



Overview of Opportunities and Challenges of Solar Photovoltaic Promotion in Uganda

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The purpose of this paper is to provide an overview of the opportunities and challenges of solar photovoltaic (PV) promotion in Uganda. The study followed a review approach of relevant scientific, technical and government papers. The review indicated that, for Uganda, rising energy demand and access, need to reduce carbon footprint, lack of grid extension to rural communities, and improved livelihoods by productive uses of solar PV systems, emerge as key drivers for solar energy uses in this country. However, the study found that high initial investment cost, inadequate research and development, lack of human capacity and training, lack of information and public awareness, and quality control of products are the main challenges facing mass adoption of this technology. Furthermore, this study fosters the understanding of solar energy uses and provides policy recommendations that could mitigate these challenges, in a least developed country Uganda.

Keywords: Solar energy, solar radiation; photovoltaic; electricity; feed in tariff; greenhouse gas emissions; Uganda.

1. INTRODUCTION

Africa is endowed with vast amounts of solar resources, the continents' solar energy conversion systems' markets are still in their early stages of development [1]. Solar photovoltaic (PV) is one of the viable and environmentally friendly renewable technologies that could partially and wholly replace fossil-fuels technologies as a source of electricity generation both at large-scale (utility-scale) and small-scale (decentralized and behind the meter-scale and off-grid) levels. Recent trends in solar photovoltaic and associated electronic systems development as result of improved technology and cost reduction, solar PV-based energy systems are expected to continue to play significant role in global present and future energy mix. As shown in Fig. 1, there is a steady increase in the global trend of solar PV cumulative installed capacity from about 72 GW in 2011 to 707.5 GW in 2020. Of the total renewable energy generation capacity (including hydropower power) of 2 588 GW at the end of 2019, solar PV accounted for 627 GW and CSP accounted for 6.2 GW [2].

Uganda's location astride the equator makes solar PV a viable power potential. Fig. 2 shows that there is spatial variation in solar radiation across the country, with relatively low solar radiation in western region to relatively high solar radiation in eastern and northern regions of the country. Given Uganda's total surface area of 236040 km², and, on average, over 5 kWh/m²/day global solar radiation on horizontal surface, Uganda has more than 400,000 TWh of

solar energy potential, each year falling on its surface area. This is equivalent to over 15 000 times the total primary energy consumption in Uganda in 2017, which is 0.097 Million Quad (or 28.43 TWh) [3].

Fig. 2 suggests that solar energy is the most promising and abundant resource in Uganda and the current data on solar indicates that solar energy resources in the country are situated along the equator [5] and this allows Uganda to enjoy a high insolation of close to 8hours of sunshine daily, all through the year [5].

Solar energy can be used for various applications, such as electricity generation (through solar photovoltaic and steam turbine technologies), water heating, cooking, water distillation, water pumping, drying of agricultural and animals' products and passive building heating. Despite these various potential uses of solar energy coupled with its excellent potential, even though there is recent development of utility based-solar PV, has been limited to small-scale applications (solar lanterns and chargeable lamps, residential water heating systems, water pumping) and for traditional uses.

Researchers have made efforts to elucidate the potential contribution of solar energy as key for decarbonization and enhancement of future sustainable development of the human society [6]. In Nigeria, Ohunakin et al. [7] investigated solar energy and development. The prospective motives for broad development of solar energy conversion systems in Nigeria are also examined in their paper, as are some of the barriers and

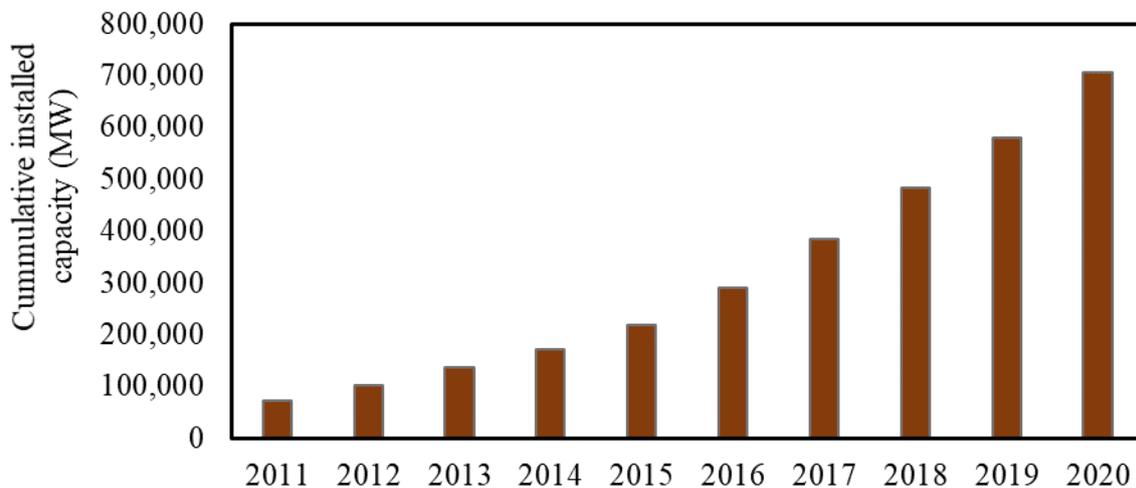


Fig. 1. Global trend of solar PV cumulative installed capacity [2]

