Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2025, Volume 13, Issue 1, 1130550

Original Research Article

Analysis of Renewable Energy Deployment and Investment for Rural Health Facility Electrification: A Case Study of Kenya, Ghana, and Rwanda

Katundu Imasiku[1]* and Lorraine Saunyama[2]

[1]School of Industrial and Systems Engineering, Georgia Institute of Technology, 765 Ferst Drive, Atlanta, Georgia, USA

e-mail: kimasiku3@gatech.edu

[2]Institute for Health Management – Southern Africa, Ground Floor, Quantum Office Park, Platinum Road, Ibex Hill,

Lusaka, Zambia

Lorraine.saunyama@ihmafrica.org

Cite as: Imasiku, K., Saunyama, L., Analysis of Renewable Energy Deployment and Investment for Rural Health Facility Electrification: A Case Study of Kenya, Ghana, and Rwanda, J.sustain. dev. energy water environ. syst., 13(1), 1130550, 2025, DOI: https://doi.org/10.13044/j.sdewes.d13.0550

ABSTRACT

Access to energy is essential for quality human services and is key to accomplishing local and regional healthcare services provision and people's social well-being. Selected case studies of Kenya, Ghana, and Rwanda with key institutional data for the year 2019 show a generally low access to electricity. This article assesses how unreliable energy supply and poor energy financing in rural health facilities can affect health service delivery. The selected case studies are analysed considering demographic rationale, electrification rates in rural health canters, and child mortality rates. Poor electricity supply to rural health facilities is associated with poor health service delivery and outcomes. The study found that investment business models and financing initiatives vary by country. However, decision-makers can use the findings to make informed decisions and develop public-private investment strategies that breed new and innovative financing business models to provide and scale up cleaner energy resources like renewable energy resources and technologies in rural health centers. Further, increased collaborations between financial institutions and health institutions are recommended to support strategic investments for improved health facility electrification and health service delivery, thereby contributing to the United Nations sustainable development goals 3 and 7. This study is limited to evaluating the impact of poor electricity access to rural health facilities and how renewable energy systems can offer quick cheap solutions in the case study countries using credible secondary data qualitatively.

KEYWORDS

Renewable energy; Financial investment, Rural health facilities, Health service delivery, Kenya, Ghana, and Rwanda.

INTRODUCTION

Global access to energy particularly in areas with poor and marginalized individuals like in the sub-Saharan African (SSA) rural areas is a fundamental goal that aligns with the United Nations Sustainable Development Goal Seven (7) which emphasizes affordable and cleaner

* Corresponding author

energy for all by 2030. However, almost 85% of those without access to electricity globally, live in sub-Saharan Africa, translating to be 1.3 billion people. This points to the need to heavily invest in renewable energy resources and cleaner technologies in SSA. Moner-Girona *et al.* estimates that the needed upfront investment cost to provide electricity with solar photovoltaics to more than 50,000 primary health facilities that currently lack electricity is about €484 million [1]. Further, the lack of cleaner energy resources compromises sustainable health systems, exacerbates respiratory diseases, and causes global warming which may also cause skin diseases and climate change. Climate change also affects crop-yield and ecosystems which may consequently lead to water borne diseases. In summary, the lack of cleaner technologies and renewable resource power generation compromises health delivery [2].

Rural health facilities are a national and international priority because they play a pivotal role in health care. However, there is inadequate electricity to support rural health services in many nations. With the recent drop in the cost of renewable energy equipment especially solar PV equipment, it is now possible to provide vaccines and other basic health care services in remote areas. Several national and international institutions, NGOs, and private firms are slowly deploying renewable energy systems to rural communities in developing countries where health care in rural areas is a priority [3].

Some key factors to consider when addressing energy access and reliable supply to rural health facilities may include one or a combination of; reliability of the local grid; availability of renewable energy resources such as biomass, solar, and wind; cost and availability of conventional energy resources like gasoline, propane, and diesel; government incentives and policies; system reliability requirements; technical capacity and fund availability for system development and maintenance and other preferred operational characteristics like noise or emissions [4].

One way to measure the impact of investing more resources is to observe the mortality rate. Analysing case studies of Kenya, Ghana, and Rwanda in SSA shows that poor electricity supply can contribute to poor health delivery in health facilities. Access to electricity is crucial to providing effective healthcare systems [5] while poor supply of electricity to health facilities, especially those that are in rural areas has led to compromised health systems in Kenya [6], [7], Ghana and Rwanda [8], [9]because most of the medical equipment and appliances are powered using electricity. One such critical appliance is the refrigerator which is used to store medicines and vaccines at certain temperatures to avoid damage to medicines and their potency [3]. In addition, other support equipment like telecommunications is critical to healthcare systems[6], [10]. Olatomiwa et al reviewed the existing energy solutions for rural health facilities, thereby analysing different approaches and the geographical energy mix for effective healthcare delivery in rural health centers and found that hybrid renewable energy systems, like solar PVs, are ideal and more reliable electricity provision in rural health facilities [11]. The purpose of this study is to assess the impact of poor electricity supply in rural areas in Kenya, Ghana, and Rwanda. Second, it analyses how renewable energy investments may impact the health sector in rural health centers by proposing ways to improve the already existing investment health business models, such as increasing capital injection into the energy sector in rural areas to improve electrification to health centers.

Previous studies by Yvonne Jie Chen *et al* in the Jyotigram Yojana (JGY) health program in India, showed that improving electricity supply enhanced the operational capacity of health facilities, especially in the primary health centers (PHCs), through increased availability and functionality of several key medical devices and equipment. Through the JGY program, an increase in electricity resulted in increased utilization of health services and a higher probability for children to receive important vaccinations and antenatal care for pregnant women. Finally, the study concludes that reliable electricity can be an effective tool for improving health systems, including employee retention and health system finance and infrastructure investments[12]. Further, Castan *et al.* emphasized that energy access is a critical enabler of healthcare delivery and access to medical technologies, especially during a health pandemic.

The study also identified two key energy requirements for sustainable health systems in facilities are firstly for the provision of electricity for lighting, vaccines and medication refrigeration and equipment for sterilization, heating, and incineration [13]. To emphasize the need for solar PV system deployment in rural health centers. Magda Moner-Girona *et al.* identified an existing gap between the electrification of healthcare facilities in sub-Saharan Africa and showed that providing decentralized photovoltaic (PV) systems to healthcare facilities can offer a clean, reliable, quick, and cost-effective solution [14]. The World Health Organization (WHO) reports that while 15% of health facilities in SSA, have no access to electricity, there is an urban-rural divide that shows that rural health facilities have more reliable electricity than rural health facilities in most countries in SSA[15]. A successful business case that is Wassha, a solar home business provided electricity for lighting and charging mobile phones to more than 10,000 homes, within three years (2019-2023) through lanterns which citizens in Tanzania rent for 500 Tanzanian shillings (0.20 US$) a night [16].

