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Is Ghana Ready to Attain Sustainable Development Goal (SDG) Number 7?—A Comprehensive Assessment of Its Renewable Energy Potential and Pitfalls

Michael Acheampong
Oklahoma State University

Qiuyan Yu
University of South Florida

Funda C. Ertem
Technische Universität Berlin

Lucy E.D. Enomah
University of South Florida

Shakhawat H. Tanim
University of South Florida, stanim@mail.usf.edu

See next page for additional authors

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Authors

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Review

Is Ghana Ready to Attain Sustainable Development Goal (SDG) Number 7?—A Comprehensive Assessment of Its Renewable Energy Potential and Pitfalls

Michael Acheampong [1,*], Qiuyan Yu [2], Funda Cansu Ertem [3], Lucy Deba Enomah Ebude [2], Shakhawat Tanim [2], Michael Eduful [2], Mehrdad Vaziri [2] and Erick Ananga [4]

[1] Department of Geography, Oklahoma State University, 360 Murray Hall, Stillwater, OK 74078, USA
[2] College of Arts and Sciences, School of Geosciences, University of South Florida, 4202 E. Fowler Avenue, NES 107 Tampa, FL 33620-5550, USA; qiuyanyu@mail.usf.edu (Q.Y.); debaenomah@mail.usf.edu (L.D.E.E.); stanim@mail.usf.edu (S.T.); mkeduful@mail.usf.edu (M.E.); mehrdadv@mail.usf.edu (M.V.)
[3] Department of Biotechnology, Technische Universität Berlin, Ackerstr. 76, ACK24, 13355 Berlin, Germany; ertem@campus.tu-berlin.de
[4] Department of Political Science and Legal Studies, East Central University, 1100 E. 14th St, Ada, OK 74820, USA; eananga@ecok.edu
* Correspondence: michael.acheampong@okstate.edu; Tel.: +1-347-759-4392

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Abstract: Ghana has declared support for the UN Sustainable Development Goal (SDG) number seven which most importantly target ensuring universal access to affordable, reliable and modern energy services. This target presents a formidable challenge to Ghana because the country still relies mainly on traditional biomass as its primary source of energy coupled with a chronically fragile hydropower sector. In this study, we assess Ghana's potential in achieving sustainable goal number seven. Specifically, we comprehensively review the breakthroughs and impediments Ghana has experienced in its efforts towards improving its renewable energy potential. We note that while Ghana has made significant stride toward attaining energy efficiency, its effort at large-scale biofuel development hit a snag due to issues of "land grabbing" emanating both from local and foreign entities. In another breadth, several pilot studies and research initiatives have demonstrated the possibility of diversifying the energy sector with other renewable energy options including solar, wind, and small hydro. In spite of challenges encountered with the development of biofuels, our review concludes that Ghana retains vast reserves of renewable energy potential, which can be harnessed with the constantly improving technological advancements as it pursues SDG number seven.

Keywords: renewable energy; Ghana; sustainable development goals; biofuel; solar energy

1. Introduction

The 1970s oil crisis, the declining fossil fuel reserves, as well as global climate change has made many countries to seek low carbon alternatives to their energy supply [1–6]. Indeed, today many countries around the world continue to invest in energy supply. These efforts are supported by the United Nations' Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) [2,7–10]. The report emphasizes the need for nations especially those in the developing world to find alternatives to the traditional fossil fuel-driven civilization. Accordingly, the IPCC therefore recommends as a policy that in order to forestall some of the most egregious consequences of climate change, at least 80 percent of global energy supply must be based on renewables by 2050 [2,11].

In recent years, different international treaties such as the Kyoto Protocol and other climate-related agreements have urged some countries to develop comprehensive policies and strategic mechanisms to accelerate the movement towards the era of low- or zero-carbon energy economies [1,12]. For instance, Brazil was already fueling 46 percent of its domestic energy supply from renewable sources by the year 2007 [13]. The European Union (EU) has also responded to these calls by introducing the "20-20-20" climate targets. In this vision, the EU member countries committed to the goal of reducing their GHG emissions by 20 percent in 2020 compared to 1990 levels, by increasing the share of renewable energy to total energy supply to 20 percent [2,14–16]. The Clean Development Mechanism (CDM) defined in Article 12 of the Kyoto Protocol allows industrialized countries to earn certified emission reduction (CER) credits by supporting emission-reduction projects in developing countries [1,12,17]. This was to give flexibility to industrialized nations towards achieving their Kyoto emission reduction targets while promoting development in developing countries, especially those located in Africa south of the Sahara [9].

The challenges that plague sub-Saharan Africa are not necessarily unique. Mainly, the lack of access to electric grids at a reasonable price inflicts the most damage to sub-Saharan African countries, including Ghana [18]. According to IEA [19], three billion people around the world still rely on traditional biomass for cooking and heating. An average household in sub-Sahara is estimated to spend more than 30 percent of their budget on biomass fuel. This trend is projected to remain if no serious action is taken by the affected countries. In fact, the IEA [19] forecast that sub-Saharan Africa along with South Asia remain the only regions of the world where consumption of traditional biomass for energy will likely increase rather than decrease by 2030.

Ghana's problem mimics the sub-Saharan picture. Like most countries in African and South Asia, energy demand due to population explosion poses a significant policy and climate challenge. In Ghana, a majority of households depend on biomass as the main source of energy, which is associated with several environmental, health, and social effects [18,20]. Additionally, Ghana's once abundant and reliable hydropower has shown signs of stress under the pressure of increasing population and aging equipment, leading the country to increasingly rely on thermal power plants to support electricity generation [4,9,21]. While the introduction of thermal power plants has helped fill some of the gaps in Ghana's electrification, it has also contributed to increasing the price of electricity, without necessarily being able to contain the chronic energy crisis the country has contended with in the past few years. This has happened despite the fact that Ghana recently discovered commercial quantities of oil, which together with a cheap natural gas supply from Nigeria supports its fossil-based electricity production [5,21,22].

Load shedding ("dumsor" as known in local slang) combined with the constantly depleting firewood in remote areas, as a result of unregulated exploitation of trees, challenges Ghana to aggressively pursue renewable energy alternatives. Therefore, increasing renewable energy performance in the country to diversify its electricity supply has become a top policy agenda for the government. In the National Energy Strategy of 2010, Ghana set a target of achieving universal access to electricity by the year 2020. The scientific community has long established the energy-development nexus. Sustainable energy supply is therefore recognized as an important catalyst for sustainable development, as it directly impacts important development indicators such as the quality of health, education and water supply among others [18,23].

During the Millennium Development Goals (MDGs) era, while there were no specific targets set for energy, it was acknowledged that reliable and socially acceptable energy services were a prerequisite for attainment for the set goals [2,4,18,22]. However, in the new era of Sustainable Development Goals (SDGs), the United Nations (UN) took the critical step to emphasize the need for renewable and sustainable energy sources to support global goals through the Secretary-General's Sustainable Energy for All initiative, by outlining targets in goal number seven [2,24]. Among the specific targets are the following: (a) ensure universal access to affordable, reliable and modern energy services; (b) to substantially increase the share of renewable energy to global energy mix by 2030; (c) to double the rate of improvement of energy efficiency in countries around the globe by 2030; (d) to facilitate access to renewable and clean energy technology and promote investment in energy infrastructure by 2030; and (e) to increase supply of modern and sustainable energy services for all in developing countries through infrastructure expansion and technology upgrade by 2030 [24].

To achieve the SDG number seven targets, Ghana has to mobilize all available resources in the direction of harnessing its renewable energy potential [25]. With less than 25 percent of its original forest currently standing, and having stretched the limits of its hydro-and-thermal power plants, the country is in dire need of new energy innovation. A study by Deichmann et al. [12] support this initiative by revealing the important role that decentralized renewable energy can play if a country like Ghana will achieve the overarching goal of sustainable energy for all.

Based on this foundation, this review is taken with an overall goal of examining Ghana's renewable energy potential as envisaged by SDG number seven. Specifically, we investigate the trend in Ghana's energy consumption; and the feasibility and extent to which renewable energy can support the nation developmental goals and carbon emission reduction. The paper is organized as follows. After the introduction, we present a description of the study area. In the third section, we present an overview of Ghana's energy sector. Fourth, we undertake a comprehensive review and a critical appraisal of Ghana's renewable energy drive, as well as the adoptability of other novel concepts and technologies in Ghana pursuit of SDG number seven. In the fifth section, implications for increasing uptake of renewable energy in Ghana is documented. The sixth section presents prospects and challenges for Ghana in the course of achieving the SDG goal. Section 7 summarizes the article, while recommendations for policy and future research directions are presented in section eight.

2. Study Area and Methodology

2.1. Overview of Ghana

Ghana is located in the western part of the African continent. It borders Ivory Coast to the west; Burkina Faso to the north, Togo to the east and the Atlantic Ocean to the south. The country encompasses a total land mass of approximately 239,460 km^2 which is divided into ten administrative regions. Currently, Ghana's population stand at 27 million of which 55% of the people live in urban centers. Two of the biggest cities, Kumasi and Accra, account for nearly 20 percent of the total country population. The population is projected to grow at 2 percent per annum [26,27].

Ghana's economy is largely informal. Most people mainly rely on small scale agriculture and domestic trading. In fact, Agriculture employs 60 percent of the work force. The remaining group are either employed in industry (29 percent) or the service sector [20,27–29]. Agriculture alone contributes 40 percent of the gross domestic product (GDP) and 35 percent to total export earnings [20,22,27–30]. The two most important crops in Ghana are maize and cocoa [20]. However, historically gold and cocoa are known to have contributed most in foreign exchange earnings [27].

Agricultural land makes up about 148,500 km^2 of the total land area (Table 1) [27,31,32]. Ghana's agriculture is largely rain dependent. There are six distinct agro-ecological zones that make up the country (Sudan Savanna, Guinea Savanna, Transition, Semi-deciduous Forest, Rain Forest, and Coastal Savanna [20,30]). These zones are delineated based on climate, natural vegetation, and soils.

Table 1. Details of Land Use Characteristics [31,32].

Characteristic and Unit	Size
Surface Area (km^2)	239,460
Agricultural Land Area (km^2)	148,500
Agricultural Land Area (%)	69.1
Permanent Cropland (%)	11.9
Arable Land Area (ha)	4,100,000
Arable Land Area (%)	20.7
Arable Land Area (ha per person)	0.2
Forest Land Area (km^2)	52,862
Forest Land Area (%)	21.2

Ghana's industrial sector is a fledgling one that contributes about 25 percent of the GDP. The industrial sector consist mainly of food, timber, textiles, cement, oil refinery, cement, aluminum, and pharmaceuticals, among others [27,33,34]. Duku et al. [27] noted that poverty in Ghana displays significant variation between sectors. The poor are predominantly concentrated in the informal sector. Subsistence food crop farmers, who engage in farming primarily for consumption, are the poorest. They are followed by the section of population engaged in micro- and small scale enterprises, of which nearly 30 percent live below the poverty line [27,35–37].

2.2. Methodology

In this paper, we synthesize information obtained from several sources. These sources include academic articles, government-level reports, research reports, agency websites, conference proceedings and books. To obtain relevant academic literature on Ghana's renewable energy development and SDGs, we performed keywords searches in the most prominent search engines including Google Scholar, Science Direct and Web of Science. To supplement information for peer-reviewed academic literature, we also did general google search to obtain relevant non-peer reviewed publications. Additionally, we obtained published reports from websites of several relevant agencies.

3. Overview of Energy Supply and Consumption in Ghana

Ghana's deploys its primary energy sources for the following purposes: electricity generation, transportation, heating, and cooking. As illustrated in Figure 1, Ghana primarily depends on biomass for the bulk of its primary energy supply [38]. According to Ghana Energy Supply, energy consumption peaked in 2008 with Biomass in the form of word and charcoal accounting for nearly 72% of primary energy. Petroleum and electricity accounted for the remaining percentages [5,20,22,27,39].

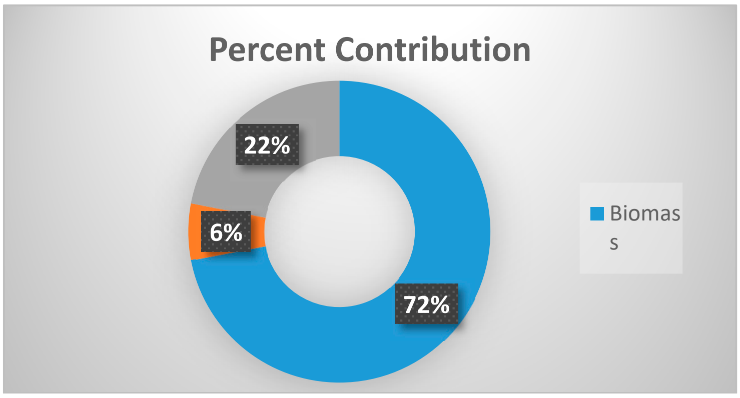

Figure 1. Percent Contribution of Various Energy Sources to Total Energy Supply in 2008 [38].

Recent population increase coupled with urbanization has propelled the overall energy demand in Ghana. Figure 2 depicts the pattern of growth of final energy consumption from the three main contributors of primary energy [40]. Of the total energy consumed in the country, residential activities take more than half.

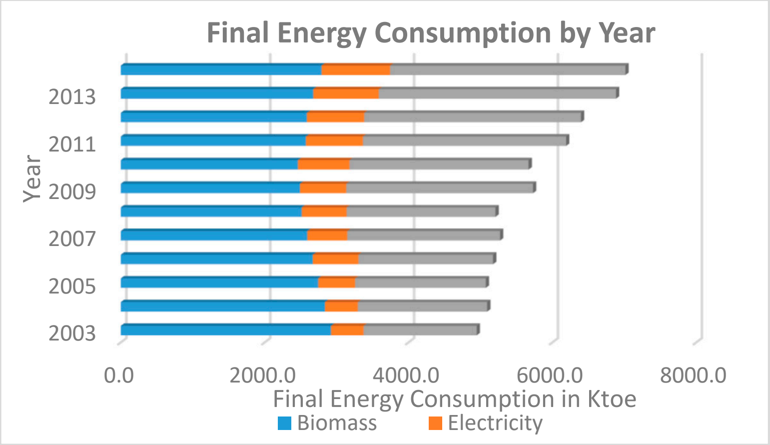

Figure 2. Total Energy Consumption by Type of Energy, 2003–2014 [40,41].

3.1. Woodfuel

The high share attributed to residential activities is mainly because of woodfuel consumption at the household level [20,42]. This is because Ghanaian households are dominated by low income earners who primarily depend on biomass as a primary source of energy. They also employ traditional and low-technology wood energy systems for cooking and heating [18,27]. Figure 3 indicate that the nearly 90 percent of the Ghanaian population rely on woodfuels for cooking, with details of regional breakdown presented [20,22]. In 2010, Ghana Energy Commission conducted a survey which revealed that roughly 40 percent of Ghanaian population is wholly dependent on unprocessed firewood for cooking and heating. An average household uses about 1065 kg of firewood yearly. However, there exist important disparities between regions and areas, as in the case of total woodfuel. According to the survey, about 62 percent of rural population used firewood, as compared to about 26 percent of the urban population. In a similar breadth, while urban households consume an average of about 986 kg of firewood in a year, rural households consume an average of 1113 kg. The survey estimated about 72 percent of inhabitants in the Savannah regions use firewood as compared to an estimated 57 percent and 52 percent for forest and coastal areas, respectively [22,38].

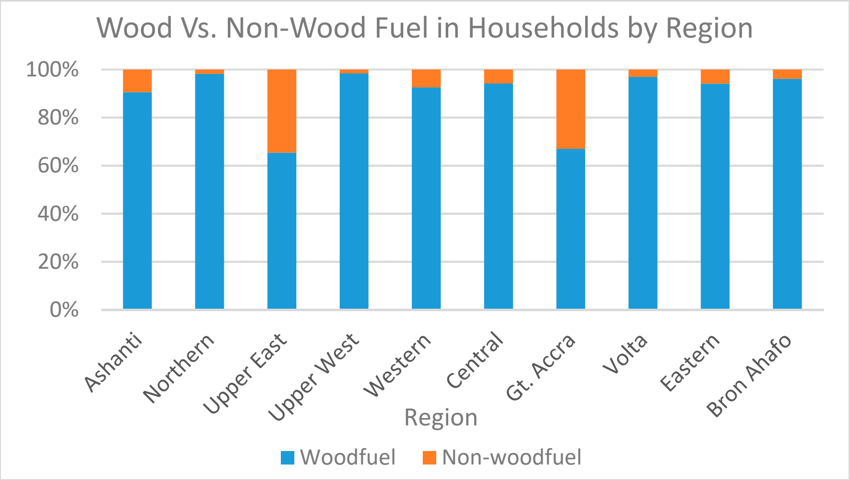

Figure 3. Source of Cooking Fuels for Households in All Ten Regions in Ghana [30].

The Food and Agriculture Organization (FAO) statistics [33] noted that the amount of wood fuel consumed in Ghana nearly doubled from a value of about 20 million m^3 in 2004 to over 35 million m^3 in 2008. In this period, charcoal consumption increased from about 750 thousand m^3 to 1.5 million m^3. It is further noted that about 90 percent of all wood fuels consumed in Ghana are sourced directly from standing forest, with the remaining coming from residues resulting from logging and sawmill activities among others [22]. Thus dependency on wood fuel has played a significant role in the fast-paced deforestation that Ghana has witnessed over past decades. At the turn of the century, Ghana's forest cover has since dwindled from over 8 million hectares to 1.6 million hectares today [18,20,27,30,42].

Fallout from Initiatives to Reduce Traditional Biomass Consumption and Wastage

Traditionally, the wood fuel industry in Ghana has been minimally regulated. However, currently the Energy Commission has begun to introduce a ban on the export of charcoal that is produced from unapproved sources. Standing forests, in this case, constitute an unapproved source while on the other hand residues from sawmills as well as forest established for charcoal production purposes constitute approved sources. Since 2002 the Energy Commission provided permits to exporters of charcoal that are deemed legitimate according to the government instituted guidelines [22].

