapers, threshers, and pickers are common attachments (Zheng & Zhou, 2023).

Solar tractors/harvesters can function in off-grid and isolated parts of China, which is especially useful in rural agricultural communities with limited access to traditional power sources. Solar tractors/harvesters employ extremely efficient electric motors that deliver steady power and torque (Gorjian et al., 2021). These devices are dependable and need little upkeep. Solar tractors and harvesters run silently and emit no direct pollutants, resulting in a healthier and more pleasant working environment for operators and surrounding communities. Solar tractors with battery storage can prolong their working hours, allowing farmers to work in low-light conditions or at night. Solar tractors are flexible for both small-scale and large-scale agricultural operations in China since they are appropriate for a wide range of crops and farming jobs. The usage of solar PV energy-powered tractors promotes China's drive to greener and more effective farming operations (Thomas et al., 2023). The initial cost of solar tractors/harvesters may be more than that of typical diesel-powered tractors, which may be a barrier to adoption for certain Chinese farmers. Solar tractors and harvesters in China, like those in other countries, rely on sunshine to operate, which might be a constraint during gloomy or wet weather. Proper management of the tractor's battery system is critical for long-term efficiency and performance. Solar tractors with battery storage can prolong their working hours. Solar tractors are flexible for both small-scale and large-scale agricultural operations in China since they are appropriate for a wide range of crops and farming jobs. The usage of solar PV energy-powered tractors promotes China's drive to greener and more effective farming operations (Thomas et al., 2023).

Fig. 8 Solar-powered tractor for agricultural usage (Tariq et al., 2021). Reproduced with permission under the terms of the Creative Commons CC-BY license.

4. Socioeconomic impact of solar PV energy on agriculture in China

Solar PV energy has a major and far-reaching socioeconomic influence on agriculture in China (Xie et al., 2022). Solar PV technology has played an important role in revolutionizing Chinese agriculture, making it more sustainable, efficient, and financially feasible (Luo et al., 2023). Solar PV-powered irrigation systems allow farmers to give their crops a continuous and predictable water supply. This has resulted in higher yields, improved food security, and enhanced agricultural revenue for farmers (Luo et al., 2023). Fig. 11 depicts the quick growth in solar expansion as well as the rapid performance in poverty reduction. Solar irrigation and other methods save energy expenses connected with farming operations. This means increased revenues for farmers and better socioeconomic situations in rural areas (Wang et al., 2020). Solar PV technology has increased access to power in distant and off-grid rural regions. Supplying dependable energy to homes, businesses, and schools has enhanced the general quality of life in these areas. The solar energy sector, including solar PV system manufacture and installation, has created job possibilities. This increase in employment is beneficial to rural economies. Solar PV initiatives in rural regions, such as the "Photovoltaic Poverty Alleviation Program," have contributed to poverty alleviation by providing new income-generating options for rural communities. As a result, the economic disparity between urban and rural areas has narrowed (Khalaf et al., 2023).

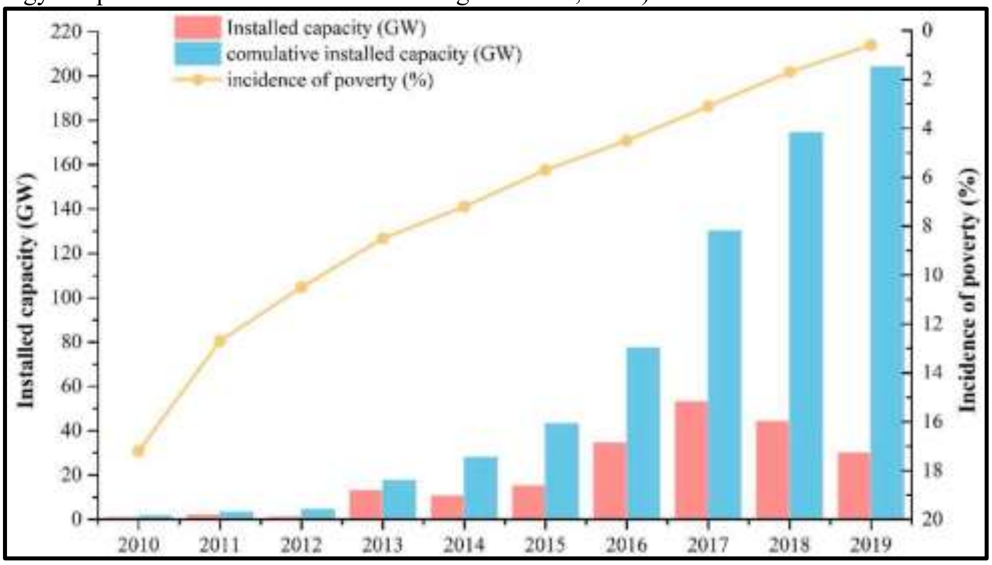

Fig. 11 depicts the quick growth in solar expansion as well as the rapid performance in poverty reduction (Li et al., 2022). Reproduced with permission. License number 5684160503242.