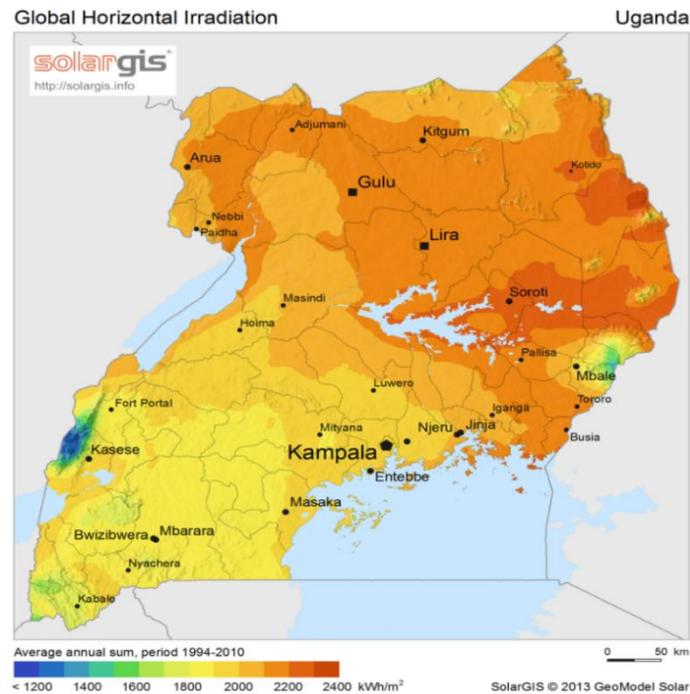


Fig. 2. Solar Resource Map, showing global horizontal irradiation [4]

problems, as well as procedures and policy measures to overcome the barriers and encourage the use of this resource. Kiefer and Del Río [8] on the other hand delved on the analysis of the barriers and drivers to concentrating solar power in the European Union. The results of their study suggested a need to combine different policies in order to activate the drivers and/or mitigate the barriers. Xue et al. [9] also looked into the challenges to solar photovoltaics adoption in Norway, as well as potential remedies. More specifically, Xue et al. [9] noted that the high initial costs of PVs, as well as a limited knowledge and awareness of the potential benefits, were the main barriers for people and the private sector, while limited funding, a lack of pilot projects to learn from, and risk uncertainty were the main barriers.

To this end, Do et al. [10] examined the underlying drivers and barriers for solar photovoltaic diffusion in Vietnam. Accordingly, Do et al. [10] found out that, a generous feed-in tariff (FIT) of US\$93.5/MWh for new projects, together with supporting policies such as tax exemptions, were found to be the key proximate drivers of Vietnam's solar PV boom. In addition, other drivers included, the government's desire to enhance energy self-sufficiency and the public's demand for local environmental quality. More so, Do et al. [10] observed that, limited

transmission grid capacity and complex administrative procedures were among the key barriers. Engelken et al. [11] compared the drivers, barriers, and opportunities of business models for renewable energies while Wassie and Adaramola [12] examined the socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems: Evidence from southern Ethiopia. A cross-sectional study of 605 rural households and a direct field investigation of 137 solar PVs/lanterns were used to investigate the drivers and impacts of rural electrification with solar photovoltaic (PV) systems in Ethiopia. The data was analysed using multiple linear regression and economic analysis. The adoption of solar PV systems in rural Ethiopia is increasing, according to the findings, and their impact looks to be significant.

Likewise, Irfan et al. [13] explored on the adoption of solar photovoltaic technology among Indian households, by examining the influence of entrepreneurship. According to their findings, entrepreneurship has a favourable and significant impact on the likelihood of solar photovoltaic technology adoption. The likelihood of being in the casual workforce increases with family size, residency in rural areas, and being in the informal workforce, according to the data. Age, income, and belonging to a higher caste category, on the other hand, diminish the

likelihood. While Thomas et al. [14] studied the diffusion of solar home systems in Rwandan refugee camps. The findings revealed that solar home systems can offer households a significant advantage over existing energy solutions and are, in most circumstances, compatible with refugees' basic energy demands and expectations. However, the cost of systems was identified as one of the major impediments, and without subsidies, additional cost reductions, or payment model changes, solar home systems are unlikely to offer electricity to a large number of houses and small businesses in the camps.

Some researchers also focused on other energy resources such, pumped hydro [15], Biogas [16]. In Uganda, Aarakit et al. [17] studied adoption of solar photovoltaic systems in households, Wabukala et al., [18] reviewed the assessment of wind energy development, opportunities, and challenges, Fashina et al., [19] focused on the drivers and barriers to renewable energy applications and development while

Bhamidipati et al., [20] examined agency in transition in transnational actors in the development of the off-grid solar PV regime in Uganda. Mugagga and Chamdimba [21], examined the status of Solar PV in Uganda. They segmented the Solar PV markets, analysed challenges and suggested policy and regulatory framework, but this study lacked an in-depth analysis of the opportunities and challenges to solar energy uses in Uganda and their presentation was not adequately supported by empirical evidence. In the current study, Table 1 presents a summary of selected studies on potential, opportunities and challenges facing renewable energy technologies in different countries. The aim of this paper, therefore, is to extend on the study by [21] and highlight the main potential advantages and favourable conditions in Uganda to accelerate solar PV (and other solar energy conversion systems) development, and to discuss challenges militating against the use of this technology in the Ugandan context.

Table 1. Summary of relevant empirical studies

References	Title	Approach and key finding
Amir and Khan [22]	Assessment of renewable energy: Status, challenges, COVID-19 impacts, opportunities, and sustainable energy solutions in Africa	<ul style="list-style-type: none"> • Reviewed Covid-19 impacts in the African energy sector through a rigorous analysis based on major issues governing sustainable solutions for Africa. • Need for power grid restructuring, energy storage technologies, and parallel mitigation of environmental factors with seasonal variations. • Proposed review analysis of bringing a better opportunity for all issues towards sustainable solutions, which will ease the renewable energy status in Africa. • Inevitable need to focus on having strong government policy frameworks and proper regulations. • Combined efforts are required in attracting foreign investments and to address feasible issues like setting-up targets.
Aarakit et al.[17]	Adoption of solar Photovoltaic in households: a case of Uganda	<ul style="list-style-type: none"> • This study employs a nationally representative data set from Uganda's National Electrification Survey of 2018 to analyse factors influencing households' choice of solar PV system. • Conditional mixed process model was estimated for quantification of associations between flexible payment mechanism, influential persons, access to grid electricity and solar PV adoption in the first stage, then type of solar PV adopted in the second stage. • Determinants of adoption as well as type of solar PV adopted are heterogeneous. • Specifically, flexible payment mechanism is

