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The Future of Solar Energy in Sudan: Opportunities and Challenges

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Abstract

This article highlights the potential applications of solar energy and its role in enhancing economic development in Sudan. Empirical data gathered from various focus group discussions (FGDs), statistics from the International Renewable Energy Agency (IRENA), and innovative economic and technical ideas from developed countries were utilized to thoroughly articulate and explain the opportunities and challenges facing the future of solar energy in Sudan. The conclusion emphasizes the need for a comprehensive effort from individuals, government sectors, policymakers, and civil society across the country to encourage and support the utilization of solar-based electricity.

Keywords: Digital transformation, SDGs Agenda, International Renewable Energy Agency, Solar Energy, Solar Micro-grid, Solar Grid Connected System, sustainability

1. Introduction

The solar system is one of the cleanest and most accessible renewable sources of energy, which is abundant, sustainable, and free. Solar energy is readily available and easy to harness, even in remote areas. It can be converted into electricity using photovoltaic cells and thermal panels. Photovoltaic cells can be arranged to form photovoltaic panels, which generate direct current (DC) electricity. This DC current can be easily converted into alternating current (AC) electricity for various applications. Today, in addition to solar energy, other renewable sources such as wind, biofuels, and hydroelectric power play a crucial role in creating a clean and reliable energy future. The benefits of these sources are numerous and diverse, including a cleaner environment and reduced costs. Traditionally, electricity has often been generated by burning fossil fuels such as oil, coal, and natural gas. The combustion of these fuels releases a variety of pollutants into the atmosphere, including carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). These pollutants contribute to the formation of acid rain and smog. Furthermore, carbon dioxide from burning fossil fuels is a significant contributor to greenhouse gas emissions. These emissions can significantly alter the world's environment and exacerbate the problem of global warming. Renewable energy, on the other hand, consists of clean energy resources. In fact, today, utilizing renewable energy to replace conventional fossil fuel sources can prevent the release of pollutants into the atmosphere and help combat the problem of global warming. For example, using solar energy to supply power to a million homes would reduce CO_2 emissions by 4.3 million tons per year[1]. In this work, we explore the opportunities and challenges associated with the deployment of solar energy in Sudan. The remainder of the paper is organized as follows: Section 2 outlines the practical setup of solar systems. Section 3 discusses the key economic opportunities that solar energy presents for the country. Section 4 highlights the main challenges facing the large-scale deployment of solar systems, and Section 5 concludes the paper.

2. The Main Solar System Design and setup

Today, there are several methods for installing solar systems tailored to various services. It is crucial to choose the most appropriate solar configurations for specific applications. This section illustrates and explains the different solar system configurations methods, including grid-connected solar systems, solar micro-grid, and standalone system connected to customer.

2.1. Grid-connected solar system

A grid-connected photovoltaic system is an electricity generating solar power system that is connected to the utility grid. A typical grid-connected PV system consists of solar panels as shown in figure 1, one or several inverters, and power conditioning units are connected to the grid. They range from small residential and commercial rooftop systems to large utility-scale solar farm power stations. When conditions are right, the grid-connected PV system supplies all it is power to the utility grid. Today, in India a lot of grid connected systems are in operations [2-4]. In sub-division of grid-connected PV system the solar system is basically used to energize small residential and commercial load services and the excess power is connected to the utility grid as reported in [5-7]

Figure 1. Example Solar panels of grid-Tied System/On-grid system of Elfashir Solar farm (5 MW Capacity Project)

2.2. Solar system connected to micro-grid

A solar micro-grid is a renewable energy system that operates independently of the main grid; however, it can also integrate with and interact with the main grid when desired. [8]. Micro-grids offer significant advantages to communities in need of reliable renewable energy sources. By utilizing a micro-grid, communities can achieve greater stability in their power systems, as these systems can operate independently from the main grid, which may be vulnerable to natural disasters and electrical faults. Additionally, micro-grids are particularly beneficial for regions with limited access to electricity, such as parts of India and Africa, as well as remote areas that are frequently affected by natural disasters. Figure 2, shows a typical micro-grid configuration that is widely deployed in many developing countries, such as Bangladesh, Pakistan, Indonesia, and several countries in Africa [9-12].

