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*Review Article*

# An Overview of Energy Resource and Future Concerns for Ghana's Electricity Generation Mix

**Mark Amoah Nyasapoh**,[1,2,3] **Seth Kofi Debrah**,[3,4] **Daniel Kwabena Twerefou**,[1] **Samuel Gyamfi**,[2] **and Foster Kwame Kholi**[5]

[1]*Department of Economics, University of Ghana, P.O. Box LG 57, Accra, Ghana*
[2]*Regional Center for Energy and Environmental Sustainability (RCEES), University of Energy and Natural Resources (UENR), P.O. Box 214, Sunyani, Ghana*
[3]*Nuclear Power Institute-Ghana Atomic Energy Commission, P.O. Box LG 80, Legon, Accra, Ghana*
[4]*Department of Nuclear Engineering, School of Nuclear and Allied Sciences, Atomic Energy, University of Ghana, Legon, P.O. Box AE 1, Accra, Ghana*
[5]*Hylium Industries Inc, Pangyo-ro 289 Beon-gil, Bundang-gu, Seongnam-si, Gyeonggi-do, Osan Seoul, Republic of Korea*

Correspondence should be addressed to Mark Amoah Nyasapoh; markamoah51@gmail.com

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Energy supply is a critical indicator for the global United Nations initiatives because of its immense contribution to economic development. In essence, identifying the required energy resource coupled with effective policy strategies is essential to sustainable electricity generation. Nevertheless, future electricity supply requires a range of options that must be robust and workable. Globally, the challenge of harnessing the energy resources sustainably needed for effective electricity generation is alarming. Therefore, the ability to supply a country's electricity based on the availability and affordability of resources is vital for effective governance. In this study, Ghana's energy resourcefulness and the profound effects on the future mix of electricity generation are qualitatively reviewed. In particular, the study covers the existing and potential energy resources available for sustainable electricity generation. The study revealed that Ghana mainly uses hydro, natural gas, and solar energy, among others, for electricity generation. Additionally, a framework explores a well-diversified generation mix using nuclear, coal, and more renewable energy sources in the long-term. Key issues that emerged for national consideration include the need for effective policy direction and implementation, appropriate financing concepts, fuel availability, political will, and setting. By far, this review sought to emphasize literature gaps by providing a rich and fertile ground as a template for industry operators, policymakers, and future research direction.

## 1. Introduction

Energy resources serve as fuel to produce electricity for the use of society at various levels. The electricity supply is transforming resources such as fossil fuels (coal, natural gas, and petroleum), nuclear fuel, and renewable energy (RE) sources. The ability to supply a country's electricity needs based on resource availability and affordability is vital for effective governance. The attainment of this objective revolves around a proper scope of energy planning, though with varying degrees of comprehensiveness. Successful planning of electricity supply comprises a set of options and conversion technologies to meet demands and minimize the cost of the optimal combination of generation in a centralized or decentralized stage [1–3]. The scope of energy planning involves suitable energy supply options and practical implementations beyond the identification or decision-making of technology [3, 4]. Beyond the simplistic view, energy planning can apply the multicriteria nature of energy resources at various stages along the value chain of electricity including generation, transmission, distribution, and retail [5, 6]. The latter stages are subject to an analysis of technology, socioeconomic, political, and environmental factors to balance electricity demand and supply options [1, 3–5]. These factors can successfully guide sustainable electrification in global transmission networks, including demand estimates, appropriate technologies, planning operations, transmission, and electricity distribution. Further, the imperative of sustainable electricity development requires cohesive power sector activities and infrastructural development [7].

Given the reviews mentioned above, worldwide, the socioeconomic development of many nations depends primarily on the availability of sustainable supply to meet the energy demand [8–10]. Inaccessibility of energy for electricity generation has affected several countries, reaching communities and individuals [11–15]. However, countries in Africa need electricity, including increased literacy rates, better healthcare, higher employment opportunities, and productivity innovations [14, 16–18]. Therefore, recognizing the role of energy in combating global poverty is part of the United Nations (UN) goal of achieving universal access to energy by 2030 through its initiative "Sustainable Energy for All" [19]. Compelled by population growth, goals for socioeconomic development, and environmental challenges, many countries are determined to exploit all possible energy options to secure a sustainable electricity supply [8, 20, 21]. Therefore, the increase in electricity demand for developing countries makes it imperative to take advantage of sustainable energy sources for future electricity generation security [22]. Furthermore, planning and implementation of electricity supply became a significant and current phenomenon resulting from decisions on the choice of energy options for sustainable electricity generation [23, 24]. The choice of suitable energy options for a sustainable electricity supply [25] led to the increased public interest in policies that provide the most effective strategies to sustainably maintain the energy supply in a clean environment [26].

Different countries face different demands and have different opportunities to generate electricity [8]. The best mix for almost all countries depends on exploiting the potential resources [27]. The Africa Progress Panel, indicated by Shaw et al. [28], estimated that about 600 million African people lack electricity access, requiring about 55 billion United States dollars each year in electricity investment by 2030 to fix the challenge [28]. The majority of the population without access to electricity in Africa fall within sub-Saharan African countries [29]. The World Bank data sheet for 2022 revealed that just about 8% of rural residents in West Africa have access to electricity, and 54% of the total population do not have access to electricity [30]. Compared to sub-Saharan Africa, South Asia, with the second-lowest electricity access in the world, can still boast four times rural electrification. The urban and rural electrification ratio in sub-Saharan Africa is 3.5 times higher than the global figure [11, 19]. Hence, large-scale electrification for development requires an effective approach to electricity planning in the short to medium and long-term [1–5, 31].

Ghana, located in sub-Saharan Africa, precisely western Africa, still faces challenges and the effects of limited energy resources needed to sustainably generate electricity [8, 32]. Almost two decades ago, Ghana could boast of a more reliable electricity supply and the highest grid-connected households in the whole of the African continent [33]. The country's ambition for national electrification since the 1980s has led to the expansion of the national transmission and distribution network to date [34]. The representation in Figure 1 is the main electricity transmission along the main national grid depicting the rural and town distribution network across the 16 regions of Ghana [34]. Ghana's electricity access rate is approximately 85.33%, a rate above most sub-Saharan African countries [34].

However, Ghana could not generate enough electricity due to low water levels for hydropower plants such as Akosombo and glitches in gas delivery to power gas-fired power plants. Aside from low water levels for hydroelectric power plants and gas delivery glitches for gas-fired power plants, the attempt on several occasions to provide sustainable electricity generation has faced serious challenges [22, 35, 36]. Furthermore, the renewable energy industry as discussed by Afful-Dadzie et al. [37] attributed the slow pace of penetration of renewable energy to factors such as unattractive market structures and the lack of commitment to legislative and regulatory instruments. Moreover, the electricity sector challenges, in general, arise as a result of inadequate infrastructure investment [36], nondiversification to safeguard energy security [8], high level of distribution losses, and consumer revenue nonpayments [35]. The situation of electricity supply led to recurrent impediments in electricity generation and supply in Ghana [32, 33, 38]. Hence, unreliable power supply has led to business operations challenges, affecting Ghana's economic growth and quality of life [20, 23].

Ghana's Energy Policy by the Ministry of Energy [39] envisaged increasing electricity consumption per capita to about 5,000 kWh per annum by 2030 from the current 534 kWh per annum [40]. Hence, the ambition to increase electricity consumption will meet Ghana's aim to achieve an upper-middle-income status and the UNDESA's [41] projected population of about 37 million by 2030. Ghana mainly uses hydro, natural gas, and solar energy, among others, for electricity generation [40, 42]. The country also exploits additional RE, nuclear power, and coal energy sources for future electricity supply [39]. The study by Afful-Dadzie et al. [37] enumerated outlined the unattractive market structures and regulatory instruments that impact the penetration of renewable energy. In particular, renewable energy bottlenecks were discussed per Ghana's electricity generation plan and presented suggestions for the deployment of RE in Ghana [37]. In the study, Obeng-Darko [43] argued for Ghana's 10% RE ambition to achieve 100% national electrification. However, it was realized that the low interest in Ghana's energy sector, such as renewables, is due to policy commitment that causes investor uncertainty [43]. In a recent study, Nyasapoh et al. [44] argued that despite the renewable energy potentials of Ghana, barely 59 MW has been used representing 1.12% of the national grid connection. Therefore, Aryeetey [26] and Debrah et al. [8] revealed that the ambition to achieve the required amount of electricity


Figure 1: Ghana's national interconnected system [34].

consumption to meet the desired economic growth requires the ambition and implication of the policy to harness sustainable energy options and electricity generation in a resilient manner.

This article presents the energy resource currently used in Ghana for electricity generation and the potential to sustain the supply of the future electricity mix. The article presents the reforms and policies of the power sector to date and the challenges. Also, the resource options and prospects have been outlined to aid policy direction for electricity security concerns. With this, it is expected that the electricity supply will be planned thoroughly in line with economic and industrial aspirations to help avoid unnecessary high investment in the power sector. The study adopted keyword searches in the most prominent search engines to supplement the peer-reviewed academic literature to obtain relevant literature on energy resources and future concerns for the Ghanaian electricity generation mix.

Table 1: Key institution in Ghana's energy sector [34].

| Institution | Functions |
|---|---|
| | Policy and regulation |
| Ministry of Power (MoP) | Formulates, implements, monitors, and evaluates power sector policies |
| Ministry of Energy | Formulates, implements, monitors, and evaluates energy sector policies |
| Energy Commission (EC) | Licenses, regulates, and monitors energy service providers, develops indicative national energy plans, and advises the ministry on energy policies |
| Public Utilities Regulatory Commission (PURC) | Regulates tariffs and enforcement of customer service obligations of all public utilities and IPPs |
| National Petroleum Authority (NPA) | Regulates, supervises, and monitors activities in the downstream petroleum industry |
| Petroleum Commission (PC) | Regulates and manages the utilization of petroleum resources and coordinates policies on petroleum resources |
| Environmental Protection Agency (EPA) | Distributes, monitors, and enforces environmental policies, including the energy sector |
| Ghana Investment Promotion Centre (GPC) | Encourages and promotes investment in Ghana, providing for the creation of attractive incentives framework and a transparent, predictable, and facilitating environment for investment |
| | Implementing body |
| Volta River Authority (VRA) | Generation and transmission of electricity |
| GRIDCo | Electricity transmission services |
| Electricity Company of Ghana (ECG) | Distribution of electricity in southern Ghana |
| Northern Electricity Distribution Company (NEDCO) | Distribution of electricity in northern Ghana |
| Tema Oil Refinery (TOR) | Import of crude and petroleum products, refining of crude oil, and bulk sale of petroleum products to DMC and bulk customers |
| Ghana National Petroleum Corporation (GNPC) | Oil and gas exploration |
| Bulk Oil Storage and Transportation Company (BOST) | Planning for the formation and management of strategic petroleum product stocks |
| Oil Marketing Company (OMCs) | Distribution and marketing of petroleum products |
| | Public education and research |
| The Energy Center, KNUST | Conduct research development, demonstration, and educational activities in the policy and management of energy technology |
| University of Energy and National Resources (UENR) | Provides training in science, technology, and management of energy and natural resources |
| Council for Scientific and Industrial Research (CSIR). | Pursues the implementation of government policies on scientific research and development |
| | Nongovernmental organizations |
| KITE | Energy policy studies and analyst/clean energy enterprise development |
| Association of Ghana Solar Industries (GSI) | Promotes and raises the profile of the solar industry, improves quality, develops standards, and arranges renewable energy training |
| Energy Foundation | Promotes energy efficiency, conservation measures, and renewable energy technologies |
| New Energy | Develops and implements clean initiatives |
| CEESD | Dedicated to technologies that offer engineering solutions to climate change, energy poverty, and environmental degradation |

## 2. A Historical Perspective of Ghana Electricity Supply

The generation of electricity for Ghana passed through several segments [45]. In the early stages, industrial mines and factories own diesel generators as standalone electricity generators as first-generation options. Construction of the Akosombo Dam in 1966 began the hydroelectric phase [35]. Thermal power plants that use crude oil or gas were added to the generation mix [42]. Also, solar and minihydro as RE sources have been included in the generation mix, with the development of new RE projects for Ghana [42, 46–48]. However, Ghana aimed to include coal and nuclear power in the generation mix [39]. The various institutions and stakeholders responsible for an effective energy sector and electricity supply are summarized as represented in Table 1 [34]. The table is divided into the institutional structure that represents the various roles to ensure compliance and is divided into agencies responsible for policy and regulation, implementing bodies, and the area of research needed.

*2.1. Power Sector Reforms and Policies.* For every country, the development of key sectors such as the electricity sector involves many reforms and policies. Ghana is no exception in this regard. Many reforms since 1994 eventually became policies for the electricity sector in Ghana. The first step of the reform of the energy sector was to commercialize the operations of the energy sector. As part of the power sector reform development, the electricity generation part of the power industry got participated by independent power producers (IPPs). Despite the IPP initiative, the Volta River Authority (VRA) continued to produce wholesale electricity [49]. The open regulation of the electricity industry led to the establishment of the Public Utilities Regulatory Commission Act (Act 538) and the Energy Commission by the Energy Commission Act (Act 541).

