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Review Article

Solar Based Irrigation System Application as an Option for Energy Source for Irrigation Water Management in Ethiopia: A Review

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Abstract

Electricity is the most cost-effective and efficient energy source for pumping water, but farmers with small, scattered plots might not have access to it. To raise water for irrigation, farmers rely on diesel or gasoline pumps, which is expensive and non-sustainable. For better management of water and economic benefit, considering another option for irrigation such as the solar pumped irrigation system could be important. Solar power enhances efficiency, productivity, and sustainability in agricultural operations in addition to offering a clean alternative to fossil fuels. In agriculture, it is increasingly being integrated through several innovative applications that are transforming traditional farming practices. The future of solar energy in agriculture is promising, driven by technological advancements, supportive policies, and increasing awareness of sustainable practices. The objective of the study is to identify the practical applicability of solar pump in other countries and the challenges and opportunities for its applicability in Ethiopia in irrigated agriculture. Existing scholarly research that has been published as journal articles serves as the study's methodology. The resources (Scopus and Google customized search), eligibility and exclusion criteria, review process phases, data abstraction, and analysis are all part of the methods used. The study shows that the solar radiation is the primary source of energy for solar pump and it depends on the climatic condition and geographical location of the area. Most African countries are practicing the solar pump and it was highly practiced in sub-Saharan African countries such as Kenya, Ethiopia, Sudan and also other equatorial and sub-equatorial countries. Additionally, since the North and South hemisphere are linked with permanent cloud cover and only intermittent bright sunshine, the future installation of solar pump will also be practiced in these areas such as the Congo, Gabon, Rwanda, and Senegal. It is also highly practiced in Mali for irrigation, livestock production and for domestic use. There is a growing demand for solar pump irrigation in Ethiopia. Accordingly, one of the government's strategy is to transit existing motor pump users to solar, while also introducing new solar pump irrigation to those not currently irrigating. The primary challenges of utilizing solar pumps in Ethiopia was high initial costs, while the country's abundant solar radiation and potential for increased agricultural productivity were the best opportunities for its implementation. However, this technology has to be supported through evidence by conducting research and creating awareness for the end users and other policy makers.

Keywords

Irrigation, Solar Radiation, Challenges, Opportunities, Pump

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1. Introduction

Agriculture is the mainstay of the Ethiopian economy accounting for about 46% of the gross domestic product (GDP), 85% of the export and 80% of the employment opportunities [1]. Both industry and services depend strongly on the performance of agriculture, which provides raw materials, generates foreign currency for import of essential inputs and food for the fast-growing population. Despite its importance for the national economy, agriculture is largely based on subsistence farming. The productivity of the agricultural sector is very low and lags behind the population growth rate resulting in food insecurity. Expanding irrigation farming, improving management practices, and improving inputs all contribute to increased agricultural productivity. However, potential advances are slowed by important limitations including restricted access to technology and financing. Moreover, poor research and extension services and ineffective market systems present further difficulties. The Ethiopian government created the agricultural development led industrialization (ADLI) strategy in order to tackle this issue, with the goal of using agriculture as the foundation for the nation's entire growth [2]. This approach seeks to increase food security in both rural and urban areas as well as the productivity of small-scale farmers.

The government of Ethiopia (GOE) prioritizes agriculture because raising agricultural productivity and output will boost export earnings and boost global competitiveness. It aims to modernize production techniques, increase the adoption of contemporary technologies, and utilize underutilized arable land in order to meet these goals. Infrastructure, social services, technology, marketing infrastructure, seasonal finance availability, and the establishment of a suitable institutional environment are all common elements that must be addressed in the rural sector for agricultural expansion to take place [3]. However, Ethiopian agriculture relies on unpredictable and frequently insufficient rainfall because it is predominantly rainfed [4]. Consequently, agricultural production frequently fails. Stabilizing agricultural output and reducing the adverse effects of inconsistent or insufficient rainfall are two potential benefits of irrigation. Ethiopia's population is growing at a rate of 2.6% year, and irrigation development can help mitigate some of the negative effects [5].