The use of clean, renewable energy in agriculture minimizes air pollution and greenhouse gas emissions, resulting in better environmental quality (Nwokolo et al., 2023). This provides health advantages and helps to improve the quality of life in rural areas (Luo et al., 2023). The adoption of solar PV technology in agriculture has fueled innovation and technical improvement. This has improved agricultural techniques and the competitiveness of Chinese farmers in both local and foreign markets (Wang et al., 2020). Training and capacity development for local populations are frequently included in the installation of solar PV installations. This provides farmers and rural populations with technical knowledge and skills (X. H. Chen et al., 2023). Solar-powered irrigation systems are more dependable and robust, guaranteeing uninterrupted water delivery for crops even during power outages or inclement weather. This decreases agricultural hazards and helps to maintain economic stability. In agriculture, solar-powered sensors and data analytics deliver real-time data and insights. Precision agriculture methods decreased resource waste, and higher agricultural production result from this. Solar PV project development frequently includes infrastructure development, such as upgraded roads and energy distribution networks, which benefit not just agriculture but also the broader socioeconomic growth of rural communities (Feng & Fang, 2022). Solar energy encourages energy independence by lowering dependency on fossil fuels and imported energy. This improves energy security as well as economic stability. Solar PV technology usage in agriculture contributes to China's clean energy transition, aligning with global environmental goals and showcasing the country's commitment to sustainability (Majeed et al., 2023). Overall, solar PV energy has aided rural development and the economic well-being of Chinese agricultural communities. It has not only increased agricultural efficiency, but it has also had a good social impact on rural education, employment, income, and environmental sustainability (Majeed et al., 2023).

4.1 Prospects and Recommendations

Precision agriculture is made possible by solar PV-powered sensors and data analytics. Farmers may make data-driven irrigation, fertilisation, and pest management decisions, resulting in better resource efficiency and crop quality. Solar PV system adoption in agriculture entails training and capacity-building activities for local populations. Farmers are now equipped with the technical knowledge and skills required to manage and maintain solar panels. Adoption of solar PV in agriculture benefits rural development, job creation, and poverty alleviation. It lowers income gaps between cities and rural areas and promotes rural populations' economic well-being (Jiang et al., 2023).

The usage of solar PV is consistent with China's overall clean energy transition and goal of lowering its carbon footprint (Mehmood et al., 2023). It exemplifies environmental management and long-term farming techniques. Solar PV energy utility prospects in Chinese agriculture are encouraging and coincide with the country's aims of developing sustainable and ecologically friendly farming methods. Despite these advantages, difficulties like as initial investment costs, weather reliance, and the necessity for adequate maintenance and battery management must be addressed. In general, using solar PV energy in Chinese agriculture provides a way toward cleaner, more sustainable, and economically viable farming techniques that benefit both farmers and the environment.

The applications of solar energy are pushed by the central government's and local governments' hortative policies; the government's allowance is crucial to boost the competitive power of PV production (Shuai et al., 2023). Furthermore, the Chinese central and local governments should raise PV research money to grasp key technologies such as circuit topology, MPPT control technique, and grid connection. Besides, the government should reduce or eliminate the tax, which will inspire companies and develop the PV market through government policy measures. Government measures should guarantee that investors benefit. To strengthen the energy structure, the government fund should undoubtedly be introduced in the enormous power supply project.

Ample funds and staff should be invested in PV-related research, and universities and graduate schools should be encouraged to do research in solar energy (Yang et al., 2023). Cooperation between corporations and universities should be strengthened to raise the level of research. Universities teach students to provide people with the ability to cooperate. Certainly, central and local governments should support foreign collaboration to develop domestic technologies. To increase the economic advantage of the Chinese PV sector, the PV industrial chain should be built. In particular, the scarcity of silicon material and crucial technologies should be addressed in the future. To consume huge quantities of PV goods, the PV market needs to be expanded. The attestation and detection organisation lacks communication with international organisations, and an industry-wide standard should be formed.

4.2 Discussion

Solar PV installed power capacity is expected to surpass coal by 2027, making it the world's largest. Cumulative solar PV capacity is expected to triple, increasing by nearly 1,500 GW over the period, surpassing natural gas by 2026 and coal by 2027. For the next five years, annual solar PV capacity additions will increase. Despite current higher investment costs due to rising commodity prices, utility-scale solar PV is the most cost-effective option for new electricity generation in most countries around the world. As a result of higher retail electricity prices and growing policy support to help consumers save money on their energy bills, distributed solar PV, such as rooftop solar on buildings, is also expected to grow faster. In 2022, solar PV generation increased by a record 270 TWh (up 26 %), reaching nearly 1 300 TWh. In 2022, it had the highest absolute generation growth of any renewable technology, surpassing wind for the first time in history. This rate of generation growth corresponds to the level anticipated from 2023 to 2030 in the Net Zero Emissions by 2050 Scenario. Continuous growth in the economic attractiveness of PV, massive supply chain development, and increasing policy support, particularly in China, the United States, the European Union, and India, are expected to accelerate capacity growth in the coming years. As a result, the tracking status of solar PV has been upgraded from "more effort needed" to "on track" in 2023.

