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Review Article

A Critical Review of Hybrid Solar-Biomass Renewable Energy System for Sustainable Rural Development in Nigeria

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- Hybrid power systems

Abstract

Nigeria has the largest population in Africa making it a crucial participant in reaching the 2030 Sustainable Development Goals (SDGs) established by the United Nations. However, sustainable development in Nigeria demands an emphasis on Sustainable Development Goal No. 7 (affordable and clean energy) and other climate change mitigation-related goals. Nigeria has considerable potential for solar and biomass resources. Renewable energy technologies are well-suited for off-grid services since they eliminate the need to create or upgrade expensive and complex grid infrastructure to reach remote places. The usage of renewable energy sources has increased the popularity of hybrid systems. Due to the lack of access to affordable, reliable, and sustainable energy sources, it is challenging to enhance the quality of life in rural regions of developing communities in Nigeria and Africa. These regions meet their energy needs using diesel and kerosene, which are very polluting compared to renewable energy sources. This study thoroughly reviewed hybrid renewable energy systems (HRESs) that stabilize renewables' intermittent nature to energize rural locations without access to the power grid. Hybridizing solar and biomass energy may increase energy efficiency while mitigating some disadvantages of both systems. This article gives a complete review of the hybrid solar biomass system technologies currently available. According to the findings, as biomass feedstock and solar thermal costs decrease, and fossil fuel prices rise, hybrid solar biomass power plants will become more economically feasible and thus be considered the most cost-efficient way to offer "high quality" community energy services in rural areas.

ABBREVIATIONS

ST: Solar Tower; PT: Parabolic Tower; LF: Linear Fresnel

INTRODUCTION

The urgent need for alternative energy sources to fulfill the continually increasing energy demand is a result of the rapid depletion of fossil fuels. The rising global warming trend is another reason we should minimize our use of fossil fuels. The future energy supply will primarily rely on technologies that generate power with a lower environmental impact. Renewable energy (RE) technologies encompass power generation from several renewable energy sources. These sources include biomass, hydro, geothermal, tides, and PV. The advantages of the energy systems mentioned above include better supply security, reduced carbon emissions, enhanced power quality, and increased dependability, which are crucial to their implementation [1]. Due to the nature of renewable resources, they can only be used sporadically; thus, hybrid combinations of two or more technologies for power generation and storage may improve system performance.

Hybrid renewable energy systems (HRESs) have been implemented to deal with the intermittent nature of renewables. These systems generally employ renewable energy as the primary source, with batteries and diesel generators as backups [2]. To further ensure that people have access to cheap, dependable, and environmentally friendly energy sources, these systems may also reduce costs and optimize the size of the system components.

Nigeria is a prospective market for bioenergy generation since its annual biomass output exceeds 47.97 million tonnes of oil equivalent (MTOE) annually [3]. Biomass is readily accessible as a byproduct of several manufacturing processes, including sugar refining, woodworking, and rice milling. However, customers are having difficulty securing a reliable fuel supply due to infrastructural issues and the seasonal unpredictability of biomass.a

The cost of biomass has risen significantly in recent years, but it is still a viable option. Solar power has a fickle output because of its inherent variability. Integrating single-source plants, such as combined cycle plants, may boost energy conversion efficiency. However, it does little to solve the problem of fuel scarcity, particularly for fuels only accessible at certain times of the year. Solar thermal power plants, which rely on the sun's heat to generate electricity, have similar upper limits on their output. By combining solar thermal with biomass combustion, we can get beyond the shortcomings of both systems and provide a constant, consistent energy supply throughout the year [4].

Based on the scope of this study, the following are the primary research questions explored:

1). Specifically, what efforts have been made (what have been the lessons learned) to integrate Solar/Biomass hybrid systems in underdeveloped countries?

2). If energizing and electrifying rural areas was a priority, would Solar/Biomass hybrid systems be feasible from a technical and financial standpoint? Which hybrid combinations have better techno-economic performance, and why do some thrive less?

3). What factors most influence the likelihood of a country's mini-grid being successfully implemented?

This study extensively reviewed HRES, focusing on Solar/Biomass hybrid systems. This paper aims to fill the knowledge gap by conducting a literature review on HRESs and concentrating on the primary factors that can inhibit or promote the integration of these systems. This paper also investigates the benefits and drawbacks of utilizing either biomass or solar energy, the need for solar/biomass hybrid systems, and the findings from current research on the solar-biomass hybrid system. According to the investigation results, hybrid biomass-based systems are both environmentally friendly and sustainable and have the potential to contribute to the long-running rural electricity issues in the rural communities of Nigeria and Africa (Figure 1).

Study area

Calabar, the Cross River state capital, is situated between 24°,15' and 5°,15' North and 8°,15' and 80°,25' East. The town occupies about 233 km^2 (604 km^2) and may be found in the far southeastern corner of Nigeria. The Calabar region is low and swampy, with maximum rainfall between April and October and the wettest months being June and September, which is typical of a sub-equatorial climate. About 1830mm of rain falls each year on average. While rain may be expected at any time of the year, more than 80% of the average yearly total occurs during the months highlighted. There are just a few days each year when the temperature drops below 19°C, and the annual average is 27°C [5]. Examined the cost of generating electricity in Calabar and found that the cost of operating diesel generators for self-generation was around 47.74 naira/kWh ($0.30/kWh), or almost four times more than the region's grid-connected price. As the energy from the national grid is notoriously unpredictable, most homes utilize petrol or diesel generators to provide electricity. There is noise pollution, health risks, and soil and water contamination from fuel spills caused by gasoline and diesel-powered generators. Hence proposing a solar-biomass renewable hybrid system may be of great benefit to the people of Calabar (Figure 2).

