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Examining the Progress of Decentralized Photovoltaic Systems In Rural Ghana: A Comprehensive Review

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***Abstract*—This review paper examines the development of distributed Photo Voltaic (PV) systems for rural communities in Ghana. The paper provides a review of the present situation of distributed PV systems in Ghana, highlighting the benefits and challenges associated with their implementation. The review draws on several key studies, which analyse the policy landscape, the potential for co-benefits, the barriers to development, and the economic feasibility of distributed PV systems. The findings indicate that while distributed PV systems offer numerous benefits, including increased access to electricity and reduce carbon emissions, there are several significant barriers to their development, including financial constraints, limited private sector involvement, and unfavourable policies. The review concludes by suggesting that further research is needed to explore innovative financing mechanisms, effective policy frameworks, and improved public-private partnerships, which could accelerate the deployment of distributed PV systems and improve energy access for rural communities in Ghana.**

Keywords—PV system, Rural electrification, Energy policy, Ghana, Distributed system

I. INTRODUCTION

The SDG #7, which aims to provide access to energy to everyone [1-4]gives distributed renewable energy technologies a fresh push as a means of supplying energy to millions of households by 2030, notably in Sub-Saharan Africa (SSA)[5]. One of the exceedingly significant drivers for a country's socioeconomic and industrial development is the ability to obtain and use electricity. However, in many developing countries, a significant percentage of the population does not have the means to obtain or use electricity, and conventional grid-based solutions are often not feasible because of the expensive and challenging nature of expanding the electricity distribution system to isolated locations [6]. It is believed that most of the places in the world lacking electricity are in underdeveloped areas [7]. 572 million of the 733 million people around the world who lack the ability to obtain or use electricity are Africa's population [2][8]. Ghana has taken notable steps forward in enhancing the availability of electricity to its population, with an overall access rate of 86% [2], which is noted as few of the top electricity systems in the Sub-Saharan African region. But there is a notable variation between urban electrification access rate at 94.7% and rural access rate at 74% [8-9].

The lack of electricity is generally due to a variety of factors such as lack of power, challenging terrain, and inadequate transportation. Technologies that generate energy from renewable sources, such as PV systems offer a promising solution to this problem. Over the past few years, there has been a growing concern in establishing decentralized PV systems for rural areas in Ghana [10-11].

By bridging the access gap and offering lower prices and faster connection times than grid additions, stand-alone solar systems offer a possible approach to electrifying rural communities.In general, a mini grid consists of three components: a power generation system, a distribution network that delivers electricity to remote users, and an energy storage system designed to store excess power. Mini grids can operate autonomously and deliver power, especially to those with limited access to them in remote or rural regions, using one or more generation sources (hybrid systems) [12]. It covers solar residential systems, solar microgrids and solar mini grids. But the use of technologies like these as primary means of electricity in many nations are rare, and adoption of them, particularly in rural areas, is moving slowly [13].

Within this article, the development of distributed PV systems in remote areas of Ghana will be reviewed in this study along with its present research status. To commence, a concise outline of the energy landscape in Ghana, with a focus on the issues encountered by rural communities in obtaining access to electricity will be presented.Ghana's energy sector is dominated by hydropower and thermal power generation, with the country currently facing challenges of insufficient power supply, high cost of electricity, and unreliable electricity access, particularly in rural areas[14].

Literature will then be reviewed on the socio-economic, political, and environmental factors that influence the acceptance and use of PV systems in remote regions. Specifically, the study also will examine the impact of government policies and regulatory frameworks on the success of PV projects in rural communities. Several studies have highlighted the importance of favorable government legislations and regulations to facilitate the implementation of RE technologies, including PV systems [15]. The barriers

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to distributed PV systems for rural communities will also be discussed.

II. Literature Review

A. Electricity situation in Ghana

The growth of Ghana's total electricity generation capacity, including distributed generation, from 2,170 MW to 5,481 MW in 2011 and 2021 respectively, representing a yearly increase of 9.7%. Additionally, the dependable capacity exhibited an annual growth rate of around 9.8%, surging from 1,945 MW to 4,975 MW in 2011 and 2021 respectively.

Figure 1 displays a significant 14.3% yearly growth rate in the installed thermal generation capacity, which soared from 990 MW in 2011 to 3,753 MW in 2021.In contrast, the installed capacity of grid-integrated renewable sources rose significantly, surging from 23 MW to approximately 144 MW in 2016 and 2021 [16].