Maintaining a generation growth rate consistent with the Net Zero Scenario will necessitate annual capacity additions nearly three times greater than those of 2022 until 2030. This will necessitate ongoing policy ambition and effort on the part of both public and private stakeholders, particularly in the areas of grid integration and addressing policy, regulatory, and financing challenges. PV technology, as a rapidly increasing renewable-based approach, can provide a promising choice for sustainably powering agricultural activities. PV technology can provide both heat and power demands in agriculture, with the latter being accomplished through the use of photovoltaic-thermal systems. Distributed solar PV systems are preferable in protected cultivation systems such as greenhouses, but large-scale centralized PV power plants are more viable in big farms. Several studies have been undertaken to assess the integration of PV technology with agricultural chores that are broadly classed as traditional and contemporary. Modern operations include the combination of solar PV technology with electric farm tractors and agricultural robots.

China is the world's biggest agricultural producer, but it is now experiencing major energy supply and environmental issues. China has been the world's greatest CO2 emitter since 2007, with an annual emission load of 300 million tons. Aside from the usage of crude oil and raw coal, China is the world leader in electricity consumption. China has analyzed its energy system and devised a plan for solar energy in response to the urgent challenges of post-harvest losses, energy supply, and the environment. Solar drying of agricultural goods is ecologically benign and is quickly becoming popular. The greenhouse dryer, collector dryer, collector-greenhouse hybrid dryer, integrated dryer, and focused dryer are all commercially utilized in the nation. Since 2000, more than 200 solar drying systems with a total surface of 20,000 m2 of solar collectors have been constructed in China to dry diverse commodities such as grain, vegetables, fruits, and Chinese herbal medicines. The goal is for sun-drying systems to be used for more than 50 % of grain drying by 2020, with a solar contribution of more than 40 %. Recently, a flat plate solar collector with dual function (FSDF) has been employed in a hybrid dryer system consisting of the FSDF, a water tank and auxiliary system, and a drying chamber. The yearly cost of the FSDF hybrid dryer was found to be 1.1 % less than that of electricity, 142.9 % less than that of the heat pump, and 13.7 % less than that of coal. To encourage the use of solar thermal energy in China, China has established development goals and drafted a "Renewable Energy Law"; and conducted research on near-term (2020), mid-term (2030), and long-term (2050) energy strategies for the systematic and integrated development of solar energy, focusing on market, technologies, industry, and policies; and proposed various economic incentives such as providing financial assistance through investment subsidies.

5. CONCLUSION

Agricultural power consumption in China reached 102.2 billion kWh and accounted for 1.9 % of overall energy consumption in 2021, a 3.4 percentage point decline from 2000 owing to the integration of solar PV systems into the sector. Current trends demonstrate that solar PV technology added over 10 GW of solar capacity to benefit over 2 million citizens by 2020 for irrigation, automation, and smart agricultural operations. Hence, increasing per-capita income by approximately 7 % to 8 %. By the end of 2018, a total of 15.44 million kW of solar PV poverty alleviation had been allocated nationwide to 2.24 million homes. Combining PV technology with agricultural activities results in increased yield per unit of farmed land, with values ranging from 20 to 60 % higher depending on crop variety. However, the integration of renewable energy into existing energy infrastructure lacks crucial technical, economic, and environmental components of thorough feasibility research. This research looks at the integration of solar PV electricity into the Chinese agriculture industry. Overall, using solar PV energy in Chinese agriculture provides a way toward cleaner, more sustainable, and economically viable farming techniques that benefit both farmers and the environment. The increased use of solar PV energy in agriculture has significantly transformed the sector by increasing energy efficiency, improving resource management, cutting operating costs, reducing greenhouse gas emissions, air pollution, and the environmental consequences of agricultural operations. Solar PV energy has a significant and far-reaching socioeconomic impact on Chinese agriculture, making it more sustainable, efficient, and financially viable.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All the data generated or analyzed during this study are included in this published article.

Ethical Approval

Not applicable

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author Contributions

Josephine Baffoe: Conceptualisation, Methodology, Writing-Original Draft, Writing-Review and Editing; **Li-hua Ye**: Resources, Writing-Review and Editing, Supervision; **Yefan Shi**: Resources, Validation, Formal analysis; **Hao Chen**:

Writing-Original Draft; Ai-ping Shi: Formal analysis, Writing-Review and Editing

REFERENCES

1. Adak, D., Bhattacharyya, R., & Barshilia, H. C. (2022). A state-of-the-art review on the multifunctional self-cleaning nanostructured coatings for PV panels, CSP mirrors and related solar devices. Renewable and Sustainable Energy Reviews, 159. https://doi.org/10.1016/j.rser.2022.112145
2. Adamsab, K., Saif, M., Saif, S., Khamis, I., & Talib, W. (2019). Hybrid-powered intelligent irrigation system using Oman Falaj and solar energy. Materials Today: Proceedings, 41, 260–264. https://doi.org/10.1016/j.matpr.2020.09.033
3. Ahmed, N. M., Hassan, A. M., Kassem, M. A., Hegazi, A. M., & Elsaadawi, Y. F. (2023). Reliability and performance evaluation of a solar PV-powered underground water pumping system. Scientific Reports, 13(1), 14174. https://doi.org/10.1038/s41598-023-41272-5
4. Alami, A. H., Ramadan, M., Abdelkareem, M. A., Alghawi, J. J., Alhattawi, N. T., Mohamad, H. A., & Olabi, A.-G. (2022). Novel and practical photovoltaic applications. Thermal Science and Engineering Progress, 29, 101208. https://doi.org/10.1016/j.tsep.2022.101208
5. Al-Mamun, Md. R., Roy, H., Islam, Md. S., Ali, Md. R., Hossain, Md. I., Saad Aly, M. A., Hossain Khan, Md. Z., Marwani, H. M., Islam, A., Haque, E., Rahman, M. M., & Awual, Md. R. (2023). State-of-the-art in solar water heating (SWH) systems for sustainable solar energy utilization: A comprehensive review. Solar Energy, 111998. https://doi.org/10.1016/J.SOLENER.2023.111998
6. Atalay, H., & Aslan, V. (2023). Advanced exergoeconomic and exergy performance assessments of a wind and solar energy powered hybrid dryer. Renewable Energy, 209, 218–230. https://doi.org/10.1016/j.renene.2023.03.137
7. Azarpour, A., Mohammadzadeh, O., Rezaei, N., & Zendehboudi, S. (2022). Current status and prospects of renewable and sustainable energy in North America: Progress and challenges. Energy Conversion and Management, 269, 115945. https://doi.org/10.1016/j.enconman.2022.115945
8. Barbosa, E. G., Araujo, M. E. V. de, Oliveira, A. C. L. de, & Martins, M. A. (2023). Thermal energy storage systems applied to solar dryers: Classification, performance, and numerical modelling: An updated review. Case Studies in Thermal Engineering, 45. https://doi.org/10.1016/j.csite.2023.102986
9. Benyezza, H., Bouhedda, M., Kara, R., & Rebouh, S. (2023). Smart platform based on IoT and WSN for monitoring and control of a greenhouse in the context of precision agriculture. Internet of Things, 23, 100830. https://doi.org/10.1016/J.IOT.2023.100830
10. Chand, A. A., Prasad, K. A., Mar, E., Dakai, S., Mamun, K. A., Islam, F. R., Mehta, U., Kumar, N. M., Muñoz-García, M.-Á., & Hernández-Callejo, L. (2021). Design and analysis of photovoltaic powered battery-operated computer vision-based multi-purpose smart farming robot. Mdpi.Com. https://doi.org/10.3390/agronomy11030530
11. Che, X. J., Zhou, P., & Chai, K. H. (2022). Regional policy effect on photovoltaic (PV) technology innovation: Findings from 260 cities in China. Energy Policy, 162. https://doi.org/10.1016/j.enpol.2022.112807
12. Chen, X., Du, Y., Lim, E., Wen, H., & Jiang, L. (2019). Sensor network-based PV power nowcasting with spatio-temporal preselection for grid-friendly control. Applied Energy, 255, 113760. https://doi.org/10.1016/j.apenergy.2019.113760
13. Chen, X. H., Tee, K., Elnahass, M., & Ahmed, R. (2023). Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China. Journal of Environmental Management, 345. https://doi.org/10.1016/j.jenvman.2023.118525
14. Das, G., Gould, I., Zarafshan, & J Heselden. (2022). Applications of robotic and solar energy in precision agriculture and smart farming. https://www.sciencedirect.com/science/article/pii/B9780323898669000110
15. Duque-Dussán, E., Sanz-Uribe, J. R., & Banout, J. (2023). Design and evaluation of a hybrid solar dryer for postharvesting processing of parchment coffee. Renewable Energy, 215. https://doi.org/10.1016/j.renene.2023.118961
16. Fagiolari, L., Sampò, M., Lamberti, A., Amici, J., Francia, C., Bodoardo, S., & Bella, F. (2022). Integrated energy conversion and storage devices: Interfacing solar cells, batteries and supercapacitors. Energy Storage Materials, 51, 400–434. https://doi.org/10.1016/j.ensm.2022.06.051
17. Fazal, M. A., & Rubaiee, S. (2023). Progress of PV cell technology: Feasibility of building materials, cost, performance, and stability. Solar Energy, 258, 203–219. https://doi.org/10.1016/J.SOLENER.2023.04.066
18. Feng, R., & Fang, X. (2022). China's pathways to synchronize the emission reductions of air pollutants and greenhouse gases: Pros and cons. Resources, Conservation and Recycling, 184. https://doi.org/10.1016/j.resconrec.2022.106392
19. Ghosh, A. (2023). Nexus between agriculture and photovoltaics (agrivoltaics, agriphotovoltaics) for sustainable development goal: A review. Solar Energy, 266, 112146. https://doi.org/10.1016/j.solener.2023.112146
20. Gitan, A. A., & Al-Kayiem, H. H. (2023). Assessment of hybrid solar-thermal multi-chamber dryer integrated with desiccant dehumidifier for uniform drying. Solar Energy, 262. https://doi.org/10.1016/j.solener.2023.111880
21. Going Solar. (2018). What's a Solar Greenhouse? https://goingsolar.com/why-greenhouses-are-the-ultimate-solar-energy-technology/
22. Gorjian, S., Ebadi, H., Trommsdorff, M., Sharon, H., Demant, M., & Schindele, S. (2021). The advent of modern solar-powered electric agricultural machinery: A solution for sustainable farm operations. Journal of Cleaner Production, 292, 126030. https://doi.org/10.1016/j.jclepro.2021.126030
23. Gorjian, S., Minaei, S., MalehMirchegini, L., Trommsdorff, M., & Shamshiri, R. R. (2020). Applications of solar PV systems in agricultural automation and robotics. Photovoltaic Solar Energy Conversion: Technologies, Applications and Environmental Impacts, 191–235. https://doi.org/10.1016/B978-0-12-819610-6.00007-7
24. Grant, F., Sheline, C., Sokol, J., Amrose, S., Brownell, E., Nangia, V., & Winter, A. G. (2022). Creating a Solar-Powered Drip Irrigation Optimal Performance model

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(SDrOP) to lower the cost of drip irrigation systems for smallholder farmers. Applied Energy, 323. https://doi.org/10.1016/j.apenergy.2022.119563

25. Guo, B., He, D., Zhao, X., Zhang, Z., & Dong, Y. (2020). Analysis of the spatiotemporal patterns and driving mechanisms of China's agricultural production efficiency from 2000 to 2015. Physics and Chemistry of the Earth, Parts A/B/C, 120, 102909. https://doi.org/10.1016/J.PCE.2020.102909
26. Hamidinasab, B., Javadikia, H., Hosseini-Fashami, F., Kouchaki-Penchah, H., & Nabavi-Pelesaraei, A. (2023). Illuminating sustainability: A comprehensive review of the environmental life cycle and exergetic impacts of solar systems on the agri-food sector. Solar Energy, 262. https://doi.org/10.1016/j.solener.2023.111830
27. Hoppmann, J., Peters, M., Schneider, M., & Hoffmann, V. H. (2013). The two faces of market support - How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. Research Policy, 42(4), 989–1003. https://doi.org/10.1016/j.respol.2013.01.002
28. Hu, Z. (2023). Towards solar extractivism? A political ecology understanding of the solar energy and agriculture boom in rural China. Energy Research & Social Science, 98, 102988. https://doi.org/10.1016/j.erss.2023.102988
29. Irshad, A. S., Ludin, G. A., Masrur, H., Ahmadi, M., Yona, A., Mikhaylov, A., Krishnan, N., & Senjyu, T. (2023). Optimization of grid-photovoltaic and battery hybrid system with most technically efficient PV technology after the performance analysis. Renewable Energy, 207, 714–730. https://doi.org/10.1016/j.renene.2023.03.062
30. Jahangir, M. H., Kargarzadeh, A., & Javanshir, F. (2022). Energy investigation in buildings applying a solar adsorption chiller coupled with biofuel heaters and solar heating/cooling systems in different climates. Energy Reports, 8, 15493–15510. https://doi.org/10.1016/j.egyr.2022.10.428
31. Jiang, H., Yao, L., & Zhou, C. (2023). Assessment of offshore wind-solar energy potentials and spatial layout optimization in mainland China. Ocean Engineering, 287. https://doi.org/10.1016/j.oceaneng.2023.115914
32. Kanwal, T., Rehman, S., Ali, T., Mahmood, K., Agriculture, S. V.-, & 2023, undefined. (2023). An intelligent dual-axis solar tracking system for remote weather monitoring in the agricultural field. Mdpi.Com. https://www.mdpi.com/2077-0472/13/8/1600
33. Karami, H., Kaveh, M., Golpour, I., Khalife, E., Rusinek, R., Dobrzański, B., & Gancarz, M. (2021). Thermodynamic Evaluation of the Forced Convective Hybrid-Solar Dryer during Drying Process of Rosemary (Rosmarinus officinalis L.) Leaves. Energies, 14(18), 5835. https://doi.org/10.3390/en14185835
34. Kellogg, R., & Reguant, M. (2021). Energy and environmental markets, industrial organization, and regulation. Handbook of Industrial Organization, 5(1), 615–742. https://doi.org/10.1016/bs.hesind.2021.11.017
35. Khalaf, K. A., Gamil, A., Attiya, B., & Cuello, J. (2023). Exploring the potential of concentrating solar power technologies for vertical farming in arid regions: The case of Western Iraq. Energy for Sustainable Development, 77, 101310. https://doi.org/10.1016/J.ESD.2023.101310
36. Kumar, Ch. M. S., Singh, S., Gupta, M. K., Nimdeo, Y. M., Raushan, R., Deorankar, A. V., Kumar, T. M. A., Rout, P. K., Chanotiya, C. S., Pakhale, V. D., & Nannaware, A. D. (2023). Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications. Sustainable Energy Technologies and Assessments, 55, 102905. https://doi.org/10.1016/j.seta.2022.102905
37. Kumar Sahu, B. (2015). A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. Renewable and Sustainable Energy Reviews, 43, 621–634. https://doi.org/10.1016/j.rser.2014.11.058
38. Li, J., Peng, J., Shuai, C., Wang, Z., Huang, F., & Khayyam, M. (2022). Does the solar PV program enhance the social empowerment of China's rural poor? Energy, 253, 124084. https://doi.org/10.1016/j.energy.2022.124084
39. Liang, W. (2010). Changing Climate? China's New Interest in Global Climate Change Negotiations. In China's Environmental Crisis (pp. 61–84). Palgrave Macmillan US. https://doi.org/10.1057/9780230114364_4
40. Liu, L., Wang, Z., Zhang, H., & Xue, Y. (2010). Solar energy development in China—A review. Renewable and Sustainable Energy Reviews, 14(1), 301–311. https://doi.org/10.1016/j.rser.2009.08.005
41. Lobaccaro, G., Croce, S., Lindkvist, C., Munari Probst, M. C., Scognamiglio, A., Dahlberg, J., Lundgren, M., & Wall, M. (2019). A cross-country perspective on solar energy in urban planning: Lessons learned from international case studies. Renewable and Sustainable Energy Reviews, 108, 209–237. https://doi.org/10.1016/j.rser.2019.03.041
42. Luo, P., Tang, X., Dou, X., Liu, S., Ren, K., Jiang, Y., Yang, Z., Ding, Y., & Li, M. (2023). Uncovering the socioeconomic impacts of China's power system decarbonization. Environmental Impact Assessment Review, 99. https://doi.org/10.1016/j.eiar.2022.107015
43. Majeed, Y., Khan, M. U., Waseem, M., Zahid, U., Mahmood, F., Majeed, F., Sultan, M., & Raza, A. (2023). Renewable energy as an alternative source for energy management in agriculture. Energy Reports, 10, 344–359. https://doi.org/10.1016/j.egyr.2023.06.032
44. Manna, M. C., Rahman, M. M., Naidu, R., Bari, A. S. M. F., Singh, A. B., Thakur, J. K., Ghosh, A., Patra, A. K., Chaudhari, S. K., & Subbarao, A. (2021). Organic farming: A prospect for food, environment and livelihood security in Indian agriculture (pp. 101–153). https://doi.org/10.1016/bs.agron.2021.06.003
45. Mehmood, A., Ren, J., & Zhang, L. (2023). Achieving energy sustainability by using solar PV: System modelling and comprehensive techno-economic-environmental analysis. Energy Strategy Reviews, 49. https://doi.org/10.1016/j.esr.2023.101126
46. Millot, A., Krook-Riekkola, A., & Maïzi, N. (2020). Guiding the future energy transition to net-zero emissions: Lessons from exploring the differences between France and Sweden. Energy Policy, 139. https://doi.org/10.1016/j.enpol.2020.111358
47. Morcilla, R. V., & Enano, N. H. (2023). Sizing of community centralized battery energy storage system and aggregated residential solar PV system as virtual power plant to support electrical distribution network reliability improvement. Renewable Energy Focus, 46, 27–38. https://doi.org/10.1016/j.ref.2023.05.007

48. *Muhammed, G., & Tekbiyik-Ersoy, N. (2020). Development of Renewable Energy in China, USA, and Brazil: A Comparative Study on Renewable Energy Policies. Sustainability, 12(21), 9136. https://doi.org/10.3390/su12219136*
49. *Nayanita, K., Rani Shaik, S., & Muthukumar, P. (2022). Comparative study of Mixed-Mode Type and Direct Mode Type Solar Dryers using Life Cycle Assessment. Sustainable Energy Technologies and Assessments, 53. https://doi.org/10.1016/j.seta.2022.102680*
50. *Ndukwu, M. C., Akpan, G., Okeahialam, A. N., Umoh, J. D., Ubuoh, E. A., Benjamine, U. G., Nwachukwu, C., Kalu, C. A., Mbanasor, J., & Wu, H. (2023). A comparison of the drying kinetics, energy consumption and colour quality of drying medicinal leaves in direct-solar dryer with different colours of collector cover. Renewable Energy, 216. https://doi.org/10.1016/j.renene.2023.119076*
51. *Ndukwu, M. C., Augustine, E. Ben, Ugwu, E., Ibeh, M. I., Ekop, I., Akpan, G., Udo, A. E., Ihediwa, V. E., Akuwueke, L., Mbanasor, J., & Abam, F. (2023). Drying kinetics and thermo-economic analysis of drying hot water blanched ginger rhizomes in a hybrid composite solar dryer with heat exchanger. Heliyon, 9(2). https://doi.org/10.1016/j.heliyon.2023.e13606*
52. *Nwokolo, S. C., Ogbulezie, J. C., & Ushie, O. J. (2023). A multi-model ensemble-based CMIP6 assessment of future solar radiation and PV potential under various climate warming scenarios. Optik, 285. https://doi.org/10.1016/j.ijleo.2023.170956*
53. *Philip, N., Duraipandi, S., & Sreekumar, A. (2022). Techno-economic analysis of greenhouse solar dryer for drying agricultural produce. Renewable Energy, 199, 613–627. https://doi.org/10.1016/j.renene.2022.08.148*
54. *Radovanović, M. (2023). Strategic priorities of sustainable energy development. Sustainable Energy Management, 181–277. https://doi.org/10.1016/B978-0-12-821086-4.00004-0*
55. *Rahman, M. M., Khan, I., Field, D. L., Techato, K., & Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications. Renewable Energy, 188, 731–749. https://doi.org/10.1016/j.renene.2022.02.065*
56. *Ramli, R. M., & Jabbar, W. A. (2022). Design and implementation of solar-powered with IoT-Enabled portable irrigation system. Internet of Things and Cyber-Physical Systems, 2, 212–225. https://doi.org/10.1016/j.iotcps.2022.12.002*
57. *Razzaq, A., Sharif, A., Ozturk, I., & Skare, M. (2023). Asymmetric influence of digital finance, and renewable energy technology innovation on green growth in China. Renewable Energy, 202, 310–319. https://doi.org/10.1016/j.renene.2022.11.082*
58. *Reza Rouzegar, M., Hossein Abbaspour-Fard, M., & Hedayatizadeh, M. (2023). Design, thermal simulation and experimental study of a hybrid solar dryer with heat storage capability. Solar Energy, 258, 232–243. https://doi.org/10.1016/j.solener.2023.05.003*
59. *Saini, R. K., Saini, D. K., Gupta, R., Verma, P., Thakur, R., Kumar, S., & wassouf, A. (2023). Technological development in solar dryers from 2016 to 2021-A review. Renewable and Sustainable Energy Reviews, 188, 113855. https://doi.org/10.1016/j.rser.2023.113855*
60. *Sani Theo. (2023, August 28). Solar Power Irrigation System for Sustainable Agriculture. Electronicsforu.*
61. *Satpathy, R., & Pamuru, V. (2021). Solar PV systems and applications. Solar PV Power, 243–266. https://doi.org/10.1016/B978-0-12-817626-9.00006-X*
62. *Sayed, E. T., Olabi, A. G., Elsaid, K., Al Radi, M., Alqadi, R., & Ali Abdelkareem, M. (2023). Recent progress in renewable energy based-desalination in the Middle East and North Africa MENA region. Journal of Advanced Research, 48, 125–156. https://doi.org/10.1016/j.jare.2022.08.016*
63. *Sciences, C. M.-A., & 2022, undefined. (2022). Incorporating artificial intelligence technology in smart greenhouses: Current State of the Art. Mdpi.Com. https://doi.org/10.3390/app13010014*
64. *Senthil Kumar, S., Bibin, C., Akash, K., Aravindan, K., Kishore, M., & Magesh, G. (2020). Solar powered water pumping systems for irrigation: A comprehensive review on developments and prospects towards a green energy approach. Materials Today: Proceedings, 33, 303–307. https://doi.org/10.1016/J.MATPR.2020.04.092*
65. *Shakeel, S. R., Yousaf, H., Irfan, M., & Rajala, A. (2023). Solar PV adoption at household level: Insights based on a systematic literature review. Energy Strategy Reviews, 50, 101178. https://doi.org/10.1016/j.esr.2023.101178*
66. *Shuai, J., Zhao, Y., Xiong, X., Shuai, C., & Wang, J. (2023). The co-opetition relationships of critical mineral resources for the solar PV industry between China and the world major powers. Journal of Cleaner Production, 426, 139171. https://doi.org/10.1016/J.JCLEPRO.2023.139171*
67. *Singh, S., Gill, R. S., Hans, V. S., & Singh, M. (2021). A novel active-mode indirect solar dryer for agricultural products: Experimental evaluation and economic feasibility. Energy, 222. https://doi.org/10.1016/j.energy.2021.119956*
68. *Sovacool, B. K. (2022). A perspective on treaties, maximum wages, and carbon currencies: Innovative policy instruments for global decarbonization. Energy Policy, 160. https://doi.org/10.1016/j.enpol.2021.112702*
69. *Su, X., Xu, Z., Tian, S., Chen, C., Huang, Y., Geng, Y., & Chen, J. (2023). Life cycle assessment of three typical solar energy utilization systems in different regions of China. Energy, 278. https://doi.org/10.1016/j.energy.2023.127736*
70. *Suresh, B. V., Shireesha, Y., Kishore, T. S., Dwivedi, G., Haghighi, A. T., & Patro, E. R. (2023). Natural energy materials and storage systems for solar dryers: State of the art. Solar Energy Materials and Solar Cells, 255, 112276. https://doi.org/10.1016/j.solmat.2023.112276*
71. *Tang, W., Feng, G., Tan, Q., Xu, Z., Feng, K., & Lu, X. (2023). Current situation and trend analysis of rural electrification in China. IOP Conference Series: Earth and Environmental Science, 1171(1), 012016. https://doi.org/10.1088/1755-1315/1171/1/012016*
72. *Tariq, G. H., Ashraf, M., & Hasnain, U. S. (2021). Solar Technology in Agriculture. Technology in Agriculture. https://doi.org/10.5772/INTECHOPEN.98266*
73. *Thomas, S. J., Thomas, S., Sahoo, S. S., G, A. K., & Awad, M. M. (2023). Solar parks: A review on impacts, mitigation mechanism through agrivoltaics and techno-economic analysis. Energy Nexus, 11. https://doi.org/10.1016/j.nexus.2023.100220*
74. *Urban, F., Geall, S., & Wang, Y. (2016). Solar PV and solar water heaters in China: Different pathways to low carbon*

energy. Renewable and Sustainable Energy Reviews, 64, 531–542. https://doi.org/10.1016/J.RSER.2016.06.023

75. *Verma, G., Dewangan, N., Kumar Ghritlahre, H., Verma, M., Kumar, S., Kumar, Y., & Agrawal, S. (2023). Experimental investigation of mixed mode ultraviolet tent house solar dryer under natural convection regime. Solar Energy, 251, 51–67. https://doi.org/10.1016/j.solener.2022.12.052*
76. *Wang, Z., Huang, F., Liu, J., Shuai, J., & Shuai, C. (2020). Does solar PV bring a sustainable future to the poor? – an empirical study of anti-poverty policy effects on environmental sustainability in rural China. Energy Policy, 145. https://doi.org/10.1016/j.enpol.2020.111723*
77. *Wanyama, J., Soddo, P., Nakawuka, P., Tumutegyereize, P., Bwambale, E., Oluk, I., Mutumba, W., & Komakech, A. J. (2023). Development of a solar powered smart irrigation control system Kit. Smart Agricultural Technology, 5. https://doi.org/10.1016/j.atech.2023.100273*
78. *Xie, D., Chen, L., Liu, L., Chen, L., & Wang H. (2022). Actuators and sensors for application in agricultural robots: A review. Mdpi.Com. https://www.mdpi.com/2075-1702/10/10/913*
79. *Yang, L. W., Gao, X. Q., & Li, Z. C. (2023). An overview of the policies and models of integrated development for solar and wind power generation in China. Research in Cold and Arid Regions. https://doi.org/10.1016/j.rcar.2023.09.001*
80. *Yap, K. Y., Chin, H. H., & Klemeš, J. J. (2022). Solar Energy-Powered Battery Electric Vehicle charging stations: Current development and future prospect review. Renewable and Sustainable Energy Reviews, 169, 112862. https://doi.org/10.1016/J.RSER.2022.112862*
81. *Yu, Y., Liu, J., Wang, Y., Xiang, C., & Zhou, J. (2018). Practicality of using solar energy for cassava irrigation in the Guangxi Autonomous Region, China. Applied Energy, 230, 31–41. https://doi.org/10.1016/j.apenergy.2018.08.060*
82. *Zhang, H., Jing, Z., Ali, S., Asghar, M., & Kong, Y. (2024). Renewable energy and natural resource protection: Unveiling the nexus in developing economies. Journal of Environmental Management, 349, 119546. https://doi.org/10.1016/j.jenvman.2023.119546*
83. *Zhang, H., Wu, K., Qiu, Y., Chan, G., Wang, S., Zhou, D., & Ren, X. (2020). Solar photovoltaic interventions have reduced rural poverty in China. Nature Communications, 11(1), 1969. https://doi.org/10.1038/s41467-020-15826-4*
84. *Zheng, X., & Zhou, Y. (2023). A three-dimensional unsteady numerical model on a novel aerogel-based PV/T-PCM system with dynamic heat-transfer mechanism and solar energy harvesting analysis. Applied Energy, 338. https://doi.org/10.1016/j.apenergy.2023.120899*
85. *Zou, H., Du, H., Ren, J., Sovacool, B. K., Zhang, Y., & Mao, G. (2017). Market dynamics, innovation, and transition in China's solar photovoltaic (PV) industry: A critical review. Renewable and Sustainable Energy Reviews, 69, 197–206. https://doi.org/10.1016/j.rser.2016.11.053*
86. *Zukowski, M., & Woroniak, G. (2023). Estimation of energy savings resulting from the cooperation of an air to water heat pump with a solar air heater. Solar Energy, 250, 182–193. https://doi.org/10.1016/j.solener.2022.12.043*