



A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria



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ABSTRACT

Nigeria is the most populous country in Africa (7th most populous in the world) and it is strategic to the realization of the United Nations' Sustainable Development Goals (SDGs) by 2030. However, SDG No. 7 (affordable and clean energy) and other goals connected to the reduction of climate change are crucial for the attainment of sustainable development in Nigeria. This comprehensive review encompasses the discussions of the clean energy potential, obstacles to and stimulants of clean energy implementations, and renewable energy policies in Nigeria. Solar and biomass resources have been presented in this article because of their huge availability in Nigeria. Nigeria has the potential to produce an estimated 47.97 million tonnes of oil equivalent (MTOE) annually from biomass resources. Likewise, 17, 459 billion MJ/day of solar energy is incident on the total surface of Nigeria. The biomass resources which can be tapped for renewable energy production in Nigeria include *Jatropha* with high oil contents, sweet sorghum and molasses; food crops such as cassava, rice, coconut, cashew, millet, rice, oil palm, maize, and yam; agricultural residues and wastes from food crops such as cassava peels, cassava liquid sludge, mango peel, mango seed kernel, rice husks (RH), corn residues, oil palm derivatives, sugar cane straw, and bagasse; forest resources; municipal solid wastes; and animal wastes. These resources can be exploited for the production of biogas, bioethanol, biodiesel, briquettes and organic fertilizers through anaerobic digestion, transesterification, gasification, pyrolysis, and briquetting. There are also huge potentials for the deployment of solar photovoltaic (PV) and thermal systems in off-grid, grid-connected, and hybrid installations. It can be concluded that the techno-economic feasibility and environmental significance of solar power and bioenergy for Nigeria's sustainable development is site-specific and subject to factors such as incentives and financing, research and development, public enlightenment, government's policies, and private investments.

1. Introduction

On September 25, 2015, the 17 Sustainable Development Goals (SDGs) were adopted by the world leaders to replace the Millennium Development Goals (MDGs) and set a clear agenda for the eradication of poverty, inequality, and environmental pollution by 2030 [1]. A crucial goal that is well-connected to many of the other goals is SDG No. 7, which is to ensure universal access to clean and cost-effective energy [1]. As the 7th most populous country in the world, Nigeria is a strategic member of the United Nations and the country would play a vital role in the attainment of the clean energy target of the SDGs [2]. Nigeria is among the first ten leading exporters of crude oil in the world. The maximum petroleum production capacity of the country

stands at 2.5 million barrels per day. Nigeria has reserves of 28.2 billion barrels of crude oil and 165 trillion standard cubic feet (scf) of natural gas, making it one of the countries with the largest fossil fuel reserves in the world [3]. The gross domestic product (GDP) of Nigeria is the highest in Africa – US\$ 521.8 billion - and the country continues to be the most populous nation in Africa with a population of 173.6 million people [4,5]. With these statistics, it is obvious that Nigeria is a significant contributor to the world's fossil-based energy consumption. However, production of energy for local use is still abysmally low [6–8]. The electrical power currently available for national use, mainly from natural gas-powered and hydro plants, is just above 3 GW [9]. Only about 40% of the total households receive energy from the national grid while more than 45% do not have access to any form of

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electricity [10]. Of these 40% households that have access to the grid, 6% are using diesel generators as supplements while 3% are totally reliant on self-generation – possibly to avoid the distress that intermittent power supply can have on their businesses [10]. A recent report [11] examined the access of a large proportion of the populace to up-to-date electricity services in order to determine the trend of electricity use in Nigeria. In spite of the huge energy resources available in the country [12], a large chunk of the population – more than 40% – still relies on crude and conventional energy sources such as firewood and kerosene for all their energy needs. Out of this, about 20% of the population still depends on kerosene. The rural electrification programme in Nigeria is ineffective because only about 1.1% of rural residents have access to electricity [11]. The quality of electricity services in Nigeria remains poor and many Nigerians are still without access to regular electricity [13,14].

Despite its vast available renewable resources, over-dependence on fossil-fuel energy is the bane of clean electricity supply in the country [15–18]. The extent that Nigeria has fallen behind in the global energy scene can be clearly depicted by comparing the country's total installed capacity with that of Germany, a country located in a temperate region. Despite the fact that Nigeria is situated in the tropical region, Germany's installed solar capacity is now about eight times greater than the highest peak total electricity generation in Nigeria [19,20]. The highest peak energy generation in Nigeria is 4,810.7 MW of electricity and this peak was achieved on August 25, 2015 [20]. Nigeria ranks amongst the lowest in terms of electrical energy production per capita in Africa. Without any doubt, qualitative and abundant energy facilities are crucial to the sustainability of national economic progress and creation of wealth [17]. Coupled with its deleterious environmental effects, fossil fuels have also been partly responsible for the political crises and economic instability of the country [21]. Heavy dependence on fossil fuels, adverse environmental impacts of fossil fuels, and deterioration of electricity transmission and distribution facilities have necessitated clamors for investment in renewable energy [16,22]. Therefore, the development of alternative sources of energy is crucial to Nigeria's energy security and environmental preservation.

Biomass and solar resources are widely and abundantly available in Nigeria [23–27]. The available sustainable biomass resources in Nigeria include wood, grasses, shrubs, plantain peels, forage, cocoa pods, animal waste, and livestock manure [23]. Generally, these biomass resources are categorized into forestry resources, agricultural crops, municipal solid waste, agricultural crop residues, and animal wastes [28]. Since biomass is more labor-intensive (100 times more workers per unit of energy produced) compared to fossil fuels, it could also help to mitigate unemployment issues [29]. The bioenergy potential of Nigeria is 144 million tons per year [25]. In addition, the abundance of solar radiation incident on Nigeria makes it an excellent candidate for implementation of solar energy applications such as stand-alone units, off-grid decentralized systems, and large scale grid-connected applications [30–33]. Nigeria receives an estimated $20 \text{ MJ m}^{-2} \text{ day}^{-1}$ of mean insolation [19]. According to a report in 1987, a thousandth of the total solar radiation was sufficient to meet the annual consumption of the country (which was between 21 and 109 kWh back then) [34]. Currently, the total energy demand in Nigeria could be met if 0.1% of the total solar radiation is converted to electrical energy at a conversion efficiency of 1% [12]. Nigeria needs only 3.7% of its landmass to produce solar energy to meet its national demand. The dismal state of energy appropriation combined with the finite hydrocarbon reserves make it exigent for Nigeria to utilize its renewable resources to reverse a dearth in energy supply and possibly attain the full electrification of the country – for urban and rural dwellers alike [35]. Therefore, this paper aims to give a comprehensive review of the solar and biomass resources available in Nigeria; the past and present policies guiding the exploitation and conversion of these resources; existing opportunities that have not been tapped in the growing solar and biomass industry in Nigeria; concluded and ongoing

projects in this area; conversion technologies that have been deployed at all levels of management (public and private); and the environmental and economic benefits of massive deployment of solar and biomass resources for electricity and clean energy production in Nigeria.

Solar energy is the source and cornerstone of all forms of energy on earth [36]. Solar energy is invaluable because it is highly abundant in Nigeria and can be converted to any form of energy using processes consisting of few stages [37]. This review focuses on solar energy in particular because the country is in the tropical zone (just above the equator) and receives abundant sunshine all year round in many locations [22]. In addition, the potential to utilize solar energy for electricity generation in Nigeria is very high because it has been well studied using familiar and proven energy conversion technologies [37]. Today, hydropower contributes the highest percentage to the renewable energy mix in Nigeria. However, hydropower stations including the small hydropower plants require huge investments and may not be applicable for use in individual homes and small settlements [38]. Solar PV technology, for example, is maturing every day and cost of electricity from PV is sliding downwards. Another competitive advantage of solar energy is the relative ease of deploying solar energy for decentralized applications in Nigeria using readily available or ready-made technologies such as off-the-shelf PV panels [39,40]. This review also focuses on bioenergy because it is currently the least expensive and most widely used energy in Nigeria's rural areas [41]. Bearing in mind that the rural population of Nigeria is more than half of the total population [42], the importance of bioenergy as a renewable energy source in Nigeria cannot be overemphasized.

2. Biomass resources and bioenergy in Nigeria

2.1. Biomass resource potential and assessment for energy generation

Biomass is a potential source for substantial renewable energy production in Nigeria because it is widely available. There is huge amount of biomass in Nigeria that is yet to be explored; and if this resource can be tapped, it would go a long way to ameliorate the adverse socio-economic and environmental effects of clean energy shortages in Nigeria, provided that structured policies are being implemented effectively. Nigeria has the potential to produce an estimated 47.97 MTOE annually from biomass resources [43]. The Nigerian government could tap into the enormous biomass resources available to generate electricity and this will serve as a backup for the exhaustible fossil fuel resources. If biomass production for energy purposes can be a direct replacement for fossil fuel, it will help in reducing CO₂ emissions and consequently reduce global warming. Biofuels from biomass can be classified as follows: solid fuels such as solid biomass (wood, leaves, grass) and charcoal; liquid fuels such as oxygenates (methanol, ethanol) and hydrocarbons (biodiesel, synthetic diesel and synthetic gasoline); and gaseous fuels such as methane, landfill gas (from bio-degradable landfill sites), sewage gas (waste water and sewage), agricultural biogas (from farm slurries and agricultural residues) and biogas from mixture of methane, CO₂, H₂S, N₂ and water vapor [44]. Not only would the use of biogas, for example, reduce CO₂ emissions from fossil fuel combustion, CO₂ emissions would also be saved from the application of bio-manure (instead of inorganic nitrogen fertilizer) produced as a co-product from biogas processing. It is estimated that 83,600 tonnes of CO₂ can be saved annually from use of bio-manure in place of inorganic nitrogen fertilizer [45]. Other applications of biogas besides power generation such as transportation, lamp fuel and use as cooking gas would add to the overall environmental benefits of biogas.

Some bioenergy projects in Nigeria include: Epe Integrated Solid Waste Management Project in Lagos State; gas-to-energy projects at Olushosun landfill site in Lagos State; Biofuel Production Complex at

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