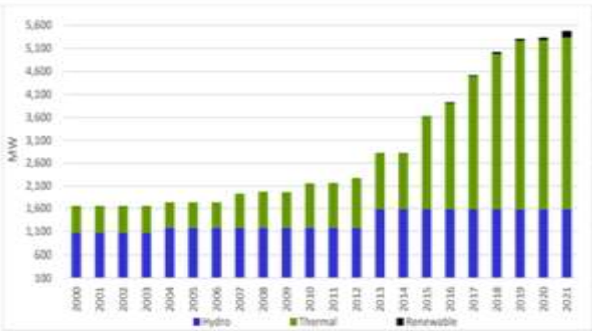

Fig. 1. Installed Generating Capacity (2000-2021) [16]

B. Solar Energy Resource Potentials and their Relevance for distributed PV system development

Ghana possesses significant solar resources and has the potential for the generation of solar power through either grid-connected or independent (off-grid) systems. Ghana's solar energy potential is estimated to be 35 exajoules (EJ), this solar potential in Ghana 100 times greater than the country's current electricity demand. According to the Ghanaian government, the average amount of solar radiation received per day ranges from 4.4 to 5.6 kWh/m2/day monthly[18]. Kumasi, which is situated in the foggy semideciduous woodland zone, experiences sunrise at 5.3 hours, while the sun sets at 7.7 hoursin Watts, Ghana [18-19], situated in the dry Savannah territory. The Upper West, part of Volta, Northern and Bono Ahafo regions receive monthly average radiation of 4-6.5KWh/m2/day, except for rain from July to September and hot, dry Harmattan winds from November to February. The areas of Brong-Ahafo, Ashanti, Western, Eastern, and some parts of Central and Volta regions in Ghana experience a mean monthly solar radiation ranging from 3.1 to 5.8 kWh/m2/day. Conversely, areas such as Greater Accra, the coastal regions of Volta, and other parts of Central Ghana receive a monthly average solar radiation of 4.0 to 6.0 kWh/m2/day, as indicated by [19], [20]. The solar resource map of Ghana is depicted in Figure 2. Given that the daily solar radiation within the country ranges from 4.0 to 6.0 kWh/m2 annually, generating solar PV power presents an encouraging opportunity to enhance the nation’s electricity supply security, as noted by [21]. However, developing this resource for PV systems has received little attention until recently.

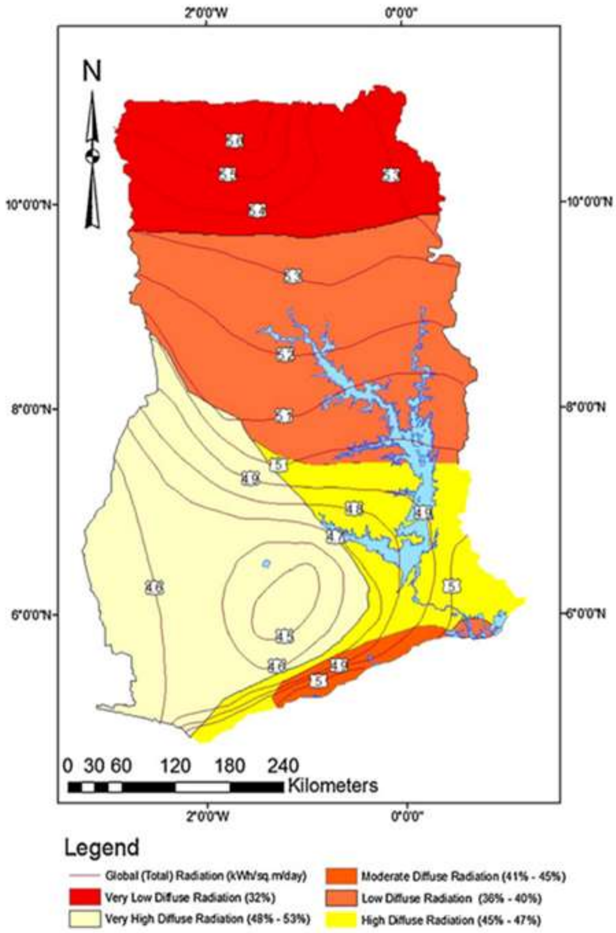

Fig. 2. Solar Resource Potential map of Ghana [18], [20], [30]

Given that Ghana experiences an annual daily solar radiation range of 4.0 to 6.0 kWh/m2, it can be inferred that solar PV power generation holds great potential as viable option to enhance the country's energy security [18], [20-21], [23] . However, this potential has been underutilized until recently, with little attention paid to developing PV systems. Therefore, various stakeholders, particularly the government, are now making efforts to leverage this resource by promoting decentralized solar PV projects such as standalone PV to facilitate the supply of electricity.