In recent years, new programs and initiatives have been implemented in order to mitigate charcoal consumption and its resulting consequences. These include; training of traditional charcoal producers to adopt efficient charcoal production methods [22], partnering with donors to disseminate and encourage the use of improved biomass energy technologies such as efficient cook stoves (see Figure 4) [22], introduction of the Kerosene Distribution Improvement (KDI) and other liquefied petroleum gas (LPG) programs in rural Ghana to leverage a switch from traditional biomass to relatively cleaner alternatives through subsidies [23,43,44]. The government has also supported several programs in urban centers which focuses on charcoal use reduction. Indeed, in the 1990 Ghana National LPG Program rolled out an aggressive campaign targeting LPG as an alternative to charcoal and firewood. This program focuses on households in urban areas, the informal commercial sector including small-scale food vendors, and catering facilities in public institutions [18,45,46]. Kemausuor et al. [18] confirm that these initiatives have been successful. In fact, statistics indicate that the LPG consumption increased more than tenfold to over 60,000 tones/year in 2004. Currently, 70 percent of all households in Ghana that utilize LPG as their main source of cooking fuel are in the two regions namely, the Ashanti and Greater Accra Regions [18].

Figure 4. Traditional Coal Pot (**Left**) and Gyapa Improved Cook Stove (**Right**) Common the Ghanaian Market.

An attempt by the government to replicate the urban success in the rural areas is laudable. However, the current initiatives have been fraught with remarkable challenges. One of the challenges as explained by Kankam and Boon [23] is that richer households are more likely to use LPG, however, the odds increases against better targeting of the rural poor who are the intended beneficiaries.

3.2. *Electricity*

Ghana generates most of its electricity from two large hydropower stations: the Akosombo and the Kpong dams. Together, they provide about 65 percent of the total 2200 MW of electricity supplied in the country [9,47]. Thermal power plants that operate on fossil fuels supply the remaining 35 percent (Figure 5).

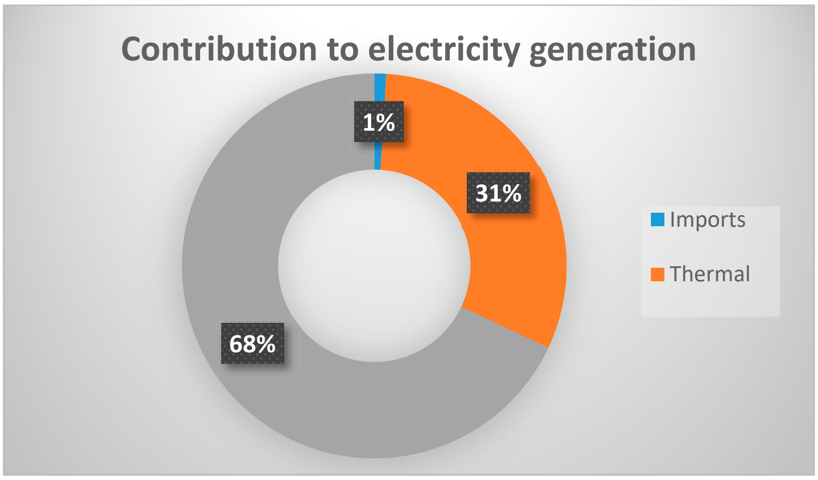

Figure 5. Percentage Contribution to Ghana's Total Energy Mix in 2010 (total = 10,232.11 TWh) [48].

The proportion of total electricity supply from thermal power plants has risen significantly over the past few years since Ghana's hydroelectric power dams were saddled with myriad of challenges [9]. Figure 6 shows that electricity supplied from thermal power plants increased from less than 10 percent in 2000 to about 30 percent in 2010.

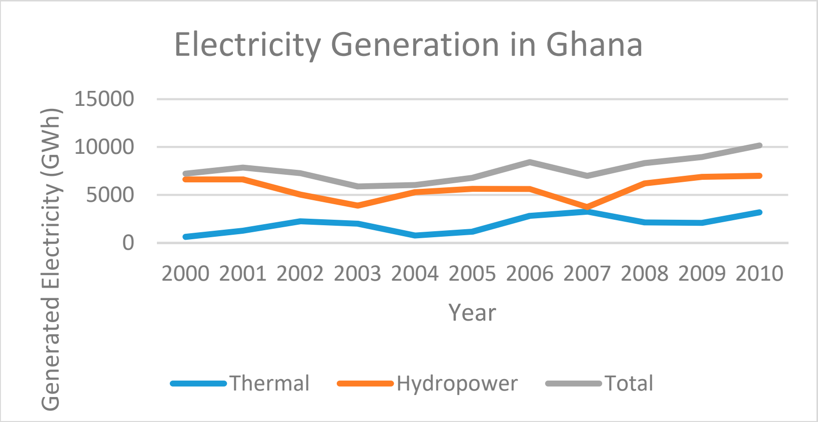

Figure 6. Electricity Generation by Source in Ghana (in GWh) [22].

The challenges that confront the hydroelectric sector stem from two main sources. First, the country's population growth and relatively high urbanization rate have increased the electricity demand, thereby putting pressure on the old power generation and supply systems. As Figure 7 shows, electricity consumed by residential class has increased in relation to industrial uses. In fact, between 2000 and 2010, electricity supplied to the residential sector increased from about 24 percent to nearly 40 percent. In the same period electricity supplied to the industrial sector decreased by over 20 percent in share, almost 70 percent to about 47 percent [22,40,49]. Secondly, Ghana has sustained hydrological shocks in recent years due to bouts of drought and unreliable rainfall patterns, increasingly making the hydroelectric power facilities unreliable because of their inability to achieve full generation status [9].

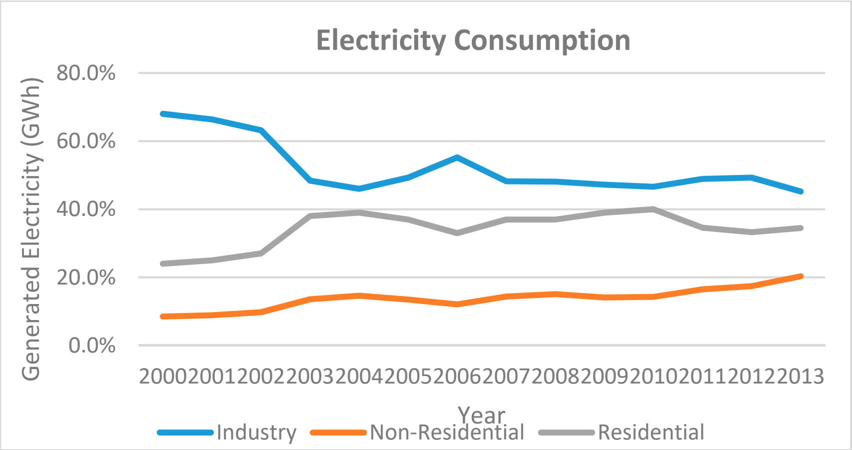

Figure 7. Percent of Share of Grid Electricity Consumed by Different Consumer Classes [40].

Ghana officially commissioned its first hydroelectric dam, the Akosombo Dam, in 1965. In 1961, the government of Ghana passed the Volta River Development Act, which established the Volta River Authority (VRA) as part of the Volta River Project. The mandate of this authority was to ensure generation and transmission of power. It was in the same year that construction of this dam officially began. In this project, the VRA installed four hydroelectric generating units. Together, they had a total capacity of 588 megawatts (MW), including an overload capacity of 15 percent [18,50]. In 1972, the VRA commissioned two additional generating units with a capacity of 324 MW, also with a 15 percent overload capacity. The Kpong hydroelectric plant, the second in Ghana, came on board in 1981 with an installed capacity of 160 MW to supplement the Akosombo Dam due to increased demand of gridded electricity by a growing population [18]. By 1990, the government drew a 30-year electrification plan to increase access to all parts of the country under the National Electrification Scheme (NES). The scheme mainly targeted the northern parts of the country, which had no grid power. To further increase total electricity generation in the country to support the project, the VRA brought on board the newly rehabilitated Tema Diesel Generating Station. The recommissioned station raised the capacity of the national electrical power to 1,102 MW, with an additional 20 MW [18].

Ghana has since then achieved steady increments in electricity production and supply, with demand also growing at an estimated 6–7 percent per annum. The government invested heavily in thermal plants due to the unreliability of hydroelectric electricity, which caused significant energy crisis in the country between 2002 and 2004, as well as in the year 2007. As Figures 7 and 8 depict, it is noticeable that total electricity supply and the per capita consumption took a great hit owing to protracted hydrological shocks [5,18,40]. In fact, in 2007, the slump in electricity supply meant that electricity accounted for only about 9 percent of total 9.50 Mtoe of final energy consumed [9,27].

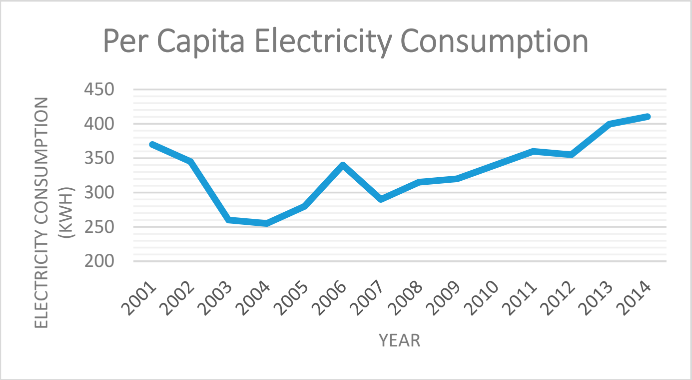

Figure 8. Pattern of Electricity Consumption per Capita in Ghana over Time from 2001–2014 [40].

By 2008, however, the significant investments undertaken in the thermal power plants increased their combined installed power generation capacity to about 831 MW. In this year, Ghana ranked as the third highest in sub-Saharan Africa only after Mauritius and South Africa, for having achieved 55 percent access rate nationwide. This achievement was remarkable since the country only had 28 percent access in 1988 [18]. Ghana's current national electricity access is about 70 percent. Within this overall high access, however, lie significant disparities between urban and rural populations. While about 78 percent of the urban population has access to electricity, only an estimated 30 percent of rural populations has access [9]. Figure 9 represents the increase in the number of communities that were connected to the national grid by 2010, within the four phases of Ghana's electrification targets over a 20-year period.

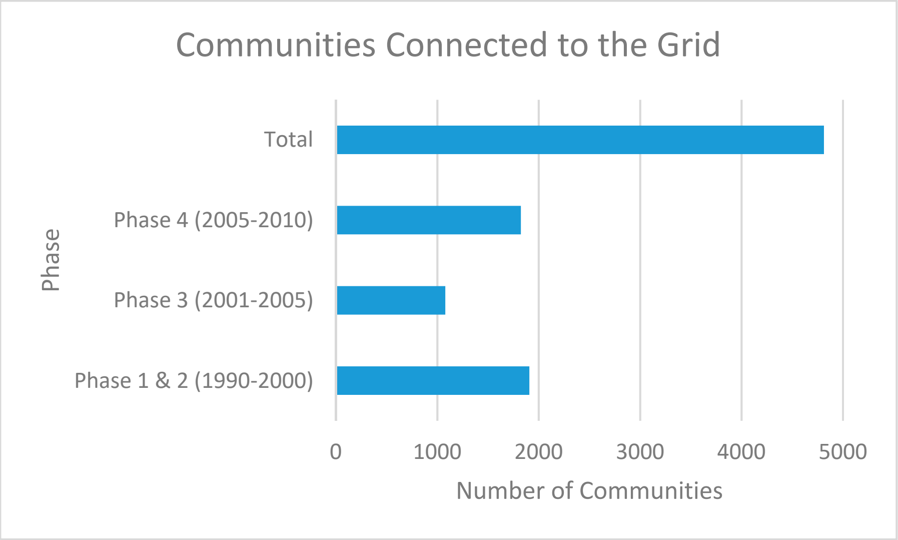

Figure 9. Number of Communities with Connection to Electricity Grid [51].

Among the important initiatives to increase electricity generation capacity in Ghana was its involvement in the West African Gas Pipeline (WAGP) project. In this project, Nigeria, Africa's leading producer of crude oil, was to supply natural gas to power thermal plants in Ghana, along with Togo and Benin. This was to reduce the reliance on expensive, imported crude oil for power plants that are located along Ghana's coast, including the Asogli and Aboadze thermal plants, which have 200 MW and 330 MW, respectively [5,27,38,52]. The WAGP started delivery of free-flowing gas to the plants after 2010 after many years of delay due to operational obstacles such as detected leaks in pipelines, missing its intended starting date in 2007 [5]. Finding oil and gas in Ghana has boosted the viability of thermal power plants, as an alternative fuel source [18].

In 2013, Ghana commissioned its third dam, the Bui Dam, in the Brong Ahafo region that was constructed on the Black Volta River. The Bui Dam project commenced in Ghana in 2007, and the Ghanaian government received support from the Chinese government on several fronts to bring this project into fruition. The new dam has also brought about a generation capacity of about 400 MW into the existing pool of electricity generation in Ghana [5]. Table 2 above summarizes electricity generation assets in Ghana, with fuel type they run on, and their installed capacity. As Gyamfi et al. [9] noted on his study, almost 90 percent of all electricity generation assets in Ghana belong to the state owned VRA, while independent power producers make up the remaining portion. It is quite evident that Ghana has aggressively pursued different initiatives and projects to expand electricity access for its population. This pursuit has been in attempt to fulfil its goal of ensuring universal access to electricity by the year 2020. Being able to widen access to a level of this magnitude has engendered some of the significant power sector reforms in Ghana over the past decades that has led to a massive restructure of institutions that run the electricity sector [23,53].

Table 2. Electricity Generation Capacity by Plant in Ghana [40].

Plant	Type of Fuel	Installed Capacity (mw)
hydro generation		
Akosombo	Water	1020
Kpong	Water	160
Bui	Water	400
Sub-total		1580
Thermal generation		
Takoradi Power Company (TAPCO)	LCO/natural gas	330
Takoradi International Company (TICO)	LCO/natural gas	220
Sunonasogli Power (Ghana) Limited (SAPP)—IPP	Natural gas	200
Cenit Energy Limited (CEL)—IPP	LCO	126
Tema Thermal 1 Power Plant (TT1PP)	LCO/natural gas	110
Tema Thermal 2 Power Plant (TT2PP)	Diesel/natural gas	50
Takoradi T3	LCO/natural gas	132
Mines Reserve Plant (MRP)	Diesel/natural gas	80
Sub-total		1248
Total		2828

* LCO—Light Crude oil.

Distribution, Oversight, and Regulation of Ghana's Electricity

Currently, government agencies dominate Ghana's electricity production and supply sectors. Ghana has a system operator, the Ghana Grid Company (GRIDCO), which operates and manages the national grid and power system, respectively. Two main companies make up the distribution sector of the electricity produced in Ghana. The Electricity Company of Ghana (ECG) is responsible for distribution of electricity in the southern sector of the country (Ashanti, Greater Accra, Eastern, Western and Volta regions) except for entities such as Volta Aluminum Company (VALCO), mines, and the Akosombo Township. Meanwhile, the Northern Electricity Distribution Company (NEDCo) handles distribution in the northern sector, comprising of Brong Ahafo, Northern, Upper East and Upper West Regions [9,22,23].

Ghana has given significant attention to policy and regulation in its electricity production and supply sectors in the past two decades through large-scale reforms. In 1997, Ghana enacted both the Public Utilities Regulatory Commission (PURC) Act (Act 538) and the Energy Commission (EC) Act (Act 541) [23,47]. Through the PURC, a public Transmission Utility Company (TUC), which manages the national electricity grid, was established [23,43]. The PURC, therefore, became the independent body responsible for the regulation and oversight of the provision of the highest quality of utility services, including electricity and water, to consumers [47]. Through its establishment, the EC also ensured an absolute decoupling of the generation and transmission sectors within Ghana's electricity [23,43].

The government, in consultation with the various key stakeholders, including generators, distributors and representatives of major consumers, tasked the PURC with setting electricity tariffs. In line with its mandate, the PURC put in place a transition plan to initiate a gradual adjustment towards economic cost recovery by 2003 [22]. According to EC [22], the automatic price adjustment formula of the Transition Plan was affected only in 2003 and 2004. In 2003, the formula was affected once, while it was affected twice in 2004. In 2004, the adjustment only affected the bulk supply tariff (BST) and the distribution service charge (DSC). The BST and DSC, combined, is the end user tariff (EUT) that the distribution companies charge. Tariffs set for industrial and commercial customers differ from that of residential customers. Currently, unsubsidized residential customers pay about an average of 10 US cents per every kWh consumed. For residential customers, there is a lifeline tariff (subsidized tariff aimed at providing support for low-income households) for low consumption. The lifeline tariff was set at 50 kWh, a significant downgrade from the maximum 100 kWh in 1990. Lifeline consumers in Ghana use electricity free of charge, with the government subsidizing their consumption [22].

While there have been efforts towards full cost recovery in Ghana's power sector, it has still proven difficult to achieve over the years because the tariffs are fundamentally set based on the costs of base-load hydropower. This means that the VRA usually runs at a loss because it is increasingly generating a significant amount of electricity from thermal plants that run on expensive oil [9,54]. This has significantly affected the speed of expansion of Ghana's electricity sector. According to Miller et al. [47], the government has recognized that the issues of comparatively low tariffs and delays in establishing a sustainable tariff regime has contributed to the reticence of many potential power sector investors in investing in the sector. To tackle this reticence, the government in recent years has attempted to increase competition in the power sector by introducing Independent Power Production (IPP) schemes and reforms, such as increasing low electricity tariffs towards internationally accepted levels [47]. This is with the hope that independent power producers can contribute to filling the electricity deficit of about 200 MW per year needed for Ghana to meet its growing electricity demands [9,48].

4. The Status Quo and Potential of Renewable Energy in Ghana

Dependable energy supply is the backbone of any modern and thriving economy. Ghana is no different and takes many steps to bolster its energy supply. Ghana's achievements in the energy sector over the past few decades have been remarkable. However, as the above discussions indicate, significant challenges persist. Enduring power outages in Ghana has gradually been woven into the psyche of consumers of electricity and significant number of rural communities still have no access to electricity. Providing energy that is less expensive, reliable, and environmentally friendly still remains a challenge.

