

A Review of the Integration of Renewable Energy in Rural Hospitals and Health Centers in Uganda

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Abstract

The integration of renewable energy in rural hospitals and health centres in Uganda offers a promising solution to the challenges of unreliable electricity access. This review examines the current state of renewable energy implementation in these facilities, focusing on its benefits, challenges, and best practices. Highlighting successful case studies, it shows how renewable energy improves healthcare access, power reliability, reduces costs, and minimizes environmental impact. The review discusses technologies such as solar photovoltaic systems, wind turbines, and biomass energy, noting their sustainability, cost-effectiveness, and potential for energy independence.

The analysis addresses the issue of inadequate electricity in rural Uganda and its negative effects on healthcare. Using recent research, journal articles, and conference presentations, it provides an overview of the energy landscape. Emphasis is placed on the importance of technical training and capacity-building programs for local technicians and healthcare workers to ensure project sustainability.

Additionally, the review explores the environmental benefits of renewable energy compared to traditional sources, offering a thorough analysis of these advantages. It identifies future research areas, such as the long-term impacts of renewable energy on healthcare outcomes and the scalability of successful projects. The insights aim to guide policymakers, healthcare ad-

ministrators, and renewable energy practitioners in developing strategies and policies to accelerate renewable energy adoption in rural healthcare facilities. Ultimately, this review seeks to enhance healthcare services in Uganda's rural communities through sustainable energy solutions.

Keywords: Renewable Energy; Energy Integration; Hospital; Health Care; Uganda

Introduction

Uganda's healthcare system faces significant challenges, particularly in rural areas where access to reliable electricity is limited. Although Uganda has almost 7000 hospitals and medical facilities, the majority of them are situated in rural regions without connection to the main electricity grid. Frequent power outages further exacerbate the situation for those connected to the grid, leading to increased risks for patients during procedures and therapies. Hospitals incur higher costs due to the need to operate diesel generators, which are expensive and environmentally damaging [1]. Uganda exhibits one of the lowest rates of power usage in Africa, with 27% of the country electrified nationwide and only 18% in rural regions, home to around 83.6% of the population [2]. This energy deficit severely impacts healthcare delivery, as many medical procedures and the storage of medicines require a consistent power supply.

Uganda's decentralized health governance includes national and district levels, with Health Centre I providing preventative and health promotion services, Health Centre II offering vaccines, emergency births, prenatal care, and outpatient treatments, and Health Centre III delivering maternity services, acute admissions, and basic laboratory services [3-5]. Renewable energy, particularly solar power, presents a viable solution to these challenges, offering a more economical and sustainable way to generate power compared to traditional methods.

The Need for Renewable Energy in Health Care

The critical shortage of reliable electricity in Uganda's rural healthcare facilities has led to increased reliance on diesel generators and other unsustainable energy sources. This not only escalates operational costs but also contributes to environmental pollution. Renewable energy, especially solar photovoltaic (PV) systems, offers a sustainable alternative. These systems provide a reliable power supply,

reducing operational costs and minimizing environmental impact [6,7].

Healthcare Challenges in Uganda

The healthcare sector in Uganda faces numerous challenges, particularly in rural areas where 83.6% of the population resides but only 18% have access to electricity [2]. Limited access to reliable power affects the functioning of essential medical equipment, the storage of medicines, and the overall quality of healthcare services. Statistics indicate that the majority of health facilities operate with inadequate infrastructure, exacerbating the health risks for patients. The lack of reliable electricity supply leads to frequent use of costly and polluting diesel generators, which further strain the financial resources of these facilities.

Importance of Technical Training and Capacity-Building Programs

The successful integration of renewable energy in healthcare facilities hinges on the availability of skilled technicians and healthcare workers who can maintain and operate these systems. Training and capacity-building programs are essential for ensuring the sustainability of renewable energy projects. These programs equip local technicians and healthcare workers with the necessary skills to manage and troubleshoot renewable energy systems, thereby enhancing their reliability and efficiency [8,9].