Increasing and maintaining food security and better nutrition depend on better agricultural water management on small farms in developing nations, especially in light of the anticipated rise in food demand and climatic variability. To boost productivity, farmers use independently owned and operated irrigation methods, frequently utilizing tiny powered pumps [6]. Compared to human labor methods, mechanized agriculture which includes irrigation equipment like pumps increases the commercial energy use per hectare [7]. In developing countries like Ethiopia, electricity is the most cost-effective and efficient energy source for pumping water, but farmers with small, scattered plots might not have access to it. Therefore, in order to raise water for irrigation, farmers rely on diesel or gasoline pumps, which is expansive and non-sustainable. Hence, for better management of water and economic benefit, considering another option for irrigation such as the solar pumped irrigation system could be important.

Solar radiation is crucial for many fields such as agriculture, meteorology, and renewable energy. Solar power not only offers a clean alternative to fossil fuels but also enhances efficiency, productivity, and sustainability in agricultural operations. In agriculture, it is increasingly being integrated through several innovative applications that are transforming traditional farming practices. Irrigation is a critical aspect of agriculture, particularly in a region which is prone to water scarcity. Solar-powered irrigation systems use photovoltaic panels to generate electricity that pumps water from underground sources, rivers, or reservoirs to irrigate crops. These systems are highly effective in off-grid and remote areas, where access to electricity is limited or non-existent. Solar irrigation reduces reliance on diesel-powered pumps, cutting down on fuel costs and greenhouse gas emissions. Solar irrigation systems are particularly beneficial in arid regions, allowing for efficient water usage and reducing losses. The future of solar energy in agriculture is promising, driven by technological advancements, supportive policies, and increasing awareness of sustainable practices. Hence it is better to study and review the barriers which could hinder the practically applicability of solar pumps in Ethiopia for irrigated agriculture. Therefore, the objective of the study is to identify its practically applicability in other countries and the challenges and opportunities for its applicability in Ethiopia in irrigated agriculture.

2. Materials and Methods

The study's approach is based on previously conducted academic research that has been published as journal papers. A systematic literature review utilizing PRISMA [8, 9] was carried out in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) declaration. The resources (Scopus and Google customized search), eligibility and exclusion criteria, review process phases (identification, screening, and eligibility), data abstraction, and analysis are all part of the methods used. One of the biggest databases for peer-reviewed publications, Scopus, serves as the primary sources for the review. Furthermore, a tailored Google search and considered a few non-peer-reviewed papers that were extremely pertinent to the goals were performed. In terms of document type, only "Articles" published in English-language fields of engineering, social science, agricultural, and environmental science were taken into consideration.

3. Over View of Solar Energy

A direct current (DC) or alternating current (AC) motor-based water pump is powered by photovoltaic (PV) technology, which transforms solar energy into electrical energy. Solar energy-based installation sites must generate an adequate amount of energy to ensure their long-term viability for supporting the required demand. The amount of solar irradiation received on the earth's surface determines the amount of solar energy that can be converted to electricity. US National Renewable Energy Laboratory (NREL) classified values in kWh/m^2/day into four categories: moderate (<4), good (4–5), very good (5–6), and excellent (>6) [10].

The solar panel is a device which is made of photovoltaic (PV) cells converts light energy obtained from the sun and converts into electrical energy for the operations of any systems [11]. When the PV cell converts the light energy to electrical energy and the electrical energy is stored in the external battery, the system starts to run [12]. The cells in the solar panel gets energized when the sun rays hit it. The excitement of the cells results in enlarge the heat energy and the terminals which is constructed in the back end of the supporting structure carries the generated heat energy and converts into the electrical energy and the electrical energy is carried through the wires and stored in the external battery. When the panel is kept under the sun light for a duration of 16 hours the panel generates theoretically 5.5 hours of total energy, in which 80% of energy is consumable without loss [13]. Solar insolation is radiation process which is measured in kWh/m^2/day. Comparing a clear day, the efficiency from the sun is less during the cloudy day, hence the energy generated is low compared to clear day.

Solar PV can constitute a reliable source of energy for pumping of irrigation water in remote areas, in particular areas which are not connected to the electricity grid or where regular supply of liquid fuels and maintenance services is not guaranteed (Figure 1). Distribution of excess electricity over local grids can also contribute to rural electrification and productive use applications. However, enormous costs associated with grid expansion in sparsely populated areas and lack of models ensuring equitable distribution of electricity subsidies are major barriers in planning and executing electrification programs [14, 15]. Across the globe, large-scale solar PV power generation is increasingly being adopted [16] resulting in development of a global PV market and support ecosystem [16]. When surface water must be transported over great distances or groundwater is the only available water source during the dry season, it can assist mitigate the impacts of drought and overcome water stress. In addition to stabilizing, increasing, and diversifying production, solar PV pumps can free up a significant amount of working time that could be used for other productive endeavors. Since its adaptability is advantageous it was applied in different parts of the sub-Sahara African countries including Ethiopia and in different parts of the world for irrigated agriculture as a source of energy due to reduced costs, improved reliability, and escalating demand within the private sector, coupled with much reduced environmental impacts [17-20].

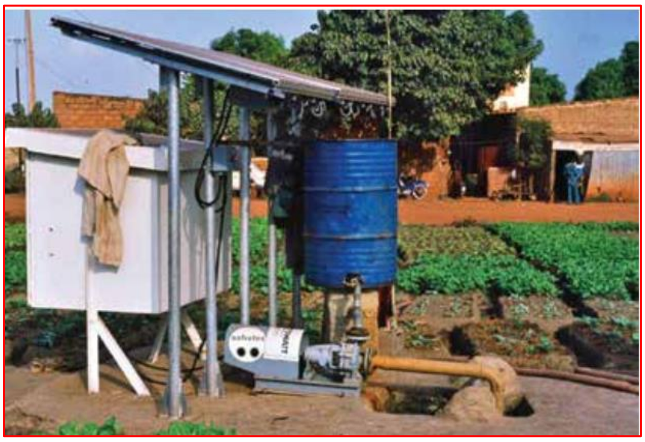

Figure 1. *A solar-powered irrigation system (source: [21]).*

3.1. Experience of Applicability of Solar Pump in Africa and Other Countries

The solar radiation is the primary source of energy for solar pump and it depends on the climatic condition and geographical location of the area. Africa is often considered and referred as the Sun continent or the continent where the Sun's influence is the greatest [22]. According to the World Sunshine Map, Africa receives many more hours of bright sunshine during the course of the year than any other continent of the Earth [23, 24]. Most African countries are practicing the solar pump due to the declining solar equipment costs [25]. It was highly practiced in sub-Saharan African countries such as Kenya, Ethiopia, Sudan and also other equatorial and sub-equatorial countries [26]. Additionally, since the North and South hemisphere are linked with permanent cloud cover and only intermittent bright sunshine, the future installation of solar pump will also be practiced in these areas such as the Congo, Gabon, Rwanda, and Senegal [25-27]. Solar based Irrigation Systems (SBISs) is also highly practiced in Mali for irrigation, livestock production and for domestic use [28].

Sudan is one of the dominantly user of solar pump in sub-Saharan African countries for booming economy, high population, land locked location, vast area, remotely separated rural areas which are not easily accessible, large reserves of oil, excellent sunshine, large mining sector and cattle farming on a large scale were factors which are most influential to the total energy scene in Sudan. Hence, tapping of solar energy for rural development is, therefore, expected to emerge as an important renewable source of energy in Sudan. According to [29], Solar systems may be able to provide trickle irrigation for fruit farming, but not usually the large volumes of water needed for wheat growing. Mali is one of the recent countries which is experiencing solar pump in Africa. After the assessment of the water availability of Mali showed that 39% of the Malian rural community lack access to water [31] and are practicing irrigation from shallow depths for cultivating vegetable gardens during the dry season [32]. After the implementation of the solar pump, they have been using the solar based irrigation for household domestic use, livestock water, and irrigation. According to [28], they are using 15% for irrigation, 60% for house hold domestic purpose and 28% for livestock water based on the study conducted in Bougouni and Koutiala districts of Mali which comprise 41% of Sikasso's region in southern Mali. Due to the use of the Solar based irrigation, the rural farmers obtain more than 40% of extra household income during the dry season from the production of vegetable crop [28].