A well-developed and diversified energy sector is one of the principal attracting forces for foreign direct investments (FDI) [55]. Like many countries in Africa, the resource pool available for Ghana to pursue renewable energy development is seemingly unlimited [18]. Even before the transition of the globe from the MDGs to the SDGs in 2015, Ghana had already adopted the Strategic National Energy Plan (SNEP) for the period of 2006–2020. With this plan, the government formally passed the Renewable Energy Act with a target of achieving a 10 percent share of these renewables in electricity production by the year 2020 [9,47,56]. The plan also set to achieve 15 percent penetration of rural electrification through decentralized renewable energy by 2015, and expanding to 30 percent by 2020 [47].

After over 10 years of adopting the SNEP, and signatory to the SDGs, this section provides a comprehensive assessment of the different forms of renewable energy resources—bioenergy, solar energy, wind energy, and small to medium hydropower—in Ghana in terms of their status quo, breakthroughs, prospects and challenges. This is in order to assess Ghana's potential to achieve the overarching goal of providing sustainable energy for all by 2030 as per the SDG number seven.

4.1. Bioenergy

4.1.1. Overview of Bioenergy

Biomass is a term used for all plants, algae, microorganisms and animals. Biomass resources encapsulates a broad range of products including wastes from agricultural activities and timber residues, as well as wastes from animals and food processing, and municipal solid wastes [27,57]. There are numerous economic and environmental benefits derived from biomass resources. Therefore, there are many competing uses of these resources at any given time. Within biomass resources are significant deposits of free energy in the form of chemical bonds that bind compounds such as carbon, nitrogen, oxygen, and sulfur, of which they consist [58,59]. When the molecules are broken, the free energy released can generate heat that can also be converted to electricity. When converted to liquid form, biomass can also be used for transportation fuel [59,60]. Apart from liquid, fuels produced from biomass can also be solid or gas [57].

As we previously noted, Ghana depends on solid biomass, in the form of fuelwood and charcoal, for about 70 percent of its primary energy supply [20]. Liquid fuels produced biomass, popularly referred to as biofuels, have been more attractive in recent decades due to the high energy densities they possess, coupled with the fact that they can be stored in light-weight tanks [61]. They have particularly risen to prominence around the globe as with the potential to provide solutions to issues such as climate change and dwindling fossil fuel deposits. This is because they are seen as a clean alternative source to fossil fuels, which can be deployed in transportation with minimal alteration to existing pumping infrastructure [2,57,62]. While biofuel development has been widespread in recent years, the idea of using biofuels for transportation purposes is not entirely new, as Rudolf Diesel fueled a 1900 engine with peanut oil [60,63]. The suitability of different forms of biomass for fuel is primarily dependent on factors such as their moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, and cellulose/lignin ratio among others [27].

There are four different classifications of biofuels depending on the feedstock utilized for their production, and stages of development, namely; first generation, second generation, third generation, and fourth generation biofuels [2]. First generation biofuels are made from feedstock such as sugarcane, cassava, and sugar beet cereals, by using their sugar and starch portions. Oil seed crops such as rapeseed, sunflower, soybean and palm oil are also used to produce first generation biofuels [64]. Second generation consists of biofuels that are produced from agricultural and forest residues. They are also produced from feedstock such as trees, jatropha, straw, bagasse, and purpose energy crops, which are said to thrive on marginal lands [15,65]. First and second generation biofuels are the most advanced [2]. Third and fourth generation biofuels are, however, relatively newer forms of biofuel that are produced based on improvements and biotechnological engineering of biomass such as algae ad other feedstock [14,65–68]. Ethanol and biodiesel are two most common biofuel products used around the world. While ethanol is commonly derived from sugar and starchy feedstock such as sugarcane, sweet sorghum, maize and cassava, biodiesel is commonly produced from oil seeds such as oil palm, coconut, sunflower, soybean and jatropha [27].

4.1.2. Potential and Policies of Bioenergy in Ghana

Ghana has significant biofuel potential for numerous reasons. First, as previously explained, agriculture dominates Ghana's economy, and produces a vast range of crops including maize, cassava, sugarcane, cocoa, and oil palm that are useful for biofuel production [20,27]. Table 3 summarizes the main agricultural produce in Ghana as of 2008 and the total amount of land area each of them covers [69].

Table 3. Major Crops Produced in Ghana as of 2008 [69].

Product	Production Quantity (1000 tons)	Crop Yield (hg/ha)	Area Harvested (ha)
Sorghum	350	10,294	340,000
Maize	1100	104,615	750,000
Sugarcane	145	2,544,385	5700
Rice	242	20,166	120,000
Cocoa beans	700	4000	1,750,000
Coffee	1.6	1650	10,000
Cassava	9650	120,625	800,000
Seed cotton	2	8000	25,000
Coconuts	316	56,936	55,500
Oil palm fruits	1900	6333	300,000
Groundnuts	4289	9317	460,000

Second, according to Gyamfi et al. [9], Ghana possesses vast arable and degraded land areas that have the potential to be used for growing energy crops that are resistant and can thrive on marginal and abandoned lands. Third, Ghana already depends on biomass for significant portion of its energy needs [5]. Finally, Ghana produces a significant amount of waste in the form of municipal solid waste, food waste, and sewage sludge or bio-solids, which can be used in the production of biofuels.

4.1.3. Explaining the "Boom and Bust" of Jatropha

Recognizing its deep potential for biofuel development, the EC of Ghana, in 2005, set up the Biofuel Committee to prepare a National Biofuel Policy (NBP). The National Parliament received this policy and passed it into legislation. The NBP's primary goal was to accelerate the development of biofuel industry in Ghana, with a special emphasis on jatropha [27,70–72]. The Biofuel Committee zeroed in on jatropha specifically because a Ghanaian biochemist, Onua Amoah, who was also the Chief Executive Officer of biodiesel processing company named Anuanom Industries Ltd., had successfully produced biodiesel from jatropha in the early 2000s [70]. The government also had a unique interest in making jatropha the target plant because it was already known to be useful for multiple purposes on the local scale including making soap from its oil and using the seeds for fertilizer [27,73]. The knowledge that a plant could make use of Ghana's vast degraded and marginal lands made the case of cultivating jatropha for biodiesel even more convincing to Ghanaians [27,70,74]. Besides, it would be a viable investment for communities as a jatropha plantation has a relatively short period of establishment that ranges from two to five years and an up to 50 years of longevity [75]. Compared to other feedstocks as depicted in Table 4, jatropha is noted as the best option for biofuel in terms of production cost [5].

Table 4. Production Cost of Biofuels by Type of Feedstock [5].

Biofuel Feedstock	Estimated Cost of Production (US$ per barrel)
Cellulose	305
Wheat	125
Rapeseed	125
Soybean	122
Sugar beets	100
Corn	83
Sugarcane	45
Jatropha	43

In the period of 2006–2007, there were hikes in global oil prices, and that gave further momentum to strategizing for fossil fuel substitution with biodiesel from cultivated jatropha and other energy crops, without threatening food security and livelihoods in Ghana [70,71,74]. The NBP outlined several recommendations in its steps towards reducing dependence on fossil fuels. One of them was to substitute 20 and 30 percent of national gasoil and kerosene consumption, respectively, with jatropha oil [72]. The plan also recommended that the country pursues replacing at least 5 percent of petroleum diesel with biodiesel by the year 2010, and 20 percent by 2015 [72,73]. Besides these, the NBP recommended that institutional barriers be removed in order to promote private sector engagement in the production of biofuel, and the management of the industry [72].

The then New Patriotic Party (NPP) government showed optimism and established the National Jatropha Project Planning Committee in 2006 to plan for jatropha biofuels development [70]. The government was to approach the jatropha cultivation with a similar model to Ghana's cocoa industry—an out-grower system—where a marketing board set up by the government would buy jatropha nuts from farmers to be processed by Anuanom Industries Ltd. Soon after the training programs, the government allotted some lands classified as "marginal" or "degraded" in 53 districts around the country for jatropha cultivation by farmers with interest. The areas cut across the savanna and forest or transitional ecological zones of Ghana [70]. As Boamah [70] noted, the government's rationale for selecting areas within these 53 districts is that cultivating on them will have little to no consequence for food crop production, as they are outside the major food production zones in the country.

The biofuel development was taking off according to plan. However, it was not long after the training and sensitization workshops that the pioneer of the jatropha initiative, Onua Amoah, died. The death of the main brain behind the government's interest in jatropha biodiesel, coupled with the discovery of oil within the borders of Ghana reduced government's interest in the project. The government later withdrew from the national biofuel project. However, it pledged that it would continue to support private investors who were interested [70]. Without the government in play, it meant that growers of jatropha had to find another market to purchase their produce. It is also important to note that the jatropha frenzy was not unique to Ghana, and therefore there were foreign interests that were ready to fill the vacuum. At this point, there was a high influx of foreign biofuel investors in the country, including companies from Canada, Italy, Norway, and Japan.

As foreign companies trooped in, their focus was fundamentally different from the main purpose for which jatropha development had been pursued in Ghana. While according to the framework developed by the biofuel committee, a government board was going to buy the jatropha seeds from the farmers for processing in Ghana, the foreign companies primarily wanted to grow jatropha as a raw material for export. The only local content in their pursuit was the lands needed for cultivation, and the labor needed for that. With the government having pulled out, there was little political will to regulate the nascent biofuel industry by the NPP government [70]. Even with the global alarm over food for fuel that had triggered the 2008 food crisis, the new government of the National Democratic Congress (NDC) that took over power in 2009, while expressing concern, continued with the policies of the previous government by encouraging foreign investments. Effectively, an industry that was being nurtured for subsistence, and community farm scales had transitioned into another cash crop industry, with no significant means of local processing [27,70].

By 2009, the government approved about 400,000 hectares of land for ScanFuel Company Limited, an affiliate of the Norwegian company ScanFuel AS, to begin one of the first large scale jatropha plantations in Ghana [27,70,76]. By August of the same year, there was a collective area of about 1,075,000 hectares of land dedicated to energy crop production around Ghana. Of this total, an estimated 730,000 hectares were located in the Brong Ahafo Region and the northern Ashanti Region, all in the forest-savanna transition zone [3,5,27,76]. According to Schoneveld et al. [76], about seventeen companies acquired the vast land area, of which fifteen were reported to be owned by foreign entities or financed by the Ghanaian Diaspora. As Schoneveld [76] further explained that all but one of the said companies operated on a business model that required large-scale feedstock plantations of more than 1000 hectares.

Besides the ScanFuel project that was located in the Agogo Traditional Council in Southern Ghana, several other projects gained prominence. The BioFuel Africa project was also another that involved a Norway based company, BioFuel Africa Ltd. The BioFuel Africa project covered an approximately 23,000 ha of land, and was located in the Northern Ghana, spanning several towns and villages including Kpachaa, Kparchee, Tua, Jachee, Sagbargu, and Chegu predominantly within the Yendi and Gonja Districts [70,77]. The project also acquired an 850 ha test farm in the Volta Region of Ghana. Another notable project was the Kimminic project that involved a 65,000 ha joint venture land deal with six traditional councils in the Brong Ahafo Region dedicated to cultivation of jatropha. The Kimminic project was funded by Canadian investors [70,76]. The European Union (EU) also funded a 500 ha jatropha project in the Northern Region as an "aid" project that was primarily for income-generation purposes for vulnerable groups, especially women [70]. According to Boamah [70], the EU project was coordinated by the University of Sassari from Italy, and collaborated with local research institutions such as Technology Consultancy Centre of the Kwame Nkrumah University of Science and Technology, the Savannah Agricultural Research Institute, and the Ministry of Food and Agriculture (MOFA). With all these projects flooding in, Ghana inevitably became known as the "Jatropha Center in Africa" [76]. Ghana, together with fellow sub-Sahara African countries Sudan, Ethiopia, Nigeria, and Mozambique, accounted for nearly a quarter of land acquired around the world for biofuel plantations [78,79].

The large-scale land acquisition that took place was unprecedented in the country. The "land grabbing" that occurred brought significant amount of conflicts, and raised concerns within communities and among civil society. This is especially because these large scale land deals in most cases had the direct involvement of chiefs, contrary to previous decades where such large scale acquisitions for agricultural activities and mining concessions were solely negotiated on the state level [3,76,77]. As Boamah [80] indicated, Ghana has a predominantly customary land tenure regime, where customary landowners such as families, clans, and stools hold over 80 percent of land. For this reason, the complicity of a head of any of these institutions could lead to loss of lands for large groups of people who may not have any legal recourse.

Many scholars have documented the consequences of large scale land acquisitions on local livelihoods and the numerous conflicts that ensued, as well as the roles of different actors [3,70,76]. For instance, Campion and Acheampong [77], using of interviews, questionnaires, and focus group discussions, investigated and catalogued the roles of chiefs in the acquisition of land, and the causes and solutions of conflicts that ensued in jatropha plantations. According to Campion and Acheampong [77], the chief who presided over the transaction of the Biofuel Africa project did not inform the community members of the transaction. Many farmers lost their farms in the process, giving rise to widespread agitation. In another project by Galten Agro Ltd., Campion and Acheampong [77] indicated that the chiefs of Fievie Traditional Area carried out the transaction when they were not the rightful owners. While the chief of New Bakpa, the rightful owner, succeeded in compelling the company to re-sign a new lease with him, members of the community did not play any role regarding the new lease. Compensation for affected farmers in this case was also absent from the renegotiation efforts. In the Kimminic project, which was located in two different communities, Campion and Acheampong [77] explained that the Nkoranza Paramount Chief gave a vast land area to the investors, without seeking the consent of local farmers who received no compensation for their lands. The ScanFuel project in Agogo had a similar story as negotiations took place between the paramount chief and the company, without the people's involvement. Campion and Acheampong [77] concluded in his study that while the conflicts were somewhat diverse in terms magnitude, the common thread that linked all of them was the land dispossession from the local people, which threatened their livelihoods.

Regarding the extent to which land dispossession impacted the livelihoods of the local people, studies such as Acheampong and Campion [3], Schoneveld et al. [76] and Boamah [80] have shown that the consequences on the local scale can be devastating, leading to resistance and conflicts. The resistance of local communities to projects that had adverse impacts on their livelihoods, and the support they gained from civil society dealt a significant blow to the jatropha industry. As Boamah [70] indicated, for example, a non-governmental organization (NGO) called the Regional Advisory and Information Network Systems (RAINS) was very vocal in its opposition to the BioFuel Africa project as it criticized the impacts of the project land tenure and food insecurity. ActionAid Ghana eventually joined the chorus of criticisms corroborating the assertions that the project was destroying livelihoods. With the growing scrutiny that the nascent industry was being subjected to, some of the projects were downsized or switched their purpose. For instance, the BioFuel Africa eventually registered only about 11,000 ha of land for the project instead of the original 23,000 ha that they earmarked for the project [70]. ScanFuel also switched the project from jatropha plantation to maize plantation in 2010, and formally changed the name of the project to ScanFarm [70,76].

While some critics have pointed to Ghana's ambition interfering with its due diligence, the country's haste was founded on good reason. This is because researchers such as Deichmann et al. [12] has shown that beyond transportation fuel, biodiesel production from jatropha is an important option to fuel minigrids for remote areas to aid decentralization of electricity supply, which supports why the country showed eagerness in tapping into such a valuable resource. Besides, while there have been a significant negative press associated with jatropha plantations in Ghana, it should not be overlooked that in communities where the companies showed interest in the well-being of community members, the people appreciated the additional employment options offered and were supportive of the project. These show that with a diligent approach, jatropha still possess the potential to contribute significantly to Ghana's energy needs and rural employment.

4.1.4. Potential of Food Crops for Biofuels

As previously noted, Ghana is home to several crops that have significant potential for biofuel production if properly tapped. Below, we discuss some of the major agricultural products with high potential as far as biofuel development is concerned.

Oil Palm

Specifically, oil palm is the focus of several advocates of biofuels due to its high yield, coupled with easy availability and affordability. In addition, researchers have noted that biodiesel possess a higher cetane number than the conventional fossil diesel—65 and 55 for the former and latter, respectively. A cetane number is an indication of the ignition delay for a fuel in an engine. Transesterification is a common process that is used to derive biodiesel straight from palm oil by reacting triglycerides with alcohol. It is the most common and accepted process because it is cheap and simple. While methanol is normally used because it is cheap, other alcohols can be used in the transesterication process [81,82]. The use of methanol can yield up to 87 percent of oil to biodiesel. As part of the process, it has also been noted through several studies that for every ton of biodiesel produced, there is 0.32 ton of glycerol produced as by-product [83,84]. There is another way through which palm oil produces biodiesel. In this process, heated oil reacts with hydrogen to produce renewable diesel fuel, which is also referred to as the hydrotreated vegetable oil (HVO). This HVO process is responsible for the removal of hydrogen from triglycerides. Hydrotreatment is relatively more expensive compared to the transesterification process [81].

Like many countries in west and central Africa, Ghana produces a significant amount of oil palm fruit [85]. The successes achieved by countries such as Malaysia and Indonesia for using oil palm in producing substantial amounts of global biodiesel makes oil palm one of the leading candidates of raw materials for biofuel development in Ghana [5]. Duku et al. [27] noted that the quantity of palm fruits that Ghana produces rose substantially between 2001 and 2009 by over 70 percent, from 1.1 million tons to 1.9 million tons [69]. MOFA [86] estimates that almost 244,000 tons of oil is produced from Ghana's oil palm industry, covering approximately 306,000 ha of plantation. While Ghana derives significantly more, in terms of revenue, from cocoa, it produces more oil palm fruits in tons [5,27,87]. A majority of oil palm plantations are located in the rain forest and deciduous zones, within the Ashanti, Western, and Eastern Regions [88]. According to MOFA [86], there is about 1 million ha of land suitable for palm plantations in the country, spread throughout the Ashanti, Western, Eastern, Volta, and Brong Ahafo Regions.

Most palm plantations are held by smallholder farmers, with farm sizes of up to 7.5 ha [5,86]. However, there are some notable medium and large scale exceptions in the country. Table 5 lists the major oil companies currently operating in Ghana, along with the areas cultivated [86].

Table 5. List of Major Oil Palm Companies and Areas Cultivated [86].