Environmental Benefits of Renewable Energy

Renewable energy sources, such as solar power, offer significant environmental benefits compared to traditional fossil fuels. Solar power systems produce minimal greenhouse gas emissions and reduce the reliance on diesel generators, which are known for their high carbon emissions and particulate matter that contribute to air pollution and health problems [10,11]. The adoption of renewable energy in healthcare facilities not only improves health outcomes

by providing reliable power but also promotes environmental sustainability by reducing the carbon footprint of these facilities.

Future Research Directions

Future research should focus on the long-term impacts of renewable energy on healthcare outcomes, the potential for scaling up successful projects, and the integration of new technologies such as energy storage systems and

smart grid solutions. Studies should also explore the socio-economic benefits of renewable energy adoption in rural healthcare settings, including improvements in healthcare delivery, economic development, and community well-being [12,13]. Investigating the barriers to widespread adoption and developing strategies to overcome them will be crucial for the continued success and expansion of renewable energy projects in Uganda's healthcare sector. Health Centre category Capacity Government categorization Energy requirements [8].

Table 1: Health Centre categorization in Uganda

Health Center	Number of Beds	Energy Requirement
I-II	0-60 beds	5-10 KWh/day
III	60-120 beds	10-20 KWh/day
IV and above	Above 120 beds	20-30 KWh/day

Appliances Used in Rural Hospitals/ Health Centers

There are several appliances used in these health facilities and some of them together their power ratings are shown in table 2 below [9,10]:

Table 2: Appliances at Health Centers

No.	Appliance	Power Rating (W)
1	Light bulbs	5-9
2	Tube Lights	18-20
3	Ceiling Fans	28 - 32
4	Centrifuge	250 – 400
5	Microscope	70
6	Refrigeration Units	40-150
7	incubator	100 -200
8	Autoclave (steam sterilizer) (19–45 L)	1200–2850
9	Desktop computer	156 –200
10	Oxygen concentrator	270-310
11	Anaesthesia machine	1440

The Need for Renewable Energy in Health Care

Hospitals and clinics in proximity to electricity grids typically depend on grid power as their primary energy source. However, disruptions such as power failures during peak demand periods pose significant challenges even in

grid-connected areas. As a result, healthcare facilities here in Uganda often resort to costly backup generators or risk being left without power altogether. In off-grid regions, diesel generators are common, supported by kerosene lamps and candles. However, their operation costs are high due to fuel expenses and maintenance challenges. A recent WHO

survey in sub-Saharan Africa showed less than 30% of diesel generators were functional on the surveyed day. Generators waste energy through excess heat, with small on-site diesel units being notably inefficient. They emit high levels of health-damaging particulate matter and CO₂, worsening air pollution and contributing to climate change. Also, in many developing countries such as Uganda energy costs are high compared to per capita incomes, notably impacting health-care budgets. Limited reviews suggest healthcare spends a larger share on energy than in developed nations. Escalating fossil fuel prices exacerbate these strains [10].

With declining costs of renewable energy technologies, they become increasingly accessible to healthcare facilities, serving as primary or backup energy sources. Photovoltaic (PV) solar power, in particular, is becoming more prevalent. A recent review led by WHO in sub-Saharan Africa highlighted a growing adoption of on-site PV solar for electricity needs, with around 15% of hospitals in Uganda integrating it alongside grid power [11]. PV systems offer somewhat greater reliability, more solar-equipped health centers reported having electricity available on the survey day compared with those using diesel generators as their primary source.

Role of Stake Holders' Engagement

Active involvement of local communities and health center personnel is fundamental to successfully implementing solar energy solutions. When community members participate actively, the solar infrastructure can be tailored to meet their unique requirements, promoting a sense of ownership and pride within the community [12]. This collaborative method not only boosts the long-term viability of solar energy utilization but also creates a direct connection between the technology and the community it supports. Additionally, involving health center personnel is essential, acknowledging their pivotal role in day-to-day functions. Their expertise aids in seamlessly integrating solar energy into existing healthcare protocols, guaranteeing that

the technology improves rather than hinders essential medical services. Furthermore, it's crucial to develop the capacity for managing solar energy. This includes providing health center staff and local residents with the requisite expertise to operate and upkeep the solar infrastructure proficiently [13,14].

Solar Energy Integration in Health Centers

1. The Case of African Solar Designs Installations in some Ugandan Health Centers [15]

African Solar Designs evaluated the availability and demand for energy at 100 health facilities, 48% of which were health centers II and 42% of which were health centers III, as part of a requirements assessment that was carried out in Uganda [15]. According to the audit, government-run, off-grid facilities that offered maternity and child health services, were situated in high-priority regions with a high population density, and were government-owned and operated to guarantee sustainability were given priority [16]. Thirty-six institutions, all classified as health centers II or III, were chosen for electrification throughout eight districts in the western area as shown below;

This installation was done in the following steps;

Step 1 -Energy audit and assessment

Step 2- Business case (technical, economic and environmental analysis)

Step 3- Procurement and site inspection

Step 4- Site survey through site survey by the vendor to collect data on the energy load

Step 5- Design of the solar systems

Step 6- Installation by the vendor and local partner

Step 7- Operation and maintenance

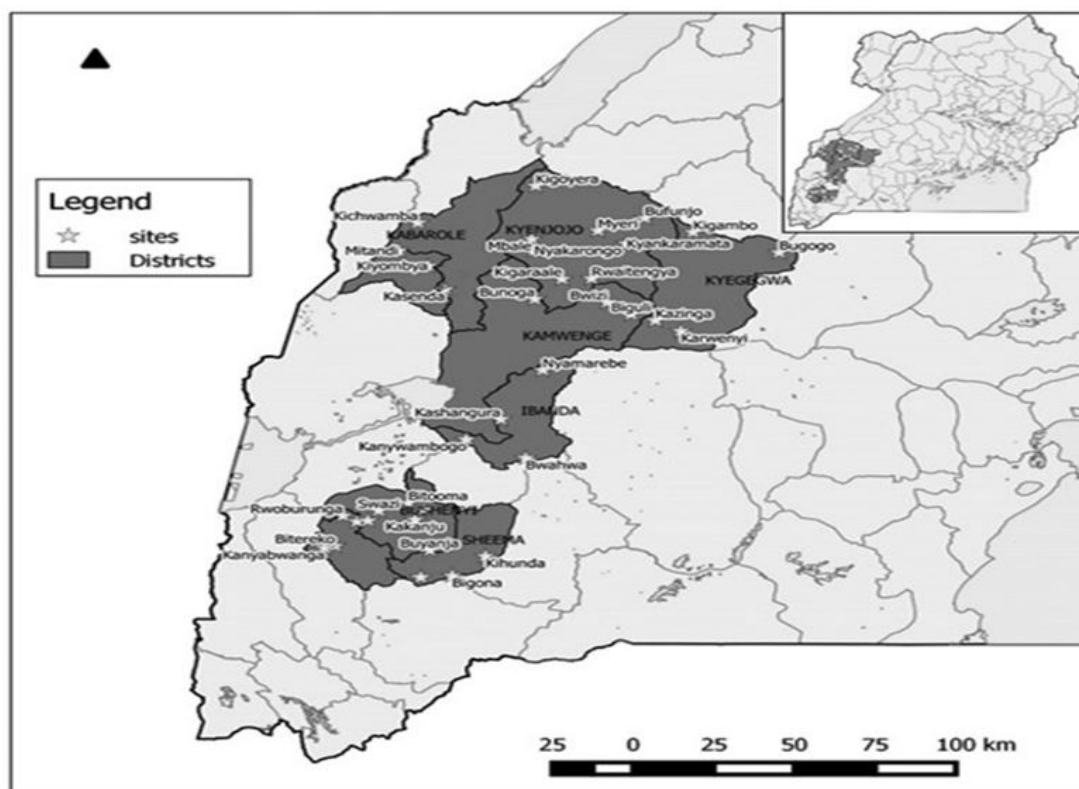


Figure 1: Coverage Area [15]

2. UNDP Solar PV Installation in Ugandan Health Centers

In the first phase of the COVID 19 response program, the United Nations Development Programme (UNDP)

worked with the World Health Organization and the Ministry of Health Uganda to support the electrification of eleven health centers nationwide (Table 2). Ongoing Site assessments were conducted in order to support an additional thirteen health centers (Table 3) [8].

Table 3: UNDP supported health centres

No.	Districts	Health Facility
1	Kamwenge	Rukunyu HC IV
2	Kiboga	Bukomero HC IV
3	Bukedea	Bukedea HC IV
4	Buyende	Kidera HC IV
5	Sironko	Budadiri HC IV
6	Oyam	Anyeke HC IV
7	Manafwa	Babulo HC IV
8	Kakumiro	Kakumiro HC IV
9	Kapelabyong	Kapelabyong HC IV
10	Kazo	Kazo HC IV
11	Omoro	Lalogi HC IV

Table 4: Health centers Undergoing assessment

Number	Districts	Health Facility
1	Nabitulak	Nabitulak HC IV
2	Terego	Omugo HC IV
3	Kwania	Kwania HC IV
4	Obongi	Obongi HC IV
5	Sheema	Shuku HC IV
6	Madi Okollo	Madi Okollo HC IV
7	Karenga	Karenga HC IV
8	Kalaki	Kalaki HC IV
9	Kasese	Nyabirango HC IV
10	Rubanda	Rubanda HC IV
11	Kole	Aboke HC IV
12	Rukiga	Kamwezi HC IV
13	Rukiga	Mparo HC IV

1. Aptech Solar Installation for 11 Health Centers in Uganda

Aptech Africa recently initiated a project, supported by UNDP and the Ministry of Health, to supply solar power to 11 health centers scattered across Uganda [17]. Each center received a solar system consisting of 12.24 KWp of solar power and 32.4 KWh of lithium-ion battery storage. The project involved installing hybrid inverters with MPPT technology, capable of operating in single or 3-phase configurations, to power the health centers using a combination of solar and grid electricity. The systems, which included ground-mounted and roof-mounted solar panels, were strategically placed in different districts of Uganda. Additionally, individual communication systems with integrated battery monitoring were installed to ensure efficient system performance. The inverters were also equipped with an online monitoring system to track various parameters and troubleshoot any issues in real-time.

This initiative underscores the importance of renewable energy in improving healthcare infrastructure and services in remote areas like Rukunyu Health Centre in Kamwenge district, Nsiika Health Center in Buhweju District, Bukomero Health Center in Kiboga District, Kakumiro Health Center in Kakumiro District, Kazo Health Cen-

ter in Kazo District, Bukedea Health Center and Budadiri Health Center in Sironko District, Bugobero Health Center in Manafwa District, Anyeke Health Center in Oyam District, Lalogi Health Center and Kapelebyong Health Center in Omoro District."

2. Austrian Ngo and Environmental Alert Solar Installation in Health Centers [18]

The collaborative endeavor known as the empowering Health Centers in Uganda (PHCU) project was jointly conceived by Südwind, an Austrian NGO, and Environmental Alert, a Ugandan NGO, and executed in partnership with key stakeholders in Uganda. The project targeted four districts—Kibaale, Kasese, Kikuube, and Kyegegwa—situated in the Albertine region, all grappling with significant energy deficiencies due to their lack of connection to the national grid. Additionally, these districts face challenges in accessibility due to their remote locations, compounded by the region's rugged terrain.

Specifically, the project aimed to improve the energy infrastructure of selected health facilities in the mentioned districts. The beneficiary health centers included Maisuka Health III in Kibaale district, Mahango Health Centre II in Kasese district, Mpara Health Centre III in Kyegegwa

district, and Kyaka Health Centre III in Kikuube district.

Ministry of Health's Energy for Rural Transformation Project [19]

The ERT Project III – Health component is a vital part of the broader ERT Programme led by MEMD, aimed at enhancing the delivery of healthcare services in rural areas by improving access to modern energy and ICT services. However, the Ministry of Health (MoH) is responsible for covering taxes, clearing and forwarding costs, user training, and maintenance expenses for solar systems through service contracts with suppliers.