Although the agricultural industry only makes up to 30% of Kenya's GDP, it is responsible for 80% of all jobs in the country [30]. However, drought and climate change often have an impact on it, which lowers the revenue of small-scale farmers in rural Kenya [21]. Solar-powered irrigation is emerging as a niche in Kenya's economy to address this issue, and numerous small and medium-sized businesses are creating supply chains and services centered around SPIS to improve solutions aimed at the country's fragmented and diverse agriculture sector, particularly the income of smallholder farmers [32]. In Kenya, solar pumps are essential because they offer a sustainable and dependable source of water for irrigation, especially in arid areas. This helps smallholder farmers increase agricultural productivity by removing the need for costly fuel-based pumps or erratic rainfall, which increases food security and income generation. This is crucial given climate change and limited access to electrical grids [33].

In Morocco, using solar pumps for domestic and agricultural irrigation is another popular agricultural strategy for mitigating and adapting to climate change. With the use of modern irrigation techniques like drip irrigation, solar-powered irrigation in Morocco combines policies to encourage farmers to use water more efficiently. This gives farmers a zero-emission technology that they may use in conjunction with an irrigation system that may use less water [34]. The majority of people in Morocco's rural areas are impoverished and socially vulnerable. Conventional energy sources are costlier and make it extremely difficult or nearly impossible to obtain irrigation or drinking water in rural locations. Out of all the energy sources now available, solar energy is the best suitable for usage in rural regions [35]. However, the government is advancing its renewable energy agenda, supporting solar technology, and looking for methods to mitigate the negative consequences of small-scale farmers losing their subsidies.

3.2. Experience of Applying Solar Pump in Ethiopia

There is a growing demand for solar pump irrigation in Ethiopia. Smallholder women and men farmers express their preference for solar pumps over other water-lifting technologies in areas where they have observed or tested the technology [36]. In Ethiopia one of the government's strategy is to transit existing motor pump users to solar, while also introducing new solar pump irrigation to those not currently irrigating. Given the number of existing and potential pump users, the scope for expanding the solar pump market for irrigation appears significant. However, Engineers and planners have stated that they avoid addressing requests for solar pumps, fearing failure and rejection by decision makers and end users [37].

In Ethiopia, the primary challenges of utilizing solar pumps in developing areas include high initial costs, limited access to technical expertise for maintenance, lack of awareness about the technology, inadequate financing options, inconsistent policy frameworks, and underdeveloped infrastructure, while opportunities lie in the country's abundant solar radiation, potential for increased agricultural productivity, rural electrification, community development initiatives, and growing government support for renewable energy adoption; however, overcoming these challenges requires robust policy development, capacity building, and innovative financing mechanisms to fully realize the potential of solar pumps in Ethiopia.

4. Conclusion

The ample availability of solar radiation in Ethiopia could be considered as the best way for applying the solar based irrigation for the production improvement, creation of job opportunity and has a great contribution for supplementing the irrigation as well as the rainfed agricultural system in the rural and dry parts of the country. The technology is eco-friendly and can best fit to any system of irrigation method dominantly drip irrigation based solar pumped irrigation. The primary challenges of utilizing solar pumps in Ethiopia was high initial costs, while the country's abundant solar radiation and potential for increased agricultural productivity were the best opportunities for its implementation. However, this technology has to be supported through evidence by conducting research and creating awareness for the end users and other policy makers.

Abbreviations

AC	Alternating Current
GDP	Gross Domestic Product
GOE	Government of Ethiopia
NREL	National Renewable Energy Laboratory
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PV	Photovoltaic
SBIS	Solar Based Irrigation Systems

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Conflicts of Interest

The author declares no conflicts of interest.

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