Biomass

Biomass originates from plants and animals and is a sustainable organic resource. According to Rahman [1], biomass is the sum of the masses of all living things, including plants, animals, and microbes, or, from a biochemical point of view, cellulose, lignin, sugars, lipids, and proteins. Boles, leaves, and branches, as well as rhizomes of grasses and roots of trees, are all examples of above-ground plant tissues that contribute to biomass. Many industrialized nations are switching from fossil fuels to biomass fuels for transportation and power production since it reduces carbon dioxide emissions [6]. Günhan M reported that 14% of global primary energy consumption comes from biomass, which accounts for 35% of immediate energy consumption in developing nations. Biomass output is estimated at 146 billion metric tons per year, most of which comes from the growth of wild plants (Figure 3).

Technologies for transforming biomass into usable forms of energy are expanding at a high rate. Developing nations often struggle to keep up since the current level of technology is beyond their human resources, industrial capacity, and technical aptitude. There is also a lack of raw materials and components for making these converters in the area. Though thermal energy is considered a great sustainable energy form, biomass conversion is also efficient [7]. Converting biomass into chemical, electrical, or mechanical energy allows for broader use. Charcoal, ethanol, and methane are all examples of these types of fuels. Fuels like this may be employed in a wide variety of energy converters to meet a wide range of requirements. Biochemical or thermo-chemical conversion processes are two possible foundations for biomass conversion technologies [8].

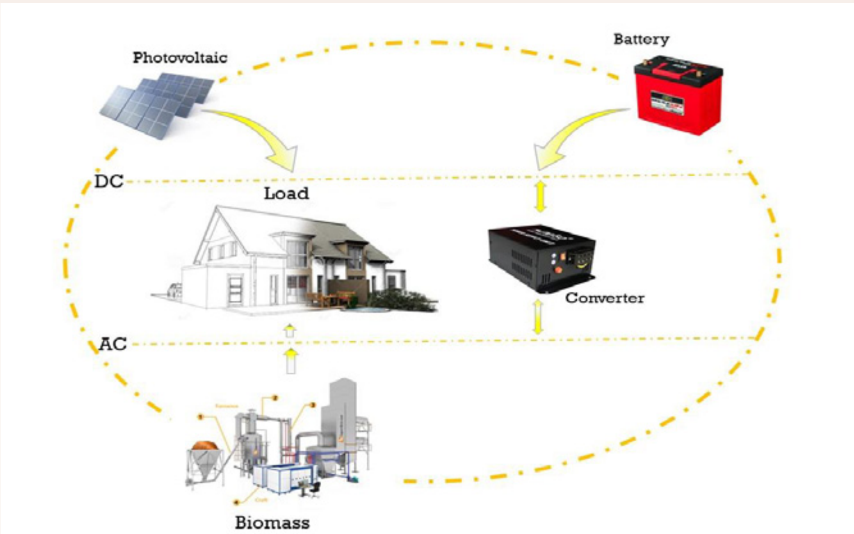

Figure 1 Pictorial Representation of the Supply of Energy Using a Solar-Biomass Hybrid system.

Figure 2 Map of Calabar, Nigeria.

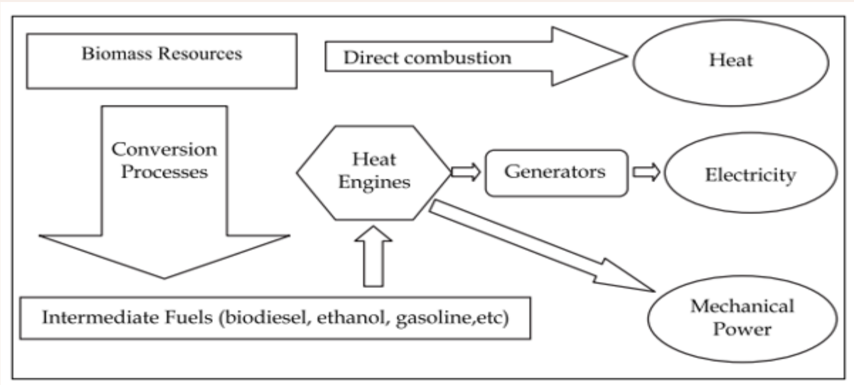

Figure 3 Biomass Energy System.

Biomass Energy Potential in Nigeria: Assets in Nigeria's biomass sector include bushes, forage plants, animal waste, crops, trees, forestry waste, and garbage from agricultural, industrial, and municipal businesses. Biomass from the ocean is also included [9]. The most potential feedstocks for the manufacturing of biofuels are crops grown in the nation's rural regions, as indicated in Figure 4. Small-scale industrial applications may utilize biofuels made from plant and agricultural biomass. The biomasses may also be used to produce low-priced biogases by fermenting them with anaerobic bacteria. While bioethanol and biodiesel compete for water resources, property, and crop plant manures, biogases made from agricultural leftovers and industrial wastes mitigate these risks, as stated by Uzoma C [9]. Feedstocks for economically viable biogas generation in Nigeria include water hyacinth, water lettuce, animal dung, industrial processing waste, urban biomass refuse, agricultural leftovers, and sewage bio-wastes [10].

According to studies, Nigeria generates over 227,500,000 kg of animal waste daily. Since 1 kilogram of animal manure may create up to 0.03 m^3, Nigeria can consistently supply roughly 6.8 million m^3 of biogas. Although biogas innovation is uncommon in Nigeria, several scientists have studied the technology, advances, and regulatory considerations involved in implementing a commercial biogas industry. Research into reactor designs that may improve anaerobic digesters has been conducted [10]. Wood waste and sawdust are two additional significant bio resources linked to the timber sector. Biomass burners are presently on the market for those interested in using sawdust and wood shavings as fuel. In rural and urban settings, biomass is mainly used for heating, drying, and cooking food. A reliable, cost-effective, and long-term production chain and transportation and conversion technologies for biomass feedstocks are required if biomass plays a more significant role in the world's energy supply [7]. The technologies that transform biomass into high-value energy carriers must meet similar criteria, including low cost, high reliability, low risk, little environmental impact, and flexibility. Biomass gasification has great promise and may be an essential enabling technology for developing integrated and flexible bio-energy systems [11]. It may be used in producing electricity, hydrogen, and Fisher-Tropsch, among other things. The potential for biomass generation in Nigeria is undeniable. Most Nigerians still rely on biomass to power their homes throughout the day [7]. With enough research and investment, biomasses may be exploited to create sustainable energy and products. About 10% of farmland is devoted to producing power (3,020,000 ha). The country is estimated to produce 30,000,000 metric tons of biomass at 10 tons per hectare yield. The average High Heating Value (HHV) of woody biomass is calculated to be 19.73 + 0.98

MJ/kg, with a probable loss of 1.4 MJ/kg owing to the latent heat of vaporization of intrinsic moisture content [11].