References	Title	Approach and key finding
		<p>positive for uptake of solar home systems and solar kit;</p> <ul style="list-style-type: none"> • Influential people were insignificant in all cases, • Grid access was negatively associated with uptake of both solar kits and solar home systems. • Rural residence, income, type of house are significant drivers of solar PV type adopted. • Conversely, education attainment was positive and significantly associated with adoption but insignificant for type of solar PV adopted. • Sex of household head was significant for uptake of solar kit.
Maka et al. [23]	Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities, and future perspectives.	<ul style="list-style-type: none"> • A general overview of the solar PV in Libyan energy generation was given. • Paper highlighted the energy challenges that faced the Libyan state, and the possibility to diagnose and suggest a strategy to develop and find solutions. • The study addresses the current situation of solar photovoltaic power in Libya, the use of solar energy, and proposed strategies adopted by Libya to encourage future applications of solar photovoltaic energy and electricity generation. • The study investigated an opportunity to exploit solar PVs to meet the deficiency in energy demand and by the affordable way.
Mugisha et al. [24]	Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia, and Rwanda.	<ul style="list-style-type: none"> • The paper provided a comparative analysis of the electrification experiences of three countries (Kenya, Ethiopia, and Rwanda) in terms of sources of funding, the challenges, and opportunities they have been experiencing as well as an analysis of policy implications. • Results showed that off-grid solar systems improve health, ICT, and micro-enterprises in rural areas. • The authors suggested that governments in these countries should generate more robust developmental schemes that provide income to rural people that pushes them above the poverty line and enables them to afford off-grid solar products.
Xue et al. [9]	Barriers and potential solutions to the diffusion of solar photovoltaics from the public-private-people partnership perspective – Case study of Norway	<ul style="list-style-type: none"> • The paper investigated the main barriers to diffusing photovoltaics for residential buildings from the public sector, private sector, and the people's perspectives in Norway. • It was reported that the high initial costs of PVs and limited information and awareness of the possible benefits are the main barriers for the people. • For the private sector, limited funding, and few pilot projects to learn from, as well as risk uncertainty are the main barriers.
Sadat et al. [25]	Barrier analysis of solar PV energy	<ul style="list-style-type: none"> • The paper assessed barriers of solar PV development using multi criteria decision making

References	Title	Approach and key finding
	development in the context of Iran using fuzzy AHP-TOPSIS method.	<p>(MCDM) and qualitative methods under uncertainty.</p> <ul style="list-style-type: none"> • The development of renewable energy systems could be facilitated by appropriate energy policies according to the recognition of major barriers. • Findings indicated that “messy economic situation” and “ineffective bureaucracy” are the most barriers hindering the development of PV energy production in Iran. Again, “Economic and financial incentives” and “mitigating bureaucratic efforts for permission approval” are the most effective solutions.
Aly et al. [26]	Barriers to large scale power in Tanzania	<ul style="list-style-type: none"> • Using the stakeholder-based approach, the paper aimed at identifying and analyzing the underlying barriers to large scale solar power in Tanzania. • The study employed a qualitative methodology where primary data was collected through 30 semi-structured interviews with experts from public institutions, research institutions, private investors, civil society organisations, development partners, and financial institutions. • Institutional barriers for the diffusion of large-scale solar power technologies were found to be predominant as they trigger financial and technological barriers. • The study consolidated the view that foreign investment and aid directed to expand electrification in Sub-Saharan Africa need reshaping for it to be a driving force.
Del Río et al. [27]	An overview of drivers and barriers to concentrated solar power in the European Union.	<ul style="list-style-type: none"> • The article aimed at identifying the relevant drivers and barriers for the deployment of concentrated solar power (CSP) in the EU in a 2030 horizon • Results showed that the higher “value” of CSP compared to other renewable energy sources (RES) was regarded as the most relevant driver, followed by the policy drivers (innovation and deployment support) and the significant cost reductions expected for the technology. • The most relevant barrier was, high cost of the technology in comparison with conventional power plants and other renewable energy technologies, closely followed by uncertain and retroactive policies.
Do et al. [10]	Underlying drivers and barriers for solar photovoltaic diffusion: The case of Vietnam	<ul style="list-style-type: none"> • The paper investigated the underlying drivers of Vietnam’s solar boom, barriers to further solar adoption, and suitable strategies for the next stage of solar adoption. • Forty-six semi-structured interviews were conducted with experts from government agencies, international organizations, non-governmental organizations, universities, research institutions, and industry. • A generous feed-in tariff (FIT) of US\$93.5/MWh

References	Title	Approach and key finding
		<p>for new projects, together with supporting policies such as tax exemptions, are found to be the key proximate drivers of Vietnam's solar PV boom.</p> <ul style="list-style-type: none"> • In addition, other drivers include the government's desire to enhance energy self-sufficiency and the public's demand for local environmental quality. • Limited transmission grid capacity and complex administrative procedures are among the key barriers.
Ugulu [28]	Barriers and motivations for solar photovoltaic (PV) adoption in urban Nigeria	<ul style="list-style-type: none"> • Using interviews, data were gathered on key barriers to and motivations for PV adoption and results analysed. • Findings indicate that the major barriers are high capital costs and lack of finance. • The key motivation for PV adoption was power outages, energy cost-savings, awareness, and access to finance.
Carstens and da Cunha [29]	Challenges and opportunities for the growth of solar photovoltaic energy in Brazil	<ul style="list-style-type: none"> • This study investigated from a socio-technical perspective the emergence of Solar Photovoltaic electricity (PV) in Brazil and identified challenges and opportunities of PV energy in the country. • The research was based on primary data covering periods 2015 to 2016 including 15 in-depth interviews with representing relevant actors from the system. • The need for the dissemination of PV energy includes the establishment of long-term clear goals, fiscal and financial incentives, and more attractive opportunities for investors as well as professional training courses. • Interesting to derive from the analysis was the impact of the niche developments on the regime and the landscape, especially in the establishment of a domestic PV energy industry, national economic growth, local and regional development, which would result from the dissemination of PV energy.
Choudhary and Srivastava [30]	Sustainability perspectives- a review for solar photovoltaic trends and growth opportunities.	<ul style="list-style-type: none"> • The paper followed a review approach to examine solar PV trends and growth opportunities. • Apart from core technology improvements, the multi-perspective review provided recommended for innovative policies adoption, substantial fall in energy cost, social acceptance, capacity building and collaborations for future energy establishment. • Sustainability perspective as a significant thought suggests a brief snapshot of fifteen innovative solar energy-based solutions for sustainable development. • Extending the portfolio of PV based cleaner energy production, requires innovation process, detailed concept analysis, pilot study, and demonstration.

