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Solar energy policy implementation in Ghana: A LEAP model analysis

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ABSTRACT

Current global climate change mitigation programs have been unable to meet the Paris Agreement's targets, and Ghana's situation is no exception. There is, therefore, an increased need for intensification of renewable energy deployment programs with an emphasis on solar energy as it constitutes about 90% of Ghana's installed renewable energy generation capacity. The study demonstrates how appropriate renewable energy policy can drive solar energy development in Ghana. Electricity demand scenarios were developed using historical data from 2000 to 2018, after which projections were made up to 2030 based on the average year-on-year electricity growth rate. Of the three electricity demand categories, residential demand experienced a steeper growth rate in comparison with the special load tariff, non-residential, and street lighting sectors. On the supply side, low, moderate, and visionary supply scenarios had increased solar penetration of 5 %, 10 %, and 15 % of the installed generation capacity respectively. While appreciable gains were made in the low and moderate supply scenarios, the visionary supply scenario could meet the renewable energy target with solar energy by 2030; leading to universal access to electricity while offsetting over 13 million metric tonnes of carbon dioxide in the process.

Introduction

Although 411 million of the global population gained access to electricity between 2010 and 2018, over 620 million people could still be without access to electricity by 2030 according to the Tracking SDG 7: The Energy Progress Report 2020 [1]. Sub-Saharan Africa (SSA) alone had about 548 million people who lacked access in 2018. Electrification efforts

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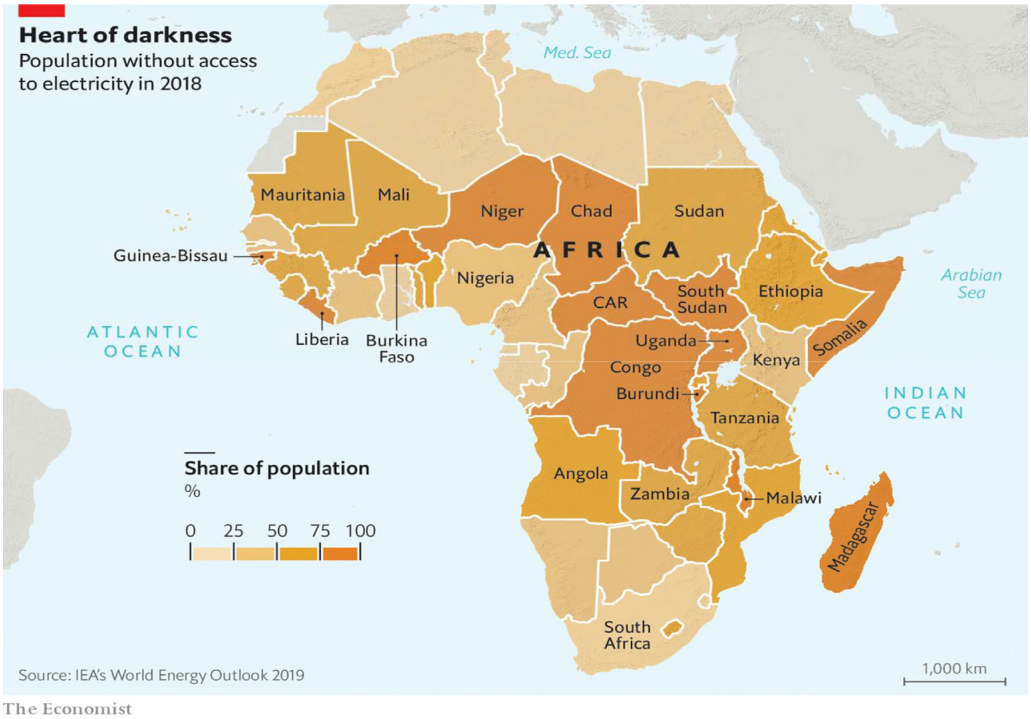

Fig. 1. Overview of electricity access in Sub Saharan Africa.

have fallen behind population growth in most SSA countries including Burkina Faso, Democratic Republic of Congo (DRC), and Niger as presented in Fig. 1 [2]. Ghana, like most developing countries in SSA, has electricity access and reliability challenges, despite the 82.5% electricity access rate the country reported as of the end of 2018 [3]. These challenges have impeded economic growth in all sectors of the economy.