C. Ghana's Solar Power Development Status

A target of incorporating 10% RE into the nation's energy mix is stated in Ghana's RE Act and RE Master Plan. The RE Act indicated that hydroelectric dams with a capacity of 100MW or less are considered as renewable energy sources. However, presently, Ghana has not established any wind energy power plants or other renewable energy facilities. Therefore, at present, the country's renewable energy mix solely relies on solar energy[24].

Solar photovoltaic (PV) energy is produced using Photovoltaic (PV) systems that utilize solar energy are connected to either on-grid or off-grid systems. The Volta River Authority (VRA) commissioned the initial installation of a 2.5 MW solar PV system on a large scale in Ghana in May 2013 located at Navrongo in the Upper East region

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Ghana[25]. Additionally, there are several other solar power installations in Ghana, including a capacity of 40 MW plant located at Onyandze, in the Gomoa East District of the Central Region of Ghana.The plant is co-owned by BXC Company and Meinergy Technology, with each enterprise being accountable for 20 MW of the plant's capacity. In addition to those, there is a 6.5 MW capacity PV system situated in Lawra, a 13 MW capacity PV system located in Kaleo all in the Upper West region of Ghana, a 51 MW capacity plant positioned in Bui, and a 30.9 MW distributed generation plant that is built and operated by state-owned electricity companies[17]. Numerous projects are currently underway throughout Ghana. One example is the second phase of the Kaleo project, with an expectation to generate 14 MW of power when completed. Additionally, plans are underway to construct an additional 200 MW capacity solar plant in the northern part of the nation. Another significant project is the ongoing 59 MW solar component of the Pwalugu Hydro-Solar hybrid plant, which is set to be finalized in 2025. [17], [25], [26]. In addition, more than 89 communities in Ghana have received thousands of small-scale solar systems with a total capacity of 793 kW. These systems have been used for a variety of things, like refrigerators for vaccines, street lighting, radios, television sets, and remote mobile phone charging systems. In addition, there are several installed PV systems for residential and commercial purposes either for main electricity or backup application in Ghana not assessed and documented[27], [28].

TABLE I. ADVANTAGES AND DISADVANTAGES OF PV SYSTEM [30]

S.No.	Advantages	Disadvantages
1	The source of fuel is abundant, easily available and virtually limitless	The cost of installation is expensive
2	The cost of operation is minimal (no need for fuel)	Solar panels do not produce electricity at night, and areas with high cloud cover may have inconsistent and uncertain power generation during the day
3	It can be quickly installed at almost any location where it is needed	The absence of cost-effective and efficient energy and storage
4	The environmental impact is minimal because there is less air pollution and fewer greenhouse gases emitted	Photovoltaic cells rely on scarce elements that could face rising costs and limited availability
5	The cost of operation and upkeep is comparatively low	They need a considerable amount of space to generate only small quantities of energy

D. Classification of PV nano/micro/mini-grids

The International Renewable Energy Agency (IRENA) has classified grid systems into five categories based on their maximum capacity, capability, and complexity. These categories include stand-alone systems, pico-grids, nano-grids, micro-grids, and mini-grids. Each of these categories serves a different purpose, ranging from providing power to a single device to meeting local demand with local production. The classification considers various factors such as voltage, pricing, and interconnectivity. In this way, the IRENA classification provides a useful framework for understanding the different types of grid systems and their capabilities in meeting energy demands in various contexts [31].

Stand-alone systems have a maximum capacity of 0.1 kW and are generally used to provide power to a single structure or a single device.Pico-grids have a maximum capacity of 1 kW and are controlled by a single entity responsible for overseeing their operation.Nano-grids have a maximum capacity of 5 kW and are designed to provide power at fixed or specific voltages. Grid operators negotiate with each other to buy or sell electricity and these systems can be interconnected or stand-alone. Direct current (DC) systems are favoured in these types of grids.Micro-grids have a maximum capacity of 100 kW and are designed to balance local energy consumption and production. They offer a range of voltages and different levels of quality and reliability options. These systems incorporate generation and can offer varying pricing.Mini grids have a maximum capacity of 100,000 kW and are designed to meet local demand with local production. Transmission is limited to 11 kV and customer connections are available.

E. Ghana's Renewable Energy Development Policies

Ghana’s renewable energy policy is closely linked to its policy goals, as set out in its renewable energy frameworks, as well as its policy institutions and policy instruments. The first step in achieving meaningful progress in renewable energy adoption is to align with these policy areas, as stated by [32][33].

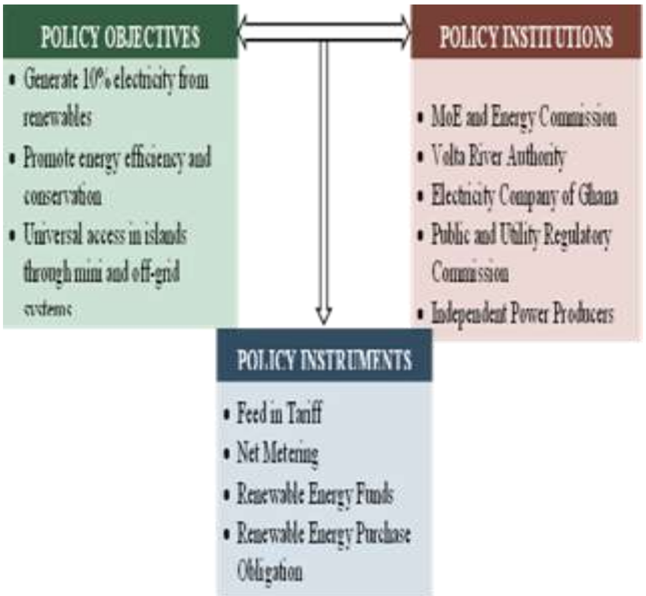

Fig. 3. The procedure of formulating renewable energy policies in Ghana [34]

F. The Renewable Energy Act

The Energy Policy paper of 2011 resulted in the enactment of a law (Act 832) that authorized Ghana's energy

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sector institutions to develop plans for integrating renewable energy sources into the country's electricity generation mix. It sought to achieve a target of generating a minimum of 10% of Ghana's electricity from RE sources by 2030, which marked a turning point in the energy mix of Ghana. Eventually, the Act has been amended to clarify its provisions and encourage greater private-sector involvement in achieving the 2030 target. As part of these amendments was the adoption of the 2019 Renewable Energy Master Plan (REMP), and the Renewable Energy Authority (REA) was established, with the Bui Power Authority (BPA) currently responsible for carrying out its duties under the Ministry of Energy's amendment to the Bui Power Act in 2020. The BPA now has the legal ability to carry out state-sponsored renewable energy projects, pursue its independent RE initiatives, and investigate clean alternative energy. All these actions will help the government's efforts to include RE sources into the energy mix.

G. Renewable Energy Master Plan

Even though the RE Act was passed to encourage the incorporation of regenerated electricity sources into Ghana's energy mix, it alone was insufficient to achieve the objectives and targets set for 2020, which were postponed until 2030. the REMP 2019 was introduced to bridge this gap by providing a detailed integrated plan and funding commitment and set policies for sustained growth and improvement of Ghana's RE resource potentials. Along with promoting renewable energy technologies to achieve the 10% target, the plan also prioritizes the socio-economic impact on areas without access to grid extension and aims to reduce climate change's harmful impacts by 2030. Ghana, as a participant in the Paris Agreement and other global agreements, has established these policy frameworks and plans as part of the country's Nationally Determined Contribution (NDC) of UNFCCC, to have a minimum of 10% of the country's electricity generation come from renewable sources by 2030.

H. Renewable Energy (Solar PV Mini-Grid) Policies and Institutions

Ghana's renewable energy strategy is cantered on policy incentives and flexible regulations to encourage collaboration between investors in the RE field. The regulations include the renewable energy purchase obligation, net metering, renewable energy funds (REF), and feed-in tariff, which are enforced by the Energy Ministry and the Commission of Energy to ensure that energy policies are implemented at lower levels of government. Independent Power Producers act as investors, technology developers, and renewable energy source producers, and they must adhere to a tariff threshold set by Public Utility Regulatory Commission (PURC) to prevent consumer exploitation. The Commission of Energy monitors the net metering process when the IPPs feed power produced into the grid. Although these regulations do not apply to micro-grids in remote and island communities, the PURC still controls the tariffs. Additionally, Bui Power Authority and Volta River Authority have been instrumental in driving renewable energy in Ghana by developing and managing some stand-alone solar photovoltaic and mini grids in remote areas and island locations across the country.