References	Title	Approach and key finding
		<ul style="list-style-type: none"> • The development strategies would overcome the barriers to development and advance the implementation process. • The energy innovation system is never an easy process due to the complexity of technological success, public acceptance and environmental sensitivity, which affects the product supply chain.
Kiefer and del Río [8]	Analyzing the barriers and drivers to concentrating solar power in the European Union. Policy implications	<ul style="list-style-type: none"> • The paper aimed at empirically identifying and ranking the drivers and barriers to the deployment of concentrated solar power (CSP) in the EU in the past and the future at two different levels of analysis: System/grid or macro level and project/investment or micro level. • An expert elicitation and an investors' survey were carried out for this purpose. The results differed across the two levels (experts and investors), time frames and CSP designs. • The survey of investors highlights the relevance of dispatchability, key technology and investors' features as drivers, and stress the importance of administrative processes, construction permits and grid connection as barriers. • The results suggest the need to combine different policies in order to activate the drivers and/or mitigate the barriers.
Ohunakin et al. [7]	Solar energy applications and development in Nigeria: Drivers and barriers	<ul style="list-style-type: none"> • In this study, current perspectives of solar energy utilization as a renewable energy option in Nigeria are examined and discussed from the standpoint of sustainable development. • The possible motivations for extensive development of solar energy conversion systems in Nigeria are also discussed and some of the barriers and challenges are presented. • Steps and policy measures to overcome the barriers and facilitates the utilization of this resource are suggested.
George et al. [31]	Review of solar energy development in Kenya: Opportunities and challenges	<ul style="list-style-type: none"> • This review paper focuses on four major aspects of solar electrification in Kenya: (i) the opportunities available for solar electrification (ii) the main barriers encountered in solar electrification (iii) government policies governing solar energy and (iv) the future panorama of solar energy space. • It was reveals that there are enormous solar energy market opportunities in Kenya with great potential for investment, poverty eradication, and sustainable economic development that can only be realized if the government fully enforces the existing energy policies, reforms energy subsidies, provides favorable tax holidays and implements net metering mechanism in the country.
Tarai and Kale [32]	Solar PV policy framework of Indian States: Overview,	<ul style="list-style-type: none"> • A case study of Odisha is elaborated on how to apply the new methods to incorporate and revise state policy for betterment of solar

References	Title	Approach and key finding
	pitfalls, challenges, and improvements	<p>improvements.</p> <ul style="list-style-type: none"> Improving the state policy depends mostly on factors such as estimated PV energy potential of the region, availability of useful wasteland, and implementation cost. The study reviews and discusses the pitfalls of current solar policy framework of sixteen states identify the challenges of the sector for achieving the targets.
Mugagga & Chamdimba [21]	A comprehensive review on the status of Solar PV growth in Uganda	<ul style="list-style-type: none"> The challenges identified include technical capacity, technology awareness, high investment, unattractive feed-in tariffs (FIT), Financing associated risk, policy and regulatory framework, Policy and regulatory framework, Product standardization. Identified opportunities includes the need for a localized energy system, energy security and demand, presence of institutional framework, net metering, global and national demand for carbon emission reduction, financing mechanism, short take off times, creation of employment opportunities
Gorjian et al. [33]	Solar photovoltaic power generation in Iran: Development, policies, and barriers	<ul style="list-style-type: none"> Drivers for renewable energy growth in Iran include the strategies of the sixth development plan, "Paris Agreement" terms (- Iran obliged to reduce its GHG emissions in a range of 4% to 12% by 2030). Specifically, for solar PV, favourable solar energy resources (with annual average daily solar radiation of 4.5–5.5 kWh/m²). Some of the identified challenges are insufficient industry growth, financing problems, deficient of governing rules, and lack of a sustainable development roadmap. The authors noted that solving the identified challenges requires long-term and persisting policies to gain technical and industrial development.

The rest of the paper is arranged as follows: Section 2 presents the status of solar energy development in Uganda; Section 3 discusses the drivers for the development of this resource while Section 4 explores the key barriers to large-scale and widespread use of solar energy in Uganda and Section 5 suggests some measures and policies for promoting and accelerating the development of solar energy technologies in Uganda.

2. STATUS OF SOLAR PV DEVELOPMENT IN UGANDA

Historically, the traditional uses (such as drying of agriculture products and animal skins) of solar energy are known and have been exploited for

many generations. However, the use of solar energy (in form of solar PV) for electricity generation in Uganda is dated to early 1980s, with the early use of solar PV system is for lighting and vaccine refrigeration in health centres [34]. Thereafter, the Uganda Railways Cooperation and Uganda Post and Telecommunication Cooperation installed about 35 kW and 30 of solar PV across the country, respectively [35] and by 1992, the total capacity of solar PV installation was equivalent to 152.5 kW with at least 538 PV installations spanned across the country [36]. By 2014, the number of solar PV systems, in Uganda was estimated at about 30,000 installations, totaling 1.25 MW capacity [37].

Table 2. List of solar power plants operational in Uganda [38]

Solar power station	Location	Fuel type	Installed Capacity (MW)	Year completed	Owner
Bukuzindu Hybrid Solar and Thermal Power Station	Bukuzindu Kalangala District	Solar power & Diesel fuel	0.8	2014	KIS & Uganda Development Corporation
Soroti Solar Power Station	Soroti District	Solar	10	2016	Access Power MEA (Access), Total Eren
Tororo Solar Power Station	Tororo District	Solar	10	2017	Simba Telecoms Limited, Building Energy SpA
Kabulasoke Solar Power Station	Kabulasoke, Gomba District	Solar	20	2019	Xsabo Power Limited
Mayuge Solar Power Station	Bufulubi, Mayuge District	Solar	10	2019	Tryba Energy
Tororo PV Power project	Tororo District		10	2020	Tororo PV Power Co. Ltd
Total cumulative installed capacity			60.8		

The launching of the Rural Electrification Strategy and Plan (RESP) in 2001 and introduction of Feed-in tariff (FiT) by the Government of Uganda (GOU) has significantly increased utility-scale solar PV installed capacity to 60.8 MW [38]; shown in Table 2, shows the list of utility-scale solar PV power plants operational in Uganda), which represent 4.1% of total installed grid-connected power in Uganda [38] and, according to [39], to an overall installed capacity to 82.2 MW (utility-scale and small-scale applications). However, lack of coordination and data collection, actual solar PV installed capacity from various categories would be higher than the official value.