Nigeria's agricultural strategy places a premium on food production, but that does not diminish the significance of electricity generation. To a large extent, cultivating biomass might improve Nigeria's economy. As entire biomass, bio-waste, or bio-residues, energy crops have the most potential as bio-energy feedstocks in the United States [12]. Access to arable land is essential for any assessment of potential. The ongoing progress of energy crops is significantly influenced by artificial or natural manures and other inputs, whereas lignocellulosic crops have lesser needs [7]. Biomass is an exciting new avenue for transforming plant matter into energy or fuel for internal combustion engines. The absolute energy and environmental life cycle sustainability of bio-based renewable fuels depends on land use and bioenergy generating management [13] (Figure 4).

Solar Energy System

The vast sustainable and renewable worldwide transmission of energy is primarily due to the increasing global demand for energy and the related environmental difficulties and concerns. Power is produced in CSP plants by concentrating solar energy onto a fluid (usually synthetic oil) at high temperatures (above 37.50C) [14]. The Rankine cycle's superheated features are exploited to generate energy, and this is accomplished by using the hot fluid [15]. The U.S. Energy Information Administration (2014) found that concentrated solar power is not competitive with traditional fossil fuel technologies without the help of government subsidies or regulatory benefits. Innovations that decrease CSP plant construction costs and boost CSP plant efficiency are required to compete with traditional energy sources (i.e., fossil fuels) in terms of price. To achieve cost parity with conventionally produced power, CSP plants would need to be either half as expensive or twice as efficient as they are now [16]. System design is a crucial part of the economics of CSP plants (e.g., balancing the size of the plant power block and the concentrator field). However, such concerns are beyond the scope of this study (Figure 5).

Solar Energy Potential in Nigeria: The energy demands of the globe can be met by harnessing the sun's rays [17]. Nigeria's tropical location is one of her most significant advantages for promoting solar power as a renewable energy source. The sun

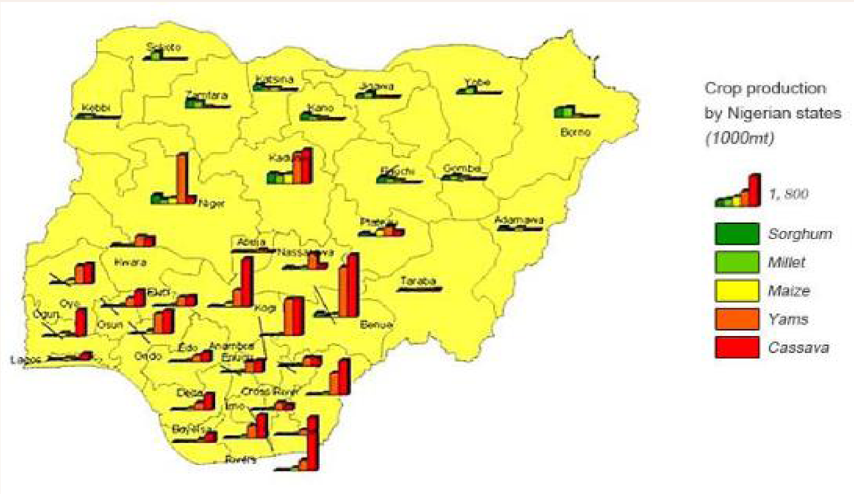

Figure 4 Crop zones of Nigeria [59].

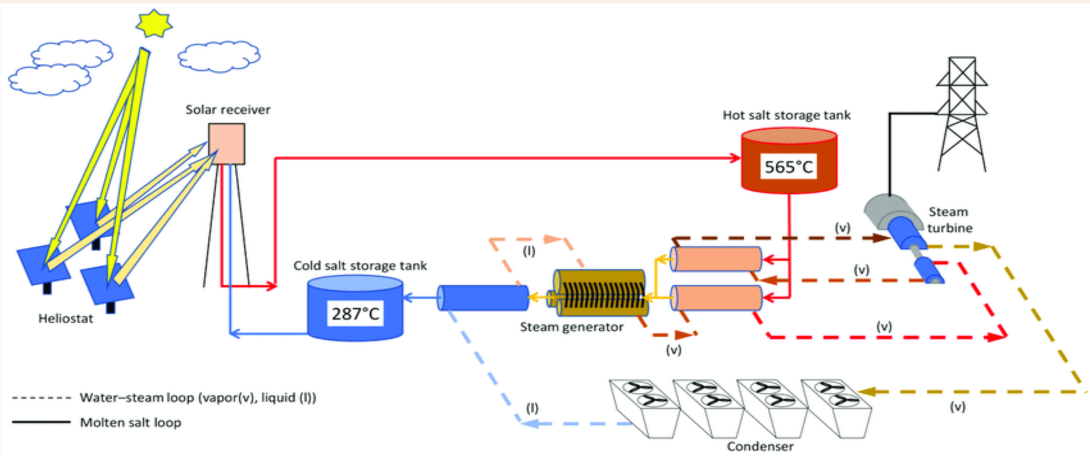

Figure 5 Concentrating Solar Power.

shines uniformly over Nigeria, with average solar radiation of 19.8 MJ/m^2.day and daily sunlight duration of 6 hours, varying from 3.5 hours near the coast to 9.0 hours towards the far northern border [18]. Due to its placement in the Earth's upper Sun Belt, Nigeria has a vast potential for solar energy. If solar panels or modules were employed to cover only 1% of Nigeria's land surface, the country's annual solar energy output would increase by almost 1753kWh (Figure 6). More than a hundred times the current power consumption of the whole country [9]. With an average of 4-7 hours of sunlight each day, the solar energy potential in Nigeria ranges from 3.5 kW/m.day to 7.0 kW/m.day [19].