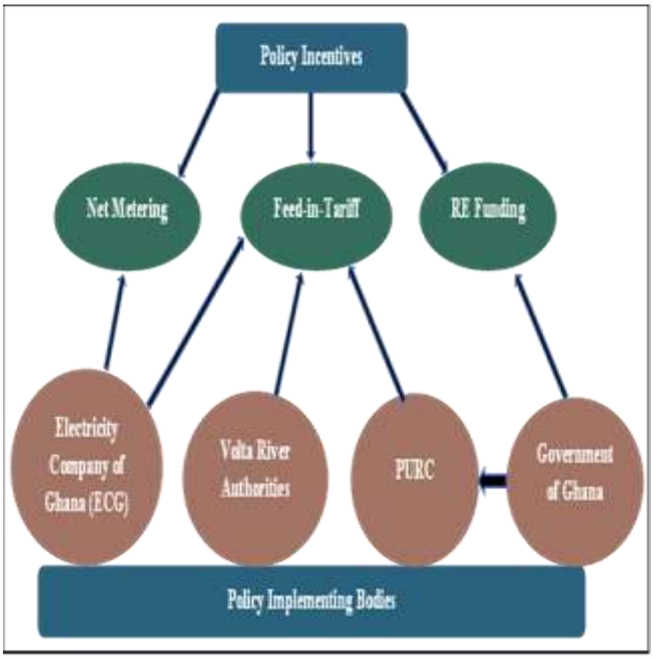

Fig. 4. Renewable Energy Policy Initiatives and Implementing Authorities [33]

The Ghanaian government's policy framework for mini-grid development and operation is an integral component of the National Electrification Scheme (NES) targeted at achieving universal electricity accessibility by the year 2030. In the public sector, the management of the policy framework for mini-grid development differs somewhat from that of the private sector. Public utilities are responsible for generating, operating, maintaining, and collecting revenue for mini grids in island locations on the Volta Lake, mainland communities within the Electricity Company of Ghana's concessional area, and mainland communities within the Northern Electricity Distribution Company's concessional area. Private sector involvement is limited to engineering, procurement, and construction (EPC) activities. The Public Utility Regulatory Commission (PURC) sets a uniform tariff rate for public utilities under Section 20 of the PURC Act (Act 538) but establishes a price threshold for private developers and operators to adhere to.

Act 832 states, it is illegal to set up or operate a mini grid that supplies electricity to anyone in any part of the country without being licensed or having a permit issued by the Energy Commission's Board. If a mini-grid's capacity is greater than 100kW but less than 1MW, it must obtain a license, whereas permits are required for a stand-alone grid with a capability of up to 100kW. Applicants need to obtain a license when they expand beyond 100kW. These permits ensure compliance with the country's environmental and spatial standards. Additionally, the Ancillary Service Charge, as a part of the Master Plan for Renewable Energy (2019), is used to support the capital cost of mini grids via the Renewable Energy Fund, which helps to apply the uniform tariff set by the PURC effectively. These policy objectives, institutions, and instruments are essential components of plans to promote private sector participation in RE development, particularly Solar Photovoltaic mini grids.

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TABLE II. SUMMARY OF KEY LITERATURE WORKS

Study	Author and Date of Publication	Methodology	Findings
Support for solar energy policy development in Ghana	D. Atsu et al, 2016[30]	Policy Analysis	• The security of Ghana's energy supply is seriously threatened by its reliance on imported energy to make up for local conventional fuel shortages, making it vulnerable to outside pressures. • The objective of Ghana's Act 832 is to improve the affordability of renewable energy technology and promote the adoption of decentralized off-grid optional technologies, such as solar PV, in regions where they can rival traditional electricity delivery. • To promote the widespread deployment of Solar Photovoltaic Systems in Ghana, major efforts must be made to train highly competent employees with intermediate-level experience.
Multiple advantages of Solar PV systems in remotes areas of Ghana	J. T. Nuru et al, 2021[35]	Climate Compatible Development	• Solar mini-grids have the potential to promote development and combat climate change, but politicians and development partners have not yet acknowledged this. Similar to this, academic debates have not sufficiently demonstrated the advantages of solar stand-alone grids for remote areas. Recognizing the many advantages of solar PV can spur interest in their implementation, and help save money by preventing the need for several projects to accomplish the same goals. • When a single project is implemented, it is possible to reap many benefits and entice investment from donor organizations.
Ghana's renewable energy development and deployment challenges: developer viewpoints	Mahama et al, 2021[36]	Prepared questionnaires using a barrier scale of 1-5	• The primary challenge in the renewable energy sector was identified as the high cost of financing, with a rating of 4.13 out of 5, due to high-interest rates. • • Inadequate motivation for renewable energy developers was another significant obstacle, with 3.93. Grid limitations, currency volatility, inadequacy of incentives, a lack of technical expertise, and inadequate training facilities are some other obstacles to RE development and implementation. • • The government of Ghana should establish a specific set of subsidies and financial incentives aimed at supporting the expansion and effective implementation of renewable energy projects throughout the country.
Lessons from Ghana for expanding solar product markets in remote areas	W.F. Steel et al, 2016 [37]	Literature review	• A complete approach that takes into account need, availability, funding, reliability, and enabling methods is required to create a viable market for solar products in rural areas lacking access to solar enterprises and financial institutions.
Possibility of using mini-grid solar systems to provide an off-grid community's energy demands	E.Y. Asuamah et al, 2021 [38]	Simulation using HOMER	• The research conducted indicates that a solar mini grid would be far more economically efficient for Nkrankrom, a region in Ghana without electricity, compared to connecting to the main power grid. To achieve the best outcome, a PV/Battery/Converter system setup is recommended. The cost of energy for this system, calculated as the Levelized Cost of Energy, is projected to be $0.107/kWh, whereas connecting to the main grid would cost $0.124/kWh. • The study emphasized that while the study's objective was achieved with satisfactory results, it is still acknowledged that grid power is more capable of accommodating very high increases in load. Off-grid power's viability is dependent on several variables, including the cost of the property, the availability of repair facilities, maintenance workers, and community support.