The energy tree presented in Fig. 2 shows Ghana's installed electricity generation plants as of 2019 which reveals that the main sources of electricity generation in Ghana are thermal and hydropower. Although the access rate is relatively high compared to neighboring countries, Ghana experienced power interruptions leading to load shedding which was a result of a deficit in the available capacity as against installed capacity. This is further explained by the 2018 case study in Fig. 3. These load-shedding exercises have retarded growth especially in the industrial sector [4,5].

Fig. 3 shows a deficit in available and installed generation capacity. The deficit in hydro generation can be attributed to the effects of climate change, which has resulted in reduced water volumes flowing into the Volta Lake [7,8] as well as the damming of the White Volta, one of the tributaries to the Volta lake by neighboring Burkina Faso, for hydropower purposes. The thermal generation plants are mainly operated as single cycle plants [9] thereby, reducing the output. The inconsistent supply of natural gas [10] also affects electricity generation from thermal sources.

Modern renewable energy sources including mini-hydro, solar, wind, solid biomass, geothermal, and tidal [12] present a reliable alternative to reaching universal access to electricity by 2030 [13], particularly for rural and off-grid communities and contribute to attaining Sustainable Development Goals (SDG) 7 and 13 simultaneously [14]. The renewable energy potentials in SSA have not been fully explored according to a study by Onyeji-Nwogu [15]. However, recent achievements in Ethiopia with the largest biogas plant in Africa taking 1400 tons of bio-degradable materials and waste to produce 80% of the electricity requirements of Addis Ababa [16] is notable. Geothermal potential energy is dominated by southern and northern African countries but Kenya has the highest installed capacity in Africa of 1037 MW according to the International Geothermal Association (IGA) [17]. In the most substantial amounts of Global Horizontal Irradiation (GHI) (approximately 10 mil km^2 of, approximately one-third of the continental area). There are 12 epicenter countries for GHI with at least 50% superb potential threshold within national limits, of which 9 are located in Africa shown in Table SM 1 [18]. For DNI, only 3 countries reach the threshold of the maximum solar potential with one in Africa –Namibia 77% [18]. In terms of installed capacity, South Africa and Morocco recorded the highest installed capacities of solar power generation plants [19]. Out of the 1411 MW, medium-to-large-scale identified renewable energy projects in the West African sub-region, about 11.5% is located in Ghana under the West Africa Power Pool (WAPP) master plan [20].

Ghana has extensive renewable energy policies to encourage renewable energy development [21]. The main renewable energy sources considered under these policies include solar, wind, biomass, tidal, landfill gas, geothermal, sewage gas, and mini hydro ($\leq$10 MW). Only a total of 1.5% of installed renewable energy capacity was achieved by the target year 2020 [22]. This failure has been attributed to several challenges including lack of competitive pricing, weak grid infrastructure, limited