The significance of this study is to help decision-makers leverage evidence-based secondary data for making informed decisions and develop public-private investment strategies that breed new and innovative financing business models to provide and scale up cleaner energy resources like renewable energy resources alongside renewable energy technologies in rural health centers. One of the advantages of exploring renewable resources and utilizing them in health facilities, especially in rural areas is that most of these health centers are remotely located and not near the national electrical grid systems [14]. This makes the deployment of renewable energy as being beneficial and significant to sustainable health systems. Further, poor health service delivery is a global challenge that needs to be closed. The connection between climate change and biodiversity loss is a global challenge, intertwined with socioeconomic and environmental issues within the framework of sustainable development and the seventeen (17) UN sustainable development goals. True transformative change, however, hinges on the mobilization of essential financial resources and technological support [17]. Sub-Saharan Africa faces significant impacts from the climate crisis, despite its minimal contribution to the problem. The projected adverse effects on health place additional strain on already burdened health systems. Urgent adaptation measures are necessary to safeguard human health. However, there is scant evidence on how adaptation is planned and implemented in SSA [18].

This research study addresses the gap in electrifying healthcare facilities in sub-Saharan Africa. It evaluates financing mechanisms and programs in case study countries, focusing on decentralized photovoltaic (PV) systems for rural health facilities. These systems provide a clean, reliable, and cost-effective solution. To address this gap, a four-step methodology of first, assessing electricity availability in rural health facilities, then a review of the effects of poor electricity supply to rural health facilities on healthcare delivery. Finally, to gain some insight on what is being done so far, capital investment (financing models) in renewable energy solutions for rural health facilities are also analyzed. The research article is structured as the introduction, material and methods, case study and analysis, research significance, policy implication and limitations, and conclusions.

Sustainable energy supply in rural health centers can (i) improve the provision of medical cold chain services, neonatal intensive care, surgery, and other medical tools, (ii) improve health logistics, especially communications and record-keeping and (iii) generally improve health care services concerning prolonged hours of operation, providing telemedicine or e-health services etc.

MATERIALS AND METHODS

The objectives of the study are (i) to review the impact of lack of reliable energy on health service delivery in rural health care facilities; (ii) to analyse the electrification investment by reviewing financing mechanisms for energy access in the selected case study areas (iii) make recommendations for policymakers on how best to achieve rural health service facility electrification.

To achieve these objectives, a four-step methodology is deployed. First, assessing electricity availability in rural health facilities in Rwanda, Kenya, and Ghana was done, and then a review of the effects of poor electricity supply in rural areas and urban areas. In the third step, an evaluation of the contribution of poor power access to health facilities on poor health service delivery was done. The last step analyses the impact of large-scale capital investment (financing models) in renewable energies in rural health facilities in Rwanda, Kenya, and Ghana.

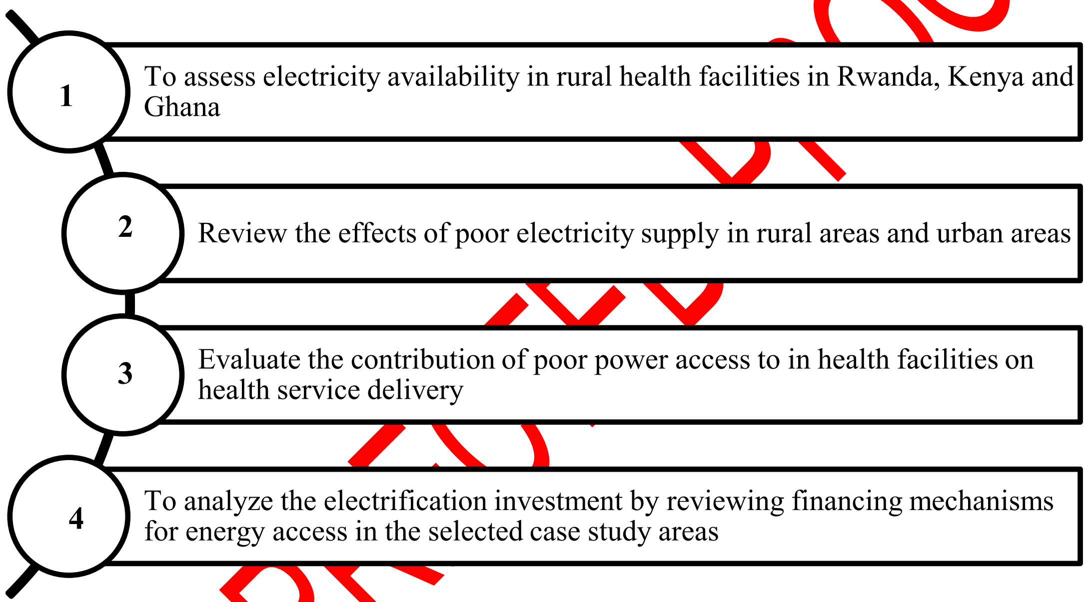

Figure 1. Research method steps.

Figure 1. shows the steps to assess energy and health systems in health facilities. With case studies of rural health facilities in Kenya, Rwanda, and Ghana, credible sources of secondary data that were used in this study include government reports, international firm reports, country-specific energy authorities, previous studies and financial institutions like the African Development Bank and the World Bank. The collected data is analyzed, with focus on the correlation between the country-specific demographics, electrification rates and health service delivery.

The available electricity rationale, including demographics, would help understand the overall national positioning and progress and contribution towards SDG 3 which emphasizes, good health and well-being for all. A review of the effects of poor electricity supply to rural health facilities brings out the socio-economic impact this can have on society in the case study counties. The third stage investigates evaluating the impact of poor electricity access in rural health facilities on healthcare delivery in the country. Lastly, the financing mechanisms and programs are reviewed to see if they address or prioritize the supply of electricity to rural health centers.

Table 1. Population, electrification and mortality rates for Kenya, Rwanda, and Ghana [19], [20], [21], [22].

	Ghana	Kenya	Rwanda
Population (2019) in million	30.4	53.7	12.95
Population density (People per km^2 - 2019)	134	94	495
Rural population (% of total population - 2019)	47%	73%	83%
Rural electrification rate (2019)	52%	14%	12%
Maternal mortality (Per 100,000 births)	319	510	290
Neonatal mortality rate (Per 100,000 births)	23.9	19.6	15.9
Child mortality rate - under five (Per 100,000 births)	47.9	41.1	35.3

Table 1 shows that Ghana has 52% of the 14.3 million people living in the rural areas supplied with electricity while Kenya and Rwanda's electrification rates are extremely low (14% and 12% respectively), with populations of about 39.2 million and 10.8 million people living in the rural areas, respectively. Further, with a largely rural population of 39.2 million people and a low rural electrification rate of only 14%, in the rural area, Kenya experiences a larger share of the high mortality rates, alluded to poor supply of power to rural health centres especially in the maternal mortality section. In 2019, the maternal, neonatal, and child mortality rates were 510, 19.6, and 19.6 deaths per 100,000 live births.

Table 2. Electricity reliability and access to healthcare facilities in Kenya, Rwanda, and Ghana [22], [23].

Country, Year (No. of Facilities)	No Electricity (%)	2024 Target Reliability (%)
Kenya, 2010 (695)		
• All facilities	26	15
• Hospital	2	24
• Other facilities	28	14
Rwanda, 2007 (538)		
• All facilities	18	41
• Hospital	2	52
• Other facilities	19	40
Ghana, 2002 (428)		
• All facilities	31	28*
• Hospital	6	34*
• Other facilities	34	26*

**Average figures for SSA adopted*

Table 2 shows that on average, 26% of health facilities in Kenya, 18% of health facilities in Rwanda and 31% of health facilities in Ghana have no electricity. Further, the reliability of the electricity supply is 15% for Kenya and 41% for Rwanda. In Rwanda, Kenya, and Ghana a general low power reliability of about 18% in Kenya, 43% in Rwanda, and 29% in Ghana is observed.

CASE STUDIES AND DISCUSSION

The three selected case studies to be discussed are Kenya, Ghana, and Rwanda. Each case study will follow the outline for the methodology given in Figure 1. To assess electricity availability in rural health facilities, review the effects of poor electricity supply and how it contributes to poor health service delivery, and analyse the existing financing mechanisms.

Rwanda case study

Step 1. Out of the 538 health centres, about 97 health facilities do not have access to electricity while 221 health facilities do not have a reliable power supply. Since 83% of Rwanda's population lives in the rural area, implies that only 12% of the population have access to electricity. From Table 1, a high mortality rate is observed among. While so many reasons may contribute to these high mortality rates, it can be inferred that some of these - deaths are accounted for by pneumonia, birth asphyxia, and meningitis among neonates and malaria, acute respiratory infections, and HIV/AIDS-related deaths [22], [24], [25], [26].

Step 2. With 83% of Rwanda's population living in rural areas and hardly having access to the national grid, Rwanda has focused on providing electricity to the rural communities so that they may benefit from several micro-hydropower projects being rolled out. For example, more than 200 kW is expected from the 22 micro-hydropower plant projects, was commissioned by the Ministry of Infrastructure government to provide electricity in Western and Northern provinces of Rwanda, to over 800 households, health centres, schools, and small businesses [27], [28].

Step 3. Although most rural communities in Rwanda are far from the national grid, Rwanda's Global horizontal irradiance (GHI) shows enormous potential to provide power to the rural health centres as a backup power supply. The studies by the GeoSUN Africa solar map further shows that the average GHI in Rwanda ranges between 4.5-5.4 kWh/m^2/day. In other efforts to improve health facility power deficit by the Solar Electric Light Fund (SELF) and the Partners in Health (PIH) organizations, five health clinics have been equipped with 3.4-4.3 kW solar photovoltaic (PV) systems to provide healthcare services for almost 400,000 Rwandans through powering laboratory equipment like blood analysis machines, microscopes, portable X-ray machine, sterilization devices, and centrifuges; provide refrigeration, telecommunications, and computers, etc In summary, poor of household electricity supply can contribute to non-neonatal deaths, because of indoor air pollution from kerosene fuel, candle, etc. and or even accidents from these poor lighting ways. Further, more indirect causes of both neonatal and non-neonatal deaths alongside the high turnover rate of health workers in rural health centres can also be attributed to poor electricity supply, [29], [30].

Step 4. To date, access to financial capital is a critical barrier to scaling up off-grid solar energy in Rwanda for basic lighting purposes and for powering basic mini-grid appliances like radios and televisions. Some Solar Light firms in Rwanda are attracting foreign and local debt and this has led to the establishment of the Scaling-Up Renewable Energy Program in Low Income Countries (SREP) - funded renewable energy fund. This promotes private sector investment in off-grid power solutions, especially in innovative financial schemes like Pay-as-you-go (PAYG) and debt-equity, Energising Development Rwanda (EnDev), and the SIDA-funded Scaling-up Off-Grid Energy (SOGER) programs. Further, the SREP-funded Renewable Energy Fund (REF) enhances mini-grid financing for health centers through its direct lending window approach. By December 2017, USD 34 million was invested in Solar Home Systems (SHS), while larger companies like Mobisol managed to secure debt-equity financing mechanisms amounting to USD 35 million in 2017. With these great financing mechanisms in place, Rwanda managed to attract USD 55 million in capital investment in 2019. Table 3 shows the current off-grid electrification status in Rwanda [31], [32]. Table 3 gives the current renewable energy power supply status of off-grid systems in Rwanda.

Table 3. Rwanda's Off-grid electrification status

Category	2018	2024 Target	Gap	Number of companies
Solar Home Systems (SHS	253,181	1,274,180	1,020,999	27
Mini grids (MG)	3,582	326,884	323,302	9
Total Off-grid	256,763	1,601,063	1,344,300	36

Table 3 shows the current renewable energy power supply in terms of SHSs and MGs, with targets for the year 2024.Although Rwanda has attracted substantial financial investment, a large gap as high as 50% still needs to be closed [32].

To further enhance financing mechanisms in Rwanda, the government has established the renewable energy investing model - the SREP-funded Renewable Energy Fund (REF) that is implemented in collaboration with the Rwanda Development Bank (RDB). The objective of Rwanda's SREP Investment plan is to accelerate off-grid electricity access through stand-alone solar systems and renewable energy-based mini-grids through its Four-window Initiative that is implemented through the Rwanda Development Bank (RDB). Figure 2 shows the schematic window framework for the Rwanda REF Financing Program.

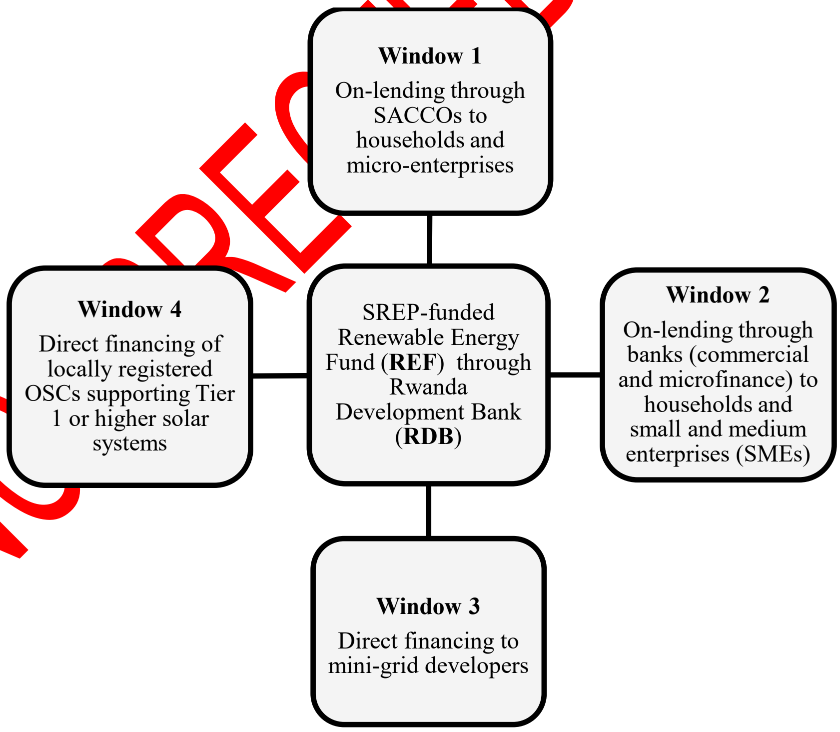

Figure 2. SREP Funds - REF renewable energy financing framework in Rwanda

Figure 2 shows the four renewable energy financing mechanisms by RDB to a corporative initiative called Umurenge SACCO – Window 1, commercial, microfinance – Window 2, mini-grid developer – Window 3, and to local off-grid firms in Window 4 [31].

Due to poor public-private partnership relationships alongside pockets of bureaucratic issues to access the funds, small local firms are disadvantaged in accessing these funds while the large multinational companies easily meet the strict financing criteria put in place (Window

4). This implies that the impact of these funds requires capacity building within BRD to ably handle these financing programs and this will also extend the duration for the expected program outcomes. So far, the REF and RDB programs have demonstrated the ability to fulfill the International Monetary Fund's SDG financing framework (Billions to Trillions) which is implemented through the Official Development Assistance (ODA) to invest billions in aid or grants in developing nations to catalyse and harvest trillions out of the public and private sector [33].

Kenya case study

Step 1. In Kenya, the ongoing pursuit to extend country the electrical network has brought about an increase in power access, especially in the Western part of Kenya. Although 73% of Kenya's population lives in rural areas, the electrification rates in rural households remain extremely low, averaging 5% and 22% for rural businesses. Out of the 695 health centres, about 181 health facilities do not have access to electricity while 104 health facilities do not have reliable power supply sources [22], [34], [35].

Step 2. In Kenya, about 56% of all the health facilities have a continuous water supply annually but 25% of these health facilities have an uninterrupted power supply. This is worsened by the fact that only 42.8 % of women in these hospitals have access. In addition to inadequate water supply, rural health care faces challenges such as a shortage of skilled midwives during childbirth, high employee turnover rates, and long distances to health centers [35], [36]. The Centre for Disease Control and Prevention (CDC) – Kenya cites the top 6 killer diseases in Kenya that contribute to poor health services as evidenced by the high mortality rates in Kenya to vulnerability to deaths from diarrheal diseases, HIV/AIDS, and TB, neonatal diseases, other non-communicable diseases, mental and substance abuse, and cardiovascular diseases. The diagnostic tools for these diseases heavily depend on having reliable electricity [37].

Step 3. The absence of adequate and reliable power puts at risk the social well-being of millions of people, particularly women, and children, who frequently endure adverse effects of not having adequate healthcare services. In rural communities in Kenya, access to maternal and infant care administrations is still restricted because of the poor existence of maternal and infant care infrastructure. [35].

Specifically, pneumonia, malaria, and cancer lead Kenya's causes of death with 21,584 people dying from pneumonia in 2017, 17,553 deaths from malaria and 16,953 deaths from cancer, and HIV/AIDS being fourth with 8,758 deaths [38]. Out of all pneumonia deaths experienced in Kenya (21,584 deaths), child and maternal deaths take the largest share of almost 13,000 deaths which accounts for almost 60% of the highest killer disease [39].

Step 4. The need for more resources to power the health sector was initiated by the Cleaner Energy for Health Care Conference (CEHCC) in Nairobi, Kenya because delegates realized that Kenya was highly resource-constrained concerning delivery of power to health facilities. Further, the CEHCC also concluded that solar photovoltaics and energy-efficient medical equipment have the potential to provide more resilient health systems in Kenya and sub-Saharan Africa [40].

One notable innovative project out of the CEHCC is Kenya's Off-Grid Solar Access Project (KOSAP) which focuses on providing power to as many health facilities as possible with solar PV systems. The KASAP program is dedicated to delivering clean energy systems to the vulnerable in rural Kenya while boosting Kenya's rural electrification rate. It capitalizes on the strengths of institutional frameworks to drive country and community-led projects, significantly advancing progress towards the United Nations Sustainable Development Goals, specifically SDG 3 (Good Health and Well-being) and SDG 7 (Affordable and Clean Energy).. The conceptual framework that guides the off-grid health system scale-up projects in Kenya through the CEHCC, is given in Figure 3 [41].

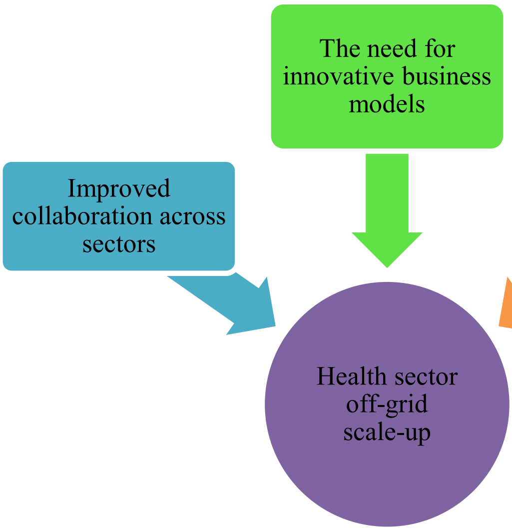

Figure 3. Kenya's Off-grid renewable energy financing model

Figure 3 shows a financing model for off-grid renewable energy model and synergies between renewable energy and health services. Although these thematic sectors hardly work hand in hand in the real world, the business world, the public sector, universities, private firms, and health practitioners need to start collaborating to improve energy access and efficiency. [49]

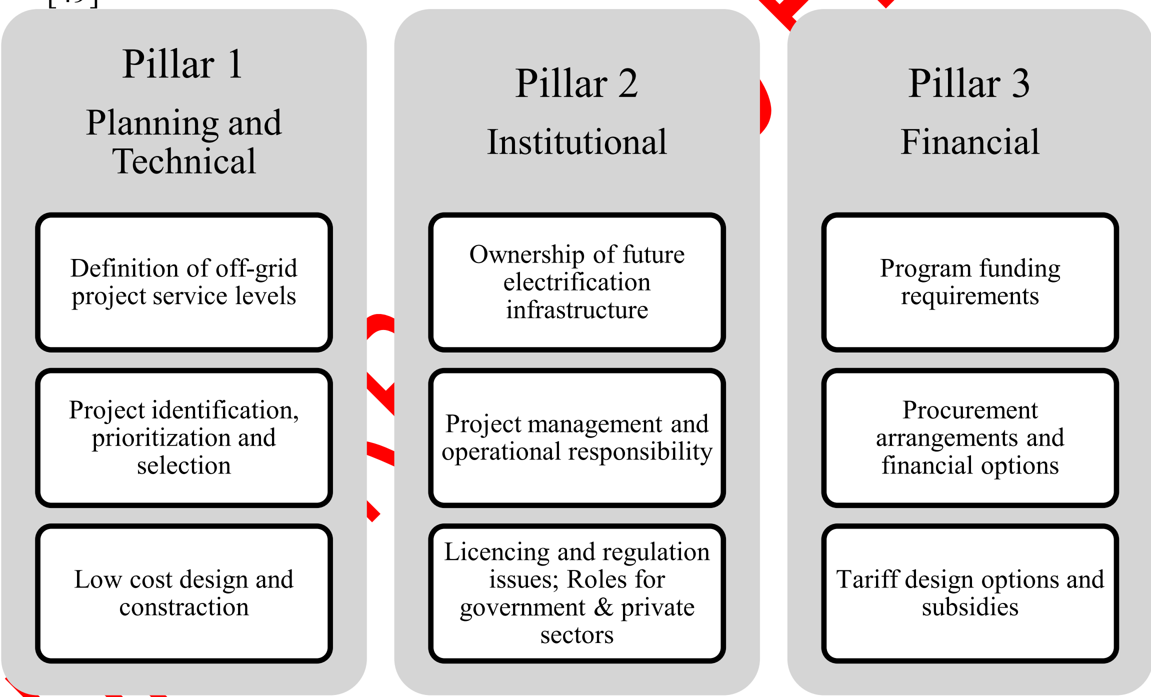

Figure 4. National electrification investment model for Kenya [42].

Figure 4 shows the three pillars (planning and technical, institutional, and financial) which presents the synergies between the six thematic areas that form the Kenya National Electrification Strategy (KNES).

The Kenya National Electrification Strategy (KNES) comprises the following six themes:

i. Assign administration levels for off-grid programs by characterizing the homes or businesses being supplied with power.
ii. Developing methodologies for distinguishing projects and prioritizing them for usage.
iii. Developing a technical specification for future electrification investment or any alteration of designs by the prescribed standards and quality of service.

iv. Defining the jobs and duties of the major organizations participating.
v. Defining acquisition plans to improve and achieve a result-based electrification program.
vi. Evaluating budgetary necessities and how they can be locally and externally financed.

To achieve universal access to electricity for all Kenyans, a 5-year investment plan that was based on 2009 demographics was done in 2017 to provide electricity supply to 5.1 million customers at a connection rate of 100,000 new connections per month. The average household size in Kenya is 3.9 and this translates to 13.77 million households in Kenya with 10.1 million households living in the rural areas and only 1.414 million households electrified (14% electrification). This projection demographically still falls short of the required electrification connections, especially in rural areas. Table 4 KNES' 5-year electrification investment budget plan and its target connections [43], [44].

Table 4 shows a 5-year breakdown of Kenya's national electrification investment plan from 2017 to 2022 with a total investment of $ 2,748.9 million to carter for only 5,651,300 connections or households. With a rural population of 39.2 million, a mare connection target of 5.7 million people still leaves a large gap. Further, Kenya's additional 5-year investment plan from 2023 to 2027 only adds $ 292.2 million to carter for an additional 767,510 connections giving a total of 6,418,810 total connections in 10 years. This investment plan is far from achieving the UN SDG 7 target concerning providing clean and affordable energy to all Kenyans by 2030. A gap of 69.6% unconnected households excluding the 14% electrification in rural areas.

Table 4. Kenya's 5 Year electrification Investment Budget Plan and Target Connection between 2017 to 2022 [43].

Intervention	Year 1 (US$)	Year 2 (US$)	Year 3 (US$)	Year 4 (US$)	Year 5 (US$)	Budget (US$)	Target Connections
Grid Expansion	36.4M	61.6M	62M	110.5M	111M	381.5M	299,601
Grid Densification	23.9M	141M	340.3M	294.8M	442.4M	1,242.4M	2,533,995
Grid Intensification	82.2M	340.4M	154.6M	34.0M	22.2M	633.4M	599,313
Mini-Grids	5.8M	3.1M	8.4M	7.5M	8.3M	33.1M	38,661
Solar Home Systems	91.5M	91.5M	91.5M	91.5M	91.5M	91.5M	2,179,730
Total	239.8M	637.6M	656.8M	538.3M	675.4M	2,748.9M	5,651,300

M- million

Ghana case study

Step 1. Out of the 428 health centres, about 133 health facilities do not have access to electricity. This implies that the remaining 295 health facilities do not have a power supply. Since 47% of Ghana's population lives in the rural area with an average 52% of its population having access to electricity points to the fact that almost 48% of Ghanaians are faced with compromised health delivery. Six of the top killer diseases in Ghana include malaria, lower respiratory infections, neonatal disorders, ischemic heart disease, stroke, and HIV/AIDS [45], [46].

Step 2. In Ghana out of 428 health facilities, about 133 health have no access to power while 120 health facilities have no reliable electricity. This also compromises health care delivery. This contributes to deaths from pneumonia, birth asphyxia, meningitis among neonates, malaria, acute respiratory infections, etc..[22], [47].

Previous studies by Opoku *et al* in community-based health planning and services (CHPS) centers with 145 patients in Mamprugu Moagduri district in the northern region of Ghana, evaluated the potential impact of solar photovoltaic systems on the healthcare system service delivery and the socio-wellbeing of community for long-term sustainability. It was found that the CHPS centers were solar PVs that improved the healthcare service delivery because a 30% drop in prevalent diseases in the Mamprugu Moagduri district was recorded. The major interventions of installing solar PVs assisted in (i) storing medicines at temperatures below 30°C, (ii) keeping vaccines at 3-7°C (like snake bite vaccines), and (iii) retention of health workers like nurses who had to walk for about 18 km to purchase ice blocks to keep the vaccines as refrigerator supplement [48].

Step 3. In Ghana's health facilities, which offer child vaccination on a routine basis, 16% are restricted in this undertaking by the absence of power or fuel to keep up the prescribed temperatures for storing medicines [49]. The unreliable power supply can cause damage to both medical equipment and any other equipment. Previous studies by Opoku et. al, found that access to power in the health centers has more effect on females and children than men because they spend more time engaging in agricultural activities and fetching firewood for cooking, which could have been used for more productive economic activities [48].

Step 4. Ghana is a hydro-dependent nation, accounting for about 60% of the total generated energy. Out of the 30.4 million people living in Ghana, 70% of them have access to power, making Ghana one of the nations with very high connection rates in sub-Saharan Africa with only 5 million people (30%) not having electricity. However, the remaining 30% is exceedingly troublesome and expensive to electrify using the Ghanaian electrical national grid because these places are remote, difficult-to-reach regions, including islands and lakeside regions. To address this deficit, a generation-mix strategy deploying hydropower and renewable energy resources like solar, and wind is an attractive power source option because it is renewable, clean, affordable, easy to deploy off the national grid. This makes renewable energy a key source for sustainable energy development among the poor majority and especially in rural health facilities. One challenge Ghana faces is the rapid population growth rate of 2% per annum. This demands that Ghana needs to over-expand its electrical generation resources to meet this rate and high demand. With 47% (14.29 million) of the population live in the rural areas by 2019 and only 52% (7.6 million people) having access to electricity in the rural area, the deficit is also expected to grow in proportion to the growing demand. The expansion plans by the Government of Ghana estimate that by 2026, the electricity demand will increase threefold to about 4,200 MW (28,000 GWh). The current peak load demand by 2019 is estimated to be 20,000 GWh, leaving a deficit of 8,000 GWh. [35], [50], [51].

Although the Ministry of Energy has planned to invest about US$ 1.4 to 2.6 billion in renewable energy, it still falls short according to the anticipated peak power demand of 28,000 GWh by 2030 and the Ghanaian National Commission for UNESCO, which also estimates that an estimated $9 billion was needed to be raised by 2019, as investment capital for renewable energy development and finance Ghana's 10-year renewable energy program.

In response, the government of Ghana has put up the Scaling-up Renewable Energy Program in Ghana Investment Plan (SREP-Ghana IP) comprising (i) the renewable energy micro-grids and stand-alone solar photovoltaic systems, (ii) the solar photovoltaic-based net-metering with energy storage systems, (iii) the utility-scale photovoltaic or Wind power generation project and (iv) the technical assistance to scale-up renewable energy. The SREP-Ghana investment program provided US$ 40 million as part of a cost-sharing or equity model as a financing strategy to unlock financing opportunities for accelerating sustainable energy development in Ghana using renewable energy resources and innovative financing strategies like pay-as-you-use models. The SREP-Ghana Investment plan further requested an additional US$ 190 million amount to make a US$ 230 million budget with contributions from the government of Ghana, the African Development Bank, the International Finance Corporation (IFC), the private sector, and other development partners, investors, financiers, and beneficiaries. Further, the government of Ghana through the Ministry of Energy has developed two 10-year phases; phase 1 - up to 2019 and phase 2 - up to 2026. However, although it is still uncertain as to how to source the funding for phase 2, the Ministry of Energy has set ambitious renewables targets as given in Table 1 but is uncertain with the financial investment sources for phase 2 [52].

Table. Ministry of Energy - Renewable Energy 2020 Targets Projects

Potential renewable energy Projects	**Target**	**Required investment US$ million**
Wind farms	50-150 MW	300-550
Grid-connected solar parks	MW	400-700
Solar lantern promotion	2 million units	150-200
Small to medium hydro	150-300 MW	450-900
Modern biomass /waste-to-energy	20-50 MW	60-150
Mini-grid projects	30-42 units	21 - 38.5
Off-grid Renewable Energy project	30,000 units	10-25
Sustainable energy cooking	2 million units	10-50
Total Investments		**US$ 1.4 - 2.6 billion**

However, the implementation of these renewable energy projects will not come without any challenges. Some transformative impacts and renewable energy outcomes for implementing renewable energy projects are that renewable energy projects will support low-carbon technologies and pathways, which reduce energy poverty, increase energy security, increase the supply of renewable energy, increase access to energy-efficient cook stoves, explore new resources for renewable energy programs roll-out to help reduce air pollution and climate change by avoiding greenhouse gas (GHG) emissions [52], [53].

Using renewable energy, Ghana can enhance its socio-economic development through a low-carbon energy development pathway alongside the existing large hydropower generation and renewable energy systems that currently only contribute a marginal 0.3% to Ghana's installed capacity despite having a large renewable energy potential base. The government of Ghana is committed to achieving the UN SDG 3 and 7 which emphasizes health well-being and energy provision and attaining sustainable energy development and sustainable health systems by scaling up the deployment of renewable energy solutions. Since most rural health facilities are in remote places, off the national grid, exploring renewables would not just reduce air pollution to reduce respiratory diseases and greenhouse gas emissions. To achieve this, adequate capacity building on renewable energy systems, and enabling investment of about US$ 9 billion will be needed to finance the second phase (2020-2030) [2], [52], [53], [54].

Some common observations in the three case studies concerning renewable energy deployment and investment for rural health facility electrification are that:

i. All governments have a general electrification program/ policy that addresses electricity access for all but lack programs that prioritize electrification of rural health facilities.
ii. The source of the funds for electrification is eternally generated through either grants or loans.
iii. Each case study country has a high population growth rate of about 2% and a prevailing electricity deficit.
iv. On average, 26% of health facilities in Kenya, 18% of health facilities in Rwanda, and 31% of health facilities in Ghana have no electricity while those with electricity

have unreliable electricity supply of about 18% for Kenya and 44% for Rwanda and 29% for Ghana.

v. A high mortality rate is also observed in all case studies have a high maternal, and neonatal child mortality rate per 100,000 births.

vi. The investment strategies are mainly public institution-based with fewer or no public-private partnerships or investments in some cases.

While these observations cannot be used to draw any solid conclusions in specific case study countries, the findings can support policy formulation and strategic planning, decision making, and overall, improve sustainable health systems in the selected case study countries.