I. Barriers to distributed PV systems development in Ghana

A review of literature on solar PV mini-grids in Ghana provides an overview of the obstacles across different dimensions or viewpoints of influence; technical(t), political(p), social(s), and economic(e)[36], [39-42].The following barriers are under these viewpoints: financial resources or funding(p), insufficient strong business models (e), unpredictable grid expansion in the future (p), influence from politics and delayed public procurement (s), limited ability to pay (e), unfavorable mini-grid policies (p), unattractive tariffs (p), low productive use (t), limited private sector involvement (p), uncertain licensing (p).

III. RESULTS AND DISCUSSION

The important research and scholarly works on the promotion of solar PV in with a particular focus on distributed PV systems Ghana are summarized in this review. The studies reviewed highlight the possible advantages of solar energy for rural areas as well as the difficulties the sector in Ghana is now experiencing.

One of the major conclusions drawn from the studies under review is the need for policy support to increase the affordability of RET's, encourage the use of stand-alone grid options like solar PV in locations where they can compete traditional electricity supply, and establish a regulatory and fiscal framework that supports local exploration and innovation to lower the costs of RET's. The Act 832 is a step at making progress towards the objective, but more actions are needed to develop skilled personnel with intermediate-level expertise to facilitate extensive adoption of solar

Photovoltaic systems in Ghana[30].Another finding from the studies under evaluation is that rural populations in Ghana could benefit from sola stand-alone grids in terms of development and reducing adverse effect of climate change. But they are still not being recognized as such by policymakers and development partners. The benefits of solar stand-alone grids for rural areas have also not been sufficiently demonstrated in scholarly discussions. Recognizing the many advantages of solar stand-alone grids can spur interest in their implementation and help save money by preventing the need for several projects to accomplish the same goals. Additionally, it is possible to entice investment from donor organizations by maximizing the benefits of a single project[35].

The most challenging barrier in the RE sector was found to be the expense of funding due to high-interest rates, which was given a rating of 4.13/5[36]. Inadequate motivation for renewable energy developers was another significant obstacle, with an average score of 3.93. Other obstacles to the development of RE have also been mentioned, such as grid limitations, currency volatility, a lack of incentives, a lack of technical expertise, and insufficient training facilities. The government of Ghana should establish a specific set of subsidies and financial incentives aimed at supporting the expansion and effective implementation of renewable energy projects throughout the country[36].

Complete approach that considers need, availability, finance, reliability, and facilitation methods is required to create a viable market for solar products in rural areas lacking access to solar enterprises and financial institutions.[37] . Off-grid power's viability is influenced by things like the cost of the land, the availability of maintenance staff, repair facilities, and community support[38].

IV. Conclusion

The reviewed literature shows that solar energy has significant potential to provide reliable and affordable electricity to rural communities in Ghana, but several barriers must be overcome to realize this potential. Policy support, financial incentives, and skilled personnel are critical factors in overcoming these barriers. The State should focus on the development of regulations and legislation that encourage growth of renewable energy projects and create a favourable environment for private sector investment. Donor agencies should also be encouraged to invest in solar energy initiatives that provide a range of advantages to rural communities in Ghana.