3. OPPORTUNITIES OF SOLAR PV DEVELOPMENT IN UGANDA

In the wake of increased energy needs emanating from increase in the population and economic growth, improving conditions of living and government target of sustainable energy for all in 2030, there is need to find other sources of energies in Uganda, which can complement hydropower, to meet this demand in clean, efficient, reliable and affordable. Even though, the potential of non-hydro power renewable resources (such as solar energy, biomass energy, geothermal, and wind energy) in the country is huge, due to its modular nature and other factors (are discussed in this Section), the focus of this paper is on solar Photovoltaic (PV) technology. Consequently, the following section

presents the main drivers for development of this energy resource in Uganda for various applications.

3.1 Energy Demand Growth and Improved Clean Energy Access

The approved Government of Uganda Vision 2040 development plan anticipated an increase in the country's power generation from the 822 MW (in 2012) to about 41 800 MW (by 2040) and electricity consumption per capita to 3668 kWh/year [40]. The proposed distribution of installed capacity of power generation by 2040 is shown in Table 3. Renewable energy resources are expected to contribute 12 700 MW (30.4%) to national grid in 2040. Furthermore, it can be deduced from this table that, solar energy resource is expected to provide about 5000MW (12%) of the Uganda's installed power capacity by 2040 and 39.4% of renewable-based power capacity. However, the current installed capacity of utility-scale solar energy-based power is 1.2% of 5 000 MW (of 2040 target). To meet this target, therefore, there is great opportunity to investment in solar energy resource for various uses by individuals as well as private and public organizations in this country.

According to Ministry of Energy and mineral development strategic development plan 2014/15 – 2018/2019 [41], electricity demand has been growing at an average of 10% per year. As such, with this enormous increase in demand for

electricity and supply-side opportunity, the development of solar energy in Uganda could serve supplementary role as source of energy for premises with access to grid electricity and major source of electricity for premises without electricity access (especially in rural areas). Otherwise, households and premises with unreliable supply and lack of electricity may tend to meet their growth in demand with the use of firewood and charcoal, which are unsustainable sources of energy as they pose a serious detriment to the environment.

Solar PV has proved very successful in providing energy services to the remote and inaccessible areas of Uganda, such as on islands and mountainous areas. Such areas include Kalangala Islands and the hills of Kigezi in Kabale, Kisoro, Mbale, Bududa and many other remote places where the national grid has not been built due to associated costs of grid extension. Thus, applying solar energy technologies in these islands and mountains would serve as the most viable option in providing electricity to these locations. Furthermore, it is possible to combine solar

energy technology with other energy resources to produce hybrid power plant. The 1.6 MW Solar-Thermal hybrid power established at Bugala Island, in Kalangala District (in Uganda), is one such of hybrid power plant. This power plant is supplying electricity to over 40 out of 49 villages on this Island.

Moreover, some solar energy conversion systems are very portable, available in different modular capacities and are easy to install (see Fig. 3). For examples, (1) solar PV modules come in different sizes ranging from less 5W to over 300 W; (2) solar heater technologies come in different sizes; (3) solar kits for charging the battery and for lighting appears in different sizes and contain number of plugging outlets. Therefore, based on their energy need and economic ability, individual and organizations can buy and install these systems. Consequently, solar energy conversion systems can be used as soothing factor for energy generation and supply as well as improving access to clean electricity, especially in rural communities, in the country.

Table 3. Present and future cumulative power generation in Uganda [42]

Source of energy	Current installed capacity (MW), Jan 2020*	Proposed installed capacity (MW), 2040**
Hydropower	1 010.7	4 500
Geothermal energy	0	1 500
Solar energy	60.8	5 000
Cogeneration	96.2	1 700
Peat energy	0	800
Nuclear	0	24 000
Thermal	101.1	4 300
Total	1 268.9	41 800





Fig. 3. Photos showing different solar PV modules.

3.2 Reducing the Carbon Footprint

During the 2020/2021 fiscal year, agriculture sector accounted for about 23.7% of GDP, and 31% of export earnings in Uganda [43], and hence, this sector is very important sector for Uganda's economy. Because of the industrialization of agriculture, most food is now produced at large-scale, with centrally located facilities, which uses energy-intensive farming practices. Due to remote location of these facilities and unreliability supply of utility-based electricity, most of these facilities use fossil-fuel-powered energy generators to run their heavy machineries to process and refrigerate foods during transportation, produce packaging materials, manufacture, and transport chemical inputs such as fertilizers as well as pesticides. Furthermore, some farmers rely on diesel-gasoline-based water pumping systems for irrigation purposes. Therefore, the use of fossil-fuels in Uganda for agriculture activities has aggravated greenhouse gas emissions (GHGs) in this country. Hence, use of renewable energy technologies, especially solar PV technology, can reduce dependence on these fossil-fuels resources, and therefore, GHGs in Uganda. For residential, non-farming commercial and industrial electricity users, adoption of solar PV can reduce health hazards through reduced indoor air pollution and noise [24]. In addition, by 2035, the transport sector would be the largest driver of growth in energy sector emissions in Uganda, followed by residential, then

manufacturing and finally construction [44]. Thus, the desire is to safeguard the environment and control emissions by intensifying the use of renewable energy-based electricity, more specifically, solar PV technologies. Solar energy could be used in powering vehicles like the recently unveiled Kira Motors' electric buses known as Kayoola buses in Uganda. In addition, in agro-processing industries such as tea processing industries, solar energy could be used for drying tea instead of using firewood. In nutshell, use of solar PV (and solar thermal systems) would be helpful in mitigating against continuous increasing in GHG emissions in Uganda.

3.3 Establishment of the Energy Sector Reforms and Feed-in Tariffs

In 2002, the Government of Uganda approved the National Energy Policy (Power sub-sector reform). This reform was aimed at stimulating provision of sufficient, consistent, and cost-effective power supply in Uganda to meet the increasing energy demand, as well as to promote efficient operations of the power sector with the aim of driving energy access [45]. The reform provided opportunities for private organizations, businesses, and individuals to invest and contribute electrical power generation in the country. Additionally, the reform paved way for the initiation of the Renewable Energy Policy, which drive the application and development renewable energy resources). As a result,

Table 4. Current approved FiT for applicable technologies in Uganda (2019 – 2021) [47]

Technology	Installed capacity, IP (MW)	FiT (US\$/kWh)
Hydro	10 < IP ≤ 20	0.0751
	5 < IP ≤ 10	0.0792 - 0.0751*
	0.5 < IP ≤ 5	0.0792
Bagasse (co-generation)	0.5 < IP ≤ 20	0.0793
Solar PV	0.5 < IP ≤ 20	0.0710**

*Computed as a regressive allocation of costs with increases in plant's installed capacity; ** Maximum return on equity of 10%.

Uganda has seen some private investors penetrate the solar energy market, such as G-tech Energy Solutions, Konserve Advisory Services Ltd, Solar Point Uganda, Kishen Enterprises (U) Ltd, Nughasa Power Solutions, JK-Energies Ltd, Makambo Technical Services Ltd, Power Trust Uganda Limited and UltraTec (U) Ltd. Therefore, because of the energy reform there are now more opportunities for different players to invest in solar energy development in this country.

To reinforce solar PV use, the Government of Uganda, established Feed-in Tariff (FiT) structure as a policy tool designed to stimulate investment in the renewable energy sources. FiT usually implies promising producers of solar PV above-market price for what they deliver to the grid. In Uganda, historically, the FiT is technology based, covers all renewable energy resources and applicable to installed capacity ranging from 0.5MW to 20 MW. For Solar PV, the initial FiT was fixed as US\$ 0.1637/kWh for projects [42], which are licensed between 2016 and 2018 [46]. As shown in Table 2, the introduction of FiT has resulted in established of five solar PV power plants with total installed capacity of 60 MW and they are contracted for 20 years each on approved FiT, which is reported to be generous [42]. However, due to commercial maturity of this technology, the current FiT is US\$0.071/kWh for project licensed from 2019 to 2021 [47]. This is reflected in lower FiT for solar PV when compared with this priority renewable technologies (as shown in Table 4). It should be noted that FiT values shown in the Table 4 are paid by the Ugandan, however, the FiT received by the developer are higher than these values.

3.4 Improve Livelihood and Enhancement of Economic Impacts

Uganda Bureau of Statistics (UBOS) found out that 13.3% of the Ugandan youths aged 18-30 years were unemployed [38] and [48]. Furthermore, UBOS's population projections

reports for 2015-2020 indicated that the youth age group constitutes 23% of the total national population. Therefore, unemployment rate among of the youth could be reduced through the development of solar energy market and supply chain and promoting its use in Uganda. This can lead to the creation of jobs in solar energy market supply chain, from the technical aspects to business and market related jobs. Therefore, promoting solar energy technologies in Uganda will play critical role in scaling down poverty levels as local communities will more likely benefit from employment opportunities, acquisition of various skills, investment prospects and improve productivity. For example, solar PV could be used to run clippers in barbershops, driers in saloons, power refrigerators and small-scale businesses in rural communities. It has been documented in many countries that potential number job opportunities resulting from solar energy development in enormous. For instance, IRENA [49] reported that solar PV development provided over 2.2 million in China and 115 000 in India and, on global level, 3.6 million are linked to solar PV. In Uganda, Gillard et al. [50] reported that development of solar streetlights could lead to growth of domestic solar technology markets and creation of over 14,000 jobs nationwide, in addition to other social benefits.

4. KEY CHALLENGES TO SOLAR ENERGY USE IN UGANDA

Despite the drivers or benefits of solar PV development for individual, private, and public in Uganda, as discussed in Section 3, there are a couple of issues that are limiting this development. Some of these issues or barriers are briefly presented in the following sub-sections.

4.1 Initial Investment Cost

On average, over 10 million (or about 28% of the population) of Ugandans are living on less than

US\$1.90 per day [51]. This implies that there is generally low disposable income among the population to invest in solar technologies, which require substantial amounts. On small-scale or rural households' level, investing in the various solar components, require relatively high initial capital, which an average Ugandan may not afford [21]. Although solar kits solutions come in different sizes, smaller sizes are relatively cheaper to acquire but inefficient in term value for money, economic life, and performance. Furthermore, these low wattage solar kits are quite expensive when compare with utility scale solar PV systems. In Uganda, different packages are typically available with several classes of price and system capability (as shown in Table 5). While the cost of solar energy systems on the global scale is continuing to reduce, evidence From Table 5 suggest that the cost for solar energy system is still exorbitant for an average Ugandan.

Even though the cost solar PV have been decreasing for some years now [47], high upfront costs for investment is still identified as a barrier for utility-scale solar PV development in Uganda [37]. Table 6 indicates that international funders

from outside the country supported all utility-scale solar power projects financially. This suggests that solar energy projects are expensive to invest by wholly Ugandan owned business, mainly due to high interest rate on bank loans in the country.