Both solar electric and thermal conversion may be utilized to harness solar energy for electrical generation. A solar-thermal application is the heating of water to produce steam to power turbines for large-scale centralized output. Unlike solar cells, which directly absorb solar radiation to produce electricity, solar-thermal systems, also known as concentrated solar power (CSP), convert heat from the sun into usable thermal energy [20]. In many solar thermal systems, water is heated by concentrating the sun's rays using a solar collector that has a reflective surface. The Federal Ministry of Power and Steel's Renewable Electricity Action Program (REAP), released by the International Center for Energy, Environment, and development in Nigeria (ICENDN), does not address this method of generating electricity. Solar-electric conversion refers to the centralized or decentralized process by which sunlight is directly converted into electric current using photocells. With photovoltaic technology, or solar-electric technology as it has been more often known, sunlight may be directly converted into electricity [21]. Component mounting structures, power equipment coordination, tracing structures, concentrator systems, and regenerative storage devices all contribute to the overall harmony of a solar system [22]. Converting solar energy into electricity may be done on a big scale linked to the national grid or on a small scale used in stand-alone systems.

The panel board of a solar cell is made up of mechanically and electrically coupled modules. Modules are groups of cells that have been electrically connected and then placed on a frame (solar panel) for easy assembly into more extensive solar arrays. Semiconductors, of which silicon is the most prevalent, make up photovoltaic (PV) cells [20]. The energy of the light that enters the cell is partially stored in the semiconductor and then released via the material. Because of the force, electrons become unbound and may travel around without hindrance. More than 70% of Nigeria's population lives in rural regions. Increasing the viability

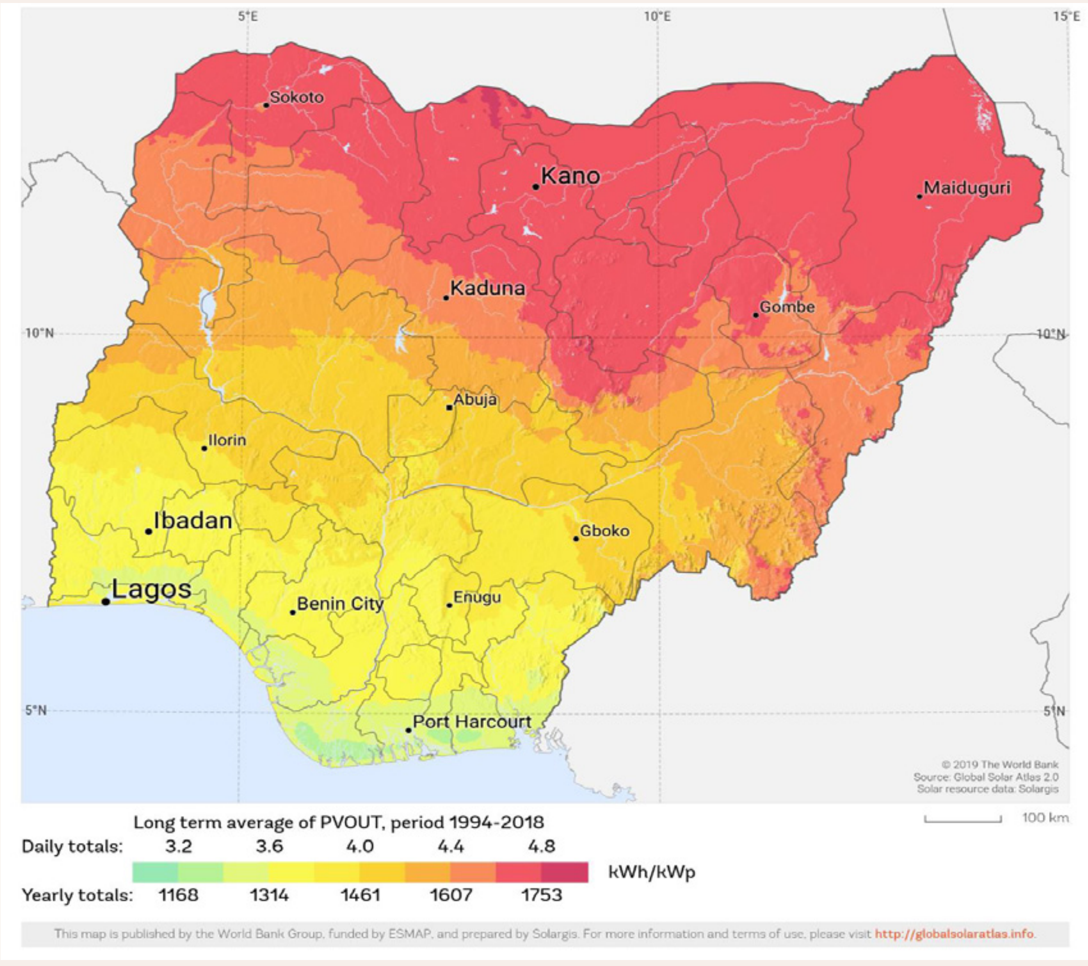

Figure 6 Photovoltaic Power Potential in Nigeria [60].

of solar energy might help reduce the suffering in Nigeria since the accessibility of energy is directly related to a country's degree of development. Since 2005, the Energy Commission of Nigeria (ECN) and the United Nations Development Program (UNDP) have reported that pilot projects, studies, and surveys conducted by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD) under the supervision of the ECN have led to the installation of several photovoltaic (PV) water pumping, electrification, and solar-thermal installations (solar crop drying) [19]. Village electrification, water pumping, vaccine refrigeration, power provision to rural clinics and schools, and the illumination of road signs and traffic lights are all examples of low and medium-power solar uses (Figure 6).