References

[1] United Nations, "Ensure access to affordable, reliable, sustainable, and modern energy for all. The role of business Key business themes addressed by this SDG Examples of key business actions and solutions Examples of key business tools The SDG targets," pp. 2–3, 2015.

[2] "Tracking SDG 7 – The Energy Progress Report 2022." https://www.worldbank.org/en/topic/energy/publication/tracking-sdg-7-the-energy-progress-report-2022 (accessed Feb. 25, 2023).

[3] ONU, "The sustainable development goals report 2019," *United Nations publication issued by the Department of Economic and Social Affairs*, p. 64, 2022.

[4] ESMAP, "2019 Tracking SDG7: The Energy Progress Report," p. 176, 2019.

[5] G. Rasagam and D. Zhu, "Delivering on the Promise of Distributed Renewable Energy Entrepreneurship in Sub-Saharan Africa," *Current Sustainable/Renewable Energy Reports*, vol. 5, no. 4, pp. 230–239, 2018, doi: 10.1007/s40518-018-0120-x.

[6] IEA, "World Energy Outlook 2021 日本語サマリー," *IEA Publications*, p. 15, 2021.

[7] A. Singh, A. Yadav, and S. Sinha, "Hybrid Power Systems: Solution to Rural Electrification," *Current Sustainable/Renewable Energy Reports*, vol. 9, no. 4, pp. 77–93, 2022, doi: 10.1007/s40518-022-00206-x.

[8] WHO. EA, IRENA, UNSD, World Bank, "Tracking SDG 7: The Energy Progress Report," *Iea*, pp. 158–177, 2022.

[9] "Access to electricity, rural (% of rural population) - Ghana | Data." https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=GH (accessed Jan. 10, 2023).

[10] S. Gyam, F. A. Diawuo, E. N. Kumi, and F. Sika, "The energy e fficiency situation in Ghana," vol. 82, no. June 2017, pp. 1415–1423, 2018, doi: 10.1016/j.rser.2017.05.007.

[11] E. O. Essandoh, G. A. Akolgo, E. N. Kumi, and ..., "Review and Analysis of Ghana's Power Sector Policies, Programmes and Reforms," *Journal of Energy and …*, vol. 6, no. 1, pp. 1–6, 2021.

[12] I. Hoeck, E. Steurer, Ö. Dolunay, and H. Ileka, "Challenges for off-grid electrification in rural areas. Assessment of the situation in Namibia using the examples of Gam and Tsumkwe," *Energy Ecol Environ*, vol. 7, no. 5, pp. 508–522, 2022, doi: 10.1007/s40974-021-00214-5.

[13] P. Yadav, P. J. Davies, and D. Palit, "Distributed solar photovoltaics landscape in Uttar Pradesh, India: Lessons for transition to decentralised rural electrification," *Energy Strategy Reviews*, vol. 26, no. July, p. 100392, 2019, doi: 10.1016/j.esr.2019.100392.

[14] S. Asumadu-Sarkodie and P. A. Owusu, "A review of Ghana's energy sector national energy statistics and policy framework," *Cogent Eng*, vol. 3, no. 1, 2016, doi: 10.1080/23311916.2016.1155274.

[15] E. N. Kumi, "The Electricity Situation in Ghana: Challenges and Opportunities," *CGD Policy Paper*, no. September, p. 30, 2017.

[16] Energy Commission, *2022 National Energy Statistics*, no. April. 2022.

[17] Energy Commission, *2022 National Energy Statistics*, no. April. 2022.

[18] M. Acheampong *et al.*, "Is Ghana ready to attain sustainable development goal (SDG) number 7?A comprehensive assessment of its renewable energy potential and pitfalls," *Energies (Basel)*, vol. 12, no. 3, pp. 7–10, 2019, doi: 10.3390/en12030408.

[19] Pazhani. A, A. J., Gunasekaran, P., Shanmuganathan, V., Lim, S., Madasamy, K., Manoharan, R., &Verma, A. (2022).Peer–Peer Communication Using Novel Slice Handover Algorithm for 5G Wireless Networks.Journal of Sensor and Actuator Networks, 11(4), 82..

[20] S. Gyamfi, M. Modjinou, and S. Djordjevic, "Improving electricity supply security in Ghana - The potential of renewable energy," *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 1035–1045, 2015, doi: 10.1016/j.rser.2014.11.102.

[21] G. Y. Obeng, H. D. Evers, F. O. Akuffo, I. Braimah, and A. Brew-Hammond, "Solar photovoltaic electrification and rural energy-poverty in Ghana," *Energy for Sustainable Development*, vol. 12, no. 1, pp. 43–54, 2008, doi: 10.1016/S0973-0826(08)60418-4.