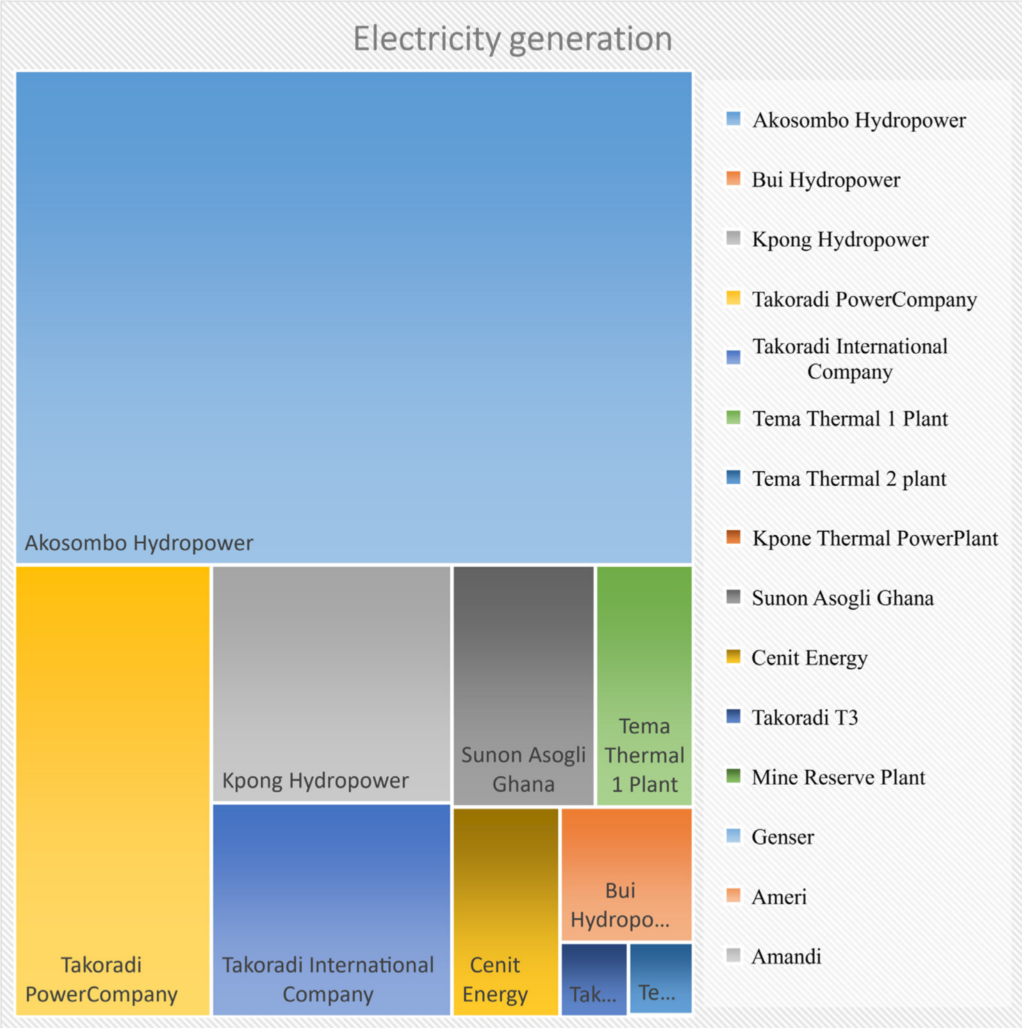

Fig. 2. Overview of the generation plants in Ghana [6].

access to funds, and inconsistent development strategies [21,22]. The Renewable Energy Master Plan (REMP) was launched in 2019 to address these challenges and provide working guidelines to achieve the country's renewable energy targets. The Renewable Energy Master Plan (REMP) is an extension of the renewable energy Act with a target to reach 10% renewables in the national electricity generation mix by 2030. The REMP was developed to provide an investment-focused framework for the development and utilization of renewable energy in the country [23]. The main goals of the REMP are outlined as follows:

1. Increase installed generation capacity from 42.5 MW in 2018 to 1363.63 MW by 2030.
2. Reduce the dependence on biomass as the main fuel for thermal energy applications.
3. Provide renewable energy-based decentralized electrification options in off-grid communities of 250 MW by 2030.
4. Promote local content and local participation in the renewable energy industry.

The REMP is to be implemented over 13 years, from 2018 to 2030 and would lead to an estimated installed capacity of 2567 MW in renewable energy plants, 225,000 jobs, and CO_2 savings of about 20.6 million tonnes by 2030 [24]. The objective of this study is to investigate the potential contribution of solar energy in achieving universal access to electricity in Ghana by 2030. The study further assesses the CO_2 emission reductions that could result from the deployment of solar energy projects towards achieving universal access to electricity.

Potential of solar energy in Ghana

Global electricity demand could be met with available solar energy potential due to its abundant, inexhaustible nature [25–27]. The Global Horizontal Irradiation and Direct Normal Irradiation maps of Ghana in Figs. 4 and 5 show the overall