Solar-Biomass Hybrid Energy System

A hybrid renewable energy system (HRES) may combine Energy from renewable sources such as the sun, Biomass, wind, and water to create a system that can be used to generate power and heat in various local environments. Combining several methods can provide steady electricity perfectly suited to the local community's needs and energy resources. According to Gil JD [22], combining solar thermal with biomass combustion helps mitigate each technology's limitations and provides a consistent supply.

Server et al., conducted a cost-benefit analysis of numerous hybrid concentrated solar power (CSP) and biomass combustion power plant (BCP) setups with an output of 10 MWe [23]. As shown by their research, there is a greater need for an initial investment in a hybrid power plant than in a concentrated solar power (CSP) or a biomass combustion power plant. The Levelized Cost of Electricity (LCOE) for the hybrid plant is 36% cheaper than that of conventional CSP and 32% higher than that of a biomass power plant.

Knowing whether or not a location is appropriate for a power plant that utilizes a combination of solar and biomass Energy is crucial, given the current state of this technology. In numerous parts of the world, researchers have looked at the technological and economic feasibility of hybrid solar-biomass electricity. Nixon et al., looked at solar-biomass hybrid power plant applications at scales ranging from 2-10 MW thermal [8]. This comprised combined heat and power and combined cooling and power plants. The plant's Levelized energy costs were higher than those of comparable conventional power plants. It is cost-effective, despite competition from renewable energy sources like wind and solar farms. The authors determined that combined heat and power (CCHP) systems that use hybrid solar-biomass power plants are viable for low- and medium-capacity projects.

Due to their longer payback times, hybrid plants cannot compete with standalone biomass plants. A lack of locally produced resources might increase the price of feedstock by a ratio of 1.2 to 3.2, which in turn would increase the cost of the transportation system and favor the economic viability of hybrid plants [23].

Additionally, Suresh et al., looked at the combination of solar PV and biomass sources for distributed systems [25]. After doing a techno-economic study, they determined that a 5 MW hybrid power plant would save money on production expenses if it is operated around the clock.

A work by Coelho B et al. [26], examined the renewable resource potential of the Portuguese Algarve region, one of the most promising areas in Europe for concentrated solar power facilities. They estimated total annual output of 1244 GWh from biomass sources such as forests and agricultural waste, 30 GWh from byproducts of the wood processing and agricultural sectors, and 219 GWh from biogas produced by sewage treatment plants [26,27]. The hybrid CSP-biomass power plant included various biomass feedstocks, including fuel pellets made from recycled materials, wood gasified using an anaerobic wastewater digester, landfill biogas, and natural gas. The study found that the lowest LCOE (0.15 €/kWh) could be achieved with a 4 MWe hybrid CSP-Biogas, which combines atmospheric volumetric central receiver system (CRS) as CSP technology with anaerobic digestion of sludge from a wastewater treatment plant (WWTP) as biogas generation technology. Considering local feeding (no collection and transportation expenditure for sludge), this hybrid system beat the other hybrid alternatives, with a 13-year payback period and an internal rate of return of 11% (net present value of 15 million euros).

By combining concentrated solar power with biomass [28], could design a system capable of producing 50 MW of Energy. The biomass boiler and solar heat setup is a series system because the feedwater is first heated to steam at 371°C by solar superheaters (series design). The off-design evaluation found that the hybrid system had an annual net solar-to-electric efficiency of 18.13%, up from 15.79% for standalone CSP, and a Levelized Cost of Electricity (LCOE) of 0.192 \$/(kW h), down from 0.077 \$/(kW h) (kW h). In addition, annual Biomass consumption is reduced by 22.53% compared to a solo biomass power system the same capacity (Figure 7).

Concentrating Solar Power (CSP), Solar Tower (ST), Parabolic Trough (PT), and Linear Fresnel (LF) combined with biomass systems are the hybrid options looked at in this evaluation since they are suitable for producing vast amounts of high-grade heat. Table 1 summarizes the various CSP-biomass and storage system combinations characterized by Peterseim et al. [29]. According to a study by Liu Q et al [30]. The best-performing system combinations were those that included both concentrated solar power (CSP) and at least one solar photovoltaic (PV) system. Key system features for selecting the hybrid system combinations investigated are summarized in Table 1.

Selection 1: Solar Tower Combined with Biomass: Table 1 demonstrates that ST technology performs substantially better than other solar power technologies that may be hybridized when it comes to direct steam production. When combined with DSG, gasification improves efficiency by 0.2%, and when combined with molten salt, it enhances efficiency by 0.1%. The high operating temperatures (540 °C) and higher steam pressures are the primary factors in reaching these greater efficiencies (130). When ST (DSG/ Molten salt) is combined with biomass combustion, steam temperatures and pressures are reduced compared to when ST is combined with gasification, leading to a poorer overall efficiency [28]. Although direct steam generation (DSG) is significant due to its higher efficiency, the solar fraction

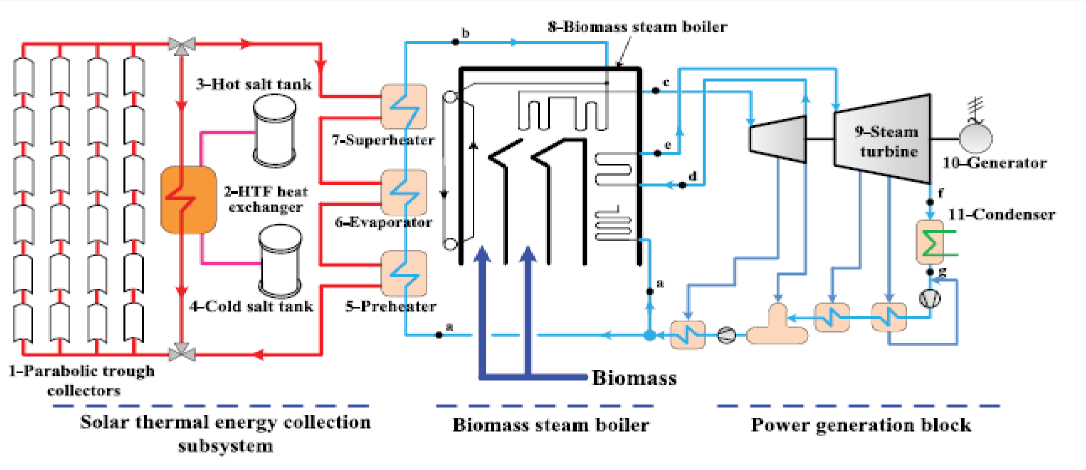

Figure 7 The flowchart of a hybrid solar-biomass energy system.