Research significance, policy implication, and limitations

The findings of this study can help decision-makers to make informed decisions that are evidence-based, replicate, or adopt public-private investment strategies capable of breeding new and innovative financing business models. Further, decision-makers can leverage existing policies or propose policy formulation to scale up renewable energy technologies in rural health centres. [50], [51]

Although the top five killer diseases in Africa are lower respiratory tract infections, HIV/Aids, diarrhoeal diseases, Ischaemic heart disease, and parasite diseases (Malaria), these will differ from one country to another depending on the investment policies that have been placed by their governments [49], [50]. Renewable energy provides a solution for powering medical equipment in rural health facilities, demonstrating its potential to enhance health system resilience and improve healthcare service delivery

This study is limited to evaluating the social impact of renewable energy usage in health systems in Kenya, Rwanda, and Ghana using credible secondary data to analyses the social impact qualitatively without using primary data that would help validate the stated demographic and mortality data. Further, it is recommended that future studies should quantify the exact greenhouse gas emission reduction that can be realized using renewable resources in rural health facilities. Quantifying the impact of renewable resources in the selected case studies over a long period with a relatively larger sample can lead to better conclusions on sub-Saharan Africa. To demonstrate the benefits of renewable energy deployment, control experiments can also be done to derive some evidence-based lessons learnt from those with and without renewable energy investment interventions.

CONCLUSIONS

In Rwanda, Ghana, and Kenya, a high neonatal mortality rate (per 100,000 births) is commonly observed, while child mortality rates (per 100,000 births) remain concerning. Among various factors contributing to high child mortality, inadequate electricity supply to rural health services stands out. The scarcity of power in healthcare centres leads to high turnover rates, discouraging qualified health professionals from working in rural areas and hindering the delivery of quality healthcare.

Moreover, poor electricity availability affects critical aspects of health services. Immunization programs suffer, medical and diagnostic equipment utilization breaks down, and necessities like lighting, refrigeration for medicines, and telecommunications systems during emergency operations become unreliable. Lack of sustainable power also strains health workers' ability to provide extended care while simultaneously contributing to carbon emissions and air pollution in homes and businesses.

To address this challenge, policymakers must allocate more funding toward rural health centre electrification. Sustainable health systems can be enhanced through strong partnerships between public and private entities including health and financial institutions. Innovative business strategies and energy financing mechanisms should prioritize off-grid and stand-alone solutions, alongside energy efficiency improvements in rural health facilities. Exploring renewable energy options reduces air pollution (a major cause of respiratory diseases), but also mitigates carbon emissions thereby aligning with SDG 13 (climate action).

Closing the gap in health service delivery requires transformative change. Renewable energy solutions (SDG 7) play a crucial role in achieving SDG 3 (good health and well-being). However, mobilizing essential financial resources and technological support remains pivotal to adapting to climate change's impact on health systems.

ACKNOWLEDGMENT

Contributions to the research by Professor Valerie Thomas of Georgia Institute of Technology, USA is appreciated and acknowledged.

REFERENCES

[1] M. Moner-Girona, G. Kakoulaki, G. Falchetta, D. J. Weiss, and N. Taylor, "Achieving universal electrification of rural healthcare facilities in sub-Saharan Africa with decentralized renewable energy technologies," *Joule*, vol. 5, no. 10, pp. 2687–2714, Oct. 2021, doi: 10.1016/j.joule.2021.09.010.

[2] K. Imasiku, V. Thomas, and E. Ntagrirumugara, "Unraveling Green Information Technology Systems as a Global Greenhouse Gas Emission Game-Changer," *Adm Sci*, vol. 9, no. 43, pp. 1–29, 2019, doi: doi:10.3390/admsci9020043.

[3] Antonio C. Jimenez and Ken Olson, "Renewable Energy for Rural Health Clinics," 1998. Accessed: Apr. 19, 2024. [Online]. Available: https://www.nrel.gov/docs/legosti/fy98/25233.pdf

[4] USAID, "Powering Health: Electrification Options for Rural Health Centers," 2024. Accessed: May 02, 2024. [Online]. Available: https://pdf.usaid.gov/pdf_docs/Pnadj557.pdf

[5] IRENA, "IRENA to Highlight Key Role of Renewables to Realisation of SDGs at UN HLPF."

[6] H. Adair-rohani *et al.*, "Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources , and reliability," vol. 1, no. 2, pp. 249–261, 2013.

[7] Centre for Affordable Housing Finance in Africa, "2019 Kenya Population and Housing Census Reports."

[8] Rwanda Energy Group, "Off Grid Electricity Expansion Programs in Rwanda," in *5th Mini Grids Action Learning Event: Reaching Universal Energy Access*, Accra, 2019, pp. 1–23.

[9] S. Kesrelioglu, "Rwanda: Off-grid Sector Status Report 2017," Rwanda, 2017.

[10] K. Imasiku, V. Thomas, and E. Ntagwirumugara, "Unpacking Ecological Stress from Economic Activities for Sustainability and Resource Optimization in Sub-Saharan Africa. Sustainability," *Susstainability*, vol. 12, no. 9, pp. 1–12, 2020, doi: 10.3390/su12093538.

[11] L. Olatomiwa *et al.*, "An Overview of Energy Access Solutions for Rural Healthcare Facilities," *Energies*, vol. 15, no. 24. MDPI, Dec. 01, 2022. doi: 10.3390/en15249554.

[12] Y. J. Chen, N. Chindarkar, and Y. Xiao, "Effect of reliable electricity on health facilities, health information, and child and maternal health services utilization: evidence from rural Gujarat, India," *J Health Popul Nutr*, vol. 38, no. 1, p. 7, Feb. 2019, doi: 10.1186/s41043-019-0164-6.

[13] V. Castán Broto and J. Kirshner, "Energy access is needed to maintain health during pandemics," *Nature Energy*, vol. 5, no. 6. Nature Research, pp. 419–421, Jun. 01, 2020. doi: 10.1038/s41560-020-0625-6.

[14] M. Moner-Girona, G. Kakoulaki, G. Falchetta, D. J. Weiss, and N. Taylor, "Achieving universal electrification of rural healthcare facilities in sub-Saharan Africa with decentralized renewable energy technologies," *Joule*, vol. 5, no. 10, pp. 2687–2714, Oct. 2021, doi: 10.1016/j.joule.2021.09.010.