Figure 2. Typical micro-grid configuration as widely deployed in a lot of developing countries such as Bangladesh, Pakistan, and Indonesia and a lot of countries in Africa [13]

3. Key opportunities

Despite significant progress over the years, approximately 60% of Sudan's population still lacks access to electricity, with many unconnected households located in close proximity to the grid. The government has traditionally relied on grid expansion efforts to improve access; however, a major part of this issue stems from the remote nature of the hundreds of thousands of communities, which raises barriers to effective electrification strategies. In today's in world, electrification serves as a gateway to many essential services, including access to clean water, basic healthcare, education, and telecommunications. Thus, the availability of energy significantly contributes to the well-being of people by facilitating fundamental economic activities, such as agriculture, digital transformation and related industries. This section elaborates on the key opportunities and abundance of solar energy available throughout the country.

3.1. Boosting the overall country generation capacity

According to the International Renewable Energy Agency (IRENA), photovoltaic (PV) technology is one of the fastest-growing renewable energy sources and is poised to play a significant role in future global electricity generation. As explained in the previous section, PV installations can be combined to generate electricity on a commercial scale (grid-connected) or arranged in smaller configurations for micro-grids or personal use. See Figure 3. The chart illustrates the trend in the cost per kilowatt-hour (*kWh)* of solar energy in China, Turkey, and Germany over the past decade. It reveals that the cost of *kWh* generated from solar systems has decreased, approaching the cost of *kWh* generated from fossil fuels.

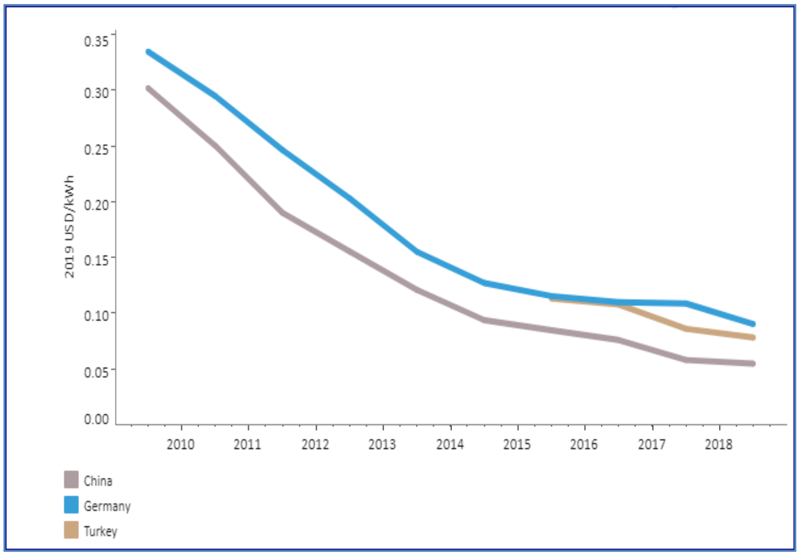

Figure 3, Solar Energy Cost in USD/ kwh, Source International Renewable Energy Agency (IRENA) [14]

Due to the decline in cost trends, solar energy generation has increased dramatically in many countries. Figure 4 shows that the total installed solar energy capacity in Egypt rose from 200 MW in 2017 to 1,600 MW in 2020. Meanwhile, in Turkey, the installed solar energy capacity increased from 3,500 MW in 2017 to 7,000 MW in 2020, as illustrated in Figure 5[14].

