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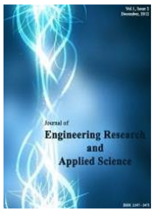

The Prospects for Electricity Generation from Biomass in African Countries

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Abstract
One of the biggest challenges facing developing countries is their energy sector. Electricity shortages are becoming increasingly worrying in some of these countries, partly due to over-reliance on fossil fuels that cannot reliably meet their energy needs. These fuels are considered environmentally harmful, causing environmental damage through greenhouse gas emissions. It is high time these countries focused their efforts on clean and renewable energy sources, such as biomass energy. Africa has sufficient reserves of residual biomass but has not made any progress in developing renewable energy sources. These could have been of paramount importance for the country's economic growth and alleviated the problem of intermittent energy supply. This study examines the situation in Africa regarding plant biomass production and some of the measures taken so far to efficiently utilize biomass for energy generation, using Nigeria as a case study.

Keywords: *Africa; developing countries ; Nigeria, fossil fuels, renewable energy, biomass*

1. Introduction

The term "biofuel" refers to a fuel derived from biomass such as algae, plants, or even animal waste [1-3]. Compared to fossil fuels such as natural gas, oil, and coal, biomass is a clean, readily available, cost-effective, and environmentally friendly energy source. Fossil fuels are harmful to the environment and emit dangerous greenhouse gases that pollute the environment and render it unusable for consumption. Therefore, they must be replaced by renewable energy sources [4-7]. Biofuel is used in both the transportation sector and in electricity generation. Various processes are used to convert biomass into electricity: direct combustion, gasification, pyrolysis, and biochemical degradation [8-10]. The most common forms of biofuel are currently bioethanol and biodiesel. Ethanol is mainly produced from carbohydrate-containing plant materials and can be blended with gasoline to increase its octane rating and reduce carbon monoxide and carbon dioxide emissions [11-14]. Biodiesel, on the other hand, can be produced from vegetable oil, recycled cooking fat, or animal fat. Biodiesel can be used as a clean, non-toxic, and biodegradable fuel in compression ignition engines, replacing fossil diesel [15-17]. It can also be blended with petroleum-based diesel [6]. The use of biofuels significantly contributes to reducing the consumption and import rate of refined fuels from other countries [18-20].

Electricity has become essential to stimulate economic activity and improve people's quality of life [11]. The use of electricity makes agricultural and industrial production processes more efficient [12]. Households need electricity for many reasons, such as cooking, lighting, refrigeration, learning, and domestic economic activities. Vital facilities such as hospitals require electricity for cooling, sterilization, and freezing. Africa currently has an installed capacity of 147 GW, comparable to the capacity China will install in one or two years. The average per capita electricity consumption in sub-Saharan Africa is only 153 kWh/year [8]. This is a quarter of India's consumption and only 6% of the global average. Nearly 600 million people in Africa lack access to electricity. Many African countries experience daily power outages. Given this situation, individuals and businesses often rely on expensive diesel power plants to meet their electricity needs, which costs some African economies between 1 and 5 percent of GDP annually. To meet growing demand, Africa urgently needs to invest more in its energy sector [11], [12], [13] [14] [15].

Analyses of various national and regional studies indicate that the continent will need around 250 GW of additional capacity by 2030 to meet growing demand. This will require a doubling of capacity expansion to around 7 GW per year in the short term

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and a quadrupling by 2030. The required investment volume is so large that governments need public-private partnerships to increase their investment in generation capacity. While access rates are improving in some countries, the business environment and policy frameworks are not yet robust enough to attract the level of private investment required to install the additional 250 GW by 2030. Many African countries suffer from opaque policy frameworks and excessive bureaucracy, while electricity subsidies and government-set prices often hinder sustainable business investment. Renewable energy technologies alone will not be sufficient to solve Africa's energy problems. For example, the policy framework, industrial structure, and social aspects of energy must also be considered. Africa has a unique opportunity, with almost two-thirds of the additional capacity needed by 2030 still unbuilt. The continent can benefit from recent global advances and cost reductions in renewable energy generation to leapfrog the development path of developed countries and move directly to a renewable energy-based system [11], [12] [13-16].

