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Review

An Overview of Energy Access Solutions for Rural Healthcare Facilities

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Abstract: Quality in healthcare service is essential in giving rural dwellers a good standard of living. It has been established that many rural locations in Sub-Saharan Africa away from the grid connection have difficulty accessing electricity. The inaccessibility of reliable energy and essential medical equipment was the leading barrier to improved healthcare delivery in these rural locations. The deficiency of basic medical equipment to power essential services due to limited or unreliable electricity access has reduced rural healthcare workers' care capabilities, resulting in higher mortality rates. This paper, therefore, reviews the existing energy solutions for rural healthcare facilities, thereby analysing different approaches and the geographical energy mix and ascertaining the effectiveness of various techniques and energy mix as solutions to effective healthcare delivery in healthcare centres. Hybrid Renewable Energy Sources (HRES) microsystems, like microgrids incorporated with solar panels and battery, is identified to ensure higher and more reliable energy access in rural healthcare centres. At the same time, the adoption of Demand Side Management (DSM) in the HRES deployment in countryside healthcare facilities is reported to decrease the initial cost of installation and improve efficiency. Lastly, in improving energy access, rural electrification planning is achieved through modelling tools related to energy access modelling.

Keywords: energy access; rural healthcare; hybrid renewable energy sources; demand side management

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1. Introduction

1.1. Background

Inaccessibility to adequate electricity has proven to be one of the most pressing concerns confronting the world, and this has affected about 1.6 billion people worldwide [1,2]. Given the distance and cost of expanding the grid, most rural areas in developing countries (including Nigeria) have difficulty accessing power. As a result, many rural healthcare facilities have been unable to fulfil their original mission adequately. This electricity inadequacy in most distant villages has widened the infrastructural development, and the economic gap has exacerbated poverty and made raising their standard of living more difficult. Research shows that roughly 17% of the world's populace cannot access a grid-connected power supply. Of the 17%, 85% of these individuals are living in rural settlements, of which Sub-Sahara Africa has the highest proportion [1,3–6].

Some elementary services, including clean water, healthcare, internet connectivity, and education, necessitate electricity for productivity [4,7–10], whereas essential healthcare services in rural areas, including lighting, medical equipment, and heating, suffer from unreliable energy supply. As a result, proper medical diagnosis and treatment are denied; therefore, many people have to find their way to cities for better diagnosis and treatment.

Additionally, healthcare workers lost interest in rendering medical services in rural healthcare centres, and those present could not operate for long hours because of inaccessibility to reliable energy [11]. The primary factor for the early closure of some healthcare centres is the lack of access to a quality power supply at night and the shortfall of staffing [5,12].

There is more rural-urban drift in sub-Saharan Africa since less or no concern has been given to rural electrification over time [3,5,13,14]. In many healthcare facilities, energy is required for adequate ventilation, temperature and water control, lighting, and medical equipment operations [11]. To avoid life risks, patients receiving medical care with ventilators or oxygen masks must not suffer from power outages. Poor power supply to rural areas causes the rural health personnel to refer many of their patients to the city for better treatment, as many die during this cause [15–17].

There is widespread agreement that healthcare centres will improve productivity if only a sufficient power supply is available [2,18–20]. A reliable energy source that will serve 24 h is essential for a healthcare centre to operate on a full scale [5,18]. Insufficient and unreliable electricity is among the significant factors blocking the fulfilment of the United Nations' Sustainable Development Goals number three (SDG-3) [17]. The primary power source of most rural health centres is generators powered with diesel or gasoline. In contrast, it cannot serve in the long run as fuel costs increase operational expenses [2,15,20]. Apart from the cost of running the generator set, there is the possibility of a health hazard resulting from the emission from the generator [21]. In this paper, an overview of the existing energy solutions for rural healthcare facilities were presented in the form of a review. Different approaches identified from the review, coupled with the geographical energy mix and the effectiveness of various approaches deployed as solutions to healthcare centres were equally explored.

1.2. Theoretical Analysis

1.2.1. Effects of No Access to Reliable Energy Sources in Rural Healthcare Centres

The World Health Organization (WHO) makes it known that good healthcare service directly depends on access to a reliable electricity supply, and saving a life without electricity will be difficult [1,6,12,22,23]. Figure 1 shows the effect of unreliable energy access on rural healthcare services [24].

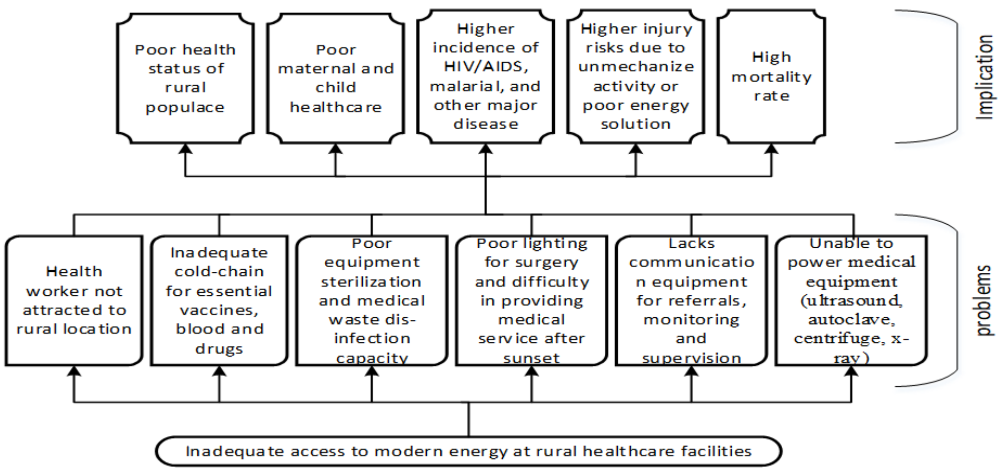

Figure 1. Energy access impacts on rural health care services [24].

The optimal approach to rural accessibility to energy is by using the natural resources available [8,21,25]. In 2014 and 2015, the National Primary Health Care Development Agency (NPHCDA) of Nigeria coordinated the construction of 91 Primary Health Centres (PHCs) across the country at an equal rate. However, most of these PHCs, worth over two billion naira, have been abandoned due to an inaccessible power supply that is reliable [5]. Multiplying the numbers of healthcare infrastructure does not impact healthcare improvement without providing an accessible power supply [22,24]. The cost spent on the inactive healthcare centres will finance the installation of off-grid solar systems for about 667 existing PHCs across the country [5].

Most of these off-grid PHCs illuminate the clinic at night with torchlight, mobile phones, and candles. For instance, a study reported that Dakwa primary healthcare centre, situated in an off-grid community in Abuja, Nigeria, uses kerosene lamps as a means of lighting at night. The midwives and healthcare staffs carry out their night work, including childbirth, using torchlight. There is a report of a midwife whose torchlight went off in the middle of delivery, and the baby was delivered in darkness [5].

1.2.2. Significance of Accessing Reliable Electricity in Rural Healthcare Centres

The social advancement of a community is defined by the regular and satisfactory supply of energy [9,10]. However, a reliable energy supply is vital to the healthy functionality of healthcare centres through technological-based medical facilities [11]. Electrification happens to be the basis of achieving standard healthcare administration in rural areas and catching the interest of health personnel for quality services [26]. Access to stable electricity will improve the health personnel's working rate and attract and motivate more skilled health workers in rural areas, thus enhancing the healthcare status of the locals [17]. However, many barriers challenge planners and policymakers to feed electricity in remote areas [27]. Several findings and research were carried out to make electricity accessible to the off-grid a success [14]. Supreme services such as diagnostics and treatment cannot be offered to patients without electricity. Most medical equipment cannot operate without electricity. A freezer/refrigerator is required to store pharmaceutical items and needs lighting at night for treatment; hence accessibility to energy is essential for exemplary healthcare services [11].

The improvement of one sector affects the other. While the output of a sector, such as energy, serves as input to many others. Therefore, every sector relies on electricity access. For instance, devices such as television, radio, or mobile phones help broadcast health news, especially during the pandemic, and access to electricity thus improves the usage of these devices to serve the expected purpose [11]. Consequently, it is necessary to enhance the living conditions of the workers and their families with facilities such as electricity access, communication, education, and other social development to entice the interest of medical workers in rural areas [10]. Furthermore, energy security catches the interest of health workers, increases facility service hours, and reduces health service expenses [25]. Thus, regular and sustainable electricity supply in healthcare facilities contribute positively to the improvement and success of healthcare [24,28].

In disease management, electricity access is essential for treatment, diagnosis, and refrigeration. A solution to energy accessibility is an immediate deployment of mini-grids for healthcare facilities in rural or urban areas with low power supply [3,11]. Small-scale hydropower may be required via mini-grid/off-grid as energy provision solutions in rural areas. This deployment will serve the healthcare facilities and provide nearby communities with sustainable energy. Small-scale hydropower could be a trusted procedure, but modification is necessary to suit the local situation and grid size [29]. Health centres can achieve high-reliable energy services through microgrids incorporated with solar panels and battery storage. Both healthcare amenities and households in urban or rural areas could benefit from a backup via solar panels and a battery storage system microgrid. Hence, danger due to power outages could be overcome as renewable backup is feasible and cost-effective in rural areas [11,15].

Furthermore, a renewable energy microsystem is a tool for producing, storing, and providing electricity that depends on renewable energy and is separated from any distribution system. Without technical maintenance to the solar PV, components will be broken down, and the system may stop working [30]. Therefore, the beneficiary can be trained on preventive and corrective maintenance of the system. The preliminary instruction given to the user will help them perform elementary maintenance, such as periodically adding distilled water to the battery.

The Service Accessibility and Readiness Assessment tool of the World Health Organisation (WHO) has identified energy accessibility as a necessity for good healthcare services and facilities. It further emphasises the importance of energy accessibility for primary applications such as lighting, refrigeration, sterilisation, ventilation, internet communication, and computer operation [25]. Additionally, functionality of equipment such as oxygen aspirators, microscopes, and electrocardiograms require dependable electricity [31].

Despite all the advantages derived from energy accessibility, there is difficulty in expanding energy in rural communities. The barriers include a lack of finance, inadequate planning, lack of community contribution, and no maintenance [25]. The cold chain of the vaccine relies totally on the availability of sustainable power. Little change in vaccine temperature renders the vaccine impotent [32]. Therefore, national immunisation programs will be successfully carried out in rural areas when reliable electricity is available. A stable electricity supply can enhance healthcare-related services like health broadcasts (sensitisation against infectious diseases) and maternal and neonatal health administration, improving society's health conditions in rural communities. Health-related news is easily accessed in rural areas through radio and television, especially for illiterate people, compared with newspapers, magazines, or any other printed information source [12]. Since access to electricity can practically improve the healthcare status and orientation of the rural populace, alternative energy systems must be developed to achieve this goal.

1.2.3. Rural Healthcare Centre Power Supply Alternative the Off-Grid Renewable Energy Systems

The extension of the electric grid to the local area is quite tricky due to the distance and cost of distribution; hence it is more convenient to utilise renewable resources or fossil fuel-based energy generation in a remote area. Moreover, renewable energy resources are the best alternative to electrifying rural healthcare centres [14]. Initially, renewable energy was categorised as peculiar innovation but is now seen as a priority energy source due to its incitement and funding rate making it easier to acquire [33].

Solar PV and wind turbine has become reasonable option economically with technological advancement; as a result, it is more appreciable for off-grid application [34], whereas sun intensity and wind speed are the base factors that define the utilisation of PV solar and wind turbine, respectively. Stand-alone and mini-grids are off-grid energy systems that outstand conventional fuels and cost-effective alternatives to increase electricity accessibility [26]. More than 60% of new electricity access will be powered by 2030 through renewable energy sources. About half of the provision will be made with standalone and mini-grid systems [26]. Energy access emanating for photovoltaic sources has tremendously given rural service a leeway in sub-Sahara Africa in line with SDG mandate. This was demonstrated during the COVID-19 pandemic where much pressure was mounted on rural health facilities [35]. Solar PV produces clean energy at an affordable cost on a small scale as the principal installation budget comprises the facilities' expenses to use the power with low or zero operating costs.

The local council owns most rural healthcare centres; therefore, the local government is expected to regulate the Hybrid Renewable Energy System (HRES) used in healthcare centres to power health facilities. At the same time, the local council budget is insufficient to provide the required maintenance of HRES. Provision for funds to maintain HRES can be secured through public-private-partnership to prevent the early breakdown of the system. Similarly, educating the staff properly on usage and the maintenance of the HRES can reduce the maintenance cost of the system, which could be done while installing the system. In addition, this training will aid energy availability for emergency or crucial medical equipment at any time [15].

Off-grid renewable energy solutions have become an option for making electricity accessible to off-grid areas due to their cost affordability and a swift decrease in technology costs [26]. Countries such as Nepal have constructed micro-hydro projects to boost the socio-economy and replace off-grid diesel generators with renewable energy or hybridised due to large possible demand [26]. With the implementation of smart devices developed from artificial intelligence and internet of things technologies, there is a chance of combining solar and wind in energy production. The electricity needs in rural healthcare centres can be grouped into (i) health personnel and facility lighting, (ii) power for special operations and essential equipment, and (iii) security lighting. African Solar Designs' need assessments discovered that off-grid energy structures, specifically the Solar PV system, supply vital energy, although inadequate for the groups of electricity needed [27]. They also discovered that there are abandoned solar PV systems in many rural healthcare centres that are not functioning due to a deficiency in PV system management. The principal factors causing the drawback were poor system operation, lack of funds for system maintenance, and lack of community intervention [13,27]. Core United Nations (UN) allied agencies acquired PV solar-powered refrigerators for cold chain conservation [5], thus improving the child immunisation program since the cold storage device is critical to keep the vaccine at the required temperature [12].

Solar PV home systems comprise a charge controller, a PV module, an inverter, and a battery connected to generate a direct current that charges the battery via the charge controller and power dc appliances. Additionally, Alternating Currents (AC) loads can be powered by the inverter [23]. Using an energy storage device in the system enhances the utilisation of the renewable energy system and reduces the need for a generator set. Eventually, the amount of fuel consumption reduces. Solar PV and wind turbines generate energy at a peak level consumed during the day; the rest of the energy stored enables power availability when solar and wind cannot supply. Lithium-ion batteries in rural areas' energy storage tools contribute to the storage of energy at a very high rate when charging, and there is less loss in the circuit during discharging of the battery. A hybrid storage unit consisting of lead-acid and lithium-ion batteries can supply maximum load demand. The setup is advantageous as the lead-acid battery charging is standardised and thus elongates the battery life span and prevents early spoilage of the battery. The Lithium-ion battery can sense a quick rise in demand and thereby ease lead-acid accumulator by carrying the peak load demand.

The environmental benefit derived from using wind, solar, or hybrid power systems, including solar and wind, is no production of harmful emissions. Moreover, a hybrid system with diesel generators is also characterised by low atmospheric emissions of greenhouse gases. However, the noise generated from turbine blades and land space occupied by constructed systems of wind or solar contributes negatively to the environment, as the land cannot be used for another purpose. Thus, it is recommended to use existing rooftops to install solar panels and locate the wind site away from residential areas, health clinics, or school environments [18,23].

Switching to the renewable energy alternative as a means of power supply in rural areas contributes to the duration of the operation in rural healthcare centres. Therefore, getting access to a reliable power supply will increase the opening hours of the off-grid rural healthcare since the health workers can get the facilities powered for operation both day and night. In addition, the cost of securing fuel reduces as the need for fuel purchase reduces. Additionally, there is a high chance of gaining access to digital medical facilities, improving the health care service, and thus ending the cause of referring patients to another clinic. In contrast, government policy has not risen to support renewable energy technology, which challenges regulations for marketing renewable energy systems and the presence of standard equipment [36].

Additionally, a recent study demonstrated the economic and technical feasibility of hybrid renewable energy systems, indicating the cost-effectiveness of Solar PV/Wind/DG/Battery that achieved CO_2 emission reduction and reliable power supply to make a case for renewables [37]. In the typical off-grid Hybrid Renewable Energy System (HRES) shown in Figure 2, the battery provided is considered for storing excess energy via a converter attached to the system. The converter provides ports for AC and DC output loads since it can receive AC and DC power as input.

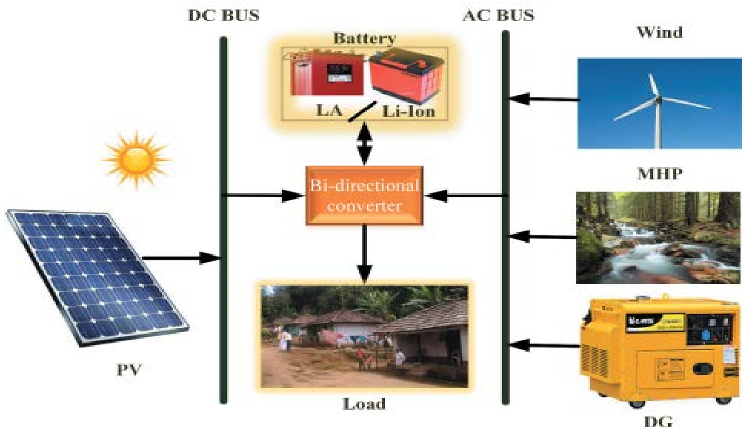

Figure 2. HRES schematic diagram.

In [38], hybrid solution of an off-grid renewable energy alternative using a hydrogen storing system bridged the gap in the energy needs of health treatment centres. Wind and solar energy assets were designed as microgrids that met the health centre's energy requirements (18.67 $\mathrm{kWh(day)}^{-1}$), which was a 10-bed size. Among the key outcomes, the average yearly wind speed of the area was 7.9 ms^{-1}, an anemometer height of 60 m and the solar irradiation of the community at 4.779 $\mathrm{kWhm}^{-2}\mathrm{day}^{-1}$. The required design for the clinic is composed of a 40 kW solar PV system, three 10 kW wind turbines, 8.6 kW, 25 kW electrolyser, a fuel cell, and a 40 kg hydrogen tank capacity. The microgrid's capital cost was \$177, 600, with a net present cost of \$206, 323. The system's levelized energy cost was 2.34 $\$(\mathrm{kWh})^{-1}$. The project covers an 8.81 km grid extension. With a distance less than the nearby grid extension of 21.35 km, the renewable energy microgrid system with a hydrogen storing alternative is worthwhile for community health centre [38].

Lamence & Tamayao [39], developed an optimal HRES design and benefits using the estimated energy consumption profile. Additionally, considering that the Philippines' position is relative to the equator, tapping maximally into the solar resources could make a difference. The assessed energy intake profile of the Rural Health Units (RHU) in the Philippines was surveyed and analysed using a works sampling technique. Los Baños, Laguna RHU was considered, and a simulation of diverse energy system structures was performed using Hybrid Optimisation of Multiple Energy Resources (HOMER) Pro. An off-grid and a grid-connected RHU were understudied. The estimated average loadability of the facility was $\sim$ 92 kWh per day. The results proved that a solar PV-grid system is best for the grid-connected setup and can minimise the cost of electricity by about 35%. Furthermore, a solar PV-diesel generator-battery combination is ideal for the off-grid situation decreasing electricity costs by about 61%. Finally, in both scenes, the solar module contributes better to the overall annual energy production and can aid in minimising emissions of greenhouse gas [40].

However, the major drawback of using HRES, such as wind turbines and solar PV systems, is affordability, owing to the expensive starting cost of purchase and installation. Therefore, the system can reduce this by adopting Demand-Side Management (DSM). DSM strategy through an energy management system can be adapted to hit the energy demands of a rural health centre that minimises CO_2 emission and guarantees low-energy costs. DSM is well-defined as energy consumption management optimising accessible and planned power-generating assets. DSM includes all activities that impact load consumption and decreases the electricity demand, which benefits the consumers and the utility. Additionally, DSM techniques offer a range of measures to minimise energy consumption, which leads to manageable demand. Furthermore, it is the traditional method of minimising peak electricity demand so that utilities can delay capacity expansion. It entails planning and implementing utility undertakings designed to encourage the time configuration and/or quantity of electricity demand in methods that will increase consumer fulfilment, yielding anticipated changes in the utility's system load pattern.

DSM is needed to achieve a better operating cost and high efficiency of the HRES [37]. The DSM strategy offers excellent advantages in the performance of HRES by varying the connected system loads at a particular time. DSM can be categorised into:

- ***Strategic conservation***: this is simply an energy conservation method where high-power-consuming electrical appliances are replaced with low-rated appliances with similar functionality. This approach ensures less power consumption and a reduction in load demand. Appliances such as DC lighting, low-wattage lamps, and replacing Cathode Ray Tube (CRT) TV sets with Plasma or Liquide Crystal Display (LCD) are typical strategic conservation which increase the HRES performance.
- ***Peak shifting***: This approach allows the operation of non-priority loads during off-peak periods. The operation of a shiftable peak load is suspended till an off-peak period when the demand is adequately low [37].

2. Methodology/Procedure

2.1. Energy Access Solutions and Demand-Side Management Strategies

The literature abounds with studies investigating the possibility of making energy accessible in rural communities through off-grid. For instance, a hybrid system to include solar PV, a generator, Inverter, and a wind turbine with a backup battery for a particular province in Iran was suggested [21]. Additionally, two-hybrid systems were examined in an Iranian coastal area to determine their efficiency. Additionally, solar and wind energy resources were evaluated by [6], and the best hybrid renewable energy source that can serve the target locations was determined for Nigeria.

The focus of the research for rural healthcare facilities prioritises consideration of operational and net present costs before selecting a hybrid renewable system. However, other system analyses of the health facilities that enhance overcoming of power supply challenges are: (i) accurately account the electrical equipment and determining which one is provided with backup and without backup, (ii) knowing the amount of fuel required for total load usage of the generator, (iii) proper estimation of time to refuel the generator, (iv) accurate load analysis to provide power for a priority load and disconnect the less priority load. Furthermore, a techno-economic analysis indicates that there will be an increase in the solar panels' size and quantity of batteries to balance the load demand when the diesel price rises [21]. Additionally, analysis has shown how sustainable development goals could be accomplished by utilising profound hybrid renewable energy innovations through implementing the DSM strategy. Homer software was utilised to model and evaluate the hybrid system efficiency [21].

Kyriakarakos and Dounis 2020 [41] carried out an investigation on energy impact on the healthcare service in a general hospital and recommend the use of Intelligent Energy Management System (IEMS) to manage other harvested energy potentials for the benefits of healthcare operation. The reliability of DSM in HRES was further demonstrated by a study which evaluated the performance of Low Rating High Cost (LRHC), Medium Rating Medium Cost (MRMC), and High Rating Low-Cost (HRLC) appliances [36,37]. The result shows that LRHC equipment consumes less power than HRLC and MRMC. Furthermore, Li-ion-based HRES (PV/MHP/BT) optimisation analysis under the CD strategy shows an environmental benefit of emission reduction by 63% when DSM is implemented compared to without DSM [4,40]. The impact of DSM in HRES was demonstrated by three case studies [21], first includes PV/Generator/converter/Battery, which generated a total amount of 16, 248, 422 kWh/yr. However, all the load demand is supplied by the generator. In this case, a high amount is spent on fuel, with high associated environmental pollution, because a generator supplies the total load.

Conversely, when the DSM strategy is applied, a lessening of the cost of energy, the net cost of fuel consumption and generator rating, and the emission from the generator set are all decreased. The second case of the hybrid system study involved PV/Generator/Converter/Battery, with a PV size of 588 kW, generator of 5220 kW, and 361 kW of the converter. After the simulation, the diesel generator supplied most of the load, while the PV system produced the remaining power of about 6%. With the application of DSM in the modelling, a reduction of 7.72% occurs in the cost of energy, an improvement in generating capacity of PV from 6% to 9% of the power generated. Case three of the analysis involved wind/PV-Generator-Converter-Battery; the generator size is 5220 kW, PV of 7750 kW, and 3078 kW. The PV system can generate 51% of the total power delivered by the hybrid system, while the diesel generator covers the remaining supply. In this case, the generator produces fewer harmful emissions than in cases 1 and 2. The DSM was also applied to the third case; the COE reduces but increases CO_2 by about 11%. The study finalises that case 3 of the analysis was found to be inexpensive to operate. Consequently, providing electrical power through a hybrid system is affordable and advantageous for healthcare centres when DSM is inculcated at the design stages.

2.2. Social and Economic Sustainability of HRES

The primary barrier to the speedy take-off of HRES solutions is its component's parts high capital cost (CAPEX), especially solar PV systems, compared to small, stand-alone diesel generators. The sharp decline in the price of solar parts over the past decade does not bring a significant reduction in the CAPEX. While the operational cost (OPEX) of an on-site solar system will generally be lower than that of a small generator requiring constant fuel inputs, the CAPEX of a stand-alone generator is much lower [42]. The operational and maintenance cost of the renewable energy system is low, but the installation cost is sometimes expensive. Proper maintenance of a solar PV system, a wind turbine, or a hybrid system enables efficient operation and supply for a more extended period [23]. The financial burden of the system procurement can be limited by leasing the system to the beneficiary. Porcaro et al. in [43] elucidated that not only the Public and Private Health Centre benefits from energy services over time but philanthropic organisations also benefit from the inevitable energy access and affirmed that the health services relied on energy services over time for its delivery. As for the rural community, where the finance might be huge to handle or meet the vendor's requirement, the government can intervene to execute the project as a national development program [42]. Hence, this will help ease the financial burden and improve the community's health, economic, and social life. In providing renewable energy systems available in remote areas in a reliable and cost-efficient manner, the cost per unit of power supply has to be lower. Furthermore, this can be done by increasing the number of consumers; thus, the load demand increases. In addition, connecting commercial establishments in need of power will reduce the burden of financial status [23].

As a form of a long-term sustainable approach, governments should hold dependable, cost-effective, and sufficient access to renewable energy as a base for improving various services such as healthcare resilience and provision of good healthcare services to guarantee fast economic growth. In addition, the government should make policies which incentivize industrial stakeholders with tax waivers; this can apply to industries dealing directly with manufacturing and installing renewable energy systems and devices, including solar panels, wind turbines, and others. Similarly, the government should ensure the provision of energy productivity improvement and utilisation principles and acceptance and improvement of energy-efficient devices and equipment such as energy star equipment and devices, clean cooking technologies and fuels [11]. The improvement in National policies will increase the potential of purchasing the renewable energy system. Furthermore, government intervention in RES importation by enforcing subsidies and reducing or abdicating import duties will ease the installation cost and make the system economical [35,36]. Sustainable penetration of hybrid renewables can also be through the improvement of standalone rural electrification.

The sustainability approach to improving energy access through renewable energy integration has seen countries in the African sub-regions initiate principles and directives that permit private institutions to establish mini-grids. For instance, since 2008, Tanzania's small power production sector has granted electricity production to the private sector, networking and marketing it to the off-grid areas [26]. Similarly, a study in Mozambique identifies small-scale hydropower and solar PV systems in rural areas as sustainable energy access approaches [29]. In addition, since electrification is seen to positively impact education, income, and a reduction in respiratory diseases—hence market share already waiting—sustainability of renewable energy access through reliable improvement is attainable by electrification and SDG-7 as authorising components. Furthermore, advancement in the production and utilisation of renewable and clean energy by developing solar energy lowers the dependence on fossil fuels and reduces deforestation and greenhouse gases.

Furthermore, PV systems are advantageous because of consistent minimisation in produced energy cost per kWh as technology advances [29]. From the case studies mentioned, Nigeria's Rural Electrification Agency (REA) can include Healthcare electrification in the rural and off-grid renewable energy into their plan for a sustainable future [5]. Standard Organisation of Nigeria can also support local developers by preventing the importation of copy solar commodities into Nigeria [5].

Providing sustainable, reliable energy access to rural healthcare facilities can elevate child health and maternal delivery. The installation of the solar PV system is done considering future energy load demand instead of making provision for the present load alone to accommodate additional facilities. This is in line with needs assessment advocacy and national partners [27]. A significant concern in solar PV systems' sustainability is the drawback presented by their battery system, which stores energy for later use. The battery usage lasts 3–5 years, after which replacement is needed, and it is the most expensive part of the PV system. In addition, chemicals in the batteries of the PV system need to be appropriately handled to prevent liable hazards [29]. However, combining PV systems and small-scale hydropower for electrification yields environmental, health, and safety advancements. The effect of spoilt batteries and other parts on the environment is unfriendly. An enlightenment campaign on the positive contribution of renewable energy to rural healthcare services is a necessary tool to ensure sustainability.

The deployment of renewable energy is associated with high initial cost, whereas proper finance of the system is a challenge that stops many from using the system [44]. To sustainably solve the problem of financing renewable energy projects, self-ownership or third-party ownership can be adopted. Self-ownership can be financed by individuals owning the system either through lending or internally generated. The latter method requires an agreement where the user will pay a certain amount based on the purchasing agreement between the parties involved. Public, private, and non-governmental organisations (NGOs) should affirm the relation to strengthening the sustainability of electrifying healthcare facilities. A decentralised energy solution, energy-efficient medical equipment, and digital technology provided in a rural healthcare centre will expedite accessibility to standard medical administration, reducing travel and medical attention costs [26]. For instance, for reliable, clean, and cheap healthcare facilities energy worldwide, the Alliance for Rural Electrification (ARE) joined hands with the Decentralised Renewable Energy (DRE) sector to immediately execute the project. In ARE's opinion, there is the feasibility of making electricity accessible to thousands of healthcare facilities in a few months with the combined forces of government, international funding partners, and philanthropies [45]. Renewable energy can serve sustainably and feasible economically if government intervention and support include market conditions and the accessibility of natural resources [44].

Table 1 shows the result of investment on energy sector in healthcare facility through Energy chain framework [42]. The analysis identified the key sensitive parameters that depends on energy status, which consequently affect the healthcare services. Some of these parameters include energy sector projects and programs, energy investments at healthcare facilities, energy and health sector policies, and capacity-building on energy aspects. Adequate funding and management of these energy sections in healthcare facilities, directly improve the functionality of almost all sections of the healthcare facilities.

Table 1. Energy chain framework for Healthcare Centre.

INPUT: Increased financing for energy interventions, including: (a) Energy sector projects and programs (b) Energy investments at healthcare facilities (c) Energy and health sector policies (d) Capacity-building on energy aspects (e) Investments in energy systems and efficient buildings (f) Health-care facility energy costs and emissions (g) Tracking supportive policies	**IMPACT OF FINANCING RENEWABLE SOLUTIONS**
OUTPUT: Enhanced elements of energy supply ecosystem (a) Assets for on-grid and off -grid energy production and supply (b) Back-up energy storage/generation (c) Capacity to operate, maintain, repair, and replace energy equipment (d) Availability of grid or off -grid power connection (e) Expansion of energy generation, transmission, and distribution, as well as management capacities of the energy supply utility (f) Availability of back-up generator energy storage	**ENHANCED ENERGY PERFORMANCE**
INTERMEDIATE OUTCOME: Healthcare facility access to modern energy services for electricity and thermal requirements. (a) Increased capacity, availability, reliability, quality, affordability, operational, sustainability, convenience and health and safety of energy supply (b) Increased compatibility of energy supply with medical-use requirements (c) Availability of stand-alone medical devices with built-in energy supply (d) Capacity and duration of energy supply (e) Electricity quality (voltage and stability) (f) Affordability and sustainability of energy supply (g) Convenience, health, and safety aspects of energy (h) Multi-tiered metric/index of access to energy	**ENERGY ACCESS**

The electrification of rural healthcare facilities should be carried out quickly and be able to serve sustainably for a more extended period. As identified by ARE, the aim of a short period of project delivery and long lifespan of the renewable energy system is achievable by public-private-partnership delivery form, which comprises smart grants and a market-oriented remuneration medium. The innovative grant enables quick project delivery by providing financial support from private investors with additional measures from banks or institutional lenders. The market-oriented scheme allows the continuous operator management of the system to ascertain a long-life span and reliability supply. ARE suggested that government should encourage public-private partnership by implementing a power purchasing agreement scheme PPA to electrify priority healthcare facilities and outlining policy for the operators to follow technical requirements to sustainably execute the project [46].

The National Primary Care Development Board, a subsidiary of the Federal Ministry of Health of Nigeria, and other sub-national primary healthcare development boards have proclaimed the intention to create a 24 h operation of PHC [5]. Hence, there must be an unceasing power supply for this to happen, and therefore it is necessary for the allocated budget to the sector to be increased to provide quality off-grid renewable energy for better operation of the already existing healthcare facilities instead of constructing new ones [5]. The sustainability plans for healthcare facilities should often consider operating funds in the budget. The budget should include electricity services and maintenance funds such as battery replacement [26]. Implementing market-oriented techniques has proven sustainable for ensuring financial and technical sustainability. General finance of the project and regular technical service (i.e., operation and maintenance) of the RE system is an opposition factor encountered in sustaining electricity supply in the rural healthcare facility due to poor budget allocations for the healthcare electrification operation. Therefore, the system needs continuous finance, including replacing the faulty parts [46]. This problem can be solved by acknowledging the market-based remuneration technique and employing a long-term public–private agreement between the government agent (Ministry of Health) in charge of the project and the project contractor. In that case, the payment for electric power consumed by the healthcare facility will be taken care of by the ministry. Eventually, the operator will achieve a premium for operating the system and maintain the excellent performance of the system. More so, technical maintenance of the system can be sustained by equipping the installation with digital control devices; this will make the operation and maintenance swifter. The company have access to the system remotely and give directive to the local technical staff. With this, appropriate monitoring will be achieved, and the system's longevity will be increased [46]. Governments, international funding partners, and philanthropies should make the qualification for the project based on the quality of the competitors' proposals, as this will raise the quality of the project and improve sustainability.

Furthermore, communities' involvement is essential throughout the system installation and operations to maintain the renewable energy system for the healthcare facilities over a more extended period. Communities' involvement will reduce or prevent vandalism acts or theft of the system. In addition, the project's prosperity can also be achieved by teaching the local technical employees how to run and sustain the system. Besides this, power projects for rural health facilities can be projected to serve the surrounding local entrepreneurs that depend on electricity for productivity. Additionally, this will aid the economic sustainability of the project and the community's development and benefit the investors. Consequently, the investment will expand rather than intended in serving only rural healthcare facilities.

In ensuring economic sustainability, rural communities should not, in any condition, bear the financial burden of the installation; they can, however, contribute by getting the site ready for the system installation. Proper planning of the best renewable energy system that fits an area must be critically done. Whether wind, solar, or wind/solar/DG hybrid system with battery storage is viable for the concerned area by seeing the renewable energy resources availability, the level of energy demand and the topographical status of the location are essential sustainability considerations [23]. A condition of 1–2 years of operation and maintenance with a training agreement between the contractor and the government communities or agency in charge of the project adds to the social sustainability status. Moreover, this will enable proper system monitoring under responsible personnel, ensuring sound recording, periodic maintenance, and proper system operation during the training [23]. A meaningful way to relieve the financial burden of the installation cost of the renewable energy system is adequate government policy regulating the marketing of RES, ensuring that the company makes product guarantees available. Funding support from an international or local institution helps communities sustainably finance RES projects [36].

Multilateral Energy Compact for Health Facility Electrification is aimed at powering 25,000 healthcare-facilities with clean and affordable energy [47]. This involved key stakeholders such as national government and global community with responsibility to consider clean cooking and access to electricity in healthcare facilities essential to protect public health and mitigate climate change; dramatically increase public and private investments in electrifying healthcare facilities and in clean cooking, taking into consideration their crucial role to achieve universal health coverage and ensure healthier populations. These also include provision of necessary human and financial resources to design and implement clean energy plans and sustainable delivery models tailored to the needs of the health sector [47].

Table 2 gives a comparative overview of the presented RE solutions including the HRS and DSM solutions. Some selected key indicators were used to systematically outline their comparative advantages.

2.3. Modelling Tools for Hybrid Energy Access Solutions

In achieving energy access, rural electrification planning is achieved through different approaches. Several models were built to evaluate energy and electricity access challenges based on short-term through long-term energy system design and operations. The variety of energy models comprises supply, demand, energy planning, forecasting, emission reduction, renewable energy, optimisation, and emerging modelling techniques that are based on artificial intelligence [48]. In 2013, International Energy Agency issued a comprehensive report on energy models, circumstances, and assumptions [49]. They were inspired by the need to find better solutions to the issues of the unevenness of renewable energy sources integration and the decarbonisation drive. The drive led to recent years witnessing a high number of model development, including new models and modelling features that are classified as commercial, open source, or free models. The model categorisation presented by Ringkjob's team [48] was structured following the overarching typology given by Després' team [50]. Finally, the solutions achieved were categorised as the general logic, the spatiotemporal resolve, and the models' economic and technological parameters.

Table 3 provides an overview of some selected modelling tools related to energy access and modelling. For each tool, the features such as purpose, software type, method or solver, modelling horizon, and availability were also outlined when possible. A careful assessment of the various features of each model provided in Table 1 offers an easy means of identifying and choosing a model that can give perceptions to the precise research question, adequately model the procedures with a spatiotemporal resolve, and hold the required economic and technological properties.

Table 2. Comparative overview of RE solutions in rural healthcare centres.

RE Solutions	Modularity & Scalability	Application Services	Deployment Area	Operations & Maintenance Cost	CO_2 & Emission?	Seasonal Output?	Backup Available?	Technical Maintenance	Safety & Environ.	Investment Cost/Capital
Natural and Renewable resources[8,14,21,25,33].	Y	All	U, R	Medium/High	N	Y—Solar, Wind & Hydro	Y	Scheduled & Periodical	H-SL	Medium & High
Off-grid Installations [26,37]	Y	All	R	Medium	Y/N	Y—Solar, Wind & Hydro	Y	Minimal & Periodical	M-SL	Medium & High
Fossil Fuel-based [26]	Y	All	U, R	High	Y	N	N	Scheduled & Periodical	L-SL	Medium
Solar PV with or without Storage, [12,27,34]	Y	All, may exclude HC.	U, R	Low	N	Y	Y	Minimal & Periodical	H-SL	High
Solar PV Home Systems [23]	Y	Exclude HC	U, R	Low	N	Y	Y	Minimal & Periodical	H-SL	High
Lithium-ion batteries & Other Storage. [23]	Y	Exclude HC	U, R	Low	N	N	–	Minimal & Periodical	M-SL	Medium & High
Hybrid storage units. [23]	Y	Exclude HC	U, R	Low	N	N	–	Minimal & Periodical	M-SL	Medium & High
Wind Turbine. [34]	Y	All	R	Low	N	Y	N	Scheduled & Periodical	M-SL	Medium
Mini-grids. [3,11,26].	N	All	U, R	Medium	Y—fossil fuel based	Y—Night hours	Y/N	Scheduled & Periodical	M-SL	Medium & High
Small & Micro Hydro. [29]	Y	All	R	Medium/High	N	Y—Low water heads	N	Scheduled & Periodical	M-SL	Medium & High
Hybrid RE & Fossil Fuel Systems. [15,26,37,38,48,49]	Y	All	U, R	Medium/High	Y—Minimal	Y	Y	Minimal & Periodical	M-SL	High
Hybrid Solar PV/Wind/DG/Battery and Wind (HRES). [2,21,36,40,49]	Y	All	U, R	Medium/High	N	Y	Y	Minimal & Periodical	M-SL	High
Microgrids- Solar PV and Battery storage. [11,15,37].	Y	All, may exclude HC.	U, R	Low	N	Y	Y	Minimal & Periodical	H-SL	High
Demand Side Management (DSM). [36,40]	–	All	U, R	–	–	–	–	–	H-SL	Low
HRES & DSM [36,40]	Y	All	U, R	Medium/High	Y—Minimal	Y	Y	Minimal & Periodical	M-SL	Low & Medium

Generic Keys: Y = Yes, N = No. **Applications Services:** Clean Water (CW), Healthcare (HC), Internet Connectivity (IC), Education & Teaching (ET), Lighting & Illumination (IL), Medical Equipment (ME), and Heating & Cooling (HC). **Deployment Area:** Urban (U), Rural (R). **Technical Maintenance:** Periodically (P), Scheduled (S). **Safety & Environment Level:** High SL (H-SL), Medium SL (M-SL), Low SL (L-SL).

Table 3. Review of some selected energy modelling tools [48].

S/N	Model	Full Name	Purpose	Developer	Available	Software Type	Method/ Solver	Temporal Resolution	Modelling Horizon
1	COMPETES	Comprehensive Market Power in Electricity Transmission and Energy Simulator	I & ODDS	Energy Research Centre of the Netherlands	Only ECA and Partners	AIMMS/GUROBI	Simulation	Hourly	User Define
2	COMPOSE	Compare Options for Sustainable Energy	ODS & S	Morten Blarke, ENER-GIANAL-YSE.DK	AC	Standalone, CPLEX or GUROBI	MAP	User Define	User Define
3	DER-CAM	Distributed Energy Resources Customer Adoption Model	I & ODDS	Lawrence Berkeley National Laboratory	F	Online:-None Licensed:-GAMS	MAP	Minutes & Hourly	$\leq$ 20 yrs
4	DESSTinEE	Demand for Energy Services, Supply and Transmission in Europe	S, I & ODDS	Imperial College London—Iain Staffell, Richard Green	OS	VBA/Excel	Simulation	Hourly	2050
5	DIETER	Dispatch and Investment Evaluation Tool with Endogenous Renewables	I & ODDS	DIW Berlin—Alexander Zerrahn & Wolf-Peter Schill	OS	Solver + GAMS	LP	Hourly	1 yr
6	EMLab-Generation	Energy Modelling Laboratory—Generation	IDS	TU Delft—Richstein, Chappin, Bhagwat & de Vries	OS	Maven JAVA	ABS	Yearly	2050
7	EMPIRE	European Model for Power system Investment with Renewable Energy	IDS	NTNU—Christian Skar et al.	UN	Xpress-Mosel	LP	User Define	40–50 yrs
8	EnergyPlan	Sustainable Energy Planning Research Group	S, DIS	Aalborg University	F	Standalone	Simulation	Hourly	1 yr

Table 3. *Cont.*

S/N	Model	Full Name	Purpose	Developer	Available	Software Type	Method/ Solver	Temporal Resolution	Modelling Horizon
9	energyPro	energyPro	I & ODDS	EMD International A/S	C	Standalone	AO	Minutes	40 yrs Max
10	ITEM	Energy Transition Model	S	Quintel Intelligence	OS	Online tool	Simulation	15 min, hr & yr	2050
11	GEM-E3	General Equilibrium Model for Economy-Energy-Environment	S	European Commission Funded Multinational Collaboration		GAMS (Solved with PATH)	CGI	5 yrs	2030 & 2050
12	GENESYS	Genetic Optimisation of a European Energy Supply System	IDS	RWTH-Aachen University—Alvarez, Bussar, Cai, Chen, Moraes, etc.	OS	Stand-alone	CMA-ES & HO	Hourly	2050
13	GridLAB-D		PSAT	US Department of Energy	OS	Standalone	ABS	Seconds	3–5 yrs
14	HOMER	Hybrid Optimisation of Multiple Energy Resources	I & ODDS	NREL—Peter Lilienthal	C	Standalone	Simulation	Minutes	Multi-year
15	HYPERSIM		PSAT	Opal-RT	C	Stand-alone	Simulation	10 micr sec	User Define
16	iHOGA	Improved Hybrid Optimisation by Genetic Algorithms	I & ODDS	Dr. Rodolfo Dufo-López—University of Zaragoza	ED	Standalone	HO	Hourly	Yearly
17	LEAP	Long-range Energy Alternatives Planning	S	Stockholm Environment Institute		AS	Simulation & LP	Yearly	20–30 Yrs

Table 3. *Cont.*

S/N	Model	Full Name	Purpose	Developer	Available	Software Type	Method/ Solver	Temporal Resolution	Modelling Horizon
18	LIBEMOD	Liberalisation MODel for the European Energy Markets	S	Frisch Centre & the Research Department at Statistics Norway		GAMS	ECE	Yearly	1–2-yrs
19	MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact	S, IDS	IIASA	UR	GAMS & ORACLE	LP	User Define	50–100 yrs
20	NEMS	National Energy Modelling System	S	US Energy Information Administration (EIA)	Free & Commercial Veriosn		Simulation	Yearly	2050
21	Remove (SOLPH)	Open Energy Modelling Framework	S, I & ODDS	Remove developing group (Reiner Lemoine Institut/ZNES Flensburg/OVGU)	OS	Solver + Python	LP, MIP	Sec to yrs	User Define
22	OSeMOSYS	The Open Source Energy Modelling System	IDS	KTH—Howells et al.	OS	GNU MathProg	LP	User Define	User Define
23	PLEXUS	PLEXOS Integrated Energy Model	I & ODS, S,	Energy Exemplar—Glenn Drayton	C	Standalone		User Define	User Define
24	POLES	Prospective Outlook on Long-term Energy Systems	S, I & ODDS	CNRS (GAEL Energy), Enerdata, JRC-IPTS			Simulations	Yearly	2050

Table 3. *Cont.*

S/N	Model	Full Name	Purpose	Developer	Available	Software Type	Method/ Solver	Temporal Resolution	Modelling Horizon
25	RAPSim	Renewable Alternative Power systems Simulation	PSAT	NES, AUU—Pöchacker, Khatib, Elmenreich et al.	OS	Standalone	Simulations	Minutes	Multi days
26	ReEDS	Regional Energy Deployment System	S (& IDS)	NREL		GAMS (Excel & R)	LP	2 yr period	2050
27	REMix	Renewable Energy Mix	I & ODS	DLR		GAMS	LP	Hourly	2 yrs
28	renpass	Renewable Energy Pathways Simulation System	ODS, S	Frauke Wiese & Gesine Bökenkamp	OS	MySQL, R, RMySQL	Simulations	Hourly	1 yr
29	RETScreen	The RETSCreen Clean Energy Project Analysis Software	IDS, S	Natural Resources Canada	F	Windows with .NET	Simulation	Year/Month/Day	100 yrs
30	SIREN	Sustainable Energy Now Integrated Renewable Energy Network	S	Sustainable Energy Now Inc.—Angus King	OS	Standalone	Simulation	Hourly	1 yr
31	SWITCH	Solar, Wind, Transmission, Conventional Generation & Hydroelectricity	I & Odds	Fripp, Johnston & Maluenda	OS	Python	Map	Hourly	User Define
32	Temora	Tools For Energy Model Optimisation & Analysis	S	NC State University—K. Hunter et al.	OS	Solver + Python	LP	Yearly	User Define
33	WEM	World Energy Model	S	International Energy Agency		others + Vensim	Simulations	Yearly	2040

Note: AC= Free Academic Version, OS = Open Source, F = Free, UN = Unknown, C = Commercial, ED = For Educational Purpose, UR = Upon Request I & ODS = Investment & Operation Support, S = Scenario, MIP = Mix Integer Programming, LP = Linear Prgramming, ABS = Agent Based Simulation, CGE = Computable General Equilibrium, CMA-ES—Covariance Matrix Adaptation Evolution Strategy, HO—Heuristic Optimisation, PSAT = Power Systems Analysis, ECE = Economic Computable Equilibrium.

There are free or commercial tools associated with electricity provision. Electrification projects can be verified in detail before execution by modelling using HOMER energy software, GEOSIM, and Network Planner [14,51]. Hybrid Optimisation of Multiple Electric Renewable Energy, National Renewable Energy Laboratory (NREL) in the United States developed HOMER [48]. This software is purposely innovated to design and proportion HRES that will suffice for the demand load [52]. The first step in designing an electrification plan is comprehending the consumers' profile and recognising the prospective site(s) and local assets [23]. Planning and decision-makers using HOMER assessed the techno-economic success and design of renewable energy systems before implementation. An analysis of HRES using HOMER determines that the Solar PV-Diesel Generator-Battery arrangement offers the most acceptable cost and diminishes emissions of harmful substances [37]. Thus, it demonstrated that optimising HRES, cost-efficient and adequate energy could be obtained in a standalone area. Similarly, a study of Hybrid renewable energy formation of micro-hydro power, wind, and solar is reinforced with DG to provide power in case the renewable sources fail to meet the demand. The HRES also provides a battery for energy storage for later consumption, which provides an Uninterruptible Power Supply (UPS), thereby supplying a crucial load for a short period if there is a temporary outage.

In a case study of northern Nigeria, [2] used the HOMER for techno-economic ability examination of the wind, diesel generator, solar PV, and battery energy mix system to power a faraway rural health centre. Contrary to other setup systems, the PV-DG-battery hybrid energy systems with 5.43 kW of PV, 2 kW of DG, 3.06 kW of power converter, and ten battery units appeared as the most acceptable and best desirable system, using a present net cost of $16,457 and a cost of energy of $0.259/kWh. This solution would profit the general environment, as it can produce tolerable carbon emissions of 1304 kg/year, which is 80% and 82.5% less than the system case studies with 3-DG/battery and 5-DG/battery, respectively. Furthermore, the study discloses that operational costs, renewable portion, fuel costs, and fuel consumption are all sensitive to changes in the sensitivity factors [21].

In [53], researchers looked at the techno-economics of three different hybrid energy systems for health centres. The HOMER software was used to weigh the possibility of using renewable energy to make available to the clinic a long-term energy supply. The clinic's existing unrealisable energy source comes from the national grid, which is insufficient for its operational hours, necessitating a more reliable and consistent supply. The modification in whole electricity demand in health centres throughout the COVID-19 pandemic lockdown was analysed and optimised using data obtained from the health centre and HOMER. According to the finding, the PV-battery-hybrid-energy system is associated with a lesser net present cost than the PV-Generator set-Battery hybrid-energy system; however, it is more expensive than a solo generator set. While it is likened to the other two hybrid energy alternatives, the generator set alone produces the maximum carbon emissions, ruling it out as a feasible option for providing electricity to the health centres. The findings of this analysis provide a premise for stakeholders and designers to optimise hybrid energy systems that cost-effectively fulfil the energy requirements of health clinics, particularly during this epidemic [53].

A study by [21] shows how healthcare sectors are under enormous strain due to the COVID-19 emergency. The increase in energy demand led to a growth in energy demand and emissions. As a result, implementing hybrid stone-alone systems based on renewable energy plays a critical part in optimising rising energy demand. This study focuses on the hospital load power management utilising HOMER Pro to create an initial model, with PV/Converter/Wind/Battery/Generator as the proposed configuration. The proposed system's levelized cost was discovered to be $0.4688. The levelized cost of energy (LCOE) of this system is 35% less than that of a solar household system. The optimised system's repayment period, return on investment, and internal rate of return is seven years, 10%, and 13%, respectively [21].

Vishnupriyan and Manoharan [54] suggested an integrated techno-economic feasibility valuation and energy management investigation of a hybrid renewable energy system to attain the requirements of non-electrified village hamlets in Tamil Nadu. Hybrid renewable energy system possibility, size optimisation [45], cost, and sensitivity evaluations were done to attain the specified area's electrical energy necessities. Additionally, a mixture of DSM and optimum tilt solar panel technique using HOMER Energy simulation was investigated. The system's optimisation outcomes were presented and contrasted with and without the DSM strategy. Also, the work by [55] showed the contribution in energy savings and expenditure that DSM can offer to grid-connected smart microgrids through the use of distributed optimisation algorithm. More so, sensitivity analysis was also performed on the variation of load, biomass, and diesel pricing to determine the most practical consideration of the system. Compared to the existing PV-DG-Battery hybrid renewable energy system, the modelling results reveal how the recommended hybrid renewable energy system design can increase the renewable proportion and provide more employment prospects for residents [54].

3. Conclusions and Policy Directions

Several rural healthcare facilities in Sub-Saharan Africa cannot satisfactorily deliver their services due to the inaccessibility of electricity. Healthcare facility necessities, such as lighting, medical equipment, and heating, remained skeletal due to unreliable energy supply. Hence, proper medical diagnosis and treatment have been deprived. This has broadened the economic and infrastructural developmental gap, exacerbated poverty, and made it more challenging to promote the living standard in rural areas. This paper reviewed solutions to improve energy access in rural healthcare facilities to address this deficit. Additionally, the diverse approaches and their corresponding effects on energy mix solutions to the healthcare centres were analysed. The following measures and policy directions are consequently deduced from the presented reviews.

- Initially, electrification is identified as a primary factor in improving the standard of healthcare administration in Sub-Saharan Africa and attracting healthcare personnel into rural areas for quality services.
- Available natural and renewable resources were identified as optimal approaches to powering rural healthcare centres. The deployment of mini-grids powered primarily by renewable energy sources and associated technologies is a solution to energy accessibility for healthcare facilities in rural or urban areas with low power supply.
- Small-scale hydropower via mini-grid or off-grid is an energy provision solution in rural areas, which possess the potential to serve healthcare facilities and provide nearby communities with sustainable energy. However, the small-scale hydropower may require modification to suit the local situation and grid size. Thus, higher and more reliable energy access in rural healthcare centres can be achieved through Hybrid Renewable Energy Sources (HRES) microsystems, such as Microgrids incorporated with solar panels and battery storage.
- Providing backup with solar panels and battery storage systems to healthcare facilities and households in urban or rural areas is considered a better, cost-effective, and operationally less-burden alternative than small-scale hydropower. Furthermore, the HRES can be aided by implementing intelligent devices developed from artificial intelligence and internet of things technologies; this allows for combining solar and wind in energy production.
- Technical maintenance of renewable energy microsystems is a necessary procedure to avoid breakdown. Therefore, as a policy measure, the benefitting communities should carry out preventive and corrective maintenance of the system. This approach ensures ownership and responsibility; the preliminary instruction given to the user will help them perform elementary maintenance, such as periodically adding distilled water to the battery.
- Since the local council, which owned the rural healthcare centre, has an insufficient budgetary allocation for the maintenance of HRES, providing funding through public-private-partnership to maintain HRES is a sure approach to prevent the early break-

down of the system. Additionally, the course of installation, training, and enlightenment of the healthcare staff on the usage and maintenance of the HRES can reduce the maintenance cost of the system. One critical component of the HRES is using an energy storage device. The storage system enhances the utilisation of the renewable energy system, reduces the need for a generator set and reduces fuel consumption.

- The adoption of DSM strategies in the HRES deployment in rural healthcare facilities is seen to lessen the start-up cost of installation and improve efficiency. In addition, DSM strategy through an energy management system can be adapted to meet the energy needs of a rural health care centre by minimising carbon emissions and guaranteeing low-cost energy.
- The financial burden of the HRES–DSM system procurement can be limited by leasing the system to the beneficiary. Alternatively, the project can be contracted out to the system operator for continuous energy system operation. As for the rural community, where the finance might be huge to handle or meet the vendor's requirement, the government can intervene to execute the project as a national development program.
- Lastly, in improving energy access, rural electrification planning is achieved through modelling tools related to energy access modelling. A careful assessment of the features of various tools offers an easy means of identifying and choosing a tool that can give perceptions of the particular research question, adequately model the processes, and retain the indispensable technological and economic properties.

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Nomenclature

HRES	Hybrid Renewable Energy Sources
DSM	Demand Side Management
SDG	Sustainable Development Goal
ECE	Economic Computable Equilibrium
PHCs	Primary Health Centres
WHO	World Health Organisation
HRES	Renewable Energy System
PV	Photo Voltaic
UN	United Nation
AC	Alternating Current
DC	Direct Current
DG	Distributed Generation
CO_2	Carbon dioxide
RHU	Rural Health Units
PSAT	Power Systems Analysis
HO	Heuristic Optimisation

CGE	Computable General Equilibrium
LP	Linear Programming
CRT	TV Cathode Ray Tube Television
LCD	Liquid Crystal Display
LRHC	Low Rating High Cost
MRMC	Medium Rating Medium Cost
HRLC	High Rating Low-Cost
kW	KiloWatt
NGOs	Non Governmental Organisations
ARE	Alliance for Rural Electrification
DRE	Decentralised Renewable Energy
PPA	Power Purchasing Agreement
RE	Renewable Energy
RES	Renewable Energy System
UPS	Uninterruptible Power Supply
LCOE	Levelized cost of energy: LCOE
COVID-19	Corona Virus
I & ODS	Investment & Operation Support
MIP	Mix Integer Programming
ABS	Agent Based Simulation
HOMER	Hybrid Optimisation of Multiple Electric Renewable Energy
CMA-ES	Covariance Matrix Adaptation Evolution Strategy
TETFund	Tertiary Education Trust Fund, Nigeria
NPHCDA	National Primary Health Care Development Agency
NREL	National Renewable Energy Laboratory
REA	Rural Electrification Agency

References

1. Franco, A.; Shaker, M.; Kalubi, D.; Hostettler, S. A review of sustainable energy access and technologies for healthcare facilities in the Global South. *Sustain. Energy Technol. Assess.* **2017**, *22*, 92–105. [CrossRef]
2. Oladigbolu, J.O.; Al-Turki, Y.A.; Olatomiwa, L. Comparative study and sensitivity analysis of a standalone hybrid energy system for electrification of rural healthcare facility in Nigeria. *Alex. Eng. J.* **2021**, *60*, 5547–5565. [CrossRef]
3. Adair-Rohani, H.; Zukor, K.; Bonjour, S.; Wilburn, S.; Kuesel, A.C.; Hebert, R.; Fletcher, E.R. Limited electricity access in health facilities of sub-Saharan Africa: A systematic review of data on electricity access, sources, and reliability. *Glob. Health Sci. Pract.* **2013**, *1*, 249–261. [CrossRef]
4. Akinyele, D.O.; Rayudu, R.K. Community-based hybrid electricity supply system: A practical and comparative approach. *Appl. Energy* **2016**, *171*, 608–628. [CrossRef]
5. Ikenna, D.; Salman, T.; Okoye, T.T. Improving Access to Clean Reliable Energy for Primary Health Care Centres in Nigeria: Situation Analysis of PHCs in the Federal Capital Territory. In *Heinrich Boell Stiftung Nigeria*; Heinrich Boell Stiftung Nigeria: Abuja, Nigeria, 2018.
6. Olatomiwa, L.; Blanchard, R.E.; Mekhilef, S.; Akinyele, D. Hybrid renewable energy supply for rural healthcare facilities: An approach to quality healthcare delivery. *Sustain. Energy Technol. Assess.* **2018**, *30*, 121–138. [CrossRef]
7. Akinyele, D.O.; Nair, N.K.C.; Rayudu, R.K.; Chakrabarti, B. Decentralised energy generation for end-use applications: Economic, social and environmental benefits assessment. In Proceedings of the IEEE Innovative Smart Grid Technologies Asia (ISGT ASIA), Kuala Lumpur, Malaysia, 20–23 May 2014; pp. 84–89.
8. Energypedia. Access to Modern Energy and the Impact on Health. 2018. Available online: https://energypedia.info/wiki/Access_to_modern_energy_and_the_impact_on_health (accessed on 23 June 2022).
9. Uzoma, C.C.; Amadi, K.C. Energy access: A key to rural development in Nigeria. *J. Soc. Sci.* **2019**, *5*, 452–456.
10. Welland, A. *Electrification of Health Clinics in Rural Areas: Challenges and Opportunities*; CMEDT-Smart Villages Initiative, c/o Trinity College: Cambridge, UK, 2017.
11. Aemro, Y.B.; Moura, P.; De Almeida, A.T. Energy access during and post-COVID-19 pandemic in sub-Saharan countries: The case of Ethiopia. In *Environment, Development and Sustainability*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 1–22.
12. Chen, Y.J.; Chindarkar, N.; Xiao, Y. Effect of reliable electricity on health facilities, health information, and child and maternal health services utilisation: Evidence from rural Gujarat, India. *J. Health Popul. Nutr.* **2019**, *38*, 1–16. [CrossRef]
13. Kaygusuz, K. Energy services and energy poverty for sustainable rural development. *Renew. Sustain. Energy Rev.* **2011**, *15*, 936–947. [CrossRef]
14. Rabetanetiarimanana, J.C.I.; Radanielina, M.H.; Rakotondramiarana, H.T. PV-Hybrid Off-Grid and Mini-Grid Systems for Rural Electrification in Sub-Saharan Africa. *Smart Grid Renew. Energy* **2018**, *9*, 171. [CrossRef]

15. Babatunde, O.M.; Adedoja, O.S.; Babatunde, D.E.; Denwigwe, I.H. Off-grid hybrid renewable energy system for rural healthcare centers: A case study in Nigeria. *Energy Sci. Eng.* **2019**, *7*, 676–693. [CrossRef]
16. Kolhe, M.L.; Ranaweera, K.I.U.; Gunawardana, A.S. Techno-economic sizing of off-grid hybrid renewable energy system for rural electrification in Sri Lanka. *Sustain. Energy Technol. Assess.* **2015**, *11*, 53–64. [CrossRef]
17. Moner-Girona, M.; Kakoulaki, G.; Falchetta, G.; Weiss, D.J.; Taylor, N. Achieving universal electrification of rural healthcare facilities in sub-Saharan Africa with decentralised renewable energy technologies. *Joule* **2021**, *5*, 2687–2714. [CrossRef]
18. Akinyele, D.O.; Rayudu, R.K. Strategy for developing energy systems for remote communities: Insights to best practices and sustainability. *Sustain. Energy Technol. Assess.* **2016**, *16*, 106–127. [CrossRef]
19. Ohunakin, O.S.; Adaramola, M.S.; Oyewola, O.M.; Fagbenle, R.O. Solar energy applications and development in Nigeria: Drivers and barriers. *Renew. Sustain. Energy Rev.* **2014**, *32*, 294–301. [CrossRef]
20. Olatomiwa, L.; Mekhilef, S.; Huda, A.S.N.; Ohunakin, O.S. Economic evaluation of hybrid energy systems for rural electrification in six geopolitical zones of Nigeria. *Renew. Energy* **2015**, *83*, 435–446. [CrossRef]
21. Chowdhury, T.; Chowdhury, H.; Hasan, S.; Rahman, M.S.; Bhuiya, M.; Chowdhury, P. Design of a standalone energy hybrid system for a makeshift health care center: A case study. *J. Build. Eng.* **2021**, *40*, 102346. [CrossRef]
22. Akinyele, D.; Rayudu, R.; Blanchard, R.E. *Sustainable Microgrids for Energy-Poor Communities: A Spotlight on the Planning Dimensions*; IEEE: Piscataway, NJ, USA, 2016.
23. Asian Development Bank. *Improving Lives of Rural Communities Through Developing Small Hybrid Renewable Energy Systems*; Asian Development Bank: Mandaluyong, Philippines, 2017.
24. Olatomiwa, L.; Mekhilef, S.; Ohunakin, O.S. Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. *Sustain. Energy Technol. Assess.* **2016**, *13*, 1–12. [CrossRef]
25. Ighravwe, D.E.; Babatunde, M.O. Determination of a suitable renewable energy source for mini-grid business: A risk-based multicriteria approach. *J. Renew. Energy* **2018**, *2018*, 2163262. [CrossRef]
26. Irena, R.E.S. *Renewable Energy Target Setting*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2015.
27. Javadi, D.; Ssempebwa, J.; Isunju, J.B.; Yevoo, L.; Amu, A.; Nabiwemba, E.; Severi, L. Implementation research on sustainable electrification of rural primary care facilities in Ghana and Uganda. *Health Policy Plan.* **2020**, *35*, 124–136. [CrossRef]
28. Olatomiwa, L. Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities. *Energy Rep.* **2016**, *2*, 141–146. [CrossRef]
29. Uamusse, M.M.; Tussupova, K.; Persson, K.M.; Bengtsson, L.; Berndtsson, R.; Zobaa, A. Access to sustainable electrification: Possibilities for rural Mozambique. *Cogent Eng.* **2020**, *7*, 1765688. [CrossRef]
30. Dávalos, A.; De Jesús Gil Herrera, R.; Colmenares, R.F.A. Comprehensive solution approach to the sustainability problem of photovoltaic systems: The Bolivian case. *Cogent Eng.* **2019**, *6*, 1691314. [CrossRef]
31. Maggio, G.; Squadrito, G.; Nicita, A. Hydrogen and medical oxygen by renewable energy based electrolysis: A green and economically viable route. *Appl. Energy* **2022**, *306*, 117993. [CrossRef]
32. Olsen, K.; Jimenez, A. *Renewable Energy for Rural Health Clinics*; National Renewable Energy Laboratory Publishing: Golden, CO, USA, 1998.
33. Akinyele, D.; Olatomiwa, L.; Ighravwe, D.E.; Babatunde, M.O.; Monyei, C.; Aikhuele, D. Optimal planning and electricity sharing strategy of hybrid energy system for remote communities in Nigeria. *Sci. Afr.* **2020**, *10*, e00589. [CrossRef]
34. Salisu, S.; Mustafa, M.W.; Olatomiwa, L.; Mohammed, O.O. Assessment of technical and economic feasibility for a hybrid PV-wind-diesel-battery energy system in a remote community of north-central Nigeria. *Alex. Eng. J.* **2019**, *58*, 1103–1118. [CrossRef]
35. Pittalis, M.; Kyriakarakos, G.; Moner-Girona, M. The role of photovoltaics in Clean Energy Access Business Models for Social Infrastructure in Sub-Saharan Africa—Existing Models and Emerging Trends. In *Encyclopedia of Sustainability Science and Technology Second Edition*; Springer: Berlin/Heidelberg, Germany, 2021.
36. Watson, J.; Johnson, O. Renewable Energy Technologies for Rural Development. 2010. Available online: https://policycommons.net/artifacts/100912/renewable-energy-technologies-for-rural-development/ (accessed on 23 June 2022).
37. Ramesh, M.; Saini, R.P. Demand Side Management based techno-economic performance analysis for a standalone hybrid renewable energy system of India. *Energy Sources Part A Recovery Util. Environ. Eff.* **2021**, *43*, 1–29. [CrossRef]
38. Ayodele, T.R.; Mosetlhe, T.C.; Yusuff, A.A.; Ogunjuyigbe, A.S.O. Off-grid hybrid renewable energy system with hydrogen storage for South African rural community health clinic. *Int. J. Hydrogen Energy* **2021**, *46*, 19871–19885. [CrossRef]
39. Lemence, A.L.G.; Tamayao, M.-A.M. Energy consumption profile estimation and benefits of hybrid solar energy system adoption for rural health units in the Philippines. *Renew. Energy* **2021**, *178*, 651–668. [CrossRef]
40. Lemence, A.L.G.; Tamayao, M.A.M. Techno-Economic Potential of Hybrid Renewable Energy Systems for Rural Health Units in the Philippines. *World Med. Health Policy* **2021**, *13*, 97–125. [CrossRef]
41. Kyriakarakos, G.; Dounis, A. Intelligent Management of Distributed Energy Resources for Increased Resilience and Environmental Sustainability of Hospitals. *Sustainability* **2020**, *12*, 7379. [CrossRef]
42. WHO; World Bank. Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings—A Review of Status, Significance, Challenges and Measurement. 2015. Available online: https://apps.who.int/iris/handle/10665/156847 (accessed on 30 June 2022).

43. Porcaro, J.; Severi, L.; Mcgregor, C. *Lasting Impact: Sustainable Off-Grid Solar Delivery Models to Power Health and Education*; UN Foundation and SEforALL: Vienna, Austria, 2019.
44. Ramesh, M.; Saini, R.P. Optimisation of a Standalone Hybrid Renewable Energy System Using Demand-Side Management for a Remote Rural Area in India. In Proceedings of the Second International Conference on Smart Energy and Communication, Jaipur, India, 20–21 March 2020; Springer: Singapore, 2021.
45. Taddonio, K. *Renewable Energy Facts Sheet: Renewables Make a Powerful Case as Hospital Energy Source*; U.S. Department of Energy: Washington, DC, USA, 2011.
46. Soler, A.; Jæger, J.; Lecoque, D. Best Practices for Electrifying Rural Health Facilities with Decentralised Renewables. 2020, pp. 1–54. Available online: https://www.ruralelec.org/sites/default/files/2020-08-31%20-%20Best%20Practices%20for%20Electrifying%20Rural%20Health%20Facilities_Final.pdf (accessed on 30 June 2022).
47. WHO. Strategic Roadmap on Health and Energy. 2022. Available online: https://www.who.int/initiatives/health-and-energy-platform-of-action/high-level-coalition-on-health-and-energy/strategic-roadmap-on-health-and-energy (accessed on 1 December 2022).
48. Ringkjøb, H.K.; Haugan, P.M.; Solbrekke, I.M.A. Review of modelling tools for energy and electricity systems with large shares of variable renewables. *Renew. Sustain. Energy Rev.* **2018**, *96*, 440–459. [CrossRef]
49. Logan, T.M.J.; Blair, N.; Sullivan, P.; Bazilian, M. RE-ASSUME: A Decision Maker's Guide to Evaluating Energy Scenarios, Modeling, and Assumptions. 2013; Available online: http://iea-retd.org/wp-content/uploads/2013/07/RE-Assume_IEA-RETD_2013.pdf (accessed on 23 August 2022).
50. Després, J.; Hadjsaid, N.; Criqui, P.; Noirot, I. Modelling the impacts of variable renewable sources on the power sector: Reconsidering the typology of energy modelling tools. *Energy* **2015**, *80*, 486–495. [CrossRef]
51. Kumar, P.; Deokar, S. *Optimal Design Configuration Using HOMER*; Springer: Berlin/Heidelberg, Germany, 2017; p. 442.
52. Olatomiwa, L.; Blanchard, R.E.; Uligwe, J. Demand side management strategies for solar-PV penetration in powering rural healthcare centre in Africa. In *the IAPE '19*; University of Oxford: Oxford, UK, 2019; Available online: https://hdl.handle.net/2134/37301 (accessed on 30 June 2022).
53. Beitelmal, W.H.; Okonkwo, P.C.; Al Housni, F.; Grami, S.; Emori, W.; Uzoma, P.C.; Das, B.K. Renewable energy as a source of electricity for Murzuq health clinic during COVID-19. *MRS Energy Sustain.* **2022**, *9*, 79–93. [CrossRef]
54. Vishnupriyan, J.; Manoharan, P.S. Prospects of hybrid photovoltaic–diesel standalone system for six different climate locations in Indian state of Tamil Nadu. *J. Clean. Prod.* **2018**, *185*, 309–321. [CrossRef]
55. Longe, O.M.; Ouahada, K.; Rimer, S.; Ferreira, H.C.; Han Vinck, A.J. Distributed Optimisation Algorithm for Demand Side Management in a Grid-Connected Smart Microgrid. *Sustainability* **2017**, *9*, 1088. [CrossRef]