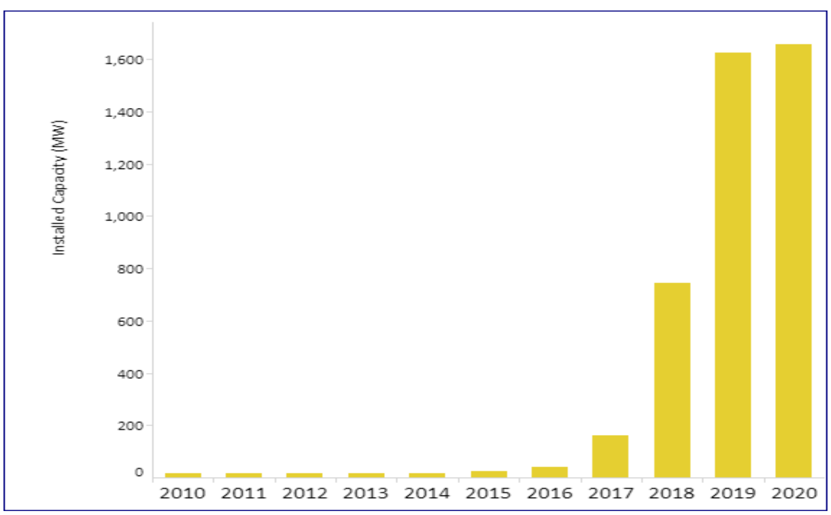

Figure 4. shows the trends in installed solar system capacity in Egypt, Source International Renewable Energy Agency (IRENA)[14]

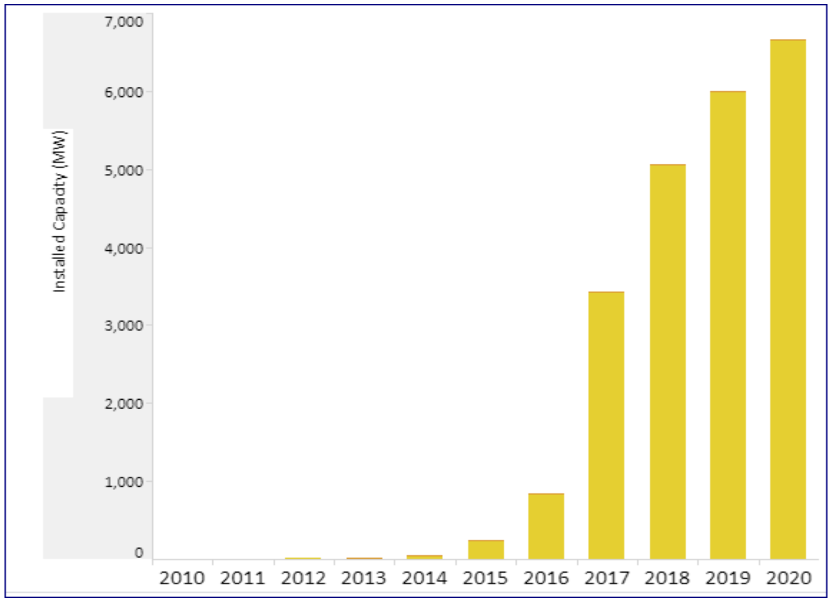

Figure 5 shows the trends in installed solar system capacity in Turkey., source: International Renewable Energy Agency (IRENA)[14]

In contrast, Figure 6 shows that the installed solar energy capacity in Sudan increased from 13 MW in 2017 to 18 MW in 2020 [14]. This figure illustrates that the country overlooks and fails to recognize the potential of its abundant solar energy resources. In fact, due to Sudan's favorable geographic location, there is a significant opportunity to establish large solar power farms connected to the national grid, which can energize its economy. Furthermore, there are excellent prospects for utilizing solar photovoltaic (PV) systems to power micro-grids, thereby providing electricity access to individuals living in remote areas who are not connected to the national power transmission system.