4.2 Lack of Information and Public Awareness

The importance of solar radiation in drying clothes and foodstuffs is widely acknowledged in Uganda, however, most Ugandans are not aware of the use of solar technologies to generate electricity, to heat water and to cook food. Moreover, few Ugandans know the costs of solar kits and related components and/or aware that there are credit facilities to acquire these facilities and maintenance services for acquired systems. This limited awareness and the fear to undertake the perceived risk by investing in these technologies has limited potential solar energy prospects [52]. This agrees with IRENA, [39] that consumer education has been stressed as one of the top challenges facing the diffusion of solar energy systems in rural areas in Kenya and the

Table 5. Solar packages and the associated costs at SolarNow Ltd Uganda [37]

Size of the Module	Battery size	Inverter	Price (UGX)
1 SolarNow 50W, 3lights and a radio		1 Mobile charger	1,050,000
2 SolarNow 250W PV Modules	SolarNow 200Ah/12V Deep-cycle Gel Batteries	1 SolarNow 1.6kW inverter/ Charger	9,500,000
1 SolarNow 100 W; 6 lights; a radio and a DC Led TV/DVD	-	-	1,800,000
1 SolarNow 250W system with 15 Lights	-	-	5,800,000
2 SolarNow 250W PV Modules	SolarNow 200Ah/12V Deep-cycle Gel Batteries	SolarNow 1.6kW Inverter/Charger	9,500,000
5 SolarNow 300W PV Modules	-	1 solar Tech Solar Pumping Inverter PB 1500L-G2	13,200,000
4 SolarNow 250W PV Modules	4 SolarNow 200Ah/12V Deep-cycle Gel Batteries	1 SolarNow 1.6 kW inverter/ Charger	14,500,000
12 SolarNow 250W PV Modules	12 SolarNow 200Ah/12V Deep-cycle Gel Batteries	1 SolarNow 3.2 kW inverter/Charger	37,000,000
9 SolarNow 250W PV Modules	8 SolarNow 200Ah/12V Deep-cycle Gel Batteries	1 SolarNow 3.2 kW inverter/ charger	27,500,000

Table 6. Investment costs of solar projects in Uganda*

Name (Installed capacity; Year)	Investment cost; Unit cost (US\$/kW)	Source of funds and owner
Soroti solar Power plant (10 MW; 2016)	US\$19 million; US\$1900/kW	Partial funding from the European Union Infrastructure Trust Fund
Tororo (10MW; 2017)	US\$19.6 million; US\$1960/kW	US \$ 14.7 million borrowed from Netherlands Development Finance Company while owners contributed US \$ 4.9 million
Kabulasoke (20 MW; 2019)	US\$24.5 million; US\$1225/kW	Owned by The Xsabo Group, which is in turn owned by Dr. David Aloba, a Ugandan resident in Germany.
Mayuge (10 MW; 2019)	US\$11 million; US\$1100/kW	Tryba Energy, a French family industrial group dedicated to solar energy.

Information extracted from different sources by the authors.

rest of Africa. To address this lack of awareness and information, public sensitization by government agencies (including educational institutions), solar equipment marketers and non-governmental organizations, to inform the populace about the benefits and opportunities of solar energy conversion systems uses.

4.3 Lack of Human Capacity and Training

The development of solar energy technologies calls for skills in the areas of engineering, physics and energy economics and governance, as well as business management and project planning and development [53]. Furthermore, capacity building in form of training on the use and development of various solar technologies is crucial for the enhancement of skills of the different groups of people. For example, lack or insufficient technically skilled leads to poor designed and installed solar PV systems, which could discourage potential future users. In addition, lack of appropriate skill by the solar PV vendors could lead to misinformation and exaggerated benefits of these technologies and this could lead to mistrust in this system, the initial promises are not met.

4.4 Quality Control of Products

There is lack of adequate standards and mechanisms to monitor and ensure quality of solar PV systems' components and kits in Ugandan market [21]. Quality control is very low both at the importation and local production levels (for local components), as well as the installation of the solar PV systems [54]. Furthermore, the high market potential has resulted in an influx of dealers selling low quality products or at worst installing the systems

incorrectly. This is partly due to lack of suitable trained professional as well as lack of necessary equipment to assess the quality of these solar products and components available in the market. Even though, these low-quality products are initially cheap, they tend to become expensive over time through additional repairs and replacement cost, which eventually influence other users' decision to adoption solar energy conversion systems negatively [55].

4.5 Inadequate Attention to Research and Development

In addition to availability of solar radiation, solar PV systems are very sensitive to environmental conditions such as ambient temperature, wind and dust as well as mode of installation (such as fixed tilt, sun-tracking, rooftop or ground-based) as well as installation angles (tilt angle and orientation) relatively to solar position [56] and [57]. Hence, the performance of solar PV systems is location specific and therefore, appropriate research is required to design, select, and install efficient systems for given application in different locations. Furthermore, solar PV modules are available in different technologies, which could influence their performance under different weather, site, and shading conditions. Thus, research and development could guide the selection of appropriate solar PV technologies (such as silicon crystalline and thin film).

4.7 Lack of Interest of Financial Institutions in Solar Loan Products

Large-scale utility solar PV, small-scale decentralized PV and solar kits (such as solar home systems) are relatively expensive for an

average business owner, households and low-income earners, respectively in Uganda (as shown in Table 5 and Table 6). To acquire these solar PV systems, corporate and individual, generally need financial support and/or loan financial institutions [58]. Furthermore, prospective solar PV companies have struggled to convince financial institutions that they can make credible technical and partners, and many micro finance institutions (MFI's) and Savings and Credit Cooperatives (SACCOs) are not interested in the provision of a solar loan product for fixed or mobile systems. As noted by [59], consumers complained about lack of technical support on the ground, and this provides additional cause for financial institutions to be skeptical about the sustainability of a solar PV portfolio. In a study by [59], it was noted that, the effects of limited financing options affect all the levels of the distribution value chain, i.e., from the manufacturer through to the importers, distributors, dealers and then to the final user of these technologies. The role of financing in promoting innovation in renewable energy has been widely acknowledged in literature [40, 60]. Therefore, without appropriate financial support subsidies and loan, as well as other financial oriented conducive environment, government targeted effort for solar PV development and use would not be achieved.

4. 8 Institutional Barriers

Even though, Uganda's energy reform has liberated energy market in this country, however, institutional configuration of Uganda's energy segment is still under government control, with the energy generation and supply assigned amongst numerous government units. Moreover, the inconsistent interpretation and application in the taxation policy incentives coupled with limited support for the sector has continually hampered the growth of off-grid solar industry across the region. Additionally, companies involved in importing solar components face unclear import regulations, customs and tax policy, which in turn

have exacerbated unhelpful misunderstandings between solar energy players, and tax and custom authorities.