[22] "POWER | Data Access Viewer." https://power.larc.nasa.gov/data-access-viewer/ (accessed Feb. 27, 2023).

[23] S. Asumadu-Sarkodie and P. A. Owusu, "A review of Ghana's energy sector national energy statistics and policy framework," *Cogent Eng*, vol. 3, no. 1, 2016, doi: 10.1080/23311916.2016.1155274.

[24] 2019 Energy Commission, "Ghana Renewable Energy Master Plan," *Ghana Renewable Energy Master Plan*, pp. 1–83, 2019.

[25] "Volta River Authority | Welcome." https://www.vra.com/ (accessed Feb. 28, 2023).

[26] "Bui Power Authority." https://buipower.com/ (accessed Feb. 28, 2023).

[27] "IRENA – International Renewable Energy Agency." https://www.irena.org/ (accessed Feb. 28, 2023).

[28] T. G. Tetteh, "Tawiah Gabriel Tetteh Review on Solar Utilization in," 2014.

[29] B. H. Essel, "Renewable Energy Policy Review, Identification of Gaps and Solutions in Ghana," *Energy Commission of Ghana and UNDP*, pp. 1–89, 2015, [Online]. Available:

DOI: rp-9788770040723.172
http://www.energycom.gov.gh/files/Renewable Energy Policy and Regulatory Gap Analysis Final(2015).pdf

[30] D. Atsu, E. O. Agyemang, and S. A. K. Tsike, "Solar electricity development and policy support in Ghana," *Renewable and Sustainable Energy Reviews*, vol. 53, pp. 792–800, 2016, doi: 10.1016/j.rser.2015.09.031.

[31] "IRENA – International Renewable Energy Agency." https://www.irena.org/ (accessed Mar. 01, 2023).

[32] A. El-kharouf and H. S. Soyhan, *Renewable Energy*.

[33] M. AdobeaOduro, S. Gyamfi, S. AsumaduSarkodie, and F. Kemausuor, "Evaluating the Success of Renewable Energy and Energy Efficiency Policies in Ghana: Matching the Policy Objectives against Policy Instruments and Outcomes," *Renewable Energy - Resources, Challenges and Applications*, 2020, doi: 10.5772/intechopen.88278.

[34] Energy Commission, "Energy (Supply and Demand) Outlook for Ghana," *Ghana Energy Commission*, vol. 5, no. No. 02/03, p. 93, 2018.

[35] J. T. Nuru, J. L. Rhoades, and J. S. Gruber, "Evidence of adaptation, mitigation, and development co-benefits of solar mini-grids in rural Ghana," *Energy and Climate Change*, vol. 2, no. January, p. 100024, 2021, doi: 10.1016/j.egycc.2021.100024.

[36] M. Mahama, N. S. A. Derkyi, and C. M. Nwabue, "Challenges of renewable energy development and deployment in Ghana: perspectives from developers," *GeoJournal*, vol. 86, no. 3, pp. 1425–1439, 2021, doi: 10.1007/s10708-019-10132-z.

[37] W. F. Steel, N. A. Anyidoho, F. Y. Dadzie, and R. H. Hosier, "Developing rural markets for solar products: Lessons from Ghana," *Energy for Sustainable Development*, vol. 31, pp. 178–184, 2016, doi: 10.1016/j.esd.2016.02.003.

[38] E. Y. Asuamah, S. Gyamfi, and A. Dagoumas, "Potential of meeting electricity needs of off-grid community with mini-grid solar systems," *SciAfr*, vol. 11, p. e00675, 2021, doi: 10.1016/j.sciaf.2020.e00675.

[39] T. Transfer, "Identification of barriers to renewable energy technology transfer to Ghana".

[40] J. T. Nuru, "Assessing Benefits and Barriers to Deployment of Solar Mini Grids in Ghanaian Rural Island Communities," pp. 1–203, 2020.

[41] Rajesh, M., &Sitharthan, R. (2022). Image fusion and enhancement based on energy of the pixel using Deep Convolutional Neural Network. Multimedia Tools and Applications, 81(1), 873-885.

[42] J. T. Nuru, J. L. Rhoades, and J. S. Gruber, "The socio-technical barriers and strategies for overcoming the barriers to deploying solar mini-grids in rural islands: Evidence from Ghana," *TechnolSoc*, vol. 65, no. April, p. 101586, 2021, doi: 10.1016/j.techsoc.2021.101586.