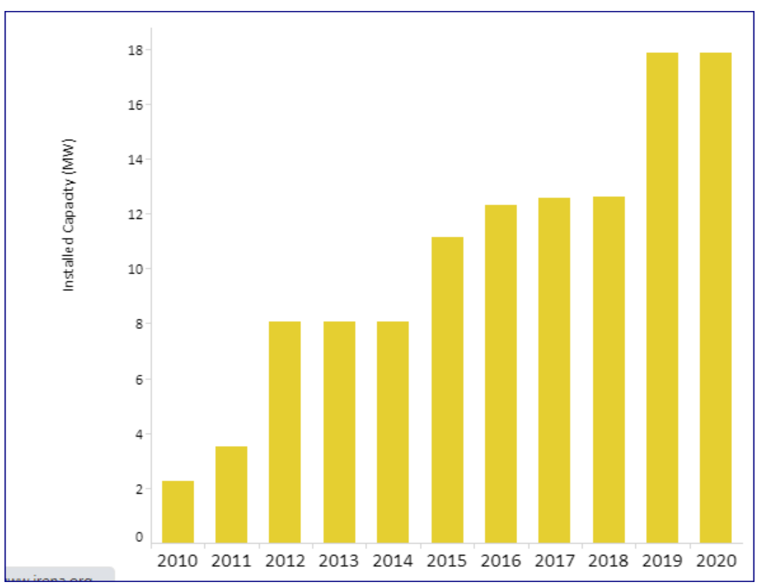

Figure 6. shows the trends in installed solar system capacity in Sudan, Source: International Renewable Energy Agency (IRENA)[14]

3.2.Connecting unfortunates far communities to the ICT infrastructure

Decentralized renewable energy facilities, such as standalone solar home systems and micro-grids, can offer alternative cost-effective solutions to the electrification challenge. Community micro-grids typically serve rural areas where the national grid is unlikely to be established in the near future. These locations are often challenging to access and even more difficult to monitor over extended periods. It is not surprising, therefore, that they have struggled to gain traction with national governments and investment opportunities. Recently, numerous studies have revealed an accelerated shift towards utilizing solar technology to address the digital divide and bridge the ICT gap between urban areas and remote regions. These studies show that the access to ICT tools in the remote communities has increased significantly by utilizing solar systems. This enhancement in the infrastructure has completely changed the way of life and economic trends on those areas. These studies conclude that the use of ICT-based devices has opened and created window opportunities in remote communities, where solar energy has made great significant contributions [15-19]. In this regard, ICT and solar energy technologies will enhance and facilitate the use of the following applications, as demonstrated by the ITU model shown in Figure 7. It is evident that solar energy will contribute to sustainability, advance the global Sustainable Development Goals (SDGs), and facilitate the digital transformation agenda in these areas by providing support. For example:

- E-Agriculture applications facilitate communication and support the development of efficient and productive farming skills among farmers. Furthermore, information and communication technology (ICT) can enhance the resilience of rural communities from both economic and nutritional perspectives. For instance, a specialized mobile application could be developed to assist farmers in promptly detecting and treating pests by utilizing image processing analysis of photographs.
- E-Education and e-Learning: Solar energy can facilitate community access to open and distance learning opportunities, enhancing capacity building for teachers and education administrators. It also provides equitable access to quality literacy, lifelong learning, and technical skills programs for children, youth, and adults. Furthermore, local teachers and educators can improve their qualifications and enhance the experiences of their students by utilizing engaging educational content.
- E-Health applications: Solar energy can provide an option to utilize telemedicine and mHealth services, improving access to diagnoses and reducing the costs associated with healthcare system access.
- Facilitate e-government initiatives by utilizing solar energy, enabling remote individuals to access essential government services and applications, such as financial services and hazard risk monitoring and alerts.