Moving forward, the significance of energy to national development led to the establishment of policies and interventions to develop and implement the energy sector reforms. The policies mainly include the 2001, 2010, and 2019 National Energy Policies [39, 45]. In the first stage of Ghana's policy development, the electricity sector development policy targeted Indigenous Hydropower Resources for Electricity Generation. The Ghana electricity sector developed from 1983 to 2001 to retrofit and modernize electricity generation facilities and national electrification schemes. Furthermore, the 2010 energy sector development policy aimed to expand capacity generation and diversify the mix of energy generation. Also, the policy intervention of the (2010) before and after led to the inclusion of thermal power generation and saw the retrofitting of the Akosombo Dam project in 2005. The Akosombo Dam retrofitting project increased the plant efficiency, prolonged the lifespan, and upgraded the plant's capacity from 912 MW to 1,020 MW [50]. In 2020, several industries, housing, and infrastructure policies were made and largely sought investment in electricity infrastructure to support Ghana's economic development aspirations [39]. In recent times, the Renewable Energy Amended Act (2020) indicated that all hydroelectricity systems like Akosombo, Kpong, and Bui power dams are defined as renewables [51]. Despite the numerous reforms and policies implemented in the Ghana power sector in the last three decades, there are significant challenges to a sustainable power supply.

## 3. Current and Future Electricity Supply

To sustainably supply the needed electricity lies in effectively identifying the electricity sector ambitions based on Ghana's current electricity supply situation.

*3.1. Status of the Electricity Supply, Challenges, and Economic Growth.* The security of a nation's wealth and socioeconomic development is attributed mainly to the sustainable electricity supply [9, 27, 52]. Hence, the growth rate of electricity consumption is an essential factor for economic development [53, 54]. Besides, several empirical studies have found that electricity consumption is positively correlated to economic growth [55–60]. Hence, the remarkable economic and social development achieved in high-income countries could not have been accomplished without significantly increasing reliable and affordable energy services to industries, social services, and households [61]. In 2004, Ghana's electricity consumption in billion kilowatt hours increased marginally to 7.09. The country currently had an installed capacity of three times, from 1,652 MW in 2000 to 2,165 MW in 2010 and 5,288 MW in 2020 [40]. Table 2 represents the total installed capacity for Ghana from 2000 to 2020 [40].

The Ghanaian economy in 2019 was rebased and valued at US$ 58.18 billion with per capita of US$ 2,214, aimed at attaining an upper-middle-income economy by 2030 [62]. Hence, the projected electricity consumption per capita of 5,000 kWh by 2030 is expected to accompany the upper-middle-income status [39]. The ambitions outlined by the [39, 62] will pressure the social infrastructure, especially the electricity sector. The Ghana Social Development Outlook (GSDO) [63] recognized that the main constraints to sustainable development are inadequate clean energy technologies, unreliable electricity, and high prices.

As mentioned above, the generation of electricity in Ghana went through several phases to reach the current mix of hydro, thermals that use either crude oil or natural gas, and renewables, mainly solar and minihydro [40]. Today, almost 85.33% of the Ghanaian population can access electricity, making Ghana one of the highest electricity access rates in sub-Saharan Africa [40, 42]. However, as the country's economy expands with population growth, the ambition to provide the required power capacity is faced with great challenges. [20, 22, 64] asserted that issues of inadequate power supply and persistent power outages heavily impacted the Ghanaian economy. [35] revealed that in 2014, the Ghanaian economy lost almost $ 680 million (2% of GDP) due to the power crisis. In addition, [63] asserted that the power crises in Ghana led to a decrease in the real GDP growth rate from 7.3% in 2013 to 4.2% in 2014 [22]. Furthermore, the loss in economic activities resulting from power crises was estimated to vary annually from 1% to 5% of GDP [64, 65].

Besides, the Africa Energy Group World Bank [66] graded Ghana's electricity sector challenges as a major limitation to economic activities in Ghana, leading to the 2007 power crisis causing about 1.8% loss to GDP. Furthermore, an ISSER estimate [63] revealed that on average, the power crisis only caused a production loss of approximately US $2.1 million daily and about US $55.8 million monthly.

Therefore, it remains the fact that a key separation between developed and developing countries is electricity [67–69]. For this reason, [63] asserted that providing reliable and affordable electricity to countries creates wealth for sustainable development. Ghana must achieve its industrial and economic aspirations on the backdrop of sustainable electricity generation as projected. Hence, there is a need to provide the appropriate mix of electricity generation from the available energy resource. Therefore, national strategies are

Table 2: Installed and dependable capacity (MW) [40].

| Year | Hydro | Thermal | Other renewable | Total | Hydro | Thermal | Other renewable | Total |
|---|---|---|---|---|---|---|---|---|
| 2000 | 1,072 | 580 | — | 1,652 | 928 | 430 | — | 1,358 |
| 2001 | 1,072 | 580 | — | 1,652 | 951 | 530 | — | 1,481 |
| 2002 | 1,072 | 580 | — | 1,652 | 974 | 530 | — | 1,504 |
| 2003 | 1,072 | 580 | — | 1,652 | 982 | 530 | — | 1,512 |
| 2004 | 1,180 | 550 | — | 1,730 | 1,040 | 500 | — | 1,540 |
| 2005 | 1,180 | 550 | — | 1,730 | 1,040 | 500 | — | 1,540 |
| 2006 | 1,180 | 550 | — | 1,730 | 1,040 | 500 | — | 1,540 |
| 2007 | 1,180 | 755 | — | 1,935 | 1,040 | 670 | — | 1,710 |
| 2008 | 1,180 | 801 | — | 1,981 | 1,040 | 695 | — | 1,735 |
| 2009 | 1,180 | 790 | — | 1,970 | 1,040 | 725 | — | 1,765 |
| 2010 | 1,180 | 985 | — | 2,165 | 1,040 | 900 | — | 1,940 |
| 2011 | 1,180 | 990 | — | 2,170 | 1,040 | 905 | — | 1,945 |
| 2012 | 1,180 | 1,100 | — | 2,280 | 1,040 | 1,005 | — | 2,045 |
| 2013 | 1,580 | 1,248 | 3 | 2,831 | 1,380 | 1,105 | 2 | 2,487 |
| 2014 | 1,580 | 1,248 | 3 | 2,831 | 1,380 | 1,187 | 2 | 2,569 |
| 2015 | 1,580 | 2,053 | 23 | 3,656 | 1,380 | 1,957 | 22 | 3,359 |
| 2016 | 1,580 | 2,192 | 23 | 3,795 | 1,380 | 2,119 | 22 | 3,521 |
| 2017 | 1,580 | 2,785 | 23 | 3,795 | 1,380 | 2,568 | 18 | 3,966 |
| 2018 | 1,580 | 3,266 | 43 | 4,889 | 1,380 | 3,058 | 34 | 4,472 |
| 2019 | 1,580 | 3,549 | 43 | 5,172 | 1,365 | 3,296 | 34 | 4,695 |
| 2020 | 1,580 | 5,649 | 59 | 5,288 | 1,400 | 3,395 | 34 | 4,842 |

needed to address issues that involve the smooth operation of the electricity sector, especially concerns about energy resources.