Table 1: Solar Biomass hybrid systems comparison [29].

CSP Options	High Temperature Working Fluid	Biomass Options	Steam Temperature (°C)	Steam Pressure (bar)	Peak Efficiency (%)
ST	DSG	Gasification	540	130	33.2
ST	Molten Salt	Gasification	540	130	32.9
ST	DSG	Combustion	525	120	33.0
ST	Molten Salt	Combustion	525	120	32.8
LF	DSG	Combustion	400	90	30.4
LF	DSG	Combustion	450	100	31.5
LF	DSG	Combustion	500	110	32.5
PT	Thermal oil	Combustion	380	80	29.5
PT	DSG	Combustion	450	100	31.5
PT	Molten Salt	Combustion	525	120	32.7
PT	Molten Salt	Gasification	540	130	32.8

of a hybrid power plant must also be optimized through the use of thermal storage to enable electricity production at night or on days with insufficient DNI; this is best accomplished with molten salt storage systems.

A commercially viable molten salt storage technique for solar towers is discussed [29]. From a financial perspective, the same study indicated a payback period of 9.7 and 9.6 years for DSG with a combustion system and 10.8 and 10.9 percent for DSG with a gasification system, respectively. When molten salt was used in conjunction with combustion and gasification, the internal rate of return (IRR) was 10.5%, and the payback time was 10.2 years [27]. Economically, molten salt energy storage with DSG fares marginally worse than DSG without storage due to the high initial capital expenditures of thermal energy storage (TES) systems.

Selection 2: Linear Fresnel Combined Biomass Fuel: The use of linear Fresnel is a viable technique for CSP power generation in the future. There are still some opportunities to increase productivity [28]. Table 1 considers three identical sets of conditions for LF DSG combustion, shifting just the temperature (from 400 to 500 degrees Celsius) and the steam pressure (from 90 to 110 bars) [27]. It has been observed that raising the temperature and pressure of a system improves its performance. Optimizing collector performance for maximum heat gains in the morning or late afternoon is crucial for operating LF systems at higher temperatures [31].

In terms of cost-effectiveness, LF CSP systems outperform every other option. The quickest payback time for these three system configurations is 8.6 years, and the internal rate of return may reach 11.5%. The reduced land requirements of LF systems, which account for a significant amount of the total investment cost, are a major factor in this [27].

Selection 3: Parabolic Trough Combined with Biomass: Since PT is the most developed of the CSP technologies, it seems to sense that it is used by the lone solar biomass plant that is now in operation. Using thermal oil as a high-temperature transfer fluid, the Termosolar Borges (TSB) hybrid power plant achieves an overall system efficiency of 29.5%. The solar field may increase the temperature by up to 300 degrees Celsius. However, supplementary choices may aid in maximizing the system's performance as a whole. By operating at 540 °C and 130 bar and combining it with molten salt and gasification, the PT system may achieve an overall 32.8% plant efficiency [31]. Although the efficiency drops somewhat when combustion is used instead of gasification, this system may be hybridized with either approach. Compared to the solar tower and linear Fresnel technologies, the economic performance of a parabolic trough with direct steam production mixed with biomass is worse. The combined payback period for PT, DSG, and biomass combustion is 14.2 years, with an internal rate of return of 8.9% [27]. The payback period for the PT using thermal oil is considerably longer at 15.7 years, and the internal rate of return is just 8.3%.

Literature Findings

A hybrid system, which includes biomass gasification and wind power facilities, was suggested by Pérez-Navarro A [32]. This hybrid setup may reduce the impact of inaccurate wind forecasts, making renewable energy more reliable. The feasibility of a solar-geothermal hybrid plant using an organic eRankine cycle was assessed by Astolfi M et al [33]. Electricity Levelized costs ranged from 145 to 280 euros per megawatt-hour (€/MWh) based on current solar prices, depending on plant location. According to a study by [30], the hybrid operation saves 29% more biomass than the biomass solo operation.

The hybrid biomass-solar thermal system was investigated by Krarouch M. [34], for use in household heating and domestic hot water production. Investment costs for hybrid Concentrating Solar Power (CSP) -biomass power facilities are higher than for traditional CSP and biomass combustion plants alone, according to research by [23]. This value, however, is much lower (a 24% save) than a simple sum of the investment expenses associated with the two conventional technologies because of the shared usage of part of the equipment. Techno-economic analysis of biomass-based hybrid renewable energy systems for rural area microgrid applications was researched by Harish VSKV et al [35]. They determined that the energy acquired via this system was $3.61 per kWh but that the extra capital cost of the grid-connected hybrid system was 8.79%. According to research by Elmorshedy MF et al.[36], operating a hybrid solar-biomass power plant may reduce biomass and land use by up to 29% compared to a biomass-only plant. Because of the declining cost of solar thermal and the rising costs of feedstock, fossil fuels, and land, they also found that hybrid plants are becoming a more viable alternative. Direct and indirect thermal transfers are two primary study topics in the hybridization option [37]. More and more countries are showing interest in the renewable and potentially carbon-reducing properties of fuels produced via the thermal conversion of biomass feedstock to minimize the release of greenhouse gases [38]. When the units are optimized for fuel production, electrical power is often needed in biomass gasification and pyrolysis facilities [37]. Using a functional model of a biogas plant, Chandra R [39], assessed the financial viability of this renewable energy option.

Additionally, Chandan R [39], realized that IC Engines run very efficiently on methanol derived from biomass methane (cattle waste). Dairy farms that use anaerobic digestion technology may lessen their environmental impact and provide a cheap and easily accessible energy source. Research work by Celli G [40], discusses where power plants should go to maximize the production of biogas and biomass. The authors described an optimization technique that considers the accessibility of biomass, the cost of transporting it, the capacity of existing power plants, and any territorial restrictions. They concluded that more excellent unit performance is possible thanks to incorporating optimization techniques inside Geographic Information Systems. Producing heat and electricity from biomass at once may help the agricultural sector become more energy efficient, reducing its carbon footprint and making it more environmentally responsible in the long run. A study by Bora BJ [41], examines biogas production and the operation of a Gas Engine. The technological, economic, and CO_2 mitigation capabilities of a solar PV-bio hybrid system were analyzed by Kumar R [42]. The hybridization of solar and biomass for combined heat and power (CHP) production in Europe is investigated by Hussain CMI [24]. Ma T suggested a hybrid renewable energy system (HRES) for an underdeveloped island that would use photovoltaic (PV) and wind turbine (WT) panels in addition to a battery for energy storage. A mathematical model was suggested to determine how depletion of renewable resources will affect battery capacity, Levelized cost of energy, surplus energy, power outage, net present price, and payback period. The results showed that the most efficient system for the research area was a lower WT size (2 kW) with a wind energy saturation of 90%.

Ahmad J et al. [44], proposed a hybrid biomass/wind/PV system for a rural application in Pakistan. The researchers looked at the feasibility of an HRES as a source of electricity in the area under consideration. Due to the system's integration with an existing electrical grid, both surplus and deficit electricity was handled automatically. It was determined that the LCOE for the hybrid system was 0.05744 dollars per kilowatt-hour (the study was done using Homer Energy Software). [45] modeled an HRES built on a WT and PV *system with battery storage in their study. Power production was 190 kW (split between PV and WT),* while storage was 10 kW. The grid was integrated into the system, and the intended energy storage technology was considered to dampen system variations. Buonomano A [46], performed a dynamic simulation that showed hybrid PV/WT systems are only profitable for consumers with consistent power consumption. Algieri A et al. [47], conducted a Performance in terms of energy, exergy, and cost of a novel multi-source renewable hybrid energy system for residential-scale combined heat and power applications in Southern Italy and found that, when adequately hybridized, biomass and solar energy outperform single-source designs in terms of useable production and system adaptability. The proposed small-scale system guarantees a 48.9% decrease in biomass consumption compared to the corresponding biomass-only apparatus. It increases the exploitation (+8.8% of electric production) of low solar radiations that are not adequate to feed a full-solar **Organic Rankine Cycle** while overcoming the solar source's stochastic and intermittent characteristics. Also, in regions where electricity from the grid and natural gas boilers are used to meet energy needs separately, the proposed solar/biomass hybrid **Organic Rankine Cycle** system guarantees a 24.2% primary energy saving, a 53.5% reduction in the unit electric and thermal production costs, and a 57.7% reduction in greenhouse gas emissions, all with a payback period equal to 7.5 years. Usón S et al. [48], evaluated a hybrid trigeneration system consisting of PV, a solar thermal collector, and a water heater by conducting an exergy analysis and an exergy cost evaluation. The suggested technology was used to deliver hot water and energy concurrently. The hybrid system was shown to have an exergy efficiency of 7.76% based on [46] simulation results. Using the Homer Energy software tool, a comparative analysis of HRES for off-grid locations in Southern Cameroon was developed by Muh E [49]. Gado MJ [50], compares the efficiency and cost of a traditional compression system to that of a novel hybrid renewable biomass-solar-wind energy system for driving both cascaded adsorption-compression refrigeration systems, according to their findings, using renewable energy sources offered two scenarios for autonomously driving the cascaded adsorption-compression system: Scenario-I uses a biomass-solar-battery setup, while Scenario II uses a biomass-solar-wind-battery system. The adsorption system in their work was powered by both biomass and thermal waste heat from photovoltaic/thermal collectors, they explore and compare the possibilities of using typical meteorological data from New Borg El-Arab city in Egypt. Their findings concluded that Scenario-I is the most economical option due to its lower refrigeration cost of $0.235 per kilowatt-hour compared to $0.237 in Scenario II. Scenario-photovoltaic/thermal I's collectors provide enough power to meet all electrical needs and an additional 16.6 kWh. Scenario II, on the other hand, produces a surplus of 15 kWh despite having fewer photovoltaic/thermal collectors installed. While biomass energy supplies the vast majority of both cases required thermal needs. [51] researched a PV-diesel-small-hydro-battery hybrid system and discovered that the planned energy system calculated a figure of 0.17 USD per kilowatt-hour. However, in thermal energy systems, where the Rankine cycle is typically used to convert thermal energy to electrical energy, a large amount of thermal energy is lost in the condenser. These systems include biomass, geothermal, parabolic trough power plants, solar power tower systems, and linear Fresnel reflector (LFR) solar power plants (SPPs). Proposing a new method to recycle waste heat can significantly boost such systems' performance. These technologies may be explored for simultaneous heating and electricity generation (common in Scandinavia).

Other studies offer alternative layouts for the integrated systems that would generate heat, cold, power, and water. Herrando M et al. [52], devised an HRES that uses PVT/PV to generate cooling, heating, and electricity. An absorption refrigeration system was built into the cooling circuit. The Bari University Campus served as the study's example location. Based on their findings, the suggested system has the potential to provide 16.3% of the university's electrical demand, as well as 20.9% of its heating and 55.1% of its cooling. It took around 16 years for the system to recoup its initial investment. Thermodynamic models for CCHP (combined cooling, heating, and power) systems using the solar thermal gasification system were proposed by [53]. The suggested system has an average energy efficiency of 56% and an exergy efficiency of 28%. As an example of a CCHP system, Chen Y [54], drew a diagram showing how compound parabolic concentrated-PV thermal solar collectors may be added to the system. The backpressure steam turbine, condensing steam turbine, and double backpressure steam turbine were all tested. It was determined that the backpressure steam turbine was the most productive method. The dynamic model was created by Han X [55], to evaluate the performance of a PV-WT-concentrating solar power tower system. According to their findings, the LCOE was $0.2775/kWh, and the recovery ratio was 30.87%. Lu Y et al. [56], looked at a solar-assisted multigenerational system that generates electricity, heat, and cold air.