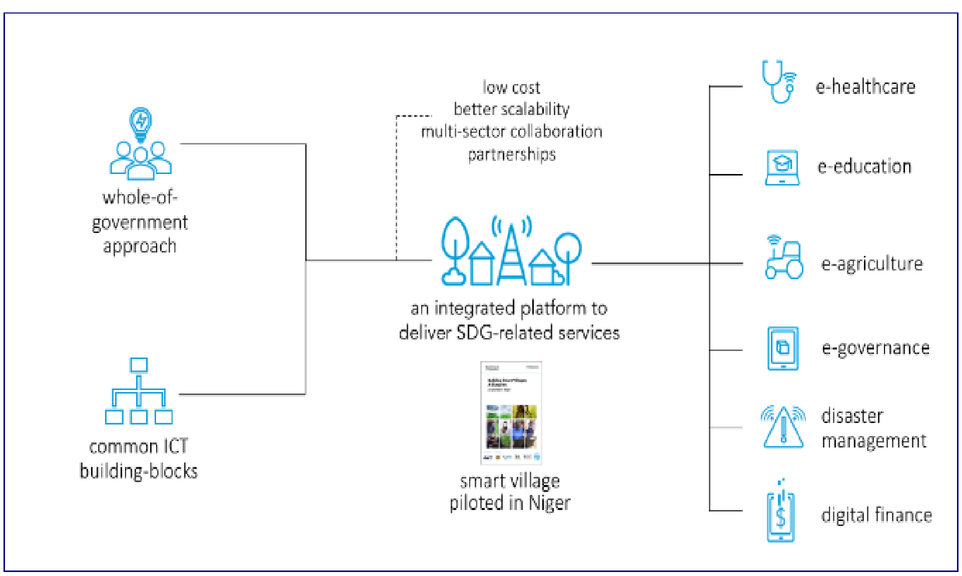

Figure 7. ITU model of applications to connect smart remote area

3.3.Providing Easy Access to Clean Water in Remote Areas

The ability of solar systems to provide continuous power in any environment makes them ideal for using for water pumping system in remote areas across many countries worldwide. Today, off-grid photovoltaic (PV) systems represent the best long-term solution, offering an excellent cost-performance this context. Currently, solar-powered systems, as shown in Figure 8, demonstrate one of the viable alternatives that have attracted considerable attention for water pumping in remote areas of Sudan. They have been deployed in many remote areas to provide clean water for both humans and livestock. Although photovoltaic (PV) systems generally have a high initial investment, they offer numerous advantages that make them attractive and appealing alternative power pumping energy system for remote areas as demonstrated in many countries around the world[20-24].

Figure 8. shows atypical solar energy system for clean water [25]

3.4. Electrification of rural areas

Access to electric power supply in remote areas has always played a significant role in promoting improvements across all sectors of society. However, according to an interview with the Finance Minister of Sudan, over 60% of the population still lacks access to electricity. Moreover, most people live in rural areas that are often isolated, sparsely populated, and characterized by inadequate infrastructure and services. In this context, the increasing focus on achieving widespread access to energy has highlighted the importance of rural electrification plans. Off-grid small-scale generation systems, such as microgrids, are regarded as one of the most viable options by many developing countries[26-31]. Figure 9 illustrates a learning example using Mirogrid for rural electrification [32].

Figure 9. Show atypical Solar energy for Rural Areas Electrification (Simple Microgrid)[32]

3.5. Solar energy for agriculture

Divided by the Nile and blessed with fertile land, Sudan's agricultural opportunities are vast and serve as a lifeline for poverty alleviation and the country's struggling economy. Agriculture presents significant prospects in Sudan; however, it often depends on diesel-powered water pumps. Recent studies indicate that the introduction of solar technology has increased land use and productivity by nearly 50%[33]. Today, photovoltaic (PV) water pumping systems may be the most cost-effective option for water pumping in locations without existing power lines [34]. They are also exceptionally well-suited for grazing operations, providing water to remote pastures [35]. In practice, simple photovoltaic (PV) power systems operate pumps directly when the sun is shining, making them most effective during the hot summer months when water is in highest demand. Generally, batteries are not required because the water is stored in tanks or pumped to fields for use during the daytime [36-39].

Figure 10. show atypical solar energy system for Agriculture[40]

4. Key challenges of utilizing solar energy

4.1. **Perceived the usefulness of the solar technology**

Technology Usefulness Model, defined by Fred Davis, refers to the degree to which an individual believes that using a specific system will enhance their job and life performance. Perceived Ease of Use (PEOU) defined by Davis as "the degree to which a person believes that using a particular system would be free from effort. If the technology is user-friendly, then barriers will be overcome. However, if it is not easy to use and the interface is complicated, people are likely to have a negative attitude toward it. To this end, extensive PEOU media programs are needed nationwide, considering all stakeholders involved in solar energy projects, including policymakers for key economic and service sectors, NGOs, and rural communities. To increase the number of solar technology users, it is essential to communicate the following important messages and tips: Solar energy technology is straightforward, cost-effective, efficient, and offers a high economic return for both individuals and the country as a whole. Generally, people will have a positive attitude and intention to use solar technology if they value its benefits and perceive its simplicity. However, perceptions may vary based on age and gender, as individuals have different perspectives.

4.2. Technical Issues for Further Research Investigation

Although the cost of solar technology has decreased dramatically in recent decades, there are still many open issues that require further research and investigation. The following list elaborates on the important research topics related to the large-scale deployment of solar energy:

- Development of a small-scale energy management system for micro-grids [41].
- Predicting solar energy generation accurately [42-44].
- Utilizing solar system frequency regulation and control [45-47].
- Selecting the optimal PV/battery size of the system [48-51].
- Optimal planning of solar generation systems [52].
- Long-term performance, losses, and efficiency analysis of solar systems [53, 54]
- Utilizing solar energy to enhance power quality in utility systems [55, 56].

4.3. Solar projects Financing problem

Given the significant anticipated economic and social benefits of solar energy, along with the considerable decrease in hardware costs for solar energy facilities over the past few decades, large-scale solar deployment in Sudan is facing a substantial financing challenge. This is primarily because the majority of lifetime costs associated with solar deployment are the upfront expenses incurred during construction (the initial cost or capital expenditure of the project). Consequently, innovation in financial, management, and commercial solutions to enhance access to capital investment should be a major focus for the government in the near future. In addition to classical power systems and project finance methods, this section briefly summarizes important innovative ideas aimed at expanding the deployment of solar energy systems. In this context, the following pioneering concepts are introduced:

- The U.S. government has introduced the practice of the Community Shared Solar (CSS) model. This model allows multiple electricity consumers, often located in close geographic proximity, to collectively finance an offsite or centralized solar project by purchasing shares or subscriptions for the power generated by the project. In practice, participants who finance the development of a CSS project receive compensation for the electricity generated by their project, along with various other economic benefits [57-64]. In fact, projects within a CSS program may be owned by a utility, a third party, a special-purpose entity created by a utility or its customers, or a charitable nonprofit organization. Ownership models have direct implications for how a project is financed.
- Introduce the structure of the nonprofit solar organization (NPS) as reported in [65] To expedite the electrification of rural areas and implement solar solutions for water pumping projects.

4.4. Training and Capacity Building

In developing countries such as Sudan, there is a lack of sufficient individual technical training and appropriate social preparation for using new technologies, such as solar systems. When end users interact with these new technologies, project failures often result from poor maintenance, misuse, inadequate installation, and a lack of understanding by the system owner, operator, or local technician. Today, extensive research focused on examining the significance of individual training in capacity-building programs for solar home system (SHS) technology transfer projects.. For example, in the Philippines, the focus of these studies is on analyzing the effectiveness of the individual training components in various projects. A survey was conducted that included a series of site visits to solar home systems (SHS) and individual surveys with system owners and operators, as well as focus group discussions with other project stakeholders. The survey results indicate that providing adequate training for users and local technicians is a crucial factor in successfully implementing rural electrification through photovoltaic (PV) power systems.. However, for training to be successful, there must be a consensus on what the target performance behaviors should be and how they should be measured. The fundamental requirements for effective training are that it reaches the appropriate individuals at the right time and delivers the relevant content.

5. Conclusion

This work explains the potential of solar energy to drive modern economies and highlights the gap in the utilization and deployment of solar systems in Sudan. The paper also sheds light on the key opportunities and challenges associated with large-scale implementation to enhance the overall electricity generation capacity of the country.

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