Coupled with these issues, Ugandan government charges various taxes on solar components and these include import duty (ID, maximum rate: 25%), withholding tax (WHT, maximum rate: 6%), value added tax (VAT, maximum rate: 18%) and infrastructural levy (ILV, maximum rate: 1.5%) [61]. Table 7 shows the applicable tax rates for Pico-PV system and solar home system (SHS) in Ugandan market. It can be observed from this table that total tax on these solar kits varies from 6% to 35.5%. In Table 8, it is observed that apart from solar module (with total tax rate of 6%), other key components of solar PV system attracted high tax rates from 24% to 50.5% (for cables, which are essential components of the system). Therefore, in general, high tax rates is an additional and discouraging cost on investment and installation of solar PV system in Uganda.

Furthermore, there is limited harmonization by the different units of the government such as Electricity Regulatory Agency (ERA), MEMD, Uganda Electricity Transmission Company Limited, Rural Electricity Agency, Uganda National Bureau of Standards, Electricity Disputes Tribunal, Directorate of water resources management and National Environmental Management Authority. This inadequate synchronization causes many delays regarding the licensing of solar energy projects. Unfortunately, the country does not have regional or national research centres, which would help in creating innovations in area of solar energy systems development. Relatedly, if national governments instituted a policy framework aimed at rolling out solar powered lighting in Uganda, the country could realize multiple co-benefits for society, the economy, and the environment.

Table 7. Tax rates for Pico-PV and solar home system in Uganda*

Type	Capacity rate (W)	ID (%)	VAT (%)	WHT (%)	ILV (%)	Total tax (%)
Pico-PV	< 1.499	10	Exempt	6	1.5	17.5
	1.5 – 2.999	10	18	6	1.5	35.5
	3 – 10.999	0	Exempt	6	0	6
SHS	11 – 20.999	0	0	0	0	6
	21 – 49.999	0	0	0	0	6

*Source: Data extracted from USEA [61]

Table 8. Tax rates for key components of a solar PV system *

Component	Size/Type	ID (%)	VAT (%)	WHT (%)	ILV (%)	Total tax (%)
Solar module		Exempt	Exempt	6	0	6
Solar charge control units	Voltage <1000V	10	18	6	1.5	35.5
DC to AC Inverters	Voltage >1000	0	18	6	0	24
Solar PV cables		25	18	6	1.5	50.5
Batteries	Flooded lead acid	35	Exempt	6	1.5	42.5
	Absorbent glass mat	35	Exempt	6	1.5	42.5
	Gel	35	Exempt	6	1.5	42.5
	Lithium	35	Exempt	6	1.5	42.5

*Source: Data extracted from USEA [61]

5. SUGGESTED MEASURES AND POLICY RECOMMENDATIONS

This section presents the various policy interventions that need to be adopted to help in overcoming the barriers identified in previous Section.

- i. Government of Uganda should remove all tax on solar kits (Pico-solar PV and SHS) and key components of solar PV system and other solar energy conversion systems (such as solar water heating systems). This in turn could reduce the overall investment cost of these solar PV systems and make it easier for potential users (that can afford it) to buy and import quality solar PV products.
- ii. Even though, it could be argued that investment in solar PV system is more economically viable now than couple of years back, decreasing FiT for solar PV from US\$0.11/kWh (in ERA-FiT -Phase II) to US\$0.071/kWh, (in ERA-FiT- Phase IV), which translate to 35.5% reduction, could lead to setback and discourage potential private investors.
- iii. Timely and accurate information to sensitize the populace about the potential benefits (such as positive impact of the environment, free and cheap energy, improving livelihood and productivity, and business and job opportunities) of use and development of solar energy conversion systems, as well as available funding opportunities and investment payment plans, will go a long way to improve solar energy technologies across the country. This could easily be achieved by campaigns on radio and free-to-air television channels, billboard information in

strategy locations in all districts, towns and cities, and education curriculum for elementary and secondary schools.

- iv. There is need for the regulators such as Uganda National Bureau of Standards (UNBS) and other agencies of the government to adopt strict guidelines regarding the standard of solar energy equipment that are been sold in Uganda. This can be achieved by equipped the Bureau with essential and standard facilities as well as with professional with required skilled. Furthermore, good relationship between the Bureau and national and international research institutions will ensure that it has correct information on quality of solar energy conversion equipment.
- v. As a catalyst to capacity building, there is need to strengthen the academic institutions in Uganda. These institutions occupy an important and envisaged central role, in contributing to capacity building for sustainable energy development. Research undertaken by these academic institutions will aid in building capacity in the area of solar energy technologies and contribute to UNBS ability to have access research-based information that could help making accurate decision on quality of solar energy components. This newly established Master and PhD in Energy economics and Governance at Makerere University of Business School Kampala, Master in Renewable Energy at Makerere University Kampala, and Master in Renewable Energy and Energy Management at Kampala International University, are some of the programmes within Uganda, that train professional and expertise in Renewable Energy. However,

the tuition fees of these programmes are currently beyond an average Ugandan to undertake.

6. CONCLUSION

The paper examines the current status of solar energy status in Uganda as well as the opportunities, barriers and suggest policy interventions that could be implemented to mitigate the challenges and barriers observed. Considering that Uganda is endowed with huge potential of solar energy resources, the country could meet all the citizens' energy needs if this resource alone is well developed.

In addition to this excellent resource, it is observed that, other benefits of the development of the resource are vast, from individual (improving livelihood and conditions of living – through job creation, improving business productivity, reduce indoor pollution, improving household access to clean energy) to community, private (such as improve productivity, less dependency on utility-grid, and reduce expenses on backup generators), and public entities (such as improving government revenue – income through individual and business income; reduce expenses on electricity transmission and distribution infrastructure, and reduction in social costs to manage crime resulting from jobless youths).

Nonetheless, the development of solar PV systems in Uganda is affected by many obstacles such as informational (in terms of knowledge and awareness), economic, institutional, social, and technical barriers. To overcome these barriers, the government can develop implementable policies, which are supported by strong political will by all relevant government agencies and actors.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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