[15] Care, "Unsafe Healthcare Facilities." Accessed: Jul. 07, 2024. [Online]. Available: https://ceh.unicef.org/events-and-resources/knowledge-library/database-electrification-health-care-facilities

[16] Ryosuke Hanafusa and Shiuchiro Sese, "Home solar business brightens in Africa," Nikkei staff writers. Accessed: Jul. 07, 2024. [Online]. Available: https://asia.nikkei.com/Business/Business-trends/Home-solar-business-brightens-in-Africa

[17] Ramón Pichs Madruga, "Linking climate and biodiversity," 2021. Accessed: Jul. 01, 2024. [Online]. Available: https://www.science.org/doi/epdf/10.1126/science.abm8739

[18] C. Nieto-Sanchez *et al.*, "How are health systems in sub-Saharan Africa adapting to protect human health from climate change threats? A scoping review and case study," 2024. [Online]. Available: www.thelancet.com/planetary-health

[19] Energy Access, "Health Facility Energy Needs Assessment Ghana Country Summary Report," 2015.

[20] O. K. Ezeh, K. E. Agho, M. J. Dibley, J. J. Hall, and A. N. Page, "The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey," *Environmental Health*, vol. 13, no. 1113, pp. 1–10, 2014.

[21] A. Franco, M. Shaker, D. Kalubi, and S. Hostettler, "A review of sustainable energy access and technologies for healthcare facilities in the Global South," vol. 22, pp. 92–105, 2017.

[22] H. Adair-rohani *et al.*, "Limited electricity access in health facilities of sub-Saharan Africa: a systematic review of data on electricity access, sources, and reliability," vol. 1, no. 2, pp. 249–261, 2013.

[23] J. Porcaro *et al.*, "Modern energy access and health," Washington, DC, 2017.

[24] Trading Economics, "Rwanda Rural Population."

[25] USAID, "Rwanda Power Africa Fact Sheet."

[26] N. Gupta *et al.*, "Causes of death and predictors of childhood mortality in Rwanda: a matched case-control study using verbal social autopsy," *BMC Public Health*, pp. 1–9, 2018.

[27] G. Poindexter, "Rwanda leases 22 small hydroelectric plants to private consortium," Hydo Review.

[28] A. Franco, M. Shaker, D. Kalubi, and S. Hostettler, "A review of sustainable energy access and technologies for healthcare facilities in the Global South," vol. 22, pp. 92–105, 2017.

[29] GeoSUN, "Solar Maps and Layers."

[30] O. K. Ezeh, K. E. Agho, M. J. Dibley, J. J. Hall, and A. N. Page, "The effect of solid fuel use on childhood mortality in Nigeria: evidence from the 2013 cross-sectional household survey," *Environmental Health*, vol. 13, no. 1113, pp. 1–10, 2014.

[31] S. Kesrelioglu, "Rwanda: Off-grid Sector Status Report 2017," Rwanda, 2017.

[32] Rwanda Energy Group, "Off Grid Electricity Expansion Programs in Rwanda," in *5th Mini Grids Action Learning Event: Reaching Universal Energy Access*, Accra, 2019, pp. 1–23.

[33] World Bank, "Financing for Development at the World Bank Group," 2018.

[34] M. Adjuik *et al.*, "Cause-specific mortality rates in sub-Saharan Africa and Bangladesh," 2006.

[35] H. Essendi *et al.*, "Infrastructural challenges to better health in maternity facilities in rural Kenya: community and health workers perceptions," *Report Health*, pp. 1–11, 2015, doi: 10.1186/s12978-015-0078-8.
[36] K. Lee *et al.*, "Electrification for 'Under Grid' households in Rural Kenya," *Dev Eng*, vol. 1, pp. 26–35, 2016, doi: 10.1016/j.deveng.2015.12.001.
[37] CDC, "Global health - Kenya," Center for Disease Control and Prevention.
[38] M. Njungunah, "Pneumonia, Malaria and Cancer Are Kenya's Leading Causes of Death," Capital News.
[39] K. Schroder and R. Kihoto, "Kenya introduces ambitious efforts to tackle pneumonia," Clinton Health Access Initiatives.
[40] United Nations Foundation, "Cleaner Energy for Health Care," in *Harnessing renewable energy and energy efficiency to create stronger, more resilient health systems*, Nairobi, 2019.
[41] J. Porcaro, "Energy and health: making the connection," Sustainable Energy for All.
[42] Ministry of Energy, "Kenya National Electrification Strategy: Key Highlights 2018," Nairobi, 2018.
[43] Ministry of Energy, "Kenya National Electrification Strategy: Key Highlights 2018," Nairobi, 2018.
[44] Centre for Affordable Housing Finance in Africa, "2019 Kenya Population and Housing Census Reports."
[45] CDC, "Global Health - Ghana," Center for Disease Control and Prevention.
[46] N. S. Ouedraogo and C. Schimanski, "Energy poverty in healthcare facilities: a 'silent barrier' to improved healthcare in sub-Saharan Africa," *J Public Health Policy*, vol. 39, pp. 358–371, 2018.
[47] R. Opoku, E. A. Adjei, G. Y. Obeng, L. Severi, and A. Bawa, "Electricity Access, Community Healthcare Service Delivery, and Rural Development Nexus: Analysis of 3 Solar Electrified CHPS in Off-Grid Communities in Ghana," *Journal of Energy*, vol. 2020, pp. 1–10, 2020, doi: 10.1155/2020/9702505.
[48] R. Opoku, E. A. Adjei, G. Y. Obeng, L. Severi, and A. Bawa, "Electricity Access, Community Healthcare Service Delivery, and Rural Development Nexus: Analysis of 3 Solar Electrified CHPS in Off-Grid Communities in Ghana," *Journal of Energy*, vol. 2020, pp. 1–10, 2020, doi: 10.1155/2020/9702505.
[49] S. Fewa, O. Schmidt, and A. Gambhira, "Energy access through electricity storage: Insights from technology providers and market enablers," *Energy for Sustainable Development*, vol. 48, pp. 1–10, 2019, doi: 10.1016/j.esd.2018.09.008.
[50] Climate Investment Fund, "Scaling-up Renewable Energy Program in Ghana (SREP)," Washington, DC, 2015.
[51] Energy Access, "Health Facility Energy Needs Assessment Ghana Country Summary Report," 2015.
[52] Climate Investment Fund, "Scaling-up Renewable Energy Program in Ghana (SREP)," Washington, DC, 2015.
[53] K. Imasiku, V. Thomas, and E. Ntagwirumugara, "Unpacking Ecological Stress from Economic Activities for Sustainability and Resource Optimization in Sub-Saharan Africa. Sustainability," *Sustainability*, vol. 12, no. 9, pp. 1–12, 2020, doi: 10.3390/su12093538.
[54] M. E. Eshun and J. Amoako-tuffour, "A review of the trends in Ghana's power sector," *Energy Sustain Soc*, vol. 5, pp. 1–9, 2016, doi: 10.1186/s13705-016-0075-y.