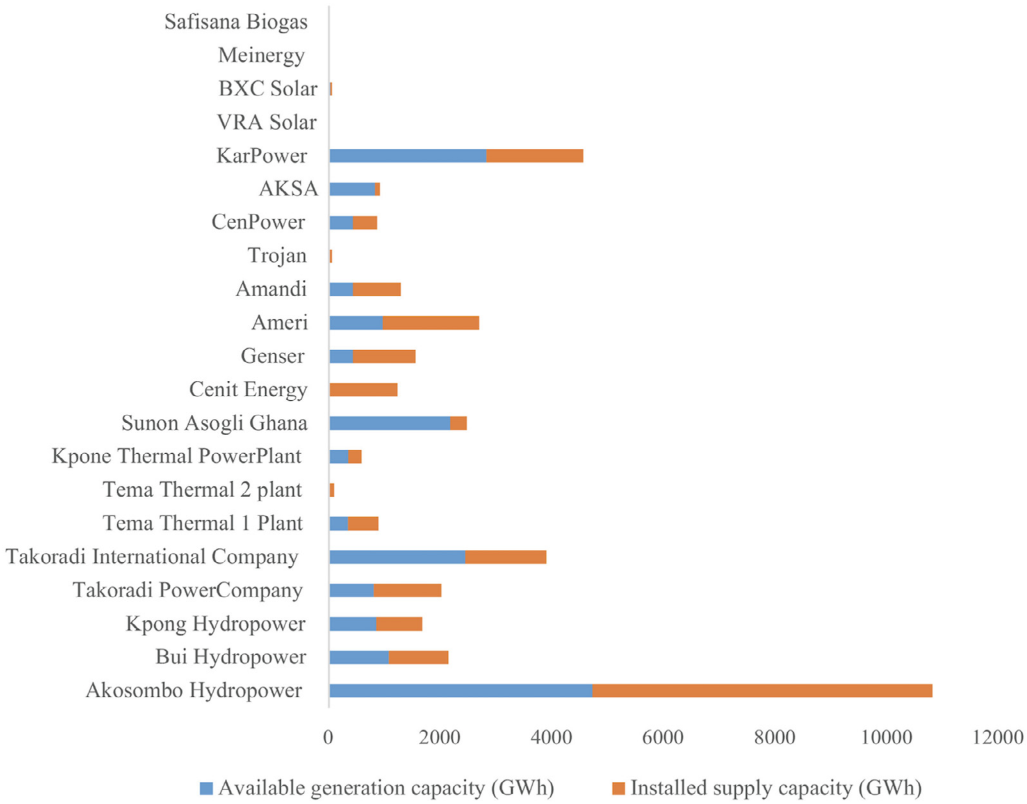

Fig. 3. Comparison of available to installed generation capacity [11].

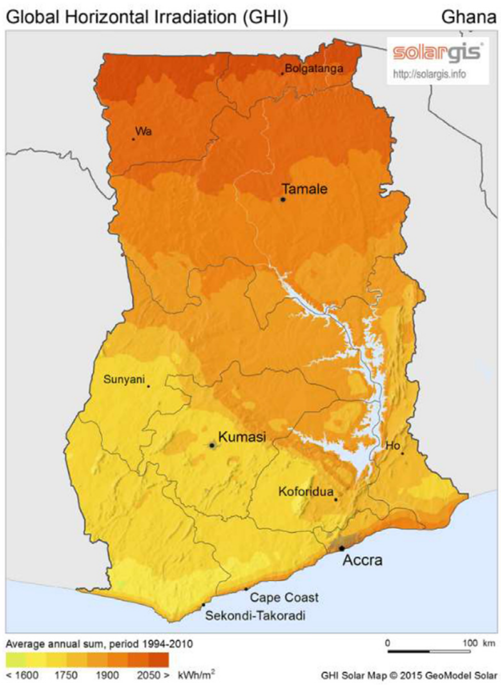

Fig. 4. GHI solar map of Ghana [31].

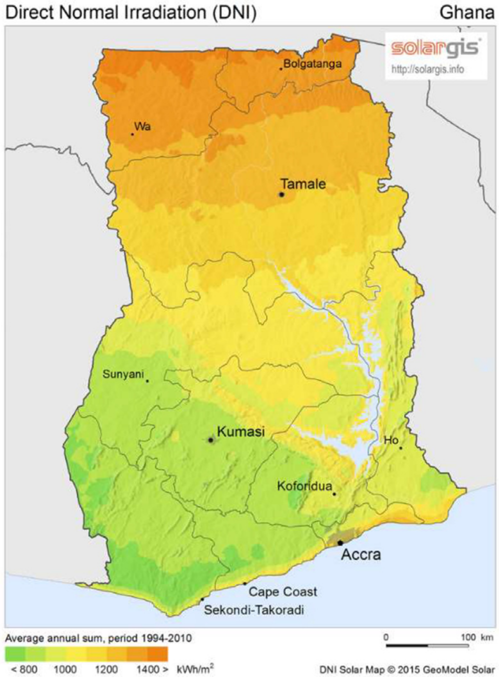

Fig. 5. DNI solar map of Ghana [31].

solar potential for thermal and photovoltaic applications. Ghana receives some of the highest amounts of radiation, globally, which makes it suitable for various solar energy applications particularly towards the northern part of the country [28]. Daily solar insolation levels range from 4 kWh/m^2 to 6 kWh/m^2 with an annual sunshine duration range between 1800 and 3000 h per annum which offers a high potential for solar electricity generation [29]. This data is further confirmed in the Solar Wind Energy Resource Assessment (SWERA) report on Ghana [30].

Despite this potential, challenges such as political will, technical expertise, availability of components, financing, availability of land, and others have hindered the growth of the sector over the years [32]. Recent advances in research have, however, reduced the cost of electricity from solar energy [33]. In Ghana, solar energy installations contribute 90% of all renewable energy installations according to a study by Gyamfi et al. [34]. The key issues affecting the implementation of solar energy projects in Ghana, in line with the Renewable Energy Global Status Report (2019) standards, are presented in Fig. 6. Energy policy is at the heart of the issues affecting the implementation of solar energy in Ghana. Others include solar energy usage in power generation as well as heating and cooling purposes, technical feasibility, equipment supply, and manufacture, as well as financing.

Policy

Ghana's Renewable Energy Act (ACT 832, 2011) [36] came into force in 2011 with key policy components comparable to global renewable energy policies. The key components required for policy analysis according to the 21st report of the Renewable Energy Policy Network [37] for renewable policy implementation assessment are power, heating & cooling, technical feasibility, financing, and equipment manufacture & supply. The five key sections are essential to the sustainability of the policy. Table SM 2 summarizes the comparison of renewable energy policies from randomly selected countries.

In 1989 the National Electrification Scheme (NES) was passed with a 30-year timeframe (1990–2020). The objective of NES was to improve electricity access in the country especially to the rural areas with populations of more than 500 people [38]. This was later expanded to include the Solar National Electrification Scheme (SNES). SNES employed the fee-for-service approach according to Steel et al. [39]. This approach was very encouraging as the use of photovoltaic systems in off-grid rural areas.

The National Energy Policy (NEP), which preceded the Renewable Energy Act in 2010, targeted adding 10% of renewable energy generation sources to the national generation mix by 2020 but has since been extended to 2030 under the REMP scale-up program. The main highlights in the NEP implementation include off-grid electrification systems, power purchase agreements, net metering systems, and licensing schemes. Additionally, the government offers a clear implementation of tax incentives and importation fee exemptions for some renewable energy components [40].

A grid code for utility-scale renewable energy grid interconnection, net metering code, a standard Power Purchase Agreement (PPA), guidelines on renewable energy purchase obligation, a detailed and concise licensing framework, and an attrac-

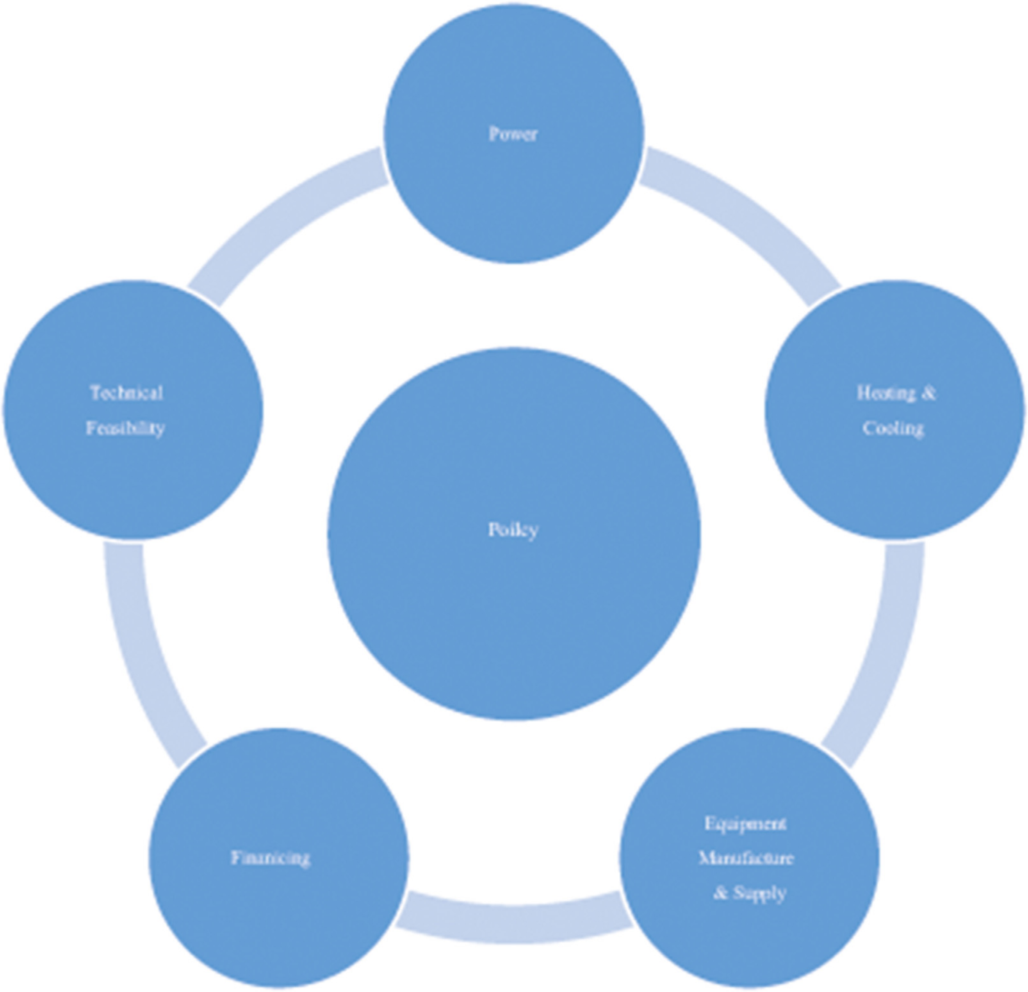

Fig. 6. Key considerations for solar implementation [35].

tive feed-in tariff (with provision for 10 and 20 years and capacity limit subject to grid impact assessment) are all measures put in place to implement the NEP. Solar photovoltaic (PV) has a guaranteed rate of GHC 0.60/kWh (US$ 0.11) for the first 10 years. The Sustainable Energy for All (SE4ALL) [41], developed in 2012, also seeks to address the provision of off-grid renewable energy-based solutions thereby complimenting ACT 832. Under SE4ALL, national electrification coverage increased from 66.7% 2008 to 76% in January 2015 [42] and 82.5% in 2019. As one of its objectives, the SE4ALL, has a target of deploying an additional 50,000 Solar Home Systems (SHS) to add up to the existing 71,600. The private sector companies also aim to deploy additional 120,000 SHS by 2030. The SHS is categorized under T1 ($\leq$30 W), T2 (30 W–150 W), and T3 ($\geq$150 W) [43].

In line with the Intended Nationally Determined Contributions (INDCs) [44], Ghana intends to generate compliance grade emission reduction units from actions in the waste and energy sectors. The Reducing Emissions from Deforestation and forest Degradation (REDD+) program [45] enlisted on the World Bank's Forest Carbon Partnership Facility (FCPF) REDD+ Readiness Programme also targets forest carbon emission reduction from 2012 to 2032. The Readiness Plan Idea Note (R-PIN) was expanded and approved in 2010 to the REDD+ program [46].

All these policy interventions coupled with average solar insolation of 4 kWh/m^2/day–6 kWh/m^2/day according to a study by Matuska and Sourek [47] have aided to put solar energy at the forefront of renewable energy deployment in Ghana.

Solar heating and cooling

Solar heating and cooling utilize solar thermal energy to provide heating and cooling for applications such as water heating [48,49], industrial process heating [50,51], cooling [52,53] to name but a few. In Ghana, solar cooling is almost non-existent compared to solar heating [54]. Solar heating is applied mainly to water heating and crop drying. The hospitality and food processing industries are the main users of solar water heaters (SWH). Flat plate and evacuated tube collectors are the commonly used types of thermal collectors in Ghana. Characteristics such as insulation and glazing affect efficiency considerably [55]. The main challenges that have been encountered in the mass adoption and usage of solar water heaters are high cost of maintenance because of the high level of chlorine in the copper pipes, low water pressure, and irregular supply from source (Ghana Water Company), which often renders many installed systems non-functional as in a study by Dao et al. [56]. Damage through sand is quite rampant along the arid regions, especially in northern Ghana.

Solar power

Solar power mainly refers to solar energy for electricity generation and lighting purposes [57,58]. In Ghana, solar electrification is one of the key applications championing solar energy implementation [59]. Efforts in the sector are summarized in Table SM 3.

There has been progressive growth in installed solar energy capacity since 2013 (mainly from solar photovoltaics) as shown in Table SM 4. Solar thermal sources have not contributed significantly to solar energy growth due to several factors but mainly the lack of political will as in a study by Ogunmodimu and Okoroigwe [60] in Nigeria. The cost of solar thermal technology, unfortunately, has not declined as in the case of solar photovoltaic systems which also discourages investment in the sector [61]. Electricity generation from solar energy has increased due to the policy interventions and concise implementation strategies mentioned in Section "*Policy*". The implementation of Act 832 (the Renewable Energy Act) has further aided the growth of the solar energy sector, although the growth rate is below the target.

Equipment supply and manufacture industry

To promote solar technology in Ghana, Strategic Security Systems (3SiL) began the solar PV module assembly in Ghana in 2015 with a production capacity of 30 MW of modules per year. Other companies include Halo International in 2016 with a production capacity of 15 MW per year and Atlas Business and Energy Systems (ABES). Africano Electro Ltd, Power Wings Company Ltd, Panasonic, and Deng Ghana Ltd, among others, are at various stages of setting up manufacturing /assembly plants for renewable energy components. Trade works Ghana Ltd., with a 12 MW per year capacity is yet to commence operations.

Technical feasibility

Several studies by Quansah et al., have been conducted in Ghana on solar photovoltaics. The studies show that most modules in Ghana meet and exceeded warranty expectations of up to 10 years at 90% capacity and 25 years at 80% capacity meeting the international standards on technical feasibility [62]. Furthermore, polycrystalline (pc-Si) solar cells have been found to be more economical [63,64]. Heterojunction Incorporating Thin (HIT) films were found to be comparatively more energy efficient [65]. Another study on solar photovoltaics in Africa [66] recommended the transition from solar home systems to grid-connected or mini-grids to achieve the 2030 target of universal access to electricity for all under the SE4ALL project. In distributed and decentralized systems, stronger regulations need to be developed. Africa also needs to integrate significant shares of large-scale centralized power plants. However, the choice of a photovoltaic panel depends on a number of factors such as the availability of land and the cost of the panel and storage [67,68] in line with the global factors. Systems with tracking are however unpopular. Ghana, therefore, has the technical capacity to increase its installed capacity.

Financing

Globally, Investment in renewable energy continued to focus on solar power, particularly solar PV, which increased its lead over wind power in 2017 [69]. Small-scale solar PV installations (less than 1 MW) had an investment increase of 15%, to USD 49.4 billion. Developing and emerging economies overtook developed countries in renewable energy investment for the first time in 2015 and extended their lead in 2017, accounting for a record 63% of the global total, due largely to China [70]. Investment in developing and emerging countries increased by 20% to USD 177 billion, while that of developed countries fell 19% to USD 103 billion [71]. China accounted for a record 45% of global investment in renewables (excluding hydropower larger than 50 MW), up from 35% in 2016, followed by Europe (15%), the United States (14%), and Asia-Oceania (excluding China and India; 11%) [59,72]. Smaller shares were seen in the Americas (excluding Brazil and the United States, 5%), India (4%), the Middle East and Africa (4%), and Brazil (2%).

Ghana accessed a US$2 billion concessional Line of Credit for Renewable Energy, following Parliament's ratification of the country's membership in the International Solar Alliance (ISA) [73]. The Green Climate Fund (GCF), since 2017, has also released funds to support Renewable energy projects. Internally generated funds, funds from the IRENA – ADF project facility, ECREEE, and the private sector will decrease the direct full financial burden on consumers' / project funders [74]. The Renewable Energy Master Plan (REMP) is a US$ 8 billion investment master plan. On annual basis, the REMP translates into an estimated US$ 620 million in investments [75]. The development of the financial domestic sector to accept and manage credits for renewable energies installations at domestic, commercial, and industrial levels must be further developed in Ghana.

Methodology

This paper employs the Low Emissions Analysis Platform (LEAP) to model solar energy development in line with the REMP towards attaining universal access to electricity by 2030. LEAP was also used to model scenarios of energy as well as the CO_2 emission reductions in the respective scenarios up to 2030 similar to the study by Kemausuor et al. [76]. A model was developed in the Low Emissions Analysis Platform (LEAP) to forecast energy demand using historical data. Data on electricity demand was divided into four subsectors namely, residential, non-residential, special load tariff (SLT), and street lighting sectors. Existing energy generation plants were included in the model to study the energy demand and supply dynamics. Greenhouse gas (GHG) associated with energy generation are estimated in the model. A reference scenario was developed using existing demand and supply data. From the reference scenario, other scenarios were developed to depict the various levels of solar penetration in the energy supply plan. The methodology used consists of positive projection scenarios similar to studies by Emodi et al. [77] for Nigeria and Nieves et al. [78] for Columbia.

Low emissions analysis platform (LEAP)

LEAP is a software tool for energy policy, climate change mitigation, and air pollution decline forecasting. It is an integrated modeling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy. It can be used to account for both the energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks, in addition to tracking GHG. LEAP is designed around the concept of long-range scenario analysis. Scenarios are self-consistent storylines of how an energy system might evolve.

LEAP is not a model for any specific energy system, but a tool that can be used to generate models of diverse energy systems, where each needs its own unique data sets. LEAP supports a variety of different modeling methodologies: on the demand side these range from ascending, end-use accounting techniques to descending macroeconomic modeling. On the supply side, LEAP runs a range of accounting, simulation, and optimization methodologies for modeling electric sector generation and capacity expansion planning, but also malleable and easy to allow LEAP to incorporate data and results from other more specialized models. This study focused on data from the demand and supply side.

LEAP's modeling capabilities operate at two basic conceptual levels. In one methodology, LEAP's built-in calculations handle all energy, emissions, and cost-benefit accounting calculations. On the other hand, users enter spreadsheet-like expressions that can be used to specify time-varying data or to generate a wide variety of sophisticated multi-variable models, thus enabling econometric and simulation approaches to be embedded within LEAP's overall accounting and optimization frameworks. This paper utilized the built-in calculations method.

Model parameters

The base year used for the model was 2013 because that was the year the renewable energy Act (ACT 832) was enforced. The end year for the model was 2030 in line with the target year specified in the Renewable Energy Master Plan (REMP) and the target for Act 832. In modeling energy demand and supply in LEAP, historical data from 2013 to 2018 (from the Ghana Energy Commission) was used to project demand and supply from 2019 to 2030.

Demand and supply projections

Energy demand data was grouped under residential, non-residential, special load tariff (SLT), and street lighting sectors. The average year-on-year growth rate used in the demand projections was calculated using available historical data from the Ghana Energy Commission between 2000 and 2018. The demand projections were done along the lines of the existing energy demand sectors. On the supply side, existing generation facilities, as of 2018, were modelled in LEAP. These together were developed into the reference scenario subsequently referred to as the Business-As-Usual (BAU) Scenario from which the Solar Transition scenarios were developed.

Solar transition scenarios

Based on the Business-As-Usual (BAU) supply scenario, the Low Transition (LT) Supply Scenario, Moderate Transition (MT) Supply Scenario, and Visionary Transition (VT) Supply Scenario was developed to reflect the various levels of solar energy penetration in the generation mix. In the BAU, the actual installed generation capacity available as of the end of 2018 was deployed in the scenario to meet the electricity demand till 2023. The solar transition supply scenarios added 5%, 10%, and 15% of installed solar energy generation systems in the LT, MT, and VT, respectively.

Results and discussion

The scenarios investigated and analyzed were the Electricity demand scenario, electricity supply scenario, BAU scenario, LT scenario, MT scenario, VT scenario, carbon dioxide (CO_2) emission scenario, and lastly a comparison of carbon dioxide emission reduction scenario.

Electricity demand scenario

The electricity demand projections were based on all the demand sectors outlined in the business-as-usual scenario shown in Fig. SM 1. The total demand growth rate is calculated to be 8% per annