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Utilization of Solar Energy in Agricultural Machinery Engineering: A Review

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Abstract

Background: Various solar energy collecting systems have been developed and analyzed for agricultural applications. They include solar thermal and electric devices such as solar crop dryers, solar water pumps, solar greenhouse heating, ventilation for livestock, solar aeration pumps, solar electricity, and many more. **Purpose:** This review provides the current status of research and development in the field as well as the solar energy systems that are currently in use in the agriculture sector across the globe. **Review:** Solar energy is the largest and cheapest energy resource on earth; one hour of solar radiation exceeds the complete global energy consumption in one year. The potential annual total solar radiation in South Korea is 3.58–5.4 kWh/m^2/day. The available solar energy is sufficient for agricultural applications across the entire country. **Conclusion:** The scope of solar energy utilization in agricultural machinery engineering in South Korea and in other countries is promising.

Keywords: Agricultural industry, Photovoltaic electricity, Solar irradiation, Sustainability, Thermal devices

Introduction

Energy availability in a country is a key component in economic development, the standard of living, and the generation of wealth. With the rapid increase in energy demands, the global daily crude oil consumption has increased to 85 million barrels (National Master, 2010). Therefore, global environmental agencies have raised serious concerns over the need to reduce fossil fuel consumption due to subsequent increases in pollution levels. South Korea, among the major energy importers, imports almost all of the fuel necessary to meet its energy needs. Therefore, for energy security the, government officials have been compelled to eliminate the reliance on oil imports and to start investing in renewable technologies including solar, wind, and biofuels (Greentechmedia, 2008).

Compared to other renewable technologies, solar energy remains an ideal choice due to abundant availability and high efficiency (Kim et al., 2010). While the amount of available annual solar radiation in South Korea is not as plentiful as high irradiation countries, it is still enough to meet the basic agricultural energy requirements. For this reason, the Korean Photovoltaic Industry Association (KOPIA) aims to increase their share in the world's solar market from 2% to more than 5%, and as much as 10%, by 2020 through a collaboration with the European Photovoltaic Industry Association (PV Magazine, 2011). The KOPIA will also include the application of solar energy to the agriculture sector to dry crops, pump water, heat and cool greenhouses, electrify rural areas, and dry chicken manure.

Na et al. (2012) have used geostationary satellite imagery data to estimate the daily and monthly available solar radiation and water balance determining crop productivity, particularly for rice growth. Photovoltaic (PV) is the most effective approach to convert available solar energy into electricity. This converted electricity can be stored in a battery storage bank or used directly to operate a water pumping system for irrigation and drinking water supplies (Chandel et al., 2015; Kou et al., 1988; Arab et al., 1991; Pande et al., 2003; Mohanlal et al., 2004). A number of

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researchers have used various techniques to collect and store thermal energy from daily available solar radiation for greenhouse heating, especially during nighttime and periods of cloudy weather (Song et al., 1994; Lee et al., 2011). In addition, almost all poultry farms require continuous ventilation, especially during hot summer months; therefore, PV can be the best alternative for supplying electrical power and can ultimately save the lives of many birds. The temperature for optimum biogas production is around 40°C; therefore, it is very convenient to achieve this ideal temperature from solar energy (Su et al., 2011; Dong and Lu, 2013). Although solar energy offers many advantages, there are application drawbacks. Due to the intermittent nature of received solar radiation, the supply of photo-thermal and photovoltaic power is not continuous (Armstrong and Hurley, 2010; Imtiaz Hussain and Lee, 2014). Therefore, its direct supply for greenhouse heating could be harmful to the vegetables and crops housed there (Imtiaz Hussain et al., 2015). To address this problem, an auxiliary energy supply as well as electrical and thermal energy storage systems should be incorporated to maintain a continuous supply of power, especially for nighttime and cloudy-day heating (Mekhilef et al., 2011). These supplementary measures do increase the overall price of the solar energy collecting system.

This study presents a summarization of solar energy technology applications in agriculture. Numerous implementations of solar energy in the agriculture sector are discussed, including air and water heating for livestock, solar crop drying, greenhouse heating, solar egg incubating, solar water pumping, and rural electrification by using PV panels.

Energy sources for agriculture in South Korea

South Korea does not have any offshore oil fields and the quality of available coal is inferior and insufficient to meet energy requirements. In addition, the scope for hydroelectric power generation is very limited due to highly variable weather. Therefore, mostly conventional energy sources, including petroleum, natural gas, and electricity from the Korea Electric Power Corporation, are currently relied on for South Korean agricultural commodity production, processing, and preservation, irrigation and water supply systems, and livestock production. Due to this reliance on conventional fuels, the South Korean government has set a 30% reduction target for total greenhouse gas emissions from fossil fuels by 2020, which also includes 5.2% from the agriculture and fishery sectors (Responding to Climate Change, 2014). While South Korea by no means exists in a tropical region, the country still receives abundant solar radiation that can be applied for agricultural purposes. Thus, solar energy applications, specifically in agriculture, can replace a major portion of conventional fuels.

Solar energy resources in South Korea

Global horizontal irradiation data for South Korea show that there is a sufficient country-wide opportunity to harness a maximum solar radiation of 1600 kWh/m^2, as presented in Figure 1. The concentration of solar radiation is lowest in the northern region because of greater annual cloud coverage and rainfall compared to other parts of the country. The irradiation values are quite high in the southern portion of the country where there is less annual rainfall.

The irradiation levels increase from south to east. The southern area of the country receives more incident solar radiation all year round than other parts of the country. Further analysis shows that the maximum country-wide annual-average daily global and normal radiations are 3.58 and 5.4 kWh/m^2/day, respectively (Jo et al., 2009a;

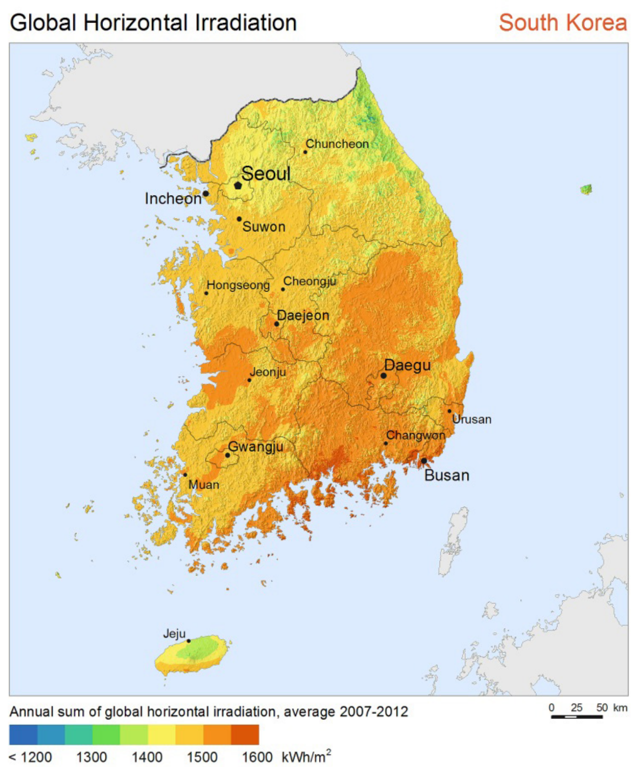

Figure 1. Annual sum of global horizontal irradiation in South Korea.

Jo et al., 2009b). The solar radiation data for South Korea demonstrate that solar energy technology is applicable to the agriculture industry.

Solar energy application in agriculture

Solar crop drying

Using the sun to dry crops and grain is one of the most widely used and most convenient applications of solar energy. This traditional method of drying crops in large open fields is inexpensive and hassle free, but this technique also offers many disadvantages like damage from birds, rain, rodents, wind, and dust. Various sophisticated designs of solar dryers have been introduced by different researchers for better end products (Abur et al., 2014; Saxena et al., 2011; Patel et al., 2013). These dryers protect fruit and grain from damage, result in a more uniform and quick drying, and reduce losses compared to the conventional open-air method (Vidya Sagar Raju et al., 2013).

For application of solar energy in agriculture, a solar drying system based on an evacuated tube collector (ETC) and auxiliary heater was constructed at the Kangwon National University, South Korea, for drying of agricultural products like potatoes, radishes, carrots, and oyster mushrooms, as illustrated in Figure 2 (Lee, 2013). Purohit et al. (2006) performed a comparative financial analysis of solar drying versus open-air drying on the basis of certain calculated results and discussions. In addition, they suggested that high cost solar drying systems appeared to be financially more feasible for cash crops (such as coffee beans, cardamom, tea, etc.) and low cost solar drying systems more feasible for perishable products (such as fruits and vegetables). Low cost solar dryers suitable for rural farming in developing countries were presented by Chua and Chou (2013). These solar dryers can be classified into two categories: passive dryers that are operated under natural cooling due to thermosyphon and active solar dryers that are operated by external means like pumps or fans.

Solar water pumps for irrigation

Most rural farms are beyond the reach of the electric company; therefore, PV power would be the best option, especially during sunny hot days when water for irrigation and livestock is crucial. Most solar pumps are equipped with a current booster, which acts like an automatic transmission, due to the intermittency of available solar energy (Linear Current Booster, 2015). Development and computational analysis of a solar water pump based on Global System for Mobile Communications (GSM) for irrigation purposes have been performed by joint venture research of Changwon National University, South Korea, and National University of Sciences and Technology, Pakistan (Mehmood et al., 2013). Gad and Safya (2011) developed theoretical models for optimum sizing and performance prediction of a PV array for water pumping systems in Egypt, as shown in Figure 3.

Different mathematical models for PV array orientation and solar radiation were developed and compared to measured data obtained from the National Aeronautics and Space Administration (NASA) website. The efficiency and flow rate of the PV water pumping system have been monitored at different solar radiations and with different pumping heads (Benghanem et al., 2013; Benghanem et

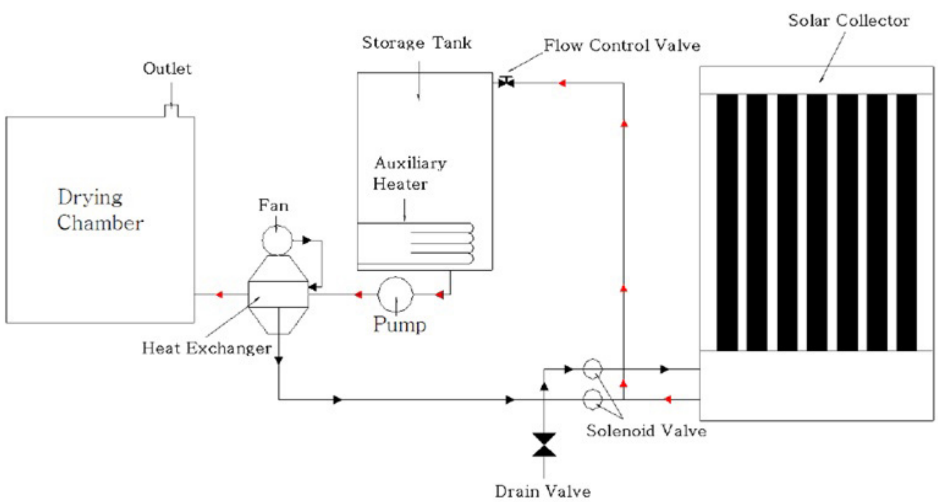

Figure 2. Schematic diagram of the solar drying system using ETC.

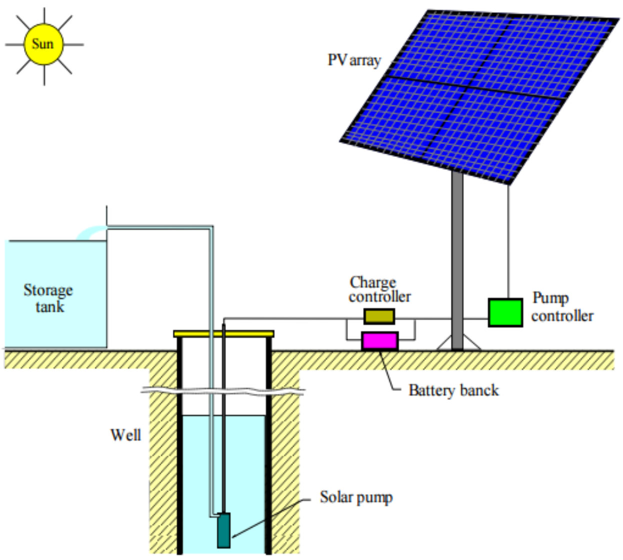

Figure 3. Schematic PV array for water pumping systems in Egypt.

al., 2014). It has been suggested that the best system output could be obtained using the selected optimum pumping head.

Solar greenhouse heating

A large number of greenhouses around the world depend on sunlight to fulfill their lighting needs, but they are not designed to use the sun for heating. Rather, they depend on conventional energy sources such as oil or gas to maintain the designed greenhouse temperature for plant growth in winter. However, solar greenhouses are constructed to use solar energy for both heating and lighting. To reduce the loss of surplus solar energy from the greenhouse to the ambient air during periods of sunshine, researchers have suggested different solar heat storage techniques with respect to the South Korean climate (Suh et al., 2009a; Suh et al., 2009b). Concentrated PV thermal technology is not yet utilized for greenhouse heating and cooling in South Korea. This hybrid system has great potential for providing thermal and electric power for heating as well as cooling of a greenhouse.

Joudi and Farhan (2014) tested the thermal performance of a parallel connected solar air heater (SAH) for heating of a novel greenhouse by varying the mass flux of air in Baghdad, Iraq, as depicted in Figure 4. In addition, the total greenhouse heating load was calculated by considering the soil surface heat gain in the energy balance method. A flat plate solar collector was tested and utilized for heating of a greenhouse in Morocco on two different types of days: a sunny day and a cloudy day (Bargach et al., 2000). The

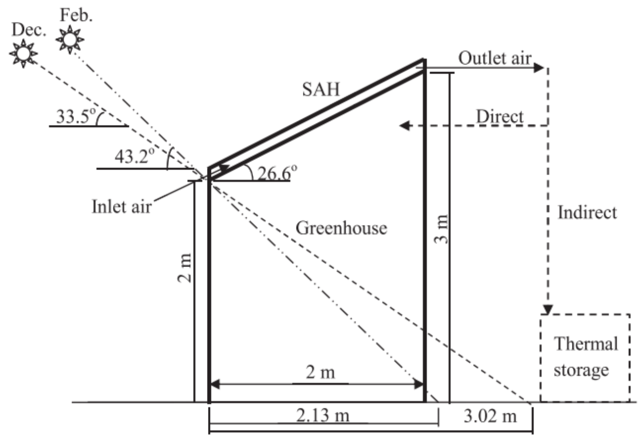

Figure 4. Single-slope greenhouse.

theoretical model results were compared with the measured experimental data for the purpose of improvement and refinement of the model for better utilization.

Ventilation for agricultural enterprises

Some agricultural enterprises in South Korea, such as chicken and pig farms, require constant ventilation, especially during the summer. The body heat from the large number of birds on a poultry farm could be lethal to the animals if the electricity supply is cut off. Similarly, pig and poultry farms raise animals in enclosed buildings to control temperatures and air quality in an effort to maintain animal health and growth. Therefore, the application of PV can be the best choice because in the event of a grid power break down, PV will take over to supply power, hence potentially saving thousands of birds. Direct current motors can also operate directly with PV power and eliminate the use of an expensive inverter. The Taiwanese government increases benefits for livestock farmers who use solar energy to generate electricity specifically for pig farms to attract others farmers to build solar farms (Focus Taiwan, 2012). Delaware's poultry farms' final report reveals the economic and technical aspects of PV application for poultry farming (Byrne and Glover, 2005). Also report suggested that PV offers additional benefits, such as security of supply, and economic and environmental advantages over grid electricity supply and conventional energy sources (Das, 2014).

Solar electricity and other agricultural applications

A solar electric system can attach directly to an electrical appliance or store electricity in a battery. In rural and remote areas with little or no grid power supply, PV systems

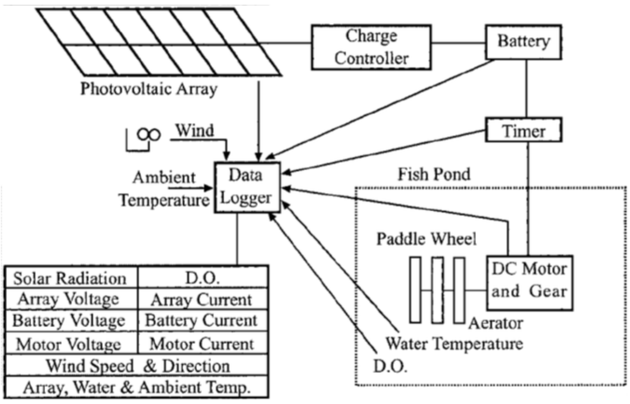

Figure 5. Schematic of a fishpond with aerator.

always offer economic and maintenance advantages over batteries alone, diesel generators, and wind turbines (Sivaraman D., Keoleian, 2010). A PV system has the potential to produce up to 80% and 25% of its total energy capacity on partly cloudy and extremely overcast days, respectively. Léna (2013) proposed a model (including detailed guidance on design, decision-making, and implementation) of off grid and rural electrification by using PV/diesel hybrid systems.. Fish and shrimp farms require aeration pumps to increase the oxygen level in water for higher productivity (Applebaum et al., 2001). The schematic of a PV fishpond aeration system proposed by Applebaum is presented in Figure 5.

A majority of these farms are located in remote-regions around the globe, so most power demand is provided by diesel. Electric fences are a good solution for farmers in remote areas and also cost-effective in the long run, particularly in countries where labor costs are high. Therefore, PV powered electric fences is the most feasible solution for pasture management, especially in off-grid areas (Sandia, 1998). Many additional agricultural areas have been identified in which solar energy can be utilized, including veterinary clinics, cattle watering, egg incubators, crop spraying, and cooling for fruit preservation. The wireless sensor network (WSN) represents an enabling technology for precision farming that can ultimately improve the agricultural output and standard of living for farming communities. Among all recent developments, the utilization of solar energy in WSN has proved to be more viable because it can yield significant energy savings (Voigt et al., 2003). Its deployment in remote and difficult areas makes the application of solar energy more economical and feasible to power this emerging technology. This system is equipped with a lithium battery to provide a stable and smooth power supply even at nighttime and during overcast conditions (Li and Shi, 2015).

Conclusion

Even though South Korea does not have an abundance of solar energy throughout the country compared to high irradiation countries, there is still an adequate amount to fulfill the requirements of the agriculture sector. The available annual average direct and global solar radiations are 5.4 and 3.58 kWh/m^2/day, respectively. With environmentally friendly government policies and progressive measures like in South Korea (5.2% carbon reduction from agriculture by 2020), other countries can also reduce greenhouse gases by replacing conventional energy sources with solar energy in the agriculture sector. Based on the global solar energy potential, utilizing this alternative energy in the agriculture sector would benefit all countries, including South Korea, socially, environmentally, and economically. All potential benefits from the use of solar energy, especially in agriculture enterprises, contribute to the development of sustainable agriculture.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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