The Main Areas of Focus Include

Providing lighting for medical buildings and staff residences. Ensuring proper refrigeration for vaccines at Health Centre II, III, and IV levels. Implementing blood refrigeration facilities at Health Centre IV. Supplying energy for essential medical equipment operation, such as microscopes, ultrasound scanners, and other low-energy consumption devices in the health Centre IV Theater, utilizing solar power. Facilitating energy provision for health education, communication, and data management purposes. The ERT Project III will be rolled out in several districts, including Alebtong, Buhweju, Buvuma, Hoima, Kaliro, Kamuli, Kapchorwa, Kasese, Kiboga, Kisoro, Kween, Kyankwanzi, Lira, Manafwa, Nakasongola, Namayingo, Otuke, Rubirizi, Busia, Butaleja, Gomba, Lwengo, and Namutumba. These districts were chosen due to their low rural electrification rates. Districts that have already benefited from ERT I & II and those slated for assistance from the United Nations Foundation Sustainable Energy for All (SE4ALL) initiatives have been excluded from this selection.

Impact of Renewable Energy on Health Care Delivery in Ugandan Rural Health Centers

As healthcare institutions adopt renewable energy (solar energy) more extensively, the benefits will become increasingly significant. Photovoltaic (PV) solar systems typically produce less than 250 grams of CO₂ per kilowatt-hour (kWh) of power generated, encompassing emissions throughout their lifecycle [20]. In contrast, standalone diesel generators emit over 1 kg of CO₂ per kWh, with emis-

sions rising proportionally for smaller systems that might operate intermittently and less efficiently [21]. Reducing particulate emissions leads to proportional reductions, which, since particulate matter contains black carbon, a potent short-lived climate pollutant, results in additional benefits for both climate and health [22].

Solar power offers numerous advantages to healthcare facilities, particularly those lacking access to the grid. In many tropical regions, solar arrays coupled with battery storage can deliver dependable power for most days of the year, with the added benefit of minimal operating expenses since no fuel is needed. Solar energy promotes better health for patients and healthcare workers by eliminating local air pollution and reducing the risks of burns from kerosene lamps [23]. Exposure to emissions from diesel or kerosene is linked to the development of cardiovascular and respiratory illnesses [24], with diesel emissions classified as carcinogenic [25].

The integration of solar power into healthcare facilities has resulted in a significant reduction in patient waiting times for diagnostic procedures, decreasing the average wait from 2 hours to just 30 minutes. This improvement demonstrates a notable enhancement in healthcare services. Similarly, monitoring the effectiveness of critical medical procedures, such as surgeries or emergency interventions, before and after the adoption of solar power offers quantitative insights into the positive impact on healthcare outcomes [26,27].

Solar power systems, whether photovoltaic (PV) or hybrid solar-generator setups, come with their share of challenges. While solar panels themselves are relatively low-maintenance, the management and replacement of batteries are crucial for their longevity. However, accessing suitable replacement batteries and spare parts locally can be problematic, particularly for health clinics relying on donated solar systems with limited maintenance funding. Moreover, local expertise in maintaining solar power systems may be lacking compared to traditional generator maintenance skills. The disposal of batteries, especially lead-acid ones which are most commonly used, poses environmental and health hazards. In regions with tropical, equatorial, or arid desert climates, lead-acid batteries typically last only a few

years before needing replacement, necessitating safe disposal to prevent lead exposure and its associated health risks, particularly among children. On the other hand, lithium batteries, which are suitable for larger applications, present fire hazards. Addressing these challenges requires the development of lithium battery designs tailored for solar charging and the establishment of effective business models for recycling lead-acid batteries [28].

Utilizing photovoltaic systems to capture sunlight enables health centers to improve energy reliability, cut costs, and lessen their environmental impact. Furthermore, embracing solar energy aligns with worldwide initiatives to advocate for clean and sustainable energy options, advancing both healthcare quality and broader objectives of environmental preservation and sustainable progress [29,30].

The Value of Training and Education Programs on this Integration

Empowering individuals with the knowledge and skills to maintain and optimize solar systems is key to ensuring their long-term viability and maximizing their benefits.