Company	Total Area (ha)	Milling Capacity (tons/hour)
Ghana oil palm development company ltd. (gopdc)	22,352	60
Twifo oil palm plantations ltd. (topp)	5924	30
Benso oil palm plantations ltd. (bopp)	6316	27
Norpalm gh. Ltd.	4000	30
Juabin oil mills	1524	15
Ayiem oil mills	250	10
Golden star	720	-
Total	41,086	172

Many varieties of the oil palm trees are cultivated in Ghana, with two main types notably divided along scale lines. While small-scale farms normally grow a variety known as dura, medium and large-scale plantations plant the tenera species. The tenera is more useful for industrial scale production because it has a smaller nut and a thicker mesocarp, and therefore produces more oil [5,89]. Small-scale farms account for nearly 80 percent of palm oil produced in the country, with the remaining portion coming from medium-and-large scale plantations [5].

The government of Ghana launched the Presidential Special Initiative (PSI) on Palm Oil Plantation and Exports that was launched around 2004 as strategy to improve the country's palm industry. In total, the PSI planned to cultivate about 100,000 ha of oil palm over a 5-year period in the country. However, the program has so far led to over 20,000 ha of small-scale oil palm farms cultivated around country [27,86]. As part of the program, was also a plan to establish 12 nurseries in the country to raise 1.2 million high-yielding seedlings to supply to farmers, while the Oil Palm Research Institute (OPRI) of the CSIR was tasked to produce 2 million of such seeds annually [27,90].

According to MOFA [86], Ghana currently still has a deficit of about 35,000 tons of palm oil. The country, therefore, imports between 5 and 10 percent of its total annual production to supplement local consumption [5]. By the estimates of analysis that Afrane [5] conducted in his study, Ghana will have to channel between 17 and 35 percent of its palm oil consumed locally to produce the quantity of biodiesel that can substitute five and 10 percent of fossil diesel consumed in the country. He argued that based on current estimates of palm oil deficit, and the high quantity of palm oil needed to be withdrawn from the local market to produce biodiesel, there is a slim possibility of achieving significant biodiesel production with oil palm. This observation, notwithstanding, with the government's continuing PSI intervention measures and the availability of vast land suitable for plantations, there still remains significant potential inherent in Ghana's oil palm industry to support biofuel production.

Cassava

Cassava is staple food in Ghana, and is therefore commonly grown. Its predominance in the Ghanaian diet stems from several factors including affordability and easy availability. In addition, cassava can thrive on lands with marginal quality in tropical regions [5]. Some of the most commonly grown species on the local level are afisiafi and abasafitaa. These two species have significantly high starch content of over 20 percent. Given this high starch content, cassava has become a suitable candidate for the production of biofuels—notably, ethanol.

For nearly two decades, there have been significant improvements in cassava strains and agricultural practices in the cassava industry. These, combined with the fact that the land area dedicated to cassava production is increasing in size, have contributed to an increase in the quantity of cassava produced in the country. Figure 10 shows the different rates at which both cassava land area and tonnage have increased [5,91]. One of the contributing reasons for the increasing cassava land area is that fallow periods are constantly decreasing in farms in the country, as in many sub-Sahara African countries. The reduction in fallow periods contributes to declining soil fertility, and farmers seeking to grow crops that can thrive in less fertile soils [5].

Afrane [5] conducted an analysis on the potential of cassava-based ethanol in replacing petrol on the local level in different scenarios. In this study, he found that based on 2009 figures, it will require about 3 percent of locally produced cassava to produce the quantity of ethanol that is capable of substituting 5 percent of petrol consumed. In using projections for 2019, he found that it will take even smaller proportion (2 percent) of local cassava to produce ethanol to replace 5 percent of petrol. By this, it means that it will require about only 10 percent of local cassava to replace 25 percent of the total quantity of petrol consumed locally.

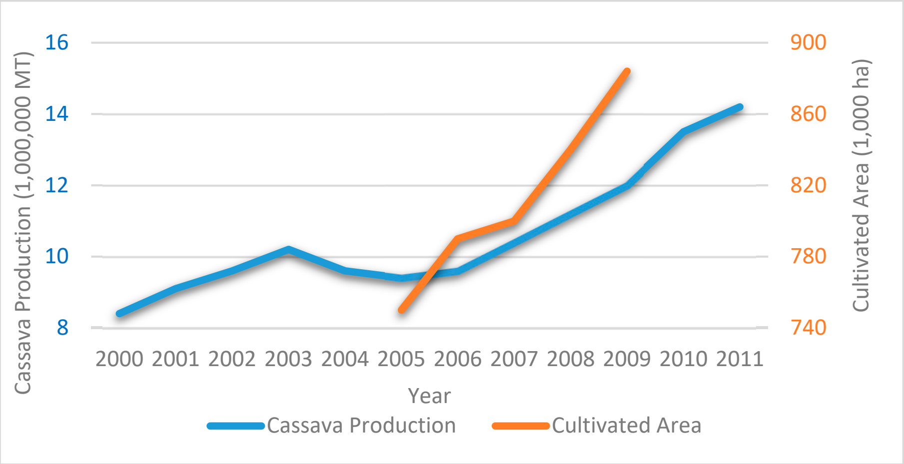

Figure 10. Annual Cassava Production and Land Area Cultivated [5,91].

The findings in Afrane [5] are an indication that unlike oil palm, using cassava as a feedstock for biofuel production in Ghana may be easier to implement, without significantly compromising food consumption. There has also been constant research in producing different varieties of cassava that have higher starch content that will be even more desirable in terms of ethanol production around the world. For example, Babaleye [92] stated that researchers from the International Institute of Tropical Agriculture in Nigeria developed species of cassava that had up to 40 percent of starch.

4.1.5. Assessing the Energy Generation Potential of Agricultural Residues and Household Wastes

Agricultural Residues

Ghana generates a sizeable amount of wastes and residues from various agricultural, forestry, industrial, and household activities, which can be channeled into energy generation purposes [9,22,27]. Specifically, biomass from agricultural by-products has especially been prominent over the past years in the production of second-generation biofuels [2,27,93]. Agricultural by-products in Ghana are classified into crop residues, agricultural industrial by-products, and animal waste [22,27]. In Ghana, farmers normally leave agricultural residues on the farm after harvesting the target crops, while some in other cases burn them. Crop residues cover a range of materials including the following: stalk of various cereal crops such as rice, maize, millet, and sorghum; cocoa pods; and straw [27]. According to Duku et al. [27], most of the by-products that emanate from agro-industrial activities are in the form of husks from cocoa, coconut, and rice; sugar cane bagasse; oil seed cakes; and empty fruit bunch (EFB) from oil palm. Animal wastes are also typically cow dung burned as a fuel.

Ghana has large swaths of land covered with cocoa plantations, as it is the most important agricultural contributor to the country's economy. Being the dominant cash crop, cocoa is grown in the Western, Ashanti, Brong-Ahafo, Central, Eastern, and Volta Regions—all in Ghana's forest zone, and covers about 1.75 million ha. Normally, cocoa pods are left on farms to mulch. Some of the husks are exported. However, they have the potential to be power generation, when compressed [27,94,95].

Residues such as stalks, cobs, and husks from maize farms also offer a significant potential as feedstock for biofuel production [27]. The quantity of maize cobs and stalks is said to be over 550,000 tons in Ghana, and this has a potential of yielding about 17.65–18.77 MJ/kg of energy [9,22]. The stalk of sweet sorghum also has a level of sugar, which makes it also suitable for the production of ethanol [27]. It is estimated that the country produces approximately 136,000 tons of sorghum stalks. Among prominent agricultural residues are also an estimated 150,000 tons and 56,000 tons of millet stalk and groundnut shells, respectively [9,22].

There is a significant amount of residues that emanate from the over 300,000 ha of palm plantations in Ghana. The three main residues from this industry are shells, fronds and EFB. The shells are particularly suitable for producing activated carbon and heating, while the EFB that is rich in potassium, and fronds have other uses such as for fertilizer and mulching purposes, respectively [27]. It is estimated that Ghana produces about 193,000 tons of palm shells annually [9,22]. Coconut trees that are found predominantly at the coastal areas of the country also generate a significant amount of residues in the form of husks and shells that also have the potential to be deployed in energy production [27].

From industrial activities, residues from the wood processing industry are said to top 1 million m^3 per annum. These residues consist of wastes generated at logging sites, and slabs, edgings, sawdust, off cuttings, peeler cores, among others that are generated from the manufacture of plywood at the factory level [18,22]. As EC [22] noted, most of these factory produced residues are concentrated in Kumasi and Accra, where large sawmills and large-scale furniture mills are located. In addition to the logging and milling residues are the biomass of trees of poor form, which are rejected for commercial sale that have significant potential for energy generation [22].

Regarding animal wastes, Bensah [96] has found that there is a considerable potential to generate significant amount of energy from them, especially in the three northern regions of the country. Cattle rearing are leading occupation for many residents in the northern regions, and therefore produce a huge quantity of cow dung. Table 6 shows that there is an average of 15 cattle per household in the three northern regions put together, with the breakdown per region. Owing to this, the potential to develop household level biogas plants due to the quantity of cow dung generated per household can be tapped to produce energy for cooking and lighting.

Table 6. Cattle Populations in the Three Northern Regions of Ghana [96].

Region	Cattle Production	No. of Cattle Owning Households	No. of Cattle Owning Agricultural Households	Average No. of Cattle Per Agricultural Household
Northern	982,287	98,090	85,142	11.5
Upper west	787,681	28,250	23,645	33.3
Upper east	454,112	47,577	39,441	11.5
Total	2,224,640	173,917	148,228	15.0

Per the preceding, it is also obvious that Ghana produces a significant stock of crop residues that have the potential to be subjected to modern biomass energy technologies such as anaerobic digestion and gasification to produce power. On the other hand, however, residues play a significant role in the traditional agricultural practices in Ghana, and any alternative uses must be pursued with caution. This is because as agricultural systems that utilize very little synthetic inputs, burning crop residues on farms can serve a range of purposes including facilitating harvesting and pest control measures. In addition, the residues that are left on farms also decay, and serve to replenish soil fertility, which absent will adversely affect productivity agricultural, and can threaten food security [1,27,97].

Municipal and Household Wastes

In Ghana, there is a huge quantity of wastes that are generated from households and municipalities, posing a significant sanitation challenge to municipal authorities and other responsible agencies. It has been estimated that the waste generated in a city in a day is about 0.6 kg/person [9,98]. The amounts of wastes produced are significantly higher for the two most populous cities in the country, namely, Kumasi and Accra, with about 1600 tons/day and about 2500 tons/day, respectively [22]. Many countries have resorted to waste-to-energy technologies, through biogas production, to achieve the dual purpose of managing wastes and generating power. In Ghana, based on the amount of wastes that is generated on a daily basis, there is a real potential towards exploiting such routes, with adequate funding.

4.2. Current Status and Potential Solar Energy Integration

Like many countries in Africa, solar energy remains an important alternative source for energy production in Ghana. Ghana's geographical location in the tropics means that there is relatively high solar radiation distributed throughout the year in all of its ten regions [18,99,100]. The Ghana Meteorological Services Agency has collected solar radiation and sunshine duration data over the past half century. Likewise, other research institutions and international organizations have also conducted similar monitoring exercises [22]. For instance, in 2002, UNDP carried out the Solar and Wind Energy Resource Assessment (SWERA) project that assessed the potential of solar energy resources in the country, based on data from the high resolution geostationary satellite Meteosat [101,102]. The country's annual daily mean of total solar radiation is estimated to be 4.0–6.5 kWh/m^2/day, with a sunshine duration of about 1800–3000 h per year [18,102,103]. Figure 11 depicts a graphical representation of the distribution of relative solar radiation intensity across Ghana.

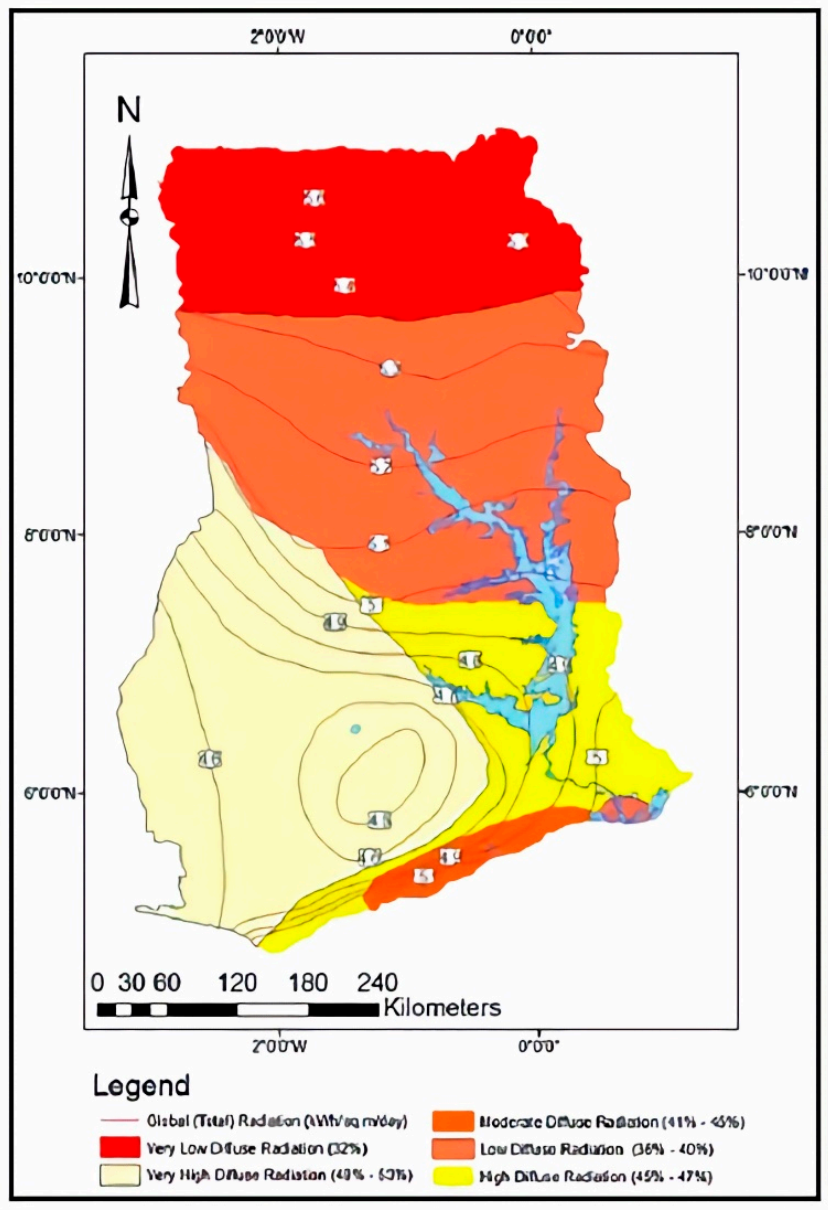

Figure 11. Distribution of Solar Radiation Intensity in Ghana [102,104].

As seen in Figure 11, the three northern regions of Ghana, with the lowest electrification rates in the country, have the highest solar energy potential [9,18]. The individual solar irradiation measurements carried out multiple locations spread throughout the country supported the assertion that the highest potential for solar energy dwells in the northern part of Ghana [104]. The monitoring exercise, for comprehensiveness and complementarity, utilized both ground and satellite measurements. In both measurement approaches, Yendi, Navrongo, and Wa, all in the three northern regions, recorded the highest solar irradiation, as shown in Figure 12 [22,104].

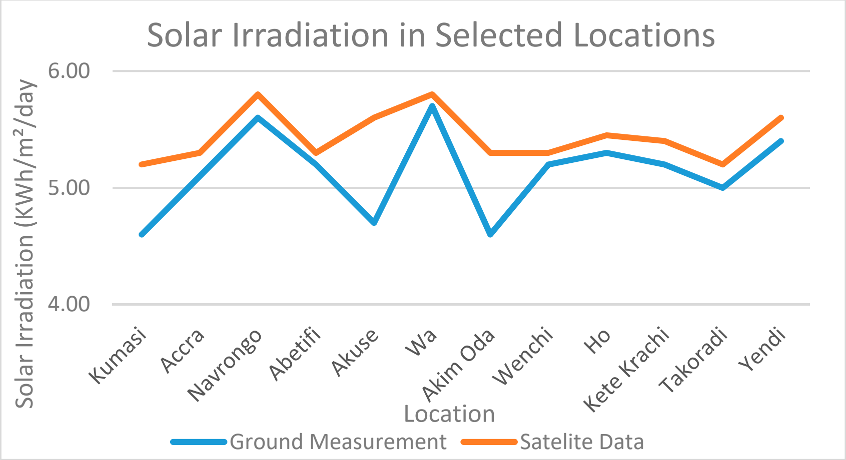

Figure 12. Distribution of Solar Energy Potential at Specific Locations in Ghana [104].

The VRA showed that the country has the interest in tapping into solar energy on a large scale by constructing a 2.5 MW solar power plant in Navrongo [4,21]. This plant, at the time of completion, was the largest in mainland West Africa. The authority has also since embarked on a project that added 155 MW of power on board through solar energy [105]. Besides the interest in large-scale deployment, the appeal of solar energy also stems from the potential for decentralization, in that it can contribute to electrification of small settlements that are far from the national grid [12,21]. In addition, solar photovoltaic (PV) systems have shown considerable potential to contribute to electricity generation for traffic lighting, water pumping, household lighting, and rural vaccine storage, among others [18,57]. By 2011, the EC estimated that about 4500 solar systems had been installed in almost 90 countries around the country, with breakdown by purpose shown in Table 7. According to Kemausuor et al. [18], the current total number of solar PV systems deployed in the country demonstrates a relatively sharp increase in solar energy development in Ghana over the past two decades and half. This is because by 1991, there were only 335 PV systems installed over the country, with a meagre 160 peak kilowatts of estimated total power generated from them [106,107].

Table 7. Solar PV Systems Installation in Ghana by Purpose [22].

Places/Purpose of Solar PV Systems Deployment	Installed Capacity (kw)	Average Annual Production (gwh)
Rural homes	450	0.70–0.90
Urban homes	20	0.05–0.06
Schools	15	0.01–0.02
Lighting of health centers	6	0.01–0.10
Vaccine refrigeration	42	0.08–0.09
Water pumping	120	0.24–0.25
Telecommunication	100	0.10–0.20
Battery charging	10	0.01–0.02
Grid connection	60	0.10–0.12
Streetlights	10	0.04–0.06
Total	853	1.34–1.82

Many researchers have conducted empirical studies that assess that impacts of solar energy development on quality of life in off-grid communities. In the study of Kankam and Boon [23], the authors examined the link between government energy policies, such as solar PV systems deployment, on rural development in the Nwodua, Langa, Bognayili, and Changnayili communities from the Northern Ghana. In the study the authors found that solar systems in homes, in addition to local kerosene have contributed significantly to lighting services in homes in non-electrified communities. In gridded communities, however, the authors found that the residents preferred electricity supply from central grid to solar energy. The authors explained that while the prospects of solar energy development is promising, the current government approach to solar energy to allow the private sector play a leading role in the context of the country's overall energy policy in has made investments unfavorable. This is because, as they argue, the solar energy sector receives significantly less subsidies compared with what conventional energy delivery receives. Kankam and Boon [23], therefore, recommended that government implements a policy that advances equal level of subsidies for solar energy delivery, in order to encourage private participation, and stimulate fair competition with conventional energy option.

Obeng and Evers [99] also conducted a study to analyze the impacts of solar PV electrification systems on micro-enterprises that are located in off-grid rural communities. In this study, the authors considered communities that are located in five out of the ten regions, namely; Northern, Upper West, Volta, Brong Ahafo and Greater Accra regions. All communities that were selected because they were beneficiaries of two major public sector solar PV electrification projects—MOE/Spanish Funded Solar PV Electrification Project and UNDP-GEF/RESPRO—that were implemented between 1998 to 2003. The authors developed a set of indicators to analyze the relationships between enterprise-level electrification status and economic output, by using systematic sampling to select those with and without solar PV electrification. The empirical results revealed a statistically significant association between solar PV lighting and increased income of US$ 5–12/day in grocery enterprises. It also revealed that some costs are avoided by using solar PV in off-grid enterprises instead of kerosene lanterns, which amounted to an estimated US$1–5/month.

The above-referenced studies provide further indication of the potential benefits of exploiting the naturally decentralized capabilities of solar energy to power small communities. Deichmann et al. [12] revealed, the estimated levelized marginal costs of electricity supply from central grids in many African countries are estimated to be between 16 and 50 cents/kWh for most demand areas but such cost steeply rises to over a dollar for most remote areas. In addition, the strength of local solar radiation determines the cost of solar PV generated electricity. In Ghana, the three northern regions have the highest incidence solar radiation, while also being the least connected to grid electricity. For these reasons, it is safe to assume that the benefits of tapping into solar energy may best be realized for rural communities in the northern part of the country. For the country to reap the exploit the potential to the maximum, however, it is important to address challenges such as improving market competitiveness with policies and interventions of fair subsidies to incentivize private sector ventures.

4.3. Status and Potential of Wind Energy Development

Wind energy remains fringe in the Ghanaian energy supply system, but it has received quite considerable amount of attention in recent years due to the fact many researchers have advocated that it is relatively cheaper compared to other renewables [108,109]. For wind energy, the wind turbines produce electrical energy by converting the kinetic energy of the wind with their rotating blades. Wind energy is appealing because it is free and available both day and night, and has an onshore technical potential of about $20{,}000 \times 10^9$–$50{,}000 \times 10^9$ kWh per year around the globe, which is greater than the current total annual world electricity consumption of about $15{,}000 \times 10^9$ kWh. Investments in wind energy have grown by about an average of 22 percent over the past 10 years, currently constitutes about 2.5 percent of global electricity supply. The economic potential of wind depends on factors such as average wind speed, intensity of turbulence, distribution of statistical wind speed, and the cost of wind turbine systems [21,57,110,111]. Anderson et al. [112] stated that it is always imperative to know the possible extent of wind resources within any country to determine its viability as an energy source, before installing a wind turbine.

To this extent, a series of assessments have been systematically conducted in Ghana to examine wind energy potential over the past 20 years [113]. The Ghana Meteorological Services Department has traditionally measured wind data in Ghana, and has observed that wind speed in most parts of the country is between 1.7 and 3.1 m/s at a height of 2 m based on data collected from 22 synoptic stations [4,9,21]. However, as NREL [114] explained, 2 m data are usually not useful when assessing the potential of wind resource for power generation at utility scale. This is attributed to the many obstructions and surface roughness near the ground [9,114]. In this regard, the Ghana EC conducted higher altitude assessments along the country's coast to assess wind resources for power generation. The assessments found the average wind speed per month to be 4.8–5.5 m/s, at an altitude of 12 m [9,113]. As part of the SWERA project, the US National Renewable Energy Laboratory (NREL) also carried out a comprehensive assessment on the potential of wind resources in Ghana, as part of the initiative to supply more reliable renewable energy resource information around the globe [56]. The NREL carried out assessments based on data collected from the U.S. National Climatic Data Center (NCDC) derived DATSAV2 global climatic database, which contains information from 21 stations in Ghana. The data collected was combined with information from the Ghana EC's wind resources measurements, satellites, and the Meteorological Services Department (MSD). The NREL developed a high resolution 1 km wind energy resource maps for the country at 50 m above ground, with the goal of showing areas with the greatest potential for large-scale wind turbines that could be connected to the country's grid [114]. Figure 13 below shows the final wind resource map as produced from the SWERA project.

According to the NREL findings, there is an estimated area of 413 km^2 in the country with a class 4–6 wind resource, categorized as good-to-excellent, which can support more than 2000 MW of wind power development. According to their findings, the amount of energy could increase to about 5640 MW, if areas with moderate potential are included. An annual average wind speed of between 7.1 and 9.0 m/s cover this range of "moderate" to "excellent" wind energy potential over a 1000 km^2 area [18,21,114,115].

As can be seen from the wind resource map, the southeast portion of Ghana, around Accra, has a Class 2 (6.2–7.1 m/s) wind resource at a height of 50 m. The northwest portion of Accra and the areas along the border of Togo to the east of the country, however, are characterized by the good to excellent Class 5 (8.4–9.0 m/s) wind resource, possessing the highest wind energy development potential in the country. It is estimated that this area that covers about 300–400 km^2 of land area can yield about 600–800 W/m^2 power density [9,113,114]. While not all areas in the country may have the potential for commercial wind energy projects, Kemausuor et al. [18] indicated that even lower wind speeds nearer ground level may be suitable for energy conversion devices such as wind-powered water pumping systems.

A more recent study has confirmed the distribution of wind resource potential in Ghana [116]. In this assessment, five modern meteorological masts of 60 m were mounted at five selected sites along Ghana's coastal zone the end of 2011. In this project, the researchers collected wind speed measurements at 40 m, 50 m and 60 m above ground, as well as the direction of wind at 47 m and 57 m above ground, in sites located in the following communities: Ningo (Greater Accra Region), Ekumfi Edumafa (Central Region), Gomoa Fetteh (Central Region), Avata (Volta Region), and Atiteti (Volta Region). Figure 14 presents the results of the wind speed measurements obtained from the assessment. After obtaining the results, they were extrapolated to produce potential wind speeds at 80 m and 100 m above ground to determine the viability of deploying commercially available wind turbines, which are of similar heights above ground. A simulation of wind turbines at all the conducted sites was also conducted, and they are produced capacitor factors that revealed that there are economically viable sites for wind-farm projects in Ghana [116].

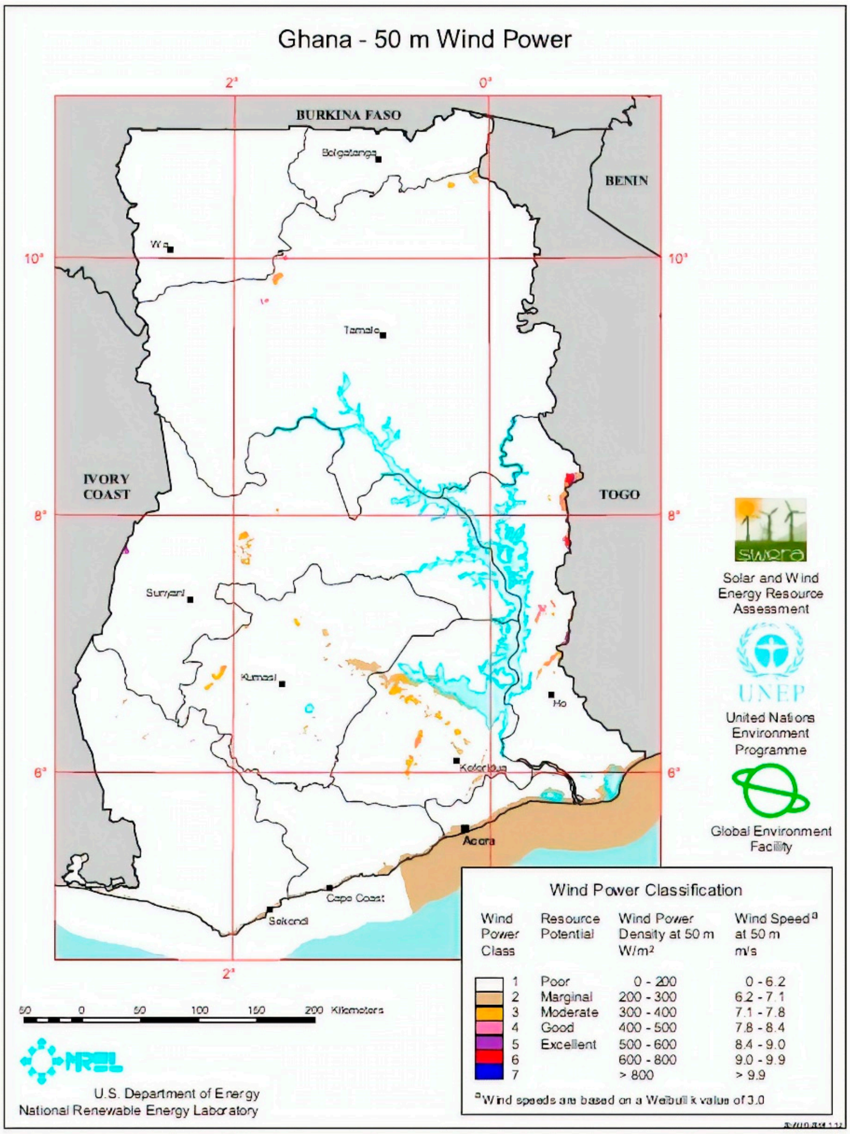

Figure 13. Map of Wind Energy Potential Distribution in Ghana with Wind Speed at 50 m Height [114].

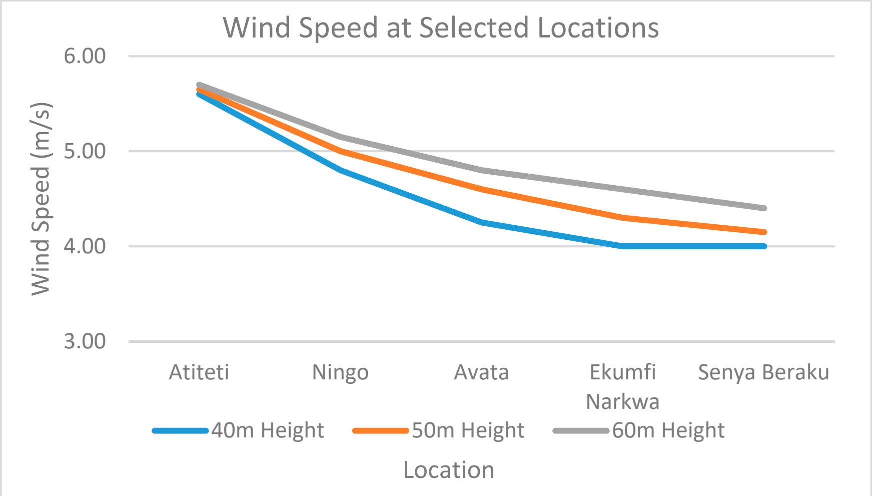

Figure 14. Measure of Wind Speed at Specific Locations in Ghana using NRG 60m XHD Wind Mast [116].

Adaramola et al. [21] has also conducted a study that showed that economic feasibility of wind energy in Ghana may depend on specifics such as the type of turbine that a developer decides to deploy. The researchers evaluated the wind energy potential and the economic viability of deploying different wind turbines for electricity generation along six selected sites along Ghana's coast. The six locations were, namely: Adafoah, Anloga, Aplaku, Mankoadze, Oshiyie, and Warabeba. According to Adaramola et al. [21], the selected areas were classified as possessing low to medium wind speed regimes. Based on existing data, the researchers elected to perform the economic analysis on selected small to medium size commercial wind turbines to ascertain the best option, in order guide government and stakeholder decisions regarding investment in wind energy resources. The researchers analyzed the performance and economic efficiency for four small commercial wind turbine models that ranged from 50 kW to 250 kW, namely: Polaris 15–50, CF-100, Garbi-150/28 and WES 30, in order of size. The cut-in wind speeds, and moderate rated wind speeds ranged from 2.2–2.7 m/s, and 9.5–13 m/s, respectively. The researchers found out that the electricity output a wind turbine achieved and its size were positively correlated, with the WES 30 achieving the greatest in all sites. However, as the authors argued, the decision on selecting a suitable turbine should not only be based on the size, but also on its ability to generate electricity at a cheaper cost, all things considered. In this context, the capacity factor of a wind turbine must be combined with the total energy output, in order to assess the economic viability of wind energy project. In terms of capacity factor, the Polaris 15-50, which was the smallest turbine in terms of size, had the highest value in all locations. In relation to end user tariffs in Ghana in 2012, the researchers concluded that overall, the CF-100 model was the most economically viable option at all the selected sites. Adaramola et al. [21] also concluded that wind turbines with a cut-in wind speed of less than 3 m/s and moderate rated wind speed between 9 and 11 m/s will be more suitable for wind energy development along the coastal region of Ghana.

From the above, it is notable that while wind energy has not achieved a significant penetration into the Ghana energy market, there is no shortage of interest in the venture. In fact, it can be seen that researchers have moved from theoretical viability assessments to practical feasibility analysis in many areas. The VRA is already erecting a 100 MW wind power plant in Kpone, while also undertaking scoping studies to construct a 150 MW plant, which will be divided equally between communities in the Volta and Greater Accra Regions [22,117]. Without doubt, the wind energy potential in the coastal Regions of Ghana seem high enough to be encouraged, and with the appropriate policies and incentives instituted, it could play a remarkable role over the next decade in Ghana's SDG number seven pursuit.

4.4. Small-to-Medium Scale Hydropower

Assessments carried out in Ghana have identified an estimated 2000 MW of additional hydropower potential around the country. Of this total, it is estimated that 1200 MW will be derived from the traditional large scale ones as those already used in the country, while small and medium scale ones could be developed around the country to supply the remaining 800 MW [9,18,118,119]. So far, researchers have identified about 70 sites that have been declared as with the potential to accommodate small and medium hydro sites around the country. Hydro sites are considered as small if they are capable of producing only less than 1 MW of electricity, while those that produce between 1 MW and 100 MW are categorized as medium. Figure 15 shows some of the prominent identified sites in Ghana as of 2011. As it can be deduced from the map, the potential of small-to-medium hydro is more concentrated in the following five regions: Brong Ahafo, Ashanti, Volta, Eastern and Central Region [9,18,120]. On the six rivers, Black Volta, White Volta, Oti River, Tano, Pra, and Ankobra alone, EC [22] has stated that there are up to 17 possible sites for hydroelectric plants that can generate over 10 MW of electricity.

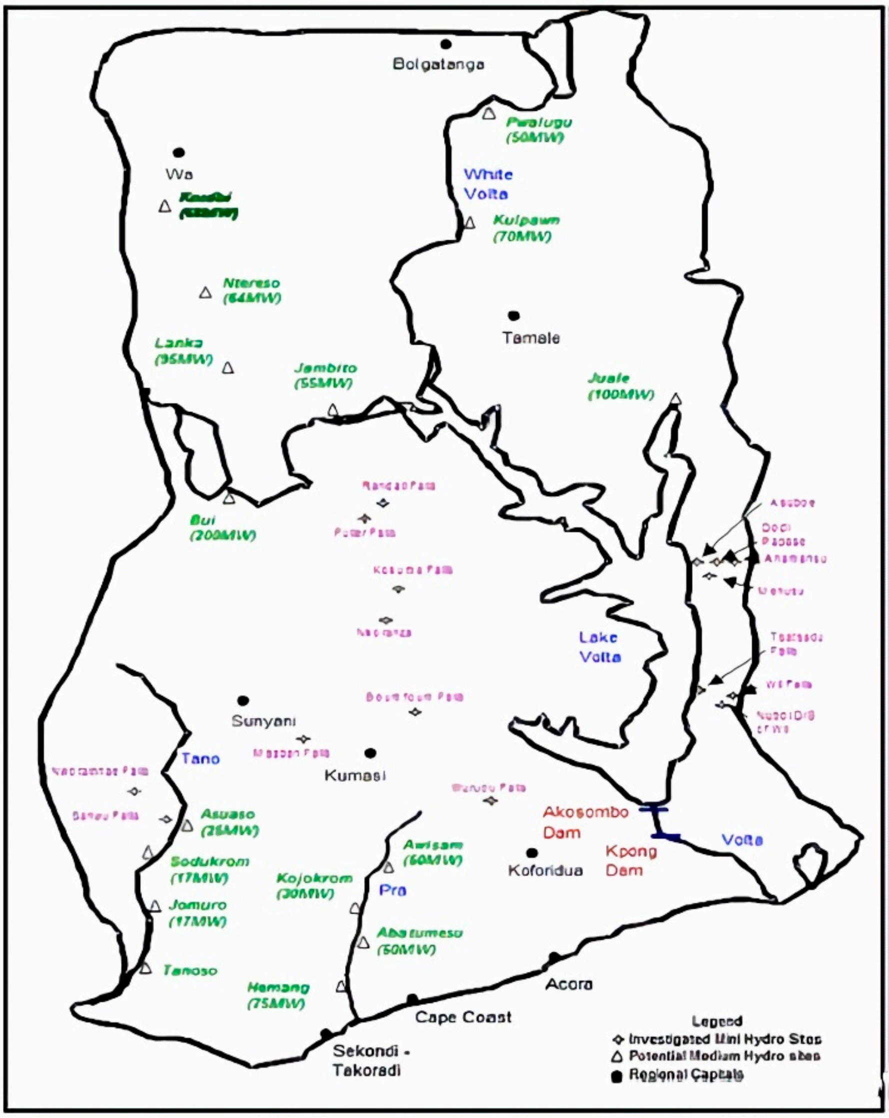

Figure 15. Small and Medium Hydro Sites in Ghana [22].

While the number of sites identified can be described as significant, Gyamfi et al. [9] asserts that none of them has been developed to produce power till today. This is because from the government's perspective, there was too little economic incentive in investing in mini-hydro projects since there was excess cheap power produced from the Akosombo and Kpong hydropower plants [9]. The neglect of mini-hydro currently seems to be a substantial waste in potential resource that could alleviate the energy struggles of Ghana since small hydro sites can be developed with relatively simple run-of-river projects [18,120]. However, it is important to note that current flows of many previously identified potential sites have waned over the years due to deforestation around catchment areas, making them less technically feasible [120].

A study conducted by Miller et al. [9] has introduced an interesting dimension to the small and medium hydro power development discourse in Ghana. According to Miller et al. [9], the reason for which the potential of small hydro power development is dwindling may be down to the technology. They explained that potential energy extraction (hydropotential) is the mode of energy generation technology that has traditionally been used for almost all large and small hydropower systems. This approach, they said, requires complex infrastructure, including the creation of dam or a weir structure to serve as a reservoir, which is often accompanied by expensive maintenance and ecological consequences such as flooding. On the other hand, the expensive infrastructure may yield minimal returns, if the water level dwindles as in the case of many of the potential small hydro sites in Ghana. Miller et al. [9] advocated that implementation of hydrokinetic power (HKP), which is a new power generation technology, may be ideal in tapping into the energy potential in the 70 dormant sites in Ghana. The HKP technology involves directly setting up a turbine in a stream to extract flow or kinetic energy, which is converted to energy. This means that a decline in water volume Apart from the easiness associated with this technology, according to Miller et al. [9], it also succeeds where the hydropotential technology fall short by exerting an overall smaller effect on the stream. This is because unlike the traditional hydropotential energy, HKP achieves less than 70 percent flow rate decrease in streams, and also results in fewer changes to downstream locations such as completely removing the water source. Through their analysis, Miller et al. [9] found that the adoption of HKP technology, apart from being more environmentally and socially benign, can convert nearby streams and rivers to robust and economically efficient reservoirs of energy, which have the capacity result in savings of 2.5 cents per kWh. From this study, it is clear that small and medium hydro energy may have even more prospects than is currently assumed, and if developed, could significantly contribute to Ghana's drive towards provision of sustainable energy for all.

5. What Will a Successful SDG 7 Pursuit Mean for Other National Goals?

Both developing and developed countries stand to benefit from increasing adoption of more reliable and environmentally friendly energy sources. Most developed countries seek to meet their targets in Kyoto protocol, while developing countries seek to minimize the already gloomy predictions of climate change on their sustenance, being that they are the most vulnerable. For developing countries, achieving sustainable energy for all, may have several concomitant benefits as researchers have intimated that there is a direct relationship between energy use and socioeconomic indicators [23,27]. Ghana is no different from its counterparts in the sub-region and around the globe. There are several ways in which Ghana's ability to make good on its commitment to achieving SDG number seven can benefit the country, and we have elaborated on some of the critical ones below.

5.1. Employment Generation and Other Socioeconomic Implications

The Ghanaian government has for the most part of the last decade sought to reduce socioeconomic inequalities by increasing employment and ensuring rapid reduction in poverty. There have been many national policies instituted to support this goal such as the Ghana Shared Growth and Development Agenda (GSGDA), which sought to maintain macro-economic stability and generate higher levels of shared growth [22]. However, the chronic power crisis that plagues it make it difficult to achieve this goal. Chien and Hu [121] have conducted studies that empirically established that increased deployment of renewable energy correlated with increasing GDP. The results of their study is at least a rough indication that Ghana's economy can see a significant improvement in its economy should it increase its use of renewable energy. Many large industries consume substantial amounts of energy, which if supplied with cheaper and more reliable energy will have a tremendous impacts in terms of profitability and growth. In Ghana, the mining industry as well as companies such as the VALCO are the kinds of businesses, whose cost of operations have been significantly increased due to energy crisis, and has been accompanied by lay-offs. In this regard, supporting energy supply to such industries with renewable energy will be imperative for job creation and security for workers.

The amount of energy consumed by large industries such as VALCO has also translated into leaving small and medium scale enterprises (SME) in gridded cities and communities vulnerable in terms of the amount of energy available to keep them running. Rolling power cuts have had significant impacts on small businesses, as most business owners have to raise funds for stand-by generators, which are solely reliant of fossil fuels. Not only does this development increase business costs, it also comes with many environmental hazards. Developing diverse renewable energy options would go a long way to alleviate the burden of uncertainty for businesses and provide employment as many researchers have observed [3,23,99]. These researchers have provided empirical proof that renewable energy projects boost businesses in off-grid communities by cost savings and extended working hours with solar PV [23,99], as well as provide direct employment in renewable energy projects such as working on biofuel plantations and biogas plants [3,20,76]. The discussion above shows that with focus on achieving SDG number seven, Ghana can alleviate its huge unemployment rate debacle, while also generally improving its economy in the process.

5.2. Environmental Benefits

The environmental threats, especially that of climate change, posed by over-reliance on fossil fuels is one that the pursuit of SDG number seven is to help combat. Renewable energy development and deployment can significantly minimize greenhouse gas (GHG) pollutant emissions in Ghana [5]. Proper implementation of policies to drive local production and use of biomass resources for biofuel production, according to Duku et al. [27] can offset negative repercussions associated with burning fossil fuels, as well as contribute to waste utilization and erosion control. Given that it is estimated that every MWh of power produced from advanced biomass technologies saves about 1.6 tons of CO_2, it means biofuel technology appropriately pursued will produce environmental benefits for Ghana [27].

Depending on how biofuel development is approached, it could either support the cause of environmental sustainability or work against it. Planting energy crops can induce large-scale deforestation, as has been seen in elsewhere in the Amazonian region [65]. Large scale forest clearance as well as extensive use fertilizers to boost production of energy crops could all accelerate release of GHGs into the atmosphere, which is contrary to the desired effect of biofuel adoption [27,93]. In addition to these, as previously observed, large scale removal of crop residues for second generation biofuels such as cellulosic ethanol can have enormously negative effects on the physical and chemical properties of soil, as they are critical to restoring soil fertility after decay [93]. With all these said, however, it is important to note that the current over-dependence on traditional woodfuels in Ghana has been a major contributor to its widespread deforestation and GHG emissions [27]. Ghana and its African counterparts are projected to release about 7 billion tons of carbon from cooking fires by the year 2050, which alone will constitute about six percent of total expected GHG emissions from the continent [122]. Ghana produces a substantial amounts of solid wastes as well as wastewater from on the household level, of which it has difficulty disposing. These wastes can be channeled into biogas digestion whose energy output can be used to supplement public energy demands such as cooking and heating, besides effectively dealing with disposal issues [20].

With such available technologies that can readily convert the large amounts of wastes to energy, there can be a drastic reduction of GHG emissions that comes from burning woodfuels [20]. Also, converting waste materials and dung can yield significant amounts of by-products such as biogas slurry—a high-value fertilizer alternative—that can be used for agricultural purposes to prevent depletion of soil fertility [123]. It is also important to note that methane, which is known to be 21 times more potent than CO_2 in terms of trapping heating in the atmosphere, is one of the main gases released from landfills. Methane is also the primary component of biogas, making up about 55–60 percent. From this, it is obvious that Ghana can achieve multiple environmental benefits should it invest in biogas as part of its attempt to achieve SDG number seven, such as clean power production, safe waste management and disposal, and drastic reductions in GHG emissions [27,85,124]. In addition to these benefits, deploying decentralized wind and solar energy systems will also help reduce the amount of GHGs expended to get rural communities onto centralized grid systems. Furthermore, such decentralized systems can help reduce the amount of GHGs released from the stand-by generators that are deployed by majority of businesses and individuals in times of power crisis in the country.

5.3. Health Implications

Using renewable energy to support household cooking and heating can be useful in saving many lives in Ghana and prevent health problems that arise from inhalation of smoke from burning biomass, especially for children who have relatively less body weight. Some of the common health conditions that can arise out of solid biomass burning include childhood acute lower respiratory infections like pneumonia, in addition to other ocular and cardiovascular diseases [20,22]. A vast majority of the population to smoke in the indoor environment due to over-dependence on woodfuels for cooking [5,20]. Ghana is said to lose over 500,000 disability adjusted life-years (DALY) —a World Health Organization (WHO) metric that estimates the burden of death and illness due to a specific risk factor—every year to indoor air pollution as a result of woodfuel burning. Even direr is WHO's estimate that indoor air pollution is culpable for taking as many as 16,600 lives on a yearly basis in Ghana. Wide-scale introduction and adoption of biogas to replace woodfuels for household purposes will, therefore, make households healthier by reducing smoke in the kitchen, and mitigate many of the aforementioned health problems [1,22].

Climate change brings with it with several health consequences, which will result from predicted extreme weather scenarios. For instance, Lane et al. [125] work have mentioned that climate change may increase the frequency of floods that can lead to the spread of water-borne pathogens into drinking water sources, as well as discharge of untreated sewage into rivers and other freshwater bodies. Increasing the use of more sustainable and renewable energy resources will minimize the release of GHGs into the atmosphere, which can reduce the effects of climate change and its accompanying health repercussions.

Park et al. [113] have also shown that using renewable energy resources can contribute to the reduction in water-borne diseases in Ghana. They noted in their study, many people have no access to fresh water for drinking. With only about 35–40 percent of Ghana's rural population with access to treated water, coupled with the unusually high levels of fluoride in water sources in northern Ghana, Park et al. [113] demonstrated that the ample supply of wind and solar energy can be tapped into as a power source for desalination systems. This can reduce the negative health consequences of consuming untreated water.

Remote areas with no gridded electricity can also be saddled with issues such as inability of safely store medicines, especially those that need refrigeration. For such areas, many lives can be saved by deploying renewable energy systems such as PV systems in medical facilities to power refrigerators to store vaccines [1]. Pursuant to the discussions above, one cannot emphasize enough the potential health benefits that Ghana will witness if it is able to successfully pursue SDG number seven.

5.4. Rural Development

Implementing policies that will increase the use of renewable systems such as decentralized PV systems in off-grid rural communities will simultaneously increase the development of those areas, and bridge their gaps with the rest of the country. For instance, the results in Kankam and Boon [23] revealed that between electrified and non-electrified households in the northern Ghana, there was a statistically significant relationship between electricity production and improving conditions for education. They also revealed that about 98 and 87 percent in electrified and non-electrified households, respectively, rated the supply of energy as very positive in its contribution to education outcomes. Kankam and Boon [23] observed that the significant contribution of energy supply towards improving conditions for education may be ascribed to light services that are generated by PV systems in homes and public places. The authors also found that community level PV installations had contributed significantly to supporting adult educational programs. Given the importance of a community's population's educational level to its development, it is without doubt that such outcomes will lead to accelerated rural development.

The results of Obeng et al.'s [99] study is also a significant one that shows that off-grid communities can see significant increase in development with increased deployment of decentralized solar PV systems. Obeng et al. [99] found that these PV systems have contributed to increasing incomes for micro-enterprises that operate within their case study communities, due to the fact that they are able to extend working hours after dark, which would not have been the case prior to the PV installations.

5.5. Women Empowerment

In the pursuit of SDG number seven, another issue that is likely to see a significant breakthrough in Ghana is women empowerment. Most Ghanaian societies are very traditional and have quite finely delineated roles for men and women. Women usually are in charge of cooking and are also the ones primarily involved in the collection of woodfuel and charcoal production. Given that deforestation and forest degradation have significantly reduced the amount of woodfuel available in fields, women are increasingly having to spend more time to collect same quantity of woodfuels they would collect before [20,126].

According to KITE [30], many rural women spend at least two to three mornings in a week to collect woodfuel. This amount of time expended just to have energy for cooking can have a significant toll on the quality of life women enjoy [20,30]. Deploying household biogas plants and solar PV systems for cooking and lighting, respectively, presents reliance on labor-saving energy technologies [23]. Women can utilize this time saved from not gathering woodfuel to engage in more productive ventures such as education [20,23]. With increased education, the illiteracy gap between men and women can be bridged, and women will become more empowered to actively engage in the formal employment sectors, where they can boost their standards of living and supplement their household incomes. Without a doubt, installing biogas plants will also bring a welcome respite to children of school going age in rural areas, who most of the time will have to spend time with their mothers hunting for woodfuel, rather than engaging in school work, which in the long run widens the educational gaps between city and rural dwellers.

5.6. Reduction in Local and Regional Conflicts

In Ghana, there are conflicts in many rural areas that could be curbed if renewable energy systems were widely deployed in the cause of providing sustainable energy for all. Such conflicts are usually between government agencies such as the Ghana Forestry Commission (FC) whose mandate is to protect forest biodiversity, and forest communities who depend on forest resources for household energy purposes. There are several flashpoints in the country because the FC tries to limit the communities' exploitation of forest resources, which they deem as one of the primary causes to forest degradation. Meanwhile, the communities also view the FC's actions as most of the time, a deliberate attempt to deny them their right to survive on the only resources which they have. With the development of biogas in such communities, there is no doubt that there will be significant less cause for conflicts [127]. Of course, it is important to reiterate that such benefits are only possible under the prudent pursuit of renewable energy, as our discussion in Section 4.1.3 shows that lack of appropriate regulatory measures for important initiatives such as establishing biofuel plantations can also breed conflict within communities.

The fossil fuel driven civilization has led to many conflicts around the world due to competition for precious hydrocarbons. As global crude oil deposits diminish in quantity, the more tensed relationships between countries become. In Africa, the rich Bakassi Peninsula has been a source of ownership disputes between Nigeria and Cameroon for several decades [1]. Ghana is also currently embroiled in a dispute with its western neighbor—Ivory Coast—over offshore hydrocarbon deposits, which is being adjudicated in the International Tribunal for the Law of the Sea (ITLOS). If Ghana will steadfastly pursue a SDG number seven to a success by diversifying to renewable energy, it means it may have less need for the hydrocarbon deposits in question. Such a development can contribute immensely to reducing tensions between the two countries, which will safeguard peace in an already volatile sub-region.

6. Facilitation of Uptake and Barriers to Renewable Energy in Ghana

Like many developing countries, the increase in carbon emissions sabotages sustainable development in Ghana [128]. Hence, the greater degree of emphasis on the expansion of renewable energy component of Ghana's energy consumption and supply in recent years. The overarching objective of the Ghanaian Government is to have a renewable energy sector that is spearheaded by private investors through the creation of an enabling environment. Some of the government's medium term national development policies are as follows: (1) focus on increasing the proportion of the local energy mix that renewable energy contribute. The government intends to achieve this by accelerating the implementation of the provision of the Renewable Energy Act, 2011, Act 832 as well as provide access to waste-to-energy technologies, while facilitating access to the grid for stand-alone renewable energy power plants; (2) encourage renewable energy use and the deployment of energy efficient appliances in public and private buildings; (3) facilitate participation of independent power producers (IPPs) in the generation and distribution of renewable energy; and (4) speed up replacement of kerosene lanterns with solar ones [129].

Besides the aforementioned goals, the government plans to establish a Renewable Energy Fund, which will be managed by the Energy Commission. These funds are intended to the used for the development and promotion of renewable energy initiatives, especially those that involve high start-up costs, and to fund the feed-in tariff for energy generated from renewable sources. For take-off of the renewable energy industry, the government is also currently reviewing the exemption of renewable energy equipment from import duty, and has also prepared a draft renewable energy Power Purchase Agreement (PPA). There are also regulations and procedures that already exist to ensure that all renewable energy providers have access to required permits and PPA [129].

While the above policies and steps are notable, there several factors that serve as major obstacles to the uptake of renewable energy in Ghana. The challenges to Ghana's renewable energy sector are multidimensional—socio-behavioral, technical, research and development, and policy—and their persistence over the years have left Ghana in a position where it is most likely unable to achieve its own set SNEP target of achieving 10 percent share of renewables in electricity production by 2020 [130].

Obeng-Darko [130] outlined several legal and regulatory issues that have served to hinder the progress of uptake of renewable energy in Ghana. Among such issues are the lack of legislative instruments to support the work of regulatory agencies in the renewable energy sector as well as the lack of institutional independence of key agencies. Obeng-Darko [130] indicated that these issues have created uncertainty in the renewable energy sector and led to a decline in investor confidence in the government's ability to create an enabling environment that supports its own renewable energy goals and targets. Arguing further in this dimension, Obeng-Darko [130] also noted that the adverse impacts of the lack of single independent regulatory authority in the renewable energy sector. He observed that this situation creates overlapping, unclear, and non-complementary policy directions for the development of the sector. Such lack of unidirectionality in policy making undermine investor confidence in the fledgling sector.

In terms of research and development, while a lot of work has been done, the data generated on renewable energy in Ghana are still considered by many investors as insufficient and/or unreliable. For a sector that is yet to be fully tapped, the inconsistency in government policy has adversely affected a dedicated and sustained effort in conducting research and generating data that investors regard as enough to justify investments of huge sums. For instance, the government's withdrawal from the national biofuel project signified a lack of interest and support on the national level, which discouraged private investors from making any huge investments in the sector. In another dimension, the government's lack of consistency in developing the renewable energy sector manifests itself in shortage of trained and skilled technical people to oversee projects, which is contributing to technological immaturity and institutional inexperience [129,130]. The importance of consistency is emphasized by Ernst and Young (EY), which developed the renewable energy country attractiveness index (RECAI). Their index shows that Ghana has, over the years, been unsuccessful in utilizing its full renewable potential. In this index, only four African countries—South Africa, Kenya, Morocco, and Egypt—made it to the top 40 countries [131]. In their report, EY [131] noted the centrality of effective public-private partnerships (PPP) in supporting research and development, and driving large-scale renewable energy projects in top performing countries. Arguing in this line, EY [131] identified Morocco and South Africa as two countries in which governments have successfully deployed PPP as an effective strategy to develop utility-scale projects. This is critical as they indicated the PPPs facilitate a more effective risk allocation between different parties.

On the socioeconomic aspect of the challenges that the nation face with uptake and growth of renewable energy, since the government of Ghana has, for decades, publicized its intentions of getting every community connected to the national grid, many households are reticent to invest in systems such as solar PV, since they anticipate eventually getting gridded power. The fact that households with connection to the grid enjoy subsidies, which those using renewable energy do not, increase the reticence of people transitioning to renewable energy use. Furthermore, this serves as a disincentive for investors as investments become unprofitable [9,18,119,129].

7. Summary

Ghana has performed creditably in the MDGs era and showed commitment to its goals. It has likewise embraced the global targets set in the SDGs, with the immediate past president co-chairing the UN Secretary General's special group of advocates to develop ground-breaking ideas and ways to implement the pursuit and adoption of renewable and more sustainable energy systems around the world [25]. While such an honor is a notable recognition of Ghana's commitment to global goals, it will be, without doubt, under the microscope of global observers and analysts in the coming years to see if its declared commitment was backed with works. The goals set for renewable energy, SDG number seven, has several targets that include increasing supply of modern and sustainable energy services for all in developing countries through infrastructure expansion and technology upgrade by 2030, and doubling the rate of improvement of energy efficiency by 2030. While these may be ambitious, Ghana is endowed remarkable deposits of renewable energy resources, which if properly tapped can achieve a well-balanced energy mix that will spur it into achieving these targets. This study has assessed Ghana's potential of achieving the SDG number seven, by comprehensively reviewing its energy scene and renewable energy potential.

Ghanaian households, which are typically low income, burn traditional biomass to meet several energy needs such as cooking and heating. For national electricity production and supply, three large hydropower stations and thermal power plants remain the main sources, while renewable energy sources play no significant role [18,20,27]. Sustainable and dependable energy systems is the hallmark of a modern economy, and the current sources of Ghana's energy seem not to check either of those boxes, given that it has been saddled with a chronic power crisis in some years over the past two decades [9,18,23]. From the review, it is obvious that the necessity of developing a well-balanced energy mix that incorporates renewable energy resources has not been totally lost on the Ghanaian government over the years, as it has explored some ventures. However, the pursuit of renewable energy development can be a double-edged sword, which if not diligently pursued could turn out to be even more problematic than its traditional counterparts.

Ghana, being a major agricultural nation, has attempted to pursue a large-scale development of biofuels within the country with the vast range of crops including maize, cassava, sugarcane, cocoa, and oil palm that are known as useful feedstocks [20,27]. In addition, the Ghanaian government developed a strategy of fossil fuel substitution with biodiesel from cultivated jatropha and other energy crops [70,71]. These plans, laudable as they seemed, failed to yield the desired results. This is because the venture which was meant to be locally driven to help wean the country off overdependence on imported fuels, grew to become a foreign venture that was geared towards export of raw materials [70]. Soon, there were accusations of "land grabbing" by foreign interests, which threatened to brew chaos in communities, and some projects had to be scaled back. While the biofuel project hit a snag, the developments in the first decade of the century showed that Ghana still has the potential to tap into it, provided it implements appropriate policies.

Studies have also shown that there is a potential in utilizing inherently decentralized renewable energy options that are naturally occurring such as solar and wind power in Ghana, especially as the technologies needed to exploit them continue to advance [12]. Kankam and Boon [23] and Obeng et al. [99] have all conducted studies that show that largely deploying solar PV in off-grid communities may improve living standards of rural communities, while sparing government coffers of trying to get distant communities on central grids. Similarly, Adaramola et al. [21] study has shown that while wind energy has not achieved a notable penetration into the Ghanaian energy market, it is an attractive option along Ghana's coastal region. However, its economic feasibility may come down to the type of turbine deployed in terms of size and capacitor factor, which will only be determined by appropriate analysis on site by site basis.

The analysis has also shown that Ghana can utilize its 70 sites with potential for small and medium hydropower generation to support its course towards achieving SDG number seven. Dernedde and Ofosu-Ahenkorah [120] have observed that lack of development of the resources combined with deforestation have led to the decline of prospects in the resource, Miller et al. [47] has introduced an interesting dimension to the discourse. They have found that Ghana can still achieve significant power generation from the small hydro sites, should it implement HKP technology.

Per the foregoing discussion, there is certainly a lot more to be done for Ghana to be on course to achieve SDG number seven, in terms of policies, research, and development. The extent to which Ghana can go in supplying sustainable energy for all by 2030 will be highly dependent on how well it can integrate renewable energy production into the mainstream of energy supply around the country. For this to be achieved, however, there is a need to address the uneven subsidy distribution that tip the scales against investing in the renewable energy sector. In addition, Ghana's experience with biofuels presents it with a worthy lesson to be diligent in implementation of renewable energy plans and policies, in order forestall potential associated problems. With all these taken into consideration, it is safe to say that even though it may be daunting, Ghana has significant potential to achieve SDG number seven.

Limitations of the Study

It is imperative to acknowledge that this review has one major limitation. There is a lack of unitary period of analysis. This is because we synthesized data and information from different time periods due to the dearth of data and the different studies conducted at different time periods.

8. Recommendations for Priority Research Areas and Policy Considerations

Without doubt, Ghana possess remarkable potential, in theory, to significantly boost local energy production and improve efficiency of energy delivery systems in order to achieve SDG number seven. For the foreseeable future, Ghana will need to institute practical measures in order to turn this theoretical potential into reality. The country will have to pursue the goal of providing sustainable energy for all, with steady developments for the various kinds of renewable energy. Since renewable energy development could be beset with its own challenges, it is important to pursue it diligently in order to neutralize possible negative fallouts. With this in mind, the authors recommend that the country give the following suggestions attention in its journey towards reaching the SDG number seven targets:

- It may be more advisable for Ghana to invest in smaller scale production that focuses on catering for local energy needs when it comes to first and second generation biofuels rather than commercial production that has been found to result in negative trade-offs due to accompanying land use change. It is clear that many villages in Ghana could benefit from alternative source of energy to alleviate domestic fuel needs. Biofuels can fill in this gap to reduce overdependence on woodfuels. We recommend that micro- and small-scale biofuel initiatives to be the focus in remote areas to offer alternative sources of energy. Raw materials in the form of agricultural wastes and residues may be enough to feed such micro and small scale initiatives, in addition to household wastes that can be used to feed household biogas plants. Community scale biofuel production plants can contribute to employment creation, without disturbing traditional agricultural livelihood base of these communities.

- While it is important to acknowledge the inherent problems in large scale first and second generation biofuel projects in Ghana, it is important to state that the potential to pursue it sustainably still remains. In this regard, the government should explore policies that reverse the import and export relationship between Ghana and their developing countries counterparts as far as biofuel development is concerned. Instead of Ghana cultivating and exporting energy crops, which has led to several "land grabbing" related conflicts, it should rather invest in importing the knowledge and technology necessary to effectively utilize its biofuel energy potential.
- In attempt to undertake large scale adoption of first and second generation biofuels, it is important to institute policies that explore combining energy crops and local food crops, on the same farm in mixed-cropping practices, rather than large scale mono-cropping. Boamah [70] has already shown that projects that are sensitive to local people's rights to food security tend to be more successful than others that do not. Apart from the fact that such mixed-cropping approaches are healthier for agricultural lands than mono-cropping in terms of limited demand for fertilizers, they also bring in a welcomed extra income avenue for local farmers on the same piece of land. Hence, they have positive socioeconomic outcomes for farmers, and are more environmentally friendly.
- To contribute in meeting targets of SDGs and carbon emissions reduction in Kyoto protocol, specific policies must be put in place before biofuels are developed and the developments must undergo careful monitoring and regulation. One of the greatest challenges for governments of developing countries to meet energy targets of SDGs will be rural electrification. These countries should design such local specific policies regarding setting up biofuel processing plants in remote rural areas to provide electricity. This, if successful will mean an alternative to placing such areas on national grids which are primarily fueled by expensive traditional fossil fuels.
- Kankam and Boon [23] and Obeng et al. [99] have provided proof that using developing and disseminating decentralized solar PV systems in villages would be one of the quickest and easiest means of providing electricity to remote communities, which can yield immediate benefits. In that sense, the government should focus on projects that disseminate solar PV to households in remote areas in the short term, as it works on building capacity of technical people for large-scale projects in the long term. With large scale projects, Ghana would be following the lead of countries like Egypt and Morocco that have already started maximizing their unique local conditions for generation of power of a large scale, by tapping into wind and solar energy to support the energy sector. While there are high costs associated with large-scale ventures such as those in Egypt and Morocco, the constant improvements in technology are likely to make them more efficient and cost-effective in the near future.
- It is imperative that the Ghanaian government show commitment to providing sustainable energy for all by revisiting its overall energy policy to expand subsidies to cover renewable energy development. This is because, as Kankam and Boon [23] noted, the government highly subsidizes conventional energy which tips the scales against renewable energy development efforts such as solar energy, which discourages private sector participation. Since the Ghanaian consumer requires government subsidies, the government's only option is to increase subsidies in the renewable energy sector to ensure fair competition. Offering such subsidies will be cost-effective in the medium-to-long term as mini-grids could be built for rural electrification, which will reduce the enormous financial strain on the finances of power utilities.

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References

1. Abanda, F.H. Renewable energy sources in Cameroon: Potentials, benefits and enabling environment. *Renew. Sustain. Energy Rev.* **2012**, *16*, 4557–4562. [CrossRef]
2. Acheampong, M.; Ertem, F.C.; Kappler, B.; Neubauer, P. In pursuit of Sustainable Development Goal (SDG) number 7: Will biofuels be reliable? *Renew. Sustain. Energy Rev.* **2017**, *75*, 927–937. [CrossRef]
3. Acheampong, E.; Campion, B.B. The effects of biofuel feedstock production on farmers' livelihoods in Ghana: The case of Jatropha curcas. *Sustainability* **2014**, *6*, 4587–4607. [CrossRef]
4. Adaramola, M.S.; Agelin-Chaab, M.; Paul, S.S. Analysis of hybrid energy systems for application in southern Ghana. *Energy Conv. Mgt.* **2014**, *88*, 284–295. [CrossRef]
5. Afrane, G. Examining the potential for liquid biofuels production and usage in Ghana. *Energy Policy* **2012**, *40*, 444–451. [CrossRef]
6. Jones, C.S.; Mayfield, S.P. Algae biofuels: Versatility for the future of bioenergy. *Curr. Opin. Biotechnol.* **2012**, *23*, 346–351. [CrossRef] [PubMed]
7. Campbell, C.J.; Laherrère, J.H. The end of cheap oil. *Sci. Am.* **1998**, *278*, 60–65. [CrossRef]
8. Drapcho, C.M.; Nhuan, N.P.; Walker, T.H. *Biofuels Engineering Process Technology*; McGraw-Hill: New York, NY, USA, 2008.
9. Gyamfi, S.; Modjinou, M.; Djordjevic, S. Improving electricity supply security in Ghana—The potential of renewable energy. *Renew. Sustain. Energy Rev.* **2015**, *43*, 1035–1045. [CrossRef]
10. Ivanhoe, L.F. Future world oil supplies: There is a finite limit. *World Oil.* **1995**, *216*, 77.
11. Climate Change 2014 Synthesis Report. Available online: https://reliefweb.int/sites/reliefweb.int/files/resources/SYR_AR5_FINAL_full.pdf (accessed on 28 January 2019).
12. Deichmann, U.; Meisner, C.; Murray, S.; Wheeler, D. The economics of renewable energy expansion in rural Sub-Saharan Africa. *Energy Policy* **2011**, *39*, 215–227. [CrossRef]
13. Biopact. Brazil: Sugarcane Bioenergy Bypasses Hydroelectric Power as Primary Energy Source. 2008. Available online: https://global.mongabay.com/news/bioenergy/2008/05/brazil-sugarcane-bioenergy-bypasses.html (accessed on 10 November 2018).
14. Bonin, C.; Lal, R. Agronomic and ecological implications of biofuels. *Adv Agron.* **2012**, *117*, 1–50.
15. Buyx, A.M.; Tait, J. Biofuels: Ethics and policy-making. *Biofuel Bioprod. Biorefin.* **2011**, *5*, 631–639. [CrossRef]
16. Demirbas, A. Political, economic and environmental impacts of biofuels: A review. *Appl. Energy* **2009**, *86*, S108–S117. [CrossRef]
17. UNFCCC. Clean Development Mechanism (CDM). 2014. Available online: https://unfccc.int/process-and-meetings/the-kyoto-protocol/mechanisms-under-the-kyoto-protocol/the-clean-development-mechanism (accessed on 11 November 2018).
18. Kemausuor, F.; Obeng, G.Y.; Brew-Hammond, A.; Duker, A. A review of trends, policies and plans for increasing energy access in Ghana. *Renew. Sustain. Energy Rev.* **2011**, *15*, 5143–5154. [CrossRef]
19. Birol, F. *Energy for All: Financing Access for the Poor*; International Energy Agency: Paris, France, 2011.
20. Arthur, R.; Baidoo, M.F.; Antwi, E. Biogas as a potential renewable energy source: A Ghanaian case study. *Renew. Energy* **2011**, *36*, 1510–1516. [CrossRef]
21. Adaramola, M.S.; Agelin-Chaab, M.; Paul, S.S. Assessment of wind power generation along the coast of Ghana. *Energy Convers. Manag.* **2014**, *77*, 61–69. [CrossRef]
22. Ghana Energy Commission. *Ghana Sustainable Energy for All Action Plan*; Ghana Energy Commission: Accra, Ghana, 2012.
23. Kankam, S.; Boon, E.K. Energy delivery and utilization for rural development: Lessons from Northern Ghana. *Energy Sustain. Dev.* **2009**, *13*, 212–218. [CrossRef]
24. Nations, U. Sustainable Development Goals-Goal 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for all. 2015. Available online: https://www.un.org/sustainabledevelopment/energy/ (accessed on 16 September 2018).

25. Secretary-General Appoints Advocates to Build Widespread Support for the Sustainable Development Goals 2016. Available online: https://www.un.org/sustainabledevelopment/blog/2016/01/sdg-advocates-press-release/ (accessed on 28 January 2019).
26. Central Intelligence Agency (CIA). World Factbook: Ghana, West Africa, 2017. Available online: https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html (accessed on 12 June 2017).
27. Duku, M.H.; Gu, S.; Hagan, E.B. A comprehensive review of biomass resources and biofuels potential in Ghana. *Renew. Sustain. Energy Rev.* **2011**, *15*, 404–415. [CrossRef]
28. Ghana Statistical Service (GSS). *Ghana in Figures*; Ghana Statistical Service (GSS): Accra, Ghana, 2008.
29. Ghana Statistical Service (GSS). *Ghana Living Standards Survey Report of the Fifth Round (GLSS 5)*; Ghana Statistical Service (GSS): Accra, Ghana, 2008.
30. Kumasi Institute of Technology. *Energy and Environment (KITE). Feasibility Study Report on Domestic Biogas in Ghana*; Submitted to Shell Foundation; Kumasi Institute of Technology: Kumasi, Ghana, 2008.
31. CIA. World Factbook—Ghana 2017. Available online: http://www.ciaworldfactbook.us/africa/ghana.html (accessed on 15 June 2017).
32. World Bank. World Development Indicators—Ghana. 2017. Available online: https://data.worldbank.org/country/ghana (accessed on 15 June 2017).
33. FAO. *State of the World's Forests*; Food and Agriculture Organisation of the UN: Rome, Italy, 2009.
34. USDA. *Assessment of Local Production for School Feeding in Ghana, 1–2 June 2009*; USDA Foreign Agricultural Service Office of Capacity Building and Development; USDA: Accra, Ghana, 2009.
35. UNDP. *Human Development Reports, Ghana: Economic Challenges, January*; UNDP: Accra, Ghana, 2009.
36. UNDP. *Human Settlement Country Profile—Ghana*; UNDP: Accra, Ghana, 2003.
37. UNDP. *Human Development Reports—Ghana*; UNDP: Accra, Ghana, 2017.
38. Ghana Energy Commission. *National Energy Statistics—2000–2008*; Ghana Energy Commission: Accra, Ghana, 2008.
39. Ofosu-Ahenkorah, A.; Essandoh-Yeddu, J.; Amankwah, K.; Dzobo, M. (Eds.) *Energy Statistics, Ghana, 2000–2008*; Energy Statistics: Accra, Ghana, 2008.
40. Ghana Energy Commission. *National Energy Statistics—2000–2014*; Ghana Energy Commission: Accra, Ghana, 2015.
41. Ghana Energy Commission. *National Energy Statistics—2000–2013*; Ghana Energy Commission: Accra, Ghana, 2014.
42. Ghana Energy Commission. *Energy Sector Review*; Ghana Energy Commission: Accra, Ghana, 2010.
43. Minstry of Energy (MoE). *National Energy Policy-Draft Final*; Minstry of Energy (MoE): Accra, Ghana, 2006.
44. Togobo-Ahiataku, W. The role of renewable energy for poverty alleviation and sustainable development in Africa: The Ghana experience in funding rural/renewable energy through levies on fossil fuels and electricity. In Proceedings of the PfA Policy Dialogue Conference, Dar es Salaam, Tanzania, 24 June 2005.
45. UNDP. *World Energy Assessment: Energy and the Challenge of Sustainability*; United Nations Development Programme; UNDP: New York, NY, USA, 2004.
46. UNDP Ghana. *Liquefied Petroleum Gas (LPG) Substitution for Wood fuel In Ghana—Opportunities and Challenges*; UNDP: Accra, Ghana, 2004.
47. Miller, V.B.; Ramde, E.W.; Gradoville, R.T.; Schaefer, L.A. Hydrokinetic power for energy access in rural Ghana. *Renew. Energy.* **2011**, *36*, 671–675. [CrossRef]
48. Ghana Energy Commission. *Energy supply and demand outlook for Ghana*; Ghana Energy Commission: Accra, Ghana, 2011.
49. Ghana Energy Commission. *Annual Report for 2010*; Ghana Energy Commission: Accra, Ghana, 2011.
50. Volta River Authority. *Profile of the Volta River Authority*; Volta River Authority: Accra, Ghana, 2017.
51. Ministry of Energy. *National Electrification Scheme (NES) Master Plan Review (2011–2020) Final*; Ministry of Energy: Accra, Ghana, 2011.
52. Asante, K. *Comment and Analysis: West African Gas Pipeline Project, Energy Review*; Ghana Energy Commission: Accra, Ghana, 2004.
53. Ejekumhene, I.; Amadu, M.B.; Brew-Hammond, A. *Power Sector Reform in Ghana: The Untold Story*; Kumasi Institute of Technology and Environment: Kumasi, Ghana, 2001.
54. USAID. *An Energy Roadmap of Ghana: from Crisis to the Fuel for Economic Freedom*; A Report by the US Government Interagency Team; USAID: Accra, Ghana, 1999.