*3.2. Future Plans for Electricity Generation.* Ghana's aspirations to attain an upper-middle-income status and the projected increase in population by 2030 will result in an accelerated rise in electricity demand [46, 62]. However, the country's energy sector faces inconsistent electricity supply amid high tariff challenges in recent decades. In addition to the alarming challenges, the industrial and economic ambitions and increasing population growth would further pressure electricity consumption beyond anticipated [70]. Hence, the energy sector implications on the Ghanaian economy would require consented efforts to improve electricity generation with some ambitions.

*3.2.1. Short-to-Medium and Long-Term Plans.* Ghana's energy policies [39, 45, 46] aim to address the challenges in the electricity sector in short to medium-term preventive strategies. The policy objective is to plan and achieve a complete cost-competitive electricity generation and supply sustainably.

As stated earlier, RE sources that include but are not limited to hydro, solar, wind, biofuels, and municipal waste are considered in Ghana. Although it settled well on natural gas issues for electricity generation, the country decided to explore alternative power sources such as nuclear and coal to enhance energy security.

*(1) Natural Gas Imports.* In addition to the gas supply from the current indigenous gas fields of Ghana and future gas resources, there is still gas from Nigeria through the WAGP and the potential for LNG imports for electricity generation [71]. The WAGP natural gas from Nigeria is expected to satisfy Ghana's future growth in gas demand for a 3,000 MW combined cycle power plant of 474 MMscf/day. Figure 2 presents the 678 km pipeline connecting with the Escravos-Lagos pipeline at the Nigeria Gas Company's Itoki natural gas export terminal to Ghana [34].

However, the installation of the pipeline in 2008 with a maximum capacity of 474 million standard cubic feet (MMscf) per day [34, 72] saw a below-average performance of 120 MMscf/day, less than the contracted volume and its accompanied volatile prices. Figure 3 further presents the annual production and imports of natural gas from 2009 to 2020 [40]. Despite the continuous decline in natural gas imports that is mainly used for electricity generation over the years, there is somehow an increase in local production [40].

Therefore, the inability of Ghana to find new economically competitive natural gas fields or sources means that current domestic natural gas resources will decline by 2030 [39]. As a result of the scarcity of indigenous energy resources, Ghana's energy supply security strategy should develop an optimal generation mix. Combining the mix of generation with external and internal energy sources will achieve Ghana's long-term socioeconomic and environmental benefits.

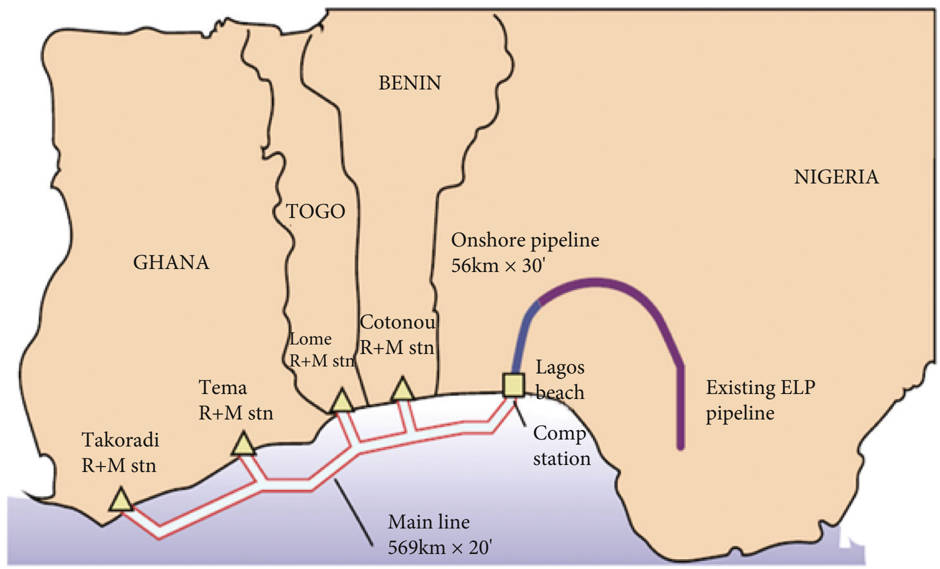


Figure 2: Schematic of the West African Gas Pipeline (WAGP) from Nigeria to Ghana [34].

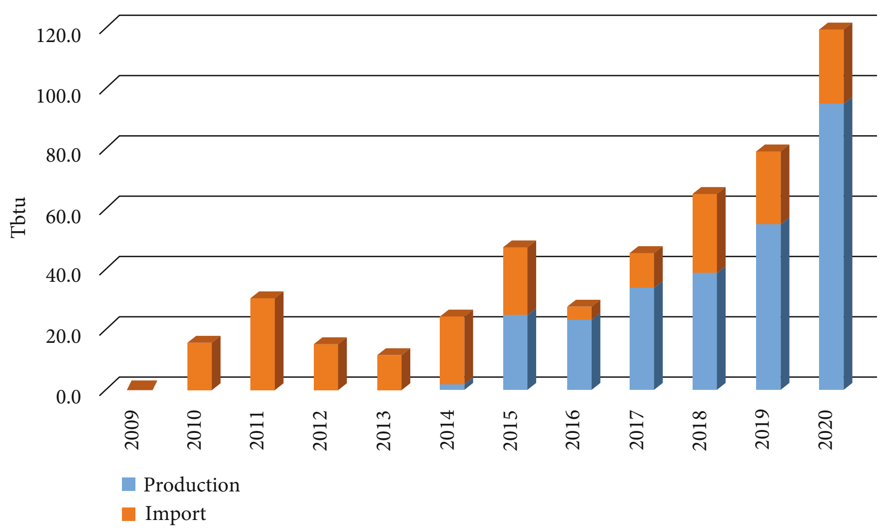


Figure 3: Annual production and imports of natural gas [40].