Suresh NS [57], looked into the state-of-the-art exergoeconomic analysis of hybrid solar-biomass energy systems in Cameroon's northern regions. They studied the Hybrids of three different types of concentrated solar power (CSP) systems—the parabolic trough collector (PTC), the linear Fresnel reflector (LFR), and the solar tower (ST) and he determined that the majority of the total exergy destructions (86.3% for PTC-BF, 92.2% for ST-BF, and 85.4% for BF) are caused by exergy destruction alone due to the solar field (LFR-BF). Taking into account the initial investment, the avoidable-endogenous exergy destruction, the cost associated with avoidable-endogenous exergy destruction, and the total cost required for the optimization, the results show that the LFR-BF hybrid system is the best cost-efficient system and the ST-BF hybrid system is the worst cost-efficient system.

An examination of the relevant literature suggests that microgrid systems powered by renewable energy have the potential to provide electricity to more remote regions throughout the world.

Challenges of Hybrid Systems

Because of its novelty, hybrid solar-biomass power generation is still a developing technology in the energy sector. However, there are few facilities in operation in the African continent, and widespread implementation of hybrid power systems is likely to face substantial technological and economic obstacles. We will go through a few potential difficulties and how to deal with them below.

Identifying a Promising Area: Finding the optimal sites for hybrid projects with a good chance of being economically viable is a primary difficulty. Due to their atypical layouts, hybrid solar-biomass power plants need to be situated in areas with abundant solar irradiation and suitable biomass materials. Fig. 6 depicts a hypothetical location where such a project may be expanded.

Technical Challenges: Designing and developing an efficient control system is one of the biggest technical hurdles facing solar-biomass plants today. Thermal energy dumping occurs when the system cannot maintain the desired turbine temperatures and pressures due to changes in solar inputs and biomass boiler demand, decreasing system efficiencies and raising Levelized costs [8]. It would be possible to implement a predictive control system to regulate the parameters of a given system, such as its temperature, pressure, and mass flow. Poor system and financial performances may come from inefficient capture of solar insolation, which design flaws can cause. One of the most critical factors in a project's ultimate success is the precision with which solar resources are measured throughout the planning phase.

To cut down on biomass resources and running expenses, maximizing a plant's solar percentage is crucial via the ideal design and integration of a high-temperature thermal energy storage (TES) unit. However, the capital cost of a hybrid plant might be significantly inflated by the addition of a TES system.

Consequently, finding ways to reduce the price of integrating the TES system via better design and production is a significant obstacle to overcome.

Biomass supply chain: The reliable and affordable delivery of vast volumes of biomass is one of the biggest obstacles facing any biomass power plant [58]. Therefore, finding or creating a reliable biomass supply chain should be a top priority for every major project. The operator must collaborate with regional and maybe European suppliers to guarantee the timely supply of high-quality biomass feedstock. In addition, a sizable biomass gathering system that can meet future needs must be constructed. Adding this to the already high initial investment costs of solar-biomass hybrid power plants is undesirable.

Economics Difficulties: The high capital costs of the technology provide the most extensive economic obstacle for hybrid solar-biomass systems. Prices will go down as more of the system's components are used. While Europe's lone hybrid power plant has been running since 2012, widespread technology adoption is necessary for significant learning. Due to its unproven status, there may be economic and technological hurdles to using the technology widely in the electric production business. This problem has been more apparent in recent years, as even CSP standalone projects have had trouble securing essential finance while accessing abundant solar resources. In Australia, for instance, projects like Solar Dawn (250 MW) and Solar Oasis (40 MW) have recently been awarded capital grant help from the government totaling AU$464 m and AU$60 m, respectively. Neither could get the last pieces of development money before they were scrapped [31]. Similar challenges affect extensive biomass power facilities. To solve these issues, public and commercial sectors must be willing to take risks on this novel and potentially dangerous technology. If more plants are to be built and technological advancements are to be made, the low feed-in tariffs now granted to this industry must be re-evaluated.

DISCUSSION

For Africa to be considered the next developed continent, solar and biomass capital subsidies should be ut in place (e.g. 30% grid-connected, 60% off-grid); hybrid solar-biomass power plants in Nigeria are a viable alternative for tri-generation (electricity, cooling, and heat) in small-to-medium sized applications (2-10 MW thermal). Industrial process heat is another feasible choice for applications that efficiently use heat. If only power is needed, there are better possibilities at these sizes. On the other hand, hybrid solar biomass power plants will become more competitive as steam energy storage systems advance, as biomass feedstock and solar thermal costs decrease, and fossil fuel prices rise, hybrid solar biomass power plants will become more economically feasible and thus be considered the most cost-efficient way. Due to their energy and exergetic efficiency, small-scale hybrid plants should prioritize technical enhancements to their heat cycle. For a small, self-sufficient rural region with an abundance of biomass as a feedstock, a system that uses just biomass is presently the most cost-effective option. It is recommended that Nigeria and other developing countries in Africa should increase the size of their hybrid power plants to generate more electricity, as this would help to maintain solar thermal competitiveness in the face of other renewable energy technologies and potentially make Nigeria a world leader in the field of hybrid solar-biomass power systems.

CONCLUSION

Due to the expensive nature of startup capital associated with solar energy and the huge expenses required to run a biomass aside their inconsistencies on availability, this review work focused on the potentials and efficiency of a cost-effective hybrid solar-biomass energy system. The literature review done shows that while pyrolysis and gasification have been identified as major environmental threats in a biomass energy system, the use of solar energy to generate thermochemical biomass processing will help mitigate such threats. It was also established that the operation and maintenance costs of biomass technology was extremely high. It can be concluded that the solar-biomass hybrid energy system does not only provide energy but also create job opportunities for the teeming youths and development for the communities. In order to provide clean community energy services to rural communities at the lowest possible cost and with the greatest possible social and environmental advantages, hybrid systems have proven to be the best solution.

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