55. Wirba, A.V.; Mas'ud, A.A.; Muhammad-Sukki, F.; Ahmad, S.; Tahar, R.M.; Rahim, R.A.; Munir, A.B.; Karim, M.E. Renewable energy potentials in Cameroon: Prospects and challenges. *Renew. Energy* **2015**, *76*, 560–565. [CrossRef]
56. Africa Review. Ghana: Government Turns to Solar to Fix Electricity Supplies. 2013. Available online: http://www.africareview.com/News/Ghana-Government-Turns-To-Solar-To-Fix-Electricity-Supplies/-/979180/1861858/-/8o03x4z/-/index.html (accessed on 15 April 2017).
57. Aliyu, A.S.; Dada, J.O.; Adam, I.K. Current status and future prospects of renewable energy in Nigeria. *Renew. Sustain. Energy Rev.* **2015**, *48*, 336–346. [CrossRef]
58. Jensen, P.D.; Mattsson, J.E.; Kofman, P.D.; Klausner, A. Tendency of wood fuels from whole trees, logging residues and roundwood to bridge over openings. *Biomass Bioenerg.* **2004**, *26*, 107–113. [CrossRef]
59. Lora, E.S.; Andrade, R.V. Biomass as energy source in Brazil. *Renew. Sustain. Energy Rev.* **2009**, *13*, 777–788. [CrossRef]
60. Demirbas, A. Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy Convers. Manag.* **2001**, *42*, 1357–1378. [CrossRef]
61. Muffler, K.; Ulber, R. Use of renewable raw materials in the chemical industry–beyond sugar and starch. *Chem. Eng. Technol.* **2008**, *31*, 638–646. [CrossRef]
62. Balat, M.; Balat, H. Recent trends in global production and utilization of bio-ethanol fuel. *App. Energy* **2009**, *86*, 2273–2282. [CrossRef]
63. Demirbas, A. Progress and recent trends in biofuels. *Prog. Energy Combust. J.* **2007**, *33*, 1–8. [CrossRef]
64. Pedroli, B.; Elbersen, B.; Frederiksen, P.; Grandin, U.; Heikkilä, R.; Krogh, P.H.; Izakovičová, Z.; Johansen, A.; Meiresonne, L.; Spijker, J. Is energy cropping in Europe compatible with biodiversity?—Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. *Biomass Bioenergy* **2013**, *55*, 73–86. [CrossRef]
65. Senauer, B. Food market effects of a global resource shift toward bioenergy. *Am. J. Agric. Econ.* **2008**, *90*, 1226–1232. [CrossRef]
66. Chisti, Y. Biodiesel from microalgae. *Biotechnol. Adv.* **2007**, *25*, 294–306. [CrossRef]
67. Cuellar-Bermudez, S.P.; Garcia-Perez, J.S.; Rittmann, B.E.; Parra-Saldivar, R. Photosynthetic bioenergy utilizing CO_2: An approach on flue gases utilization for third generation biofuels. *J. Clean. Prod.* **2015**, *98*, 53–65. [CrossRef]
68. Rawat, I.; Kumar, R.R.; Mutanda, T.; Bux, F. Biodiesel from microalgae: A critical evaluation from laboratory to large scale production. *Appl. Energy* **2013**, *103*, 444–467. [CrossRef]
69. FAOSTAT. *Crop production Ghana, 2008*; Food and Agriculture Organisation of the UN: Rome, Italy, 2008.
70. Boamah, F. Imageries of the contested concepts "land grabbing" and "land transactions": Implications for biofuels investments in Ghana. *Geoforum* **2014**, *54*, 324–334. [CrossRef]
71. Brew-Hammond, A. Bioenergy for Accelerated Agro-Industrial Development in Ghana. In Proceedings of the Keynote Address Delivered on Behalf of Ghana Energy Minister for Energy at the Bioenergy Markets West Africa Conference, Accra, Ghana, 27 October 2009.
72. Hagan, E.B. *Biofuels Assessment Report-ECOWAS Sub-Region*; AU/Brazil/UNIDO Biofuels Seminar in Africa: Addis Ababa, Ethiopia, 2007.
73. Ahiataku-Togobo, W.; Ofosu-Ahenkorah, A. Bioenergy Policy Implementation in Ghana. Available online: http://www.compete-bioafrica.net/events/events2/zambia/Session-2/2-2-COMPETE-Conference-Lusaka-Togobo-Ghana.pdf (accessed on 28 January 2019).
74. Ghana Energy Commission. *Ghana Bio-Fuels Policy. Policy Recommendations*; Final Draft, 2005; Ghana Energy Commission: Accra, Ghana, 2005.
75. Garwe, E.C.; Jingura, R.M.; Chateya, S.R.; Musademba, D.; Simbi, D.J. New approaches to the sustainable development of the biofuels industry in Zimbabwe: Propagation of Jatropha curcas for oil extraction and biodiesel production. In Proceedings of the ICS-UNIDO/CSIR International Workshop on Biofuels, Accra, Ghana, 11 December 2007.
76. Schoneveld, G.C.; German, L.A.; Nutakor, E. Towards Sustainable Biofuel Development: Assessing the Local Impacts of Large-Scale Foreign Land Acquisitions in Ghana. In Proceedings of the World Bank Land Governance Conference, Washington DC, USA, 26–27 April 2010.
77. Campion, B.B.; Acheampong, E. The Chieftaincy Institution in Ghana: Causers and Arbitrators of Conflicts in Industrial Jatropha Investments. *Sustainability* **2014**, *6*, 6332–6350. [CrossRef]

78. Deininger, K.; Byerlee, D.; Lindsay, J.; Norton, A.; Selod, H.; Stickler, M. *Rising Global Interest in Farmland: Can It Yield Sustainable and Equitable Benefits?* World Bank Publications: Washington, DC, USA, 2010. [CrossRef]
79. Schoneveld, G.C. *The Governance of Large-Scale Farmland Investments in Sub-Saharan Africa: A Comparative Analysis of the Challenges for Sustainability*; Uitgeverij Eburon: Delft, The Netherlands, 2013; p. 301.
80. Boamah, F. How and why chiefs formalise land use in recent times: The politics of land dispossession through biofuels investments in Ghana. *Rev. Afr. Polit. Econ.* **2014**, *41*, 406–423. [CrossRef]
81. Aatola, H.; Larmi, M.; Sarjovaara, T.; Mikkonen, S. Hydrotreated Vegetable Oil (HVO) as a Renewable Diesel Fuel: Trade-off between NOx, Particulate Emission, and Fuel Consumption of a Heavy Duty Engine. *SAE Int. J. Engines* **2009**, *1*, 1251–1262. [CrossRef]
82. Mikkonen, S. Second-generation renewable diesel offers advantages. *Hydro-Carbon Process.* **2008**, *87*, 63–66.
83. Pleanjai, S.; Gheewala, S.H.; Garivait, S. Environmental evaluation of biodiesel production from palm oil in a life cycle perspective. In Proceedings of the Joint International Conference on Sustainable Energy and Environment, Hua Hin, Thailand, 1–3 December 2004.
84. Supranto. The biodiesel production process from vegetable oil. *Dev. Chem. Eng. Min. Process* **2008**, *13*, 687–692. [CrossRef]
85. Wetlands International, Biofuels in Africa. *An Assessment of Risks and Benefits for African Wetlands*; AID Environment: Amsterdam, The Netherlands, 2008.
86. Ministry of Food and Agriculture. *Brief on the Oil Palm Sector in Ghana*; Ministry of Food and Agriculture: Accra, Ghana, 2017.
87. Aryeetey, E. (Ed.) *The State of the Ghanaian Economy in 2007*; Institute of Social Statistical and Economic Research, University of Ghana: Legon, Ghana, 2008; ISBN 9964-75-068.
88. World Trade Organisation. *Trade Policy Review Report by the Secretariat*; WT/TPR/S/194, December; World Trade Organisation: Geneva, Switzerland, 2007.
89. Poku, K. *Origin of Oil Palm. Small-Scale Palm Oil Processing in Africa. FAO Agricultural Services Bulletin 148*; Food and Agriculture Organization: Rome, Italy, 2002; ISBN 92-5-104859-2.
90. Gyasi, E.A. Emergence of a new oil palm belt in Ghana. *R. Dutch Soc.* **2008**, *83*, 39–49. [CrossRef]
91. Klein, U.; Phillips, D.; Wordey, M.T.; Komlaga, G. Cassava Market and Value Chain Analysis—Ghana Case Study. Available online: https://cava.nri.org/images/documents/publications/GhanaCassavaMarketStudy-FinalFebruary2013_anonymised-version.pdf (accessed on 28 January 2019).
92. Babaleye, T. *Cassava, Africa's Food Security Crop*; World Bank: International Institute of Tropical Agriculture (IITA): Ibadan, Nigeria, 1996.
93. OECD/IEA. *Sustainable Production of Second-Generation Biofuels, Potential and Perspectives in Major Economies and Developing Countries*; Information Paper; OECD/IEA: Vienna, Austria, 2010.
94. Caria, S.; Dzene, R.; Opoku, E.; Teal, F.; Zeitlin, A. Impacts of group-based microfinance in agriculture: evidence from Ghana's Coco, Abrabopa Association. Presented at the CSAE Conference, Oxford, UK, 22–24 March 2009.
95. Cuvilas, C.A.; Jirjis, R.; Lucas, C. Energy situation in Mozambique: a review. *Renew. Sustain. Energy Rev.* **2010**, *14*, 2139–2146. [CrossRef]
96. Bensah, E.C. Technical Evaluation and Standardization of Biogas Plants in Ghana. Master's Thesis, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana, 2009.
97. Cooper, C.J.; Laing, C.A. A macro analysis of crop residue and animal wastes as a potential energy source in Africa. *J. Energy S. Afr.* **2007**, *18*, 10–19.
98. Ketibuah, E.; Asase, M.; Yusif, S.; Mensah, M.Y.; Fischer, K. Comparative analysis of household waste in the cities of Stuttgart and Kumasi—Options for waste recycling and treatment in Kumasi. In Proceedings of the 19th international CODATA Conference, Berlin, Germany, 7–10 Novembe 2005.
99. Obeng, G.Y.; Evers, H.-D. Impacts of public solar PV electrification on rural micro-enterprises: The case of Ghana. *Energy Sustain. Dev.* **2010**, *14*, 223–231. [CrossRef]
100. Obeng, G.Y.; Evers, H.-D.; Akuffo, F.O.; Braimah, I.; Brew-Hammond, A. Solar photovoltaic electrification and rural energy-poverty in Ghana. *Energy Sustain. Dev.* **2008**, *12*, 43–54. [CrossRef]
101. DLR. *Solar and Wind Energy Resource Assessment (SWERA). DLR—Activities within SWERA*; DLR: Stuttgart, Germany, 2004.

102. Ministry of Energy. *Energy for Poverty Reduction Action Plan for Ghana. A Targeted Approach to Delivery of Modern Energy Services to the Poor*; Ministry of Energy: Accra, Ghana, 2006.
103. Ghana Energy Commission. *Energy Statistics 2007*; Energy Commission: Accra, Ghana, 2007.
104. Ghana Energy Commission. *Solar and Wind Energy Resource Assessment (SWERA)*; Ghana Energy Commission: Accra, Ghana, 2003.
105. Clover, I. Ghana Finalizes Plans for 155 MW Solar Park. PV Magazine, 2012. Available online: https://www.pv-magazine.com/2014/03/04/ghana-finalizes-plans-for-155-mw-solar-park_100014400/ (accessed on 23 May 2017).
106. Essandoh-Yeddu, J. *Monitoring the Performance of Solar Photovoltaic Installations in Ghana*; Ministry of Energy: Accra, Ghana, 1993.
107. Institute of Economic Affairs (IEA). *Stand alone PV Systems, IEA-PVPS Task III*; Institute of Economic Affairs: Accra, Ghana, 1999.
108. IPCC. *Renewable Energy Sources and Climate Change Mitigation Special Report of the Intergovernmental Panel on Climate Change*; Technical Support Unit Working Group III Potsdam Institute for Climate Impact Research (PIK); IPCC: Geneva, Switzerland, 2011.
109. IRENA. *Renewable Power Generation Costs: Summary for Policy Makers*; Agency IRENA: Bonn, Germany, 2012.
110. Herbert, G.J.; Iniyan, S.; Sreevalsan, E.; Rajapandian, S. A review of wind energy technologies. *Renew. Sustain. Energy Rev.* **2007**, *11*, 1117–1145. [CrossRef]
111. Global Wind Energy Council. *Global wind Energy Report: Annual Market Update*; Global Wind Energy Council: Brussels, Belgium, 2012.
112. Anderson, E.; Antkowiak, M.; Butt, R.; Davis, J.; Dean, J.; Hillesheim, M.; Hotchkiss, E.; Hunsberger, R.; Kandt, A.; Lund, J.; et al. A broad overview of energy efficiency and renewable energy opportunities for Department of Defense installations. *Contract* **2011**, *303*, 275–3000.
113. Park, G.L.; Schäfer, A.I.; Richards, B.S. Potential of wind-powered renewable energy membrane systems for Ghana. *Desalination* **2009**, *248*, 169–176. [CrossRef]
114. NREL. *Ghana Wind Energy Resource Mapping Activity*; NREL: Golden, CO, USA, 2003.
115. Antonio, J.; Akwensivie, F.; Edwin, I.A.; Brew-Hammond, A.; Akuffo, F.O. Wind energy resource assessment in Ghana. Presented at the World Wind Energy Conference, Cape Town, South Africa, 23–26 November 2003.
116. Ghana Energy Commission. *Preliminary Data Analysis Report on Wind Resource Assessment of 60 m XHD Wind Masts at Selected Sites in Ghana*; Ghana Energy Commission (GEC): Accra, Ghana, 2011.
117. Wind Energy and Electric Vehicle Review Ghana's First wind Farm. 2015. Available online: https://www.evwind.es/2015/09/26/ghanas-first-wind-farm-2/54214 (accessed on 6 July 2018).
118. Ejekumhene, I.; Atakora, S.; Atta-Konadu, R.; Brew-Hammond, A. *Implementation of Renewable Energy Technologies—Opportunities and Barriers: Ghana Country Study*; UNEP Collaborating Centre on Energy and Environment: Roskilde, Denmark, 2001.
119. UNEP. *Implementation of Renewable Energy Technologies—Opportunities and Barriers*; United Nations Environmental Program (UNEP): Nairobi, Kenya, 2002.
120. Dernedde, S.; Ofosu-Ahenkorah, A.K. *Mini Hydro Power in Ghana*; Ghana Energy Foundation: Accra, Ghana, 2002.
121. Chien, T.; Hu, J.L. Renewable energy: An efficient mechanism to improve GDP. *Energy Policy* **2008**, *36*, 3045–3052. [CrossRef]
122. Bridgwater, A.V.; Meier, D.; Radlein, D. An overview of pyrolysis of biomass. *Org. Geochem.* **1999**, *30*, 1479–1493. [CrossRef]
123. Biogas Team. *Biogas for Better Life, an African Initiative*; Biogas Team: Hague, The Netherlands, 2007.
124. Gautam, R.; Bara, S.; Herat, S. Biogas as a sustainable energy source in Nepal: Present status and future challenges. *Renew. Sustain. Energy Rev.* **2009**, *13*, 248–252. [CrossRef]
125. Lane, K.; Charles-Guzman, K.; Wheeler, K.; Abid, Z.; Graber, N.; Matte, T. Health effects of coastal storms and flooding in urban areas: A review and vulnerability assessment. *J. Environ. Public Health* **2013**. [CrossRef]
126. Energy Commission (EC). *Strategic National Energy Plan (2006–2020) and Ghana Energy Policy*; Main Version; Energy Commission: Accra, Ghana, 2006.
127. Appiah, M.; Blay, D.; Damnyag, L.; Dwomoh, F.K.; Pappinen, A.; Luukkanen, O. Dependence of forest resources and tropical deforestation in Ghana. *Environ. Dev. Sustain.* **2009**, *11*, 471–487. [CrossRef]

128. Khan, H.U.R.; Nassani, A.A.; Aldakhil, A.M.; Abro, M.M.Q.; Islam, T.; Zaman, K. Pro-poor growth and sustainable development framework: Evidence from two step GMM estimator. *J. Clean. Prod.* **2019**, *206*, 767–784. [CrossRef]
129. The Netherlands Enterprise Agency. *Sector Report on Business Opportunities for Renewable Energy in Ghana*; Embassy of the Kingdom of the Netherlands, Accra; The Netherlands Enterprise Agency: Accra, Ghana, 2016.
130. Obeng-Darko, N.A. Why Ghana will not achieve its renewable energy target for electricity. Policy, legal and regulatory implications. *Energy Policy* **2019**, *128*, 75–83. [CrossRef]
131. Ernst and Young. Renewable Energy Country Attractiveness Index. 2015. Available online: https://www.ey.com/Publication/vwLUAssets/EY-RECAI-renewable-energy-country-attraciveness-index/$FILE/EY-RECAI-renewable-energy-country-attraciveness-index.pdf (accessed on 16 January 2019).