*(2) Baseload Energy Options*. The 2019 Energy Policy Draft aims to add coal and nuclear energy options to Ghana's energy mix to serve as baseload energy options. Integrating such energy sources is expected to guarantee energy security, equity, and long-term electricity supply. The ambition to include coal and nuclear in the country's energy mix serves as a baseload option to drive the long-term industrial goal.

*(3) Nuclear Power*. Ghana currently considers including nuclear power in the energy mix to serve as baseload and low-carbon technology [8, 73, 74]. The plan to explore nuclear power in Ghana dates back to the 1960s [75]. Following the third major energy crisis in Ghana in 2007, a cabinet decision was taken in 2008 to include nuclear power in the country's generation mix within a decade [39]. It was also estimated that technological tradeoffs in Ghana's energy mix will favour nuclear due to environmental friendliness while serving as a baseload [74]. Ghana's first nuclear plant is expected to be operational by 2030.

Studies conducted in the 1970s and recently indicated that some uranium deposits in Ghana could be used as nuclear fuel [76]. Besides, there are ongoing studies to assess the commercial viability of uranium deposits. [77] revealed that if Ghana relies exclusively on imported nuclear fuel, the supply and cost of nuclear fuel are considered a lesser challenge. Nuclear power fuel is relatively cheap and has relatively less volatility in prices. Nuclear fuel constitutes about 34% of electricity generation costs compared to 87% gas and 78% coal [78].

*(4) Coal Power*. With its partner Shenzhen Energy of China in 2014, VRA proposed a 700 MW (2 × 350) "Supercritical Coal-fired Power Plant" to be sited at Ekumfi District of


Figure 4: Existing and potential hydropower sites in Ghana [80].

Table 3: Natural gas discoveries and reserves [84].

| Natural gas fields | Associated gas in-place (BCF) | Nonassociated gas-in-place (BCF) | Year of discovery | Year of start production | Year of the end of production | Expected peak daily production (mmscf/day) |
|---|---|---|---|---|---|---|
| Jubilee | 568 | 0 | 2007 | 2015 | 2022 | 100 |
| TEN | 294 | 59 | 2009-2012 | 2016 | 2027 | 85 |
| SGN | 287 | 1071 | 2009-2012 | 2016 | 2038 | 180 |

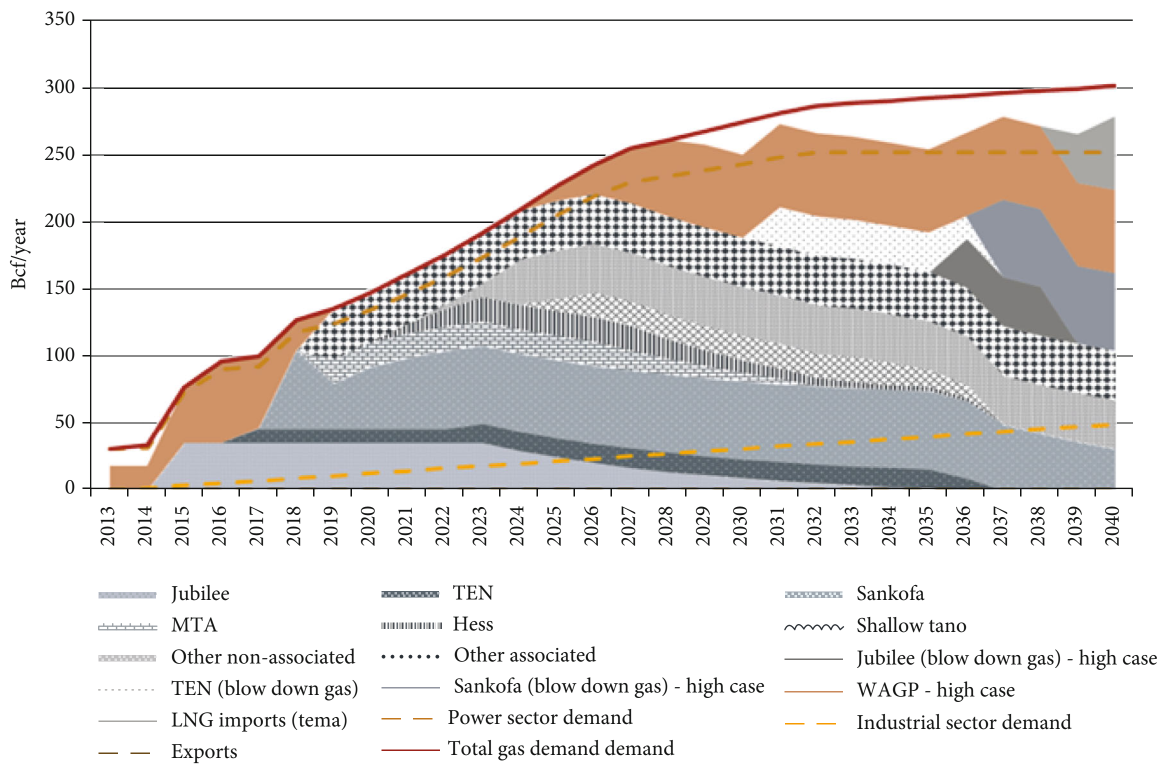


Figure 5: GNPC high-case gas supply for Ghana [84].

the Central Region pulverized coal fuel from South Africa [39]. Environmental and Social Impact Assessment (ESIA) and feasibility studies were completed to build Ghana's first coal power generation to begin operating in 2016 and completed in 2020. That being said, the coal power agenda could not be implemented due to environmental and political concerns [79]. Environmental concerns in Ghana's electricity generation mix have been further evidenced in the recent study by Nyasapoh et al. [25].

## 4. Energy Source for Ghana's Electricity Generation

Ghana's electricity generation involves a variety of fuel options among renewables. The main energy resources available for electricity production in Ghana include hydropower, oil, and natural gas, and the continued exploitation of RE options. Besides, efforts are being made to embark on more RE sources such as solar, wind biomass, and untapped hydropotentials, mainly minihydro. The country's nuclear power program and uranium deposits have also received some attention in recent times. The energy resources, their prospects for Ghana, and the availability of fuel for electricity generation are discussed.

*4.1. Hydropower.* Ghana's initiative to accelerate development with sustainable electricity generation dates back to 1963, with comprehensive strategic growth in the agricultural, industrial, and service industry "take-off." This ambition led to the investment in the Akosombo Hydro Electric Power project in 1963. The country's hydroelectric potential is estimated to be approximately 2,420 MW Figure 4 represents a map of Ghana's hydropower sites, including tapped and untapped potentials [80]. Out of the total potential, 1,580 MW, made up of 65.3% hydropotentials, has been exploited.

The current hydroexploitation in Ghana comprises the Akosombo Hydropower Plant, with an installed capacity of 1,020 MW and a dependable capacity of 900 MW and Kpong Hydroelectric Plant 160 MW with a reliable capacity of 148 MW. The Bui Hydroelectric Plant on the Black Volta River is the third hydroelectric operation in Ghana with an installed capacity of 400 MW and a reliable capacity of 342 MW. The remaining are the estimated 840 MW mini-hydroelectric power plants that have yet to be exploited to produce a reliable capacity of approximately 500 MW [81]. Unexploited hydroresources have capacities below 100 MW, classified as mini-hydropower potentials for Ghana. These include, but are not limited to, Hemang on the Pra River (90 MW), Juale on the Oti River (90 MW), Pwalugu on the White Volta River (60 MW), Lanka on the Black Volta River (95 MW), and Abemia on the Tano River (50 MW).

*4.2. Domestic Natural Gas.* The discovery of crude oil-associated natural gas in Ghana's sedimentary basins in 2007 included the offshore Cape Three Points and Jubilee Fields. Furthermore, natural gas was again found in the fields "Tweneboa, Enyenra, and Ntomme (TEN)" and "Sankofa-Gye Nyame (SGN)" [82–84]. Ghana's discovered natural gas reserves-in-place that include associated and nonassociated gas increased fourfold from 0.57 trillion cubic

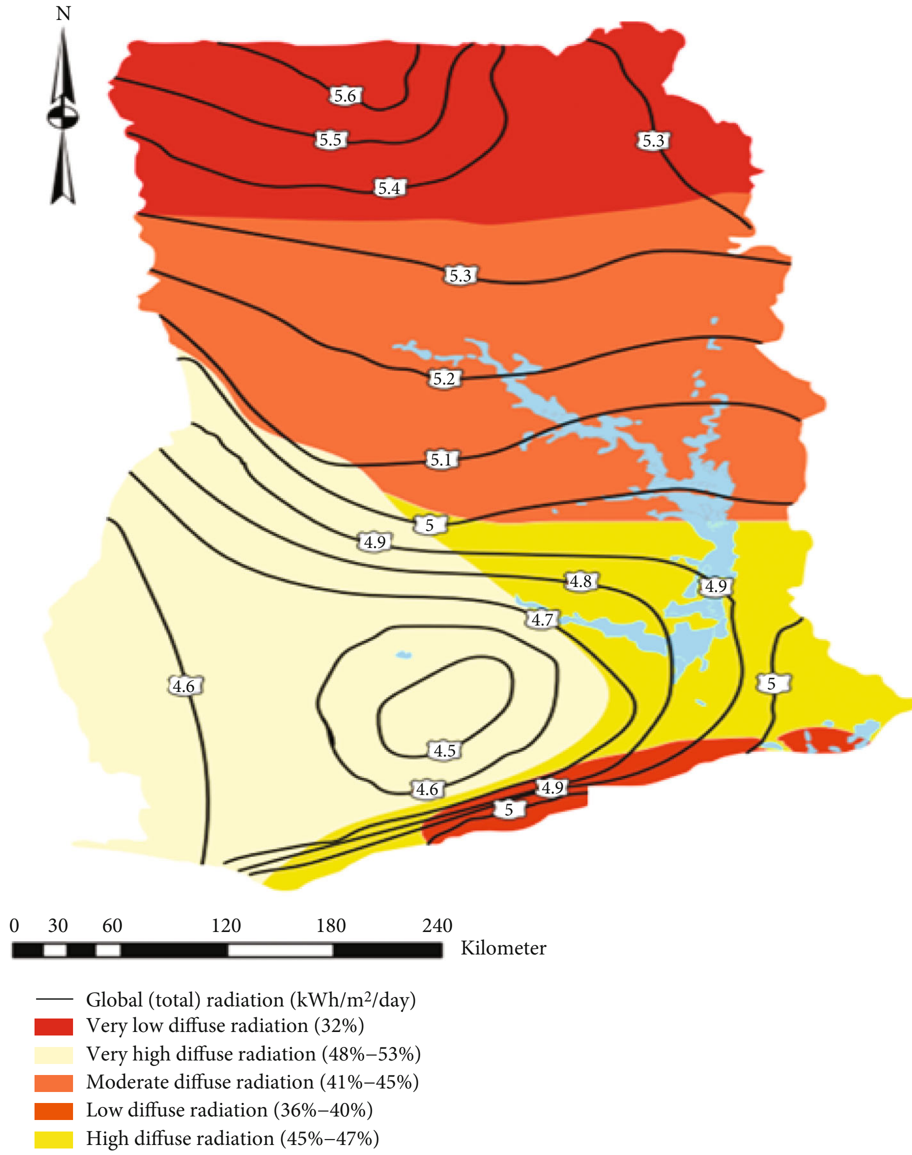


Figure 6: Global solar radiation in Ghana [80].

feet (Tcf) in 2010 to about 2.38 Tcf in 2014. Table 3 shows Ghana's natural gas field discoveries and reserves [84]. The estimate is that Ghana could recover 80% of the natural gas reserves for electricity generation. The natural gas reserves are estimated to supply electricity from a 1,200 MW combined cycle power plant with a 7800 BTU/kWh heating rate for 25 years [82, 83].

Figure 5 is the high case scenario for Ghana's natural gas situation [84]. The high case scenario assumed the country's gas sector would develop rapidly with new available domestic supplies, such as the HESS discovery field. With increasing demand, domestic energy demand is expected to grow at 8% annually until 2026 and 6% annually after that [84].

The TEN and SGN fields were available in 2016 and 2018, respectively. The supply of natural gas from the Jubilee Field will start a terminal decline from 2030 to 2036 for all case scenarios after the peak in 2019. The indication is that Ghana must ensure that measures are put in place to carry out serious exploration of discoveries to ensure long-term natural gas supply security.

Therefore, by 2025, domestic natural gas and imports will not satisfy the demand [66]. The nature of the decline in gas supply and price volatility should be a wake-up call to encourage Ghana to discover gas resources or find energy resource supplements for gas for a sustainable and well-diversified electricity generation mix.

*4.3. Renewable Energy.* Ghana is considering renewable energy (RE) as an option to ensure that the electricity generation mix is well diversified and helps minimize fossil fuel emissions [46]. RE resources for Ghana include hydro, solar, wind, biofuels, tidal/waves, and municipal waste [51]. Ghana's RE sources have the potential to increase generation at various levels. Such energy sources are mainly known for the friendliness they pose to the environment [44]. Despite any challenges, significant efforts have been made to include

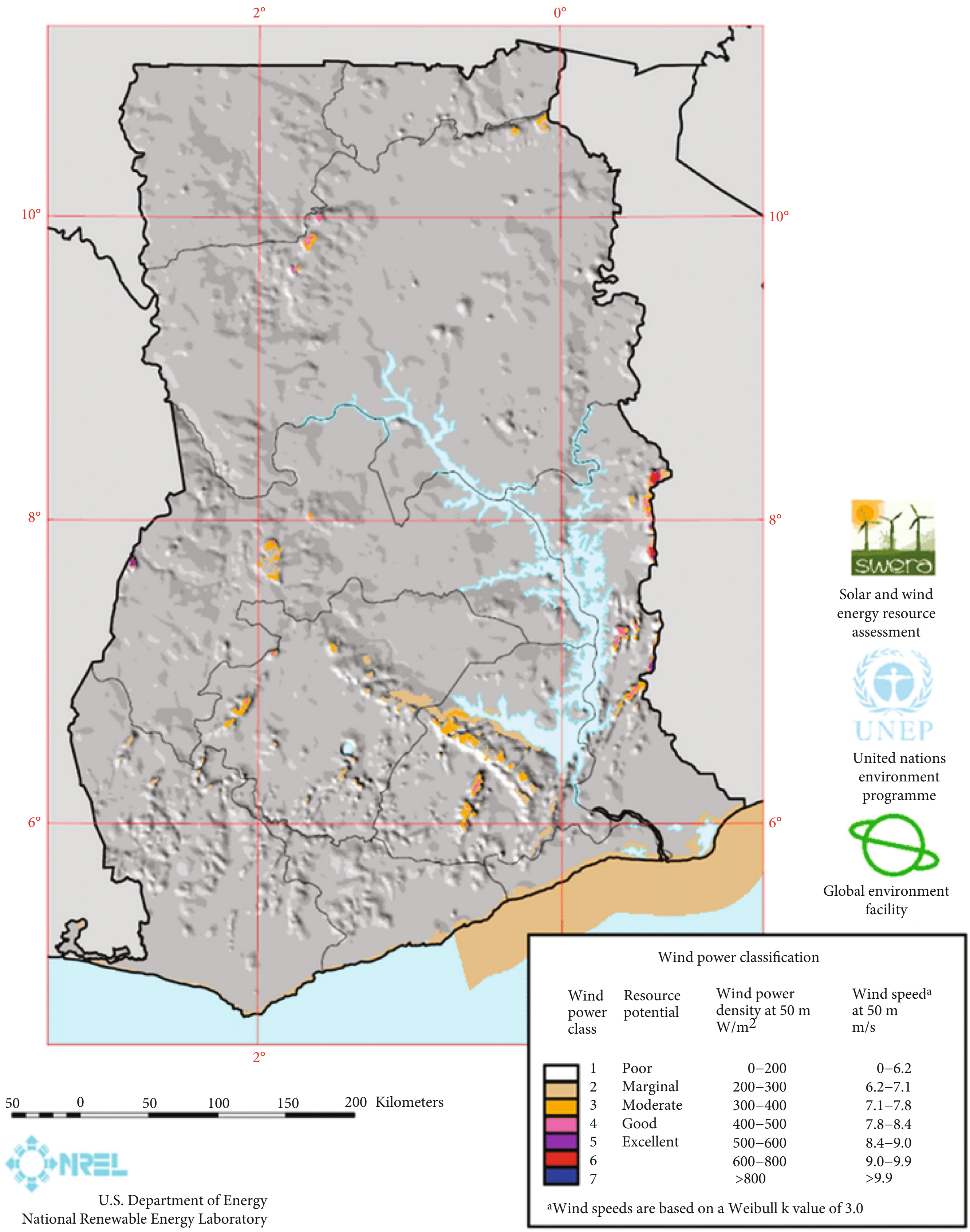


Figure 7: Wind resource map of Ghana [34].

renewable energy sources in the energy mix. Ghana's installed RE to the grid increased considerably from 2.5 MW in 2014 to about 59 MW as of 2020 [40].

*4.3.1. Mini-Hydroelectric.* The Amended Renewable Energy Bill for Ghana redefined hydropower sources and considered all as RE systems. The expectation for Ghana is that the identified 840 MW mini-hydropower sources would be developed to achieve at least 500 MW. Currently, construction works on the 60 MW Pwalugu hydropower dam are ongoing. Additionally, construction on the first 0.045 MW micro-hydrodemonstration power plant began in 2018 at the Tsatsadu Waterfalls in the Volta Region. It was completed in 2019 [40, 47, 48].

*4.3.2. Solar Energy.* The geographic area of Ghana exposes the country quite well to solar radiation which is ideal for electricity and thermal energy purposes [39]. The representation in Figure 6 shows that Ghana's solar irradiation ranges from 4.5 to 6.0 kWh/m$^2$/day, and the peaks are mainly in the northern regions of Ghana [80]. The country's sunshine hours range from 1,800 to 3,000 hours annually [85, 86].

Solar PV electricity installations' capacity as of 2020 was estimated at 59 MW, including over 85% in grid-connected areas [40, 42]. The installed capacity includes but was not limited to 3 MW and 7 MW VRA Solar at Navrongo and Lawra. Others include 20 MW BXC Solar, Meinergy 20 MW, and Bui Solar 10 MW [40]. Furthermore, the Ghana Energy Commission issued provisional licenses for more than 1.8 GW of capacity. Furthermore, the Ghana government implemented a "Rooftop Solar PV Program" in 2016 to provide a maximum load of 200 MW to relieve the national grid, thus providing solar PV panels at most 500 watts (Wp) to residential applicants who qualify with a balance of systems [70, 87]. Despite the solar energy plans initiated in Ghana, only 59 MW has been connected to the grid so far [44].

*4.3.3. Wind Power Potentials.* Although wind energy has not yet recorded significant installations in Ghana, future development potentials are approximately 300 MW (Energy Commission, 2019, 2020b; Ministry of Energy, 2019b). The country's wind potential is marginal, with annual wind speeds on the average of 4 to 6 m/s at 50 m up sea level along the coast and islands. According to satellite data from the National Renewable Energy Laboratory (NREL), wind speeds in mountainous parts of the country are above 8 m/s, especially near the Ghana-Togo border. The resource map for Ghana's wind potentials is shown in Figure 7 [34].

The assessment of wind resources along the coast at eight sites in Ghana between 2011 and 2013 indicated average monthly wind speeds at 60 m elevation [86]. Additionally, the total wind energy resource is estimated to be more than 1500 MW in Ghana.

*4.3.4. Biomass or Waste-to-Energy.* Ghana's biofuel potential is hugely based on the availability of energy crops such as oil palm fruit and jatropha [88]. Ghana's waste-to-energy technologies include the combustion of solid waste for electricity generation in combined heat and power (CHP) systems in the oil palm and wood industries [86]. The country has more than 6 MW of biomass cogeneration plants that use oil palm waste and sawmill residue. In 2018, Ghana began to use 0.1 MW of electricity from the Safisana power plant that uses biowaste [40]. Table 4 represents the residue generated during the processing of food crops and the energy content of Ghana [86].

Table 4: "Residues per unit mass of agricultural produce and their corresponding energy" [86].

| Type of residue | Ratio of residues to crop volume (t/t) | Energy of the residue (MJ/kg) |
|---|---|---|
| Maize (cobs and stalks) | 1.5 | 17.65-18.77 |
| Cassava | 0.5 | 14.24 |
| Yam straw | 0.5 | 14.24 |
| Cocoyam straw | 0.5 | 14.24 |
| Rice straw | 1.5 | 16.28 |
| Rice husk | 0.25 | 16.14 |
| Groundnut shells | 0.3 | 10.00-17.00 |
| Groundnut haulms | 2 | 10.00-17.00 |
| Oil palm shells | 0.45 | 10.00-17.00 |
| Sorghum stalks | 1 | 10.00-17.00 |
| Millet straw | 1.2 | 10.00-17.00 |

*4.3.5. Wave/Tidal Power Potentials.* Ghana's potential for wave energy for electricity has yet to be exploited despite attempts to install a 500 kW wave energy plant at Ada in the Greater Accra Region, near the estuary of the Volta River (Energy Commission, 2019; Ministry of Energy, 2019). Invariably, the enormous ocean available to Ghana makes the tidal abundance estimate for future electricity generation [44]. The signal for the strong potential of tidal wave development in Ghana follows a preliminary assessment that showed that the waves at the East of the meridian are strong, achieving a minimum of 200 MW by 2047 [89].

## 5. Conclusions

The review paper on Ghana's energy resource availability and potential for electricity generation revealed the country's richness in energy supply options. Ghana's energy potentials are in full operation to improve sustainable energy security. Current primary energy supply resources for electricity generation include hydroelectric, oil, natural gas, and renewables. Despite the energy sector development reforms and policies, it appears the institutional framework for developing comprehensive energy plans in Ghana is in the infant stage, requiring attention.

(i) Ghana recognizes the essentials of electricity in rapid economic growth and the need to attain and maintain a good urban to rural electrification ratio.

The country's failure to supply the required electricity hindered economic growth, causing 2% to 4% of GDP losses amid major power crises

(ii) Many policies and reforms have been made in the electricity sector. However, there has been a lack of effective implementation planning. The issues of coordination, commitment, and the high cost of fuel and capacity charge further obstruct sustainable electricity supply. Therefore, an ineffective supply plan for the past three decades has resulted in the purchase of emergency or unplanned power plants for a generation. This creates a lack of proper diversification of energy supply options for electricity supply in a resilient and clean environment

(iii) Amid limited hydrosites and gas reserves, a balance of the generation mix would be critical to ensure an adequate, reliable, and competitive power supply to ensure future security

(iv) In a friendly environment, harnessing the potential of energy supply options for a diversified electricity generation mix is key to ensuring long-term electricity supply security. Short- to medium-term policy plans are needed to achieve the agenda successfully

(v) Harmonization of players in the electricity sector and strong governmental commitment to implement energy sector policies are needed. Therefore, it is imperative to effectively establish proper coordination between institutions in the power sector to enable effective planning and implementation while establishing government commitment

(vi) Finally, effective power sector management, policy implementation, fuel availability, and cost are critical to achieving supply sustainability. The key issues that emerged for national consideration include the need for effective policy direction, appropriate financing concepts, and appropriate political will and setting. By far, this review sought to emphasize the literature gaps by providing a rich and fertile ground as a template for industry operators, policymakers, and future research direction

Therefore, the article presents a wake-up call to Ghana and especially developing countries to progressively invest in modern energy options for electricity generation with crucial attention to environmental concerns. Future studies are encouraged to quantitatively analyze the resource options for sustainable electricity generation for Ghana and the West-African sub-region.

## Abbreviations

BOST: Bulk Oil Storage and Transportation Company
MoP: Ministry of Power
BTU: British thermal unit
MW: Megawatt
BXC: Beijing Xiaocheng Company
NEDCo: Northern Electricity Distribution Company
CHP: Combined heat and power
NPA: National Petroleum Authority
CSIR: Council for Scientific and Industrial Research
NREL: National Renewable Energy Laboratory
EC: Energy Commission
OMCs: Oil Marketing Company
ECG: Electricity Company of Ghana
PC: Petroleum Commission
EPA: Environmental Protection Agency
PURC: Public Utilities Regulatory Commission
ESIA: Environmental and Social Impact Assessment
PV: Photovoltaic
GDP: Gross domestic product
RE: Renewable energy
GNPC: Ghana National Petroleum Corporation
SGN: Sankofa-Gye Nyame
GPC: Ghana Investment Promotion Center
Tcf: Trillion cubic feet
GRIDCo: Ghana Grid Company Limited
TEN: Tweneboa, Enyenra, and Ntomme
GSDO: Ghana Social Development Outlook
TOR: Tema Oil Refinery
GSI: Association of Ghana Solar Industries
UENR: University of Energy and National Resources
IPPs: Independent power producers
UN: United Nations
KNUST: KNUST: Kwame Nkrumah University of Science and Technology
USD: United States dollars
kWh: Kilowatt hour
VRA: Volta River Authority
LNG: Liquefied natural gas
WAGP: West African Gas Pipeline
MMscf: Million standard cubic feet
Wp: Watt-peak.

## Data Availability

No data were used to support this study, except for the tables and figures taken from sources and have been duly referenced.

## Additional Points

*Highlights.* (i) The key issues that emerged for national consideration include the need for effective policy direction, appropriate financing concepts, and appropriate political will and setting. (ii) The high-income status and the projected increase in the population of Ghana to approximately 37 million by 2030 will require an accelerated increase in electricity demand. (iii) It was revealed that Ghana uses mainly hydro, natural gas, and solar energy and exploits additional renewable sources, nuclear power, and coal for electricity security. (iv) Future electricity supply requires a resilient range of options that must be sustainable. (v) Energy resource potentials and fuel availability for power generation are critical to achieving high economic and industrial aspirations.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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