By providing training and education beyond basic maintenance skills, communities where these rural health centers are situated can become proficient in troubleshooting common issues, understanding system diagnostics, and optimizing the performance of their solar energy systems. This not only fosters a sense of ownership and responsibility but also enables communities to adapt to challenges and changes in their energy needs over time. Moreover, this empowerment contributes to the establishment of a sustainable, community-driven approach to solar energy management. Communities that are actively involved in the maintenance and optimization of their solar infrastructure are more likely to prioritize its upkeep and seek opportunities for expansion and improvement. Beyond the technical aspects, this empowerment also catalyzes positive community development by promoting self-sufficiency and resilience. By harnessing solar energy, communities can reduce their dependence on centralized energy sources, improve energy access, and create opportunities for economic growth and development. Overall, fostering a knowledge-sharing environment and empowering communities to maintain and optimize solar energy systems is essential for building sustain-

able, resilient communities and promoting the long-term success of solar energy initiatives [31].

Barriers to Solar Energy Integration

The primary hurdle to the widespread adoption of solar solutions remains the initial investment required for PV solar systems, which tends to be higher compared to small, stand-alone generators for the off-grid health centers. Despite the significant drop in the cost of solar components over the last decade, the upfront capital outlay for a solar system still exceeds that of a generator. Although the overall lifetime cost of operating an on-site solar system is typically lower than that of a small generator, which demands ongoing fuel inputs, the immediate cost of acquiring a generator is often more affordable. This upfront cost disparity can deter individuals and organizations, especially those with limited financial resources, from investing in solar solutions, even though they offer long-term economic and environmental benefits [10].

Trade barriers can significantly impede the import of solar panels into countries that lack domestic manufacturing capacity. These barriers can include tariffs, import quotas, and other restrictions that increase the cost and complexity of importing solar panels. Such barriers often hinder the ability of developing countries to transition to renewable energy sources like solar power, despite their potential for significant environmental and economic benefits [28].

Moreover, security is indeed a crucial consideration, especially in regions where theft or vandalism is a concern. Solar panels, typically installed outdoors on rooftops or in open areas, are vulnerable to theft if not adequately secured. This poses a significant risk to investments in solar energy infrastructure and can deter these rural health centers and their stake holders from adopting solar power.

Optimization of Energy Utilization to Minimize Expenses

For smaller facilities, especially those grappling with power deficits, it's crucial to tightly align demand and supply. A thorough inventory of medical equipment and appliances, along with their energy needs, forms the bedrock for meeting demands effectively. Moreover, it's vital to accu-

rately evaluate the energy demands of building infrastructure, particularly in areas where electricity powers heating, cooling, or water systems. While demand-side energy efficiency measures are often sidelined, they play a significant role. These encompass adopting more energy-efficient medical equipment like LED lights and refrigerators, as well as upgrading building systems for better energy performance [10].

Reducing costs through these measures involves various strategies. Initially, by aligning demand and supply closely, facilities can avoid unnecessary expenses related to energy shortages or oversupply. Additionally, investing in energy-efficient medical devices and building systems may require upfront capital but can lead to substantial long-term savings through reduced energy consumption. Furthermore, optimizing energy usage through demand-side measures can lower operational expenses, such as electricity bills, maintenance costs, and equipment replacements. Overall, while there may be initial investment costs, the potential for significant and ongoing cost reductions makes these initiatives financially beneficial in the long run.

Conclusion

The potential benefits of integrating renewable energy, specifically solar power, into rural Ugandan hospitals and healthcare facilities are substantial. This transition not only addresses the critical energy needs of these institutions but also enhances healthcare services and contributes to the overall well-being of the community. By embracing solar energy, these facilities can ensure a reliable electricity supply, improve the delivery of essential medical services, empower local communities, and support sustainable development initiatives. It is imperative to continue investing in and supporting solar projects to fully realize the advantages of clean energy for healthcare in rural Uganda. Further research is necessary to evaluate the long-term effects of renewable energy on healthcare outcomes, assess the scalability of successful initiatives, and explore the integration of new technologies. Through a focus on capacity building, environmental sustainability, and socio-economic advantages, the adoption of renewable energy has the potential to bring about significant transformations in the healthcare sector of rural Uganda.

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