2. Energy situation in Africa

2.1 Introduction

One story is set in the heart of sub-Saharan Africa, where lush green plains meet many different cultures. It reflects the struggles and dreams of resource-rich but energy-poor populations [16]. This story is not just about light and energy, but also about strength, challenges, and the pursuit of a better future. Imagine a young man living in a remote village in Cameroon, a sub-Saharan country. For him, as for many others, electricity is not a given. It is more like wishful thinking. In his small house, a dim oil lamp illuminates the room while he studies from a worn textbook. He is determined to learn, even in the dark. In the village, the electricity supply is unstable [17]. This reminds everyone of the energy inequality in the region. Although the world talks about the use of modern and sustainable energies, the existing old systems cannot meet the daily needs of the population. The young man's village is stuck in a vicious cycle of energy insecurity. Their dreams of education, health and a better life depend on an unreliable energy source [18], [19], [20].

As the sun rises over the vast African landscape, it is clear that something must change. The United Nations has formulated the seventh Sustainable Development Goal (SDG 7), which promises affordable, reliable, sustainable, and modern energy for all by 2030. However, the numbers reveal a problem: 600 million people in sub-Saharan Africa still lack access to electricity, and many of them suffer frequent power outages. At the center of this struggle, the young man's village stands as a smaller version of a larger problem. This is where energy poverty, human rights, and environmental sustainability intersect [11]. The 1948 Universal Declaration of Human Rights states that the availability of sufficient energy is linked to fundamental rights such as life, food, housing, health, and education. However, there is no international rule that establishes the provision of affordable, reliable, and sustainable energy as a fundamental human right [12], [13].

Given these challenges, financial interventions are necessary [14]. The results of my research highlight the gaps in the implementation and enforcement of these regulations, which lead to indiscriminate greenhouse gas emissions [15]. Addressing energy poverty while simultaneously reducing emissions is becoming a major challenge, and Africa is emerging as a unique area of research. The story goes beyond sub-Saharan Africa and spans the entire continent, examining the disparities between energy poverty and emissions. It passes through bustling cities, arid deserts, and lush green landscapes. Even countries with low vulnerability but high emissions participate in the debate, making this analysis global. By addressing the challenges of coopetition and climate policy, the protagonists of this story become agents of change. The goal is clear: to help disadvantaged communities while combating the global climate crisis. The once limited research now covers all types of energy sources and emission patterns. This provides us with an overview that helps us develop intelligent rules and plans for sustainable development [16-20].

2.2. Renewable and non-renewable energies

Renewable and non-renewable energy sources have attracted considerable attention in Africa due to their potential to meet growing energy demands while mitigating environmental impacts. Renewable energies such as solar, wind, and hydropower have emerged as a promising solution in the region. Studies show that the use of renewable energy can reduce dependence on fossil fuels, reduce greenhouse gas emissions, and improve air quality [1-5]. Furthermore, renewable energy projects often have positive social and economic impacts by supporting local jobs and access to energy in remote areas [6]. On the other hand, non-renewable energy sources such as coal, oil, and gas continue to dominate Africa's energy mix, resulting in negative environmental consequences [7]. These conventional energy sources contribute to air and water pollution, deforestation, and exacerbate climate change. Despite the challenges, the continent has recognized the need to transition to renewable energy to achieve sustainable development and address pressing environmental problems [8]. Further research is essential to improve the understanding of renewable energy technologies. It is crucial to assess their long-term environmental impacts and develop effective strategies for their widespread implementation in Africa [9-11].

2.3. Climate policy

Climate governance in Africa is a dynamic and important area that addresses the continent's unique challenges in the face of climate change. Africa's vulnerability stems from its dependence on rain-fed agriculture, its limited adaptive capacity, and widespread poverty. In recent years, there has been increasing recognition of the need for comprehensive climate policies to address these challenges and build resilience. Key aspects include adaptation strategies with a focus on agriculture, water resources, and health; mitigation efforts with an emphasis on renewable energy, energy efficiency, and sustainable practices; active participation in international climate agreements; capacity building to address institutional and technical challenges; financial support through mechanisms such as the Green Climate Fund; and an increasing emphasis on societal engagement. Despite the progress made, challenges remain. This underscores the need for continued commitment, innovation, and collaboration between governments, civil society, and the private sector to ensure Africa's sustainable development in a changing climate [1-4], [5-7], [8-11].

2.4. Fair energy growth

An equitable energy supply in Africa holds significant potential to mitigate the impacts of climate change. Access to clean, reliable, and affordable energy sources on the continent can drive sustainable development and reduce dependence on fossil fuels and associated greenhouse gas emissions [11]. African countries can harness their abundant natural resources while addressing the challenges of climate change through the deployment of renewable energy technologies such as solar and wind power [12]. However, technology incentives can be an effective strategy to accelerate progress in the energy sector, particularly in the development of climate-smart technologies. At the same time, the importance of equitable distribution of renewable energy solutions, especially among marginalized communities, is highlighted [13]. To enable the transition to low-carbon energy systems in Africa, strong policy frameworks, international partnerships, and financial support mechanisms are essential [14], [15], [16], [17].

2.5. Analysis of energy poverty and greenhouse gases

A reliable method for analyzing and understanding energy poverty and greenhouse gas emissions is the use of the Integrated Assessment Model (IAM) . Integrated assessment models of human-induced global warming have evolved naturally from energy models. In the 1970s, the Modeling Resource Group (MRG) comprehensively evaluated energy models. As part of this project, Nobel laureate economist Tjalling Koopmans investigated an energy model that predicts future energy consumption and technological progress [11]. Since then, energy modeling has been largely based on Koopmans' linear programming approach to production and Samuelson's maximization theory. The goal of IAMs is to analyze the impacts of different energy and climate policies on long-term economic growth. They identify policy options to balance economic growth and environmental sustainability under different energy, GDP, and emissions scenarios [16].

Therefore, IAMs can be used in finance to analyze the benefits and costs of different policy options, such as investments in renewable energy. Energy poverty can be studied using IAMs by using different strategies to determine their impacts. In the case of greenhouse gas emissions, IAMs can be used to evaluate the effectiveness of different emission reduction strategies and analyze the impacts of different policy measures [11]. The effectiveness of different policy options can be influenced by competition. For example, cooperation between countries can lead to significant emission reductions. However, competition between countries can lead to different policy strategies being pursued, making it more difficult to reduce global emissions [10], [11], [12], [13].

It is now clear that a moderating variable between finance, energy poverty, and greenhouse gas emissions must be defined. Coopetition, a combination of cooperation and competition, emerges as the best moderator. It strengthens the financial variable by ending energy insecurity. Furthermore, it acts as a brake on participation in activities that contribute to greenhouse gas emissions [11], [14], [18], [20].

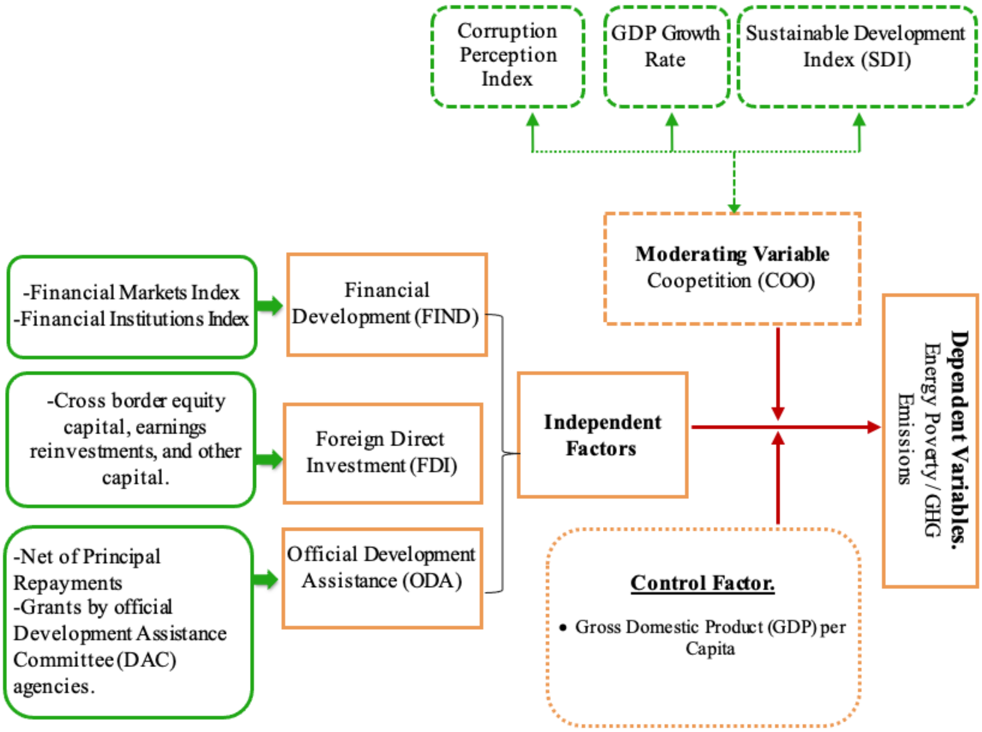

Figure 1. Integrated Assessment Model (IAM).

The objective is to determine how the relationship between independent financing and cooperation moderation affects the dependent variables (energy poverty and greenhouse gas emissions), controlling for GDP per capita. The theoretical model is presented in Figure 1.

3. Challenges of electricity supply in Nigeria

An adequate and efficient supply of electricity is crucial for the smooth functioning of any country's agriculture, industry, and mining sectors. Any shortage negatively impacts the country's economic growth and development. Nigeria has the largest economy and market in Africa. The country has abundant natural resources, namely petroleum and natural gas, limestone, iron ore, coal, zinc, lead, tin, arable land, and renewable energy sources, which have the potential to meet the country's energy needs, but these resources are underutilized [7]. Nigeria has a total area of 924,000 km², stretching from the 4th to the 14th parallel and from the 3rd to the 14th longitude [9] and a total population of approximately 200 million people [10]. Due to its large population, the demand for electricity is high, but the country is unable to fully meet this basic need of its people. The majority of Nigerians (over 60%) have no access to electricity, while the privileged few who have access to the national grid (40%) are frequently affected by power outages [11].

The country's electricity demand is around 40,000 MW [8], while the total capacity of installed power plants is about 12,000 MW, and on average, less than 4,000 MW of electricity is produced per day [9]. Over-reliance on petroleum for electricity generation has hindered the use and development of alternative energy sources such as biomass energy (biofuels), solar energy, wind energy, and hydropower. The majority of grid-connected power plants in Nigeria are powered by thermal energy from fossil gas (85%), with the remainder powered by hydropower (15%) [10]. Nigeria is geographically divided into two seasons: the dry season (including the harmattan season) and the rainy season. During the dry season, water levels in the country's hydropower plants decrease, often resulting in a sharp decline in hydropower generation [11]. The Nigerian electricity grid faces numerous challenges, including insufficient grid capacity to meet demand. The World Bank's electricity demand forecasts, shown in Figure 2, assume that the demand for grid-connected electricity will increase continuously every year from 2020, including the demand for off-grid electricity [12]. Furthermore, it is estimated that currently 50% of the electrical energy consumed in the country is generated off-grid by diesel and gasoline generators of all types and sizes. To meet the country's electricity needs, individuals, including businesses and organizations, rely on generators powered by fossil fuels [13]. This not only results in unpleasant air but also noise pollution and high energy costs. In addition, there is a high unmet demand, especially among the country's many citizens who do not have access to the electricity grid and cannot afford off-grid electricity. Therefore, the use of renewable energy could help reduce the country's intermittent electricity supply and improve environmental health and safety [14], [15], [16].

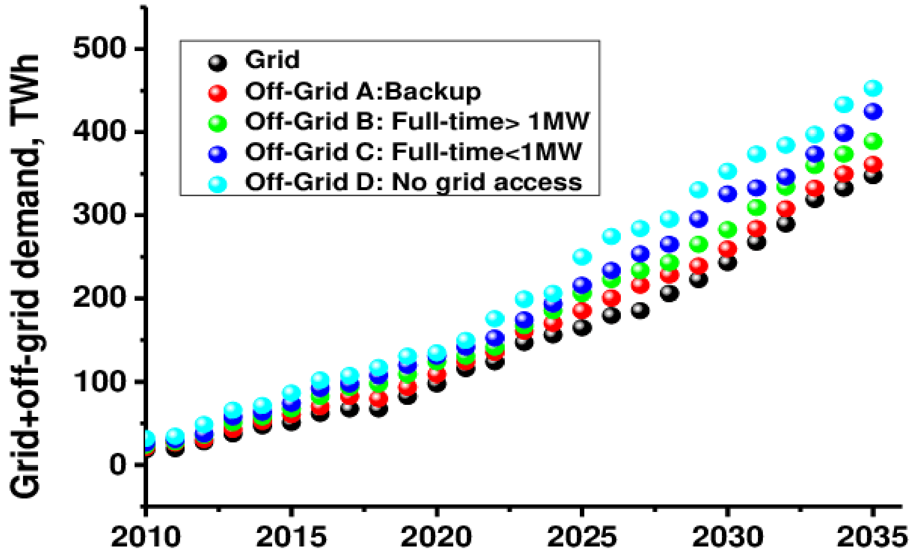

Fig. 2. Estimated electricity demand (TWh) in Nigeria (on-grid and off-grid) [11].

4. Potential for biofuel production from biomass in Nigeria

Currently, most biofuel projects in Nigeria focus on the use of food crops, so-called first-generation biomass, for biofuel production. This poses a major obstacle to biofuel production due to competition between food crops for human consumption and those for biofuels [20]. However, Nigeria generates large amounts of waste daily that could be utilized for biofuel production. This could solve the problem of using food crops as feedstock for biofuels. This waste could provide additional income to farmers and thus promote agricultural activity in the country [11].

Efficient use of these wastes could also help preserve the aesthetics of the environment by reducing soil and water pollution. Furthermore, employment could be created by educating the local population about the benefits of biomass, avoiding the constant disposal of this waste, and preserving it for energy production. Plant wastes include, among others, cassava shells, yam shells, oil palm residues (wood, fronds, fibers, husks, empty grapes), coconut waste (wood, fronds, husks, peels), plantain waste, pineapple waste, sugarcane bagasse, maize plants (corn stalks, corn husks, corn cobs, leaves), bamboo, and elephant grass. In this case, it is referred to as second-generation biomass because it consists mainly of lignin, hemicellulose, and cellulose. It also includes animal waste such as cow dung, poultry manure, pig manure, and goat dung [20]. For this article, however, we focus on some plant biomass wastes that can be utilized in Nigeria. Table 1 therefore presents the main characteristics of the country's major energy crops along with production data from 2016 to 2018.

It is estimated that Nigeria could generate 2.01×10^{6} terajoules [TJ] of energy per year from approximately 168.49 million tons of agricultural residues and waste. This is in line with Nigeria's Vision 2030 target of 45,000 MW of annual energy generation for the country [25]. The energy generation from residual biomass, shown in Table 2, can be attributed to the properties and composition of the plant cell wall. For comparison with other energy sources, water resources (small and large hydropower plants) are estimated at 14,750 MW, solar radiation at 3.5-7.0 kWh per square meter per day, and wind energy potential at 150,000 terajoules per year (generated by an average wind speed of 2.0-4.0 m/s) [26]. Based on a clear indicator, it can be said that the country's potential for electricity generation from biomass, the utilization of which has not yet been completed, could be maximized.

Table 1. Plant biomass production [11].

Biomass (plants)	Year	Production volume (tons)	Harvested area (ha)	Yield (hg/ha)	Yield (tons/ha)
manioc	2016 2017 2018	59,565,916 59,350,878 59,475,202	6,167,296 6,629,632 6,852,857	96,584 89,524 86,789	9.66 8.95 8.68
But	2016 2017 2018	11,547,980 10,420,000 10,155,027	6,579,692 6,540,000 4,853,349	17,551 15,933 20,924	1.76 1.59 2.09
Fruits of the oil palm	2016 2017 2018	7,808,866 7,743,722 7,850,000	3,052,166 3,033,892 3,015,530	25,585 25,524 26,032	2.56 2.55 2.60
coconut	2016 2017 2018	283,140 281,626 285,200	39,094 38,418 38,297	72,426 73,306 74,470	7.24 7.33 7:45 a.m.
sugar cane	2016 2017 2018	1,487,173 1,489,379 1,423,086	93,690 93,890 91,943	158,734 158,631 154,778	15.87 15.86 15.48
sweet potato	2016 2017 2018	49,384,352 47,934,183 47,532,615	5,789,107 5,840,577 5,990,184	85,306 82,071 79,351	8.53 8.21 7.94
Plantains and others	2016 2017 2018	3,032,054 3,062,963 3,093,872	494,210 498,157 502,087	61,351 61,486 61,620	6.14 6.15 6.16
pineapple	2016 2017 2018	1,565,185 1,622,989 1,664,510	189,989 195,950 199,891	82,383 82,827 83,271	8.24 8.28 8.33

Table 2. Energy potential of some common crop residues in Nigeria for 2018.

Biomass plants	**residue generated**	**production (10.3 tons)**	**Calculated residue Generated**	**energy potential (TJ)**
But	stem	7,562	11,256	176.4
rice	straw	3,420	4976	77.36
Sorghum	stem	4,894	12,850	223.6
Wheat	stem	36.8	58.7	1.24
coconut	sleeve	196	108	1.68
Fruits of the oil palm	A pile of fruit	8,724	2,264	34.52
sugar cane	Bagasse	1,686	438	6.36
cocoa	Dissect	464	467	7.52
millet	stem	4,376	12,834	198.64

Source: Ref. [11]

5. Conclusion

Although Nigeria is Africa's largest and most populous economy and has abundant energy resources, its growth is hampered by the lack of availability and reliability of electricity. Growth over the past decade has been slow, and only 17% of the population has access to clean cooking fuel. Poor infrastructure and a difficult business environment hamper foreign investment, economic progress, and diversification. By 2050, the country's population is expected to reach 400 million, and the urban population is projected to rise from 54% in 2022 to

70% in 2050. Although 55% of the population has access to electricity, 66% is underserved or without electricity, and power outages are common in both rural and urban areas. The standard of living of Nigerians is therefore low.

Africa contributes to the world's energy needs while meeting its own. North Africa's energy landscape continues to evolve thanks to a dynamic oil and gas sector and an increasing emphasis on renewables such as wind, solar, and green hydrogen. Major players such as Egypt, Algeria, and Morocco are harnessing their mineral wealth to transition to renewable energy while maintaining their position as natural gas exporters. Egypt aims to generate 42% of its electricity from renewables by 2035, thanks to significant investments in solar projects such as the Benban Solar Park . Morocco aims to achieve a renewable energy share of over 52% by 2030, focusing on large-scale solar and wind projects. In East Africa, countries such as Kenya, Ethiopia, and Tanzania are making progress in developing renewable energy and improving rural electrification. Thanks to large-scale projects such as the Lake Turkana wind farm, Kenya has achieved an electricity supply rate of over 75% and aims to generate 100% of its energy from renewable sources by 2030. The Grand Ethiopian Renaissance Dam in Ethiopia is expected to boost regional energy exports. At the same time, Southern Africa is leading the development of renewable energy, particularly solar and wind power, and South Africa dominates investment in the region. Namibia is focusing on developing renewable energy to support the production of green hydrogen, leveraging its abundant solar and wind resources. Despite significant progress in these regions, challenges remain regarding infrastructure and financing. This underscores the need for further investment and cooperation to meet growing energy demand and ensure the transition to sustainable energy systems.

Africa's electricity demand will increase by about 75% in the decade to 2030, from 680 TWh to 1,180 TWh. Overall, households will account for more than half of this increase. This rise is due to increased ownership of electrical appliances and other electrical equipment among those who already have access, as well as new household connections. Industry will meet most of the remaining demand. Total per capita electricity demand will rise from 500 kilowatt-hours (kWh) in 2020 to 700 kWh in 2030, but will remain well below that of other developing regions. Consumption is even lower in sub-Saharan Africa , although it is growing faster there than in any other region (from 170 kWh to 390 kWh).

Biomass is used as an energy source in most parts of Africa, mainly for cooking and other thermal purposes, but has low conversion efficiency. A large proportion of the population in sub-Saharan Africa lacks access to electricity, and there is no immediate solution to alleviate this problem using conventional energy sources. The efficient use of biomass in Africa can meet both cooking and electricity needs. By utilizing a small proportion (approximately 30%) of existing agricultural and forestry residues, there is potential for distributed electricity generation of approximately 15,000 to 20,000 MW. The deployment of efficient distributed electricity generation technologies through gasification could help meet this electricity demand. It also highlights the main barriers to biomass energy utilization in sub-Saharan Africa, such as resource mapping, capacity building, and technology demonstration.

This study examines the biomass resources currently available in developing countries such as Nigeria and their potential for use in the production of various biofuels. The tables and figures in this article demonstrate that Nigeria, as a representative developing country, has sufficient reserves of plant biomass. If properly utilized, these reserves could significantly help reduce fuel imports from abroad, meet the population's basic electricity needs, and ultimately contribute to GDP growth. Electricity demand in Nigeria is expected to increase throughout the year. Therefore, it is necessary to supplement the grid with an off-grid system, such as generators that operate quietly and smoothly using clean fuels instead of petroleum-based fuels. This article also highlights some measures taken by the Nigerian government to promote and increase biofuel production in the country to reduce fossil fuel consumption and protect the environment from further depletion. If Nigeria could leverage its position as one of the largest producers of some of the biomasses described here to produce biofuels from the resulting waste, this could be of great benefit to the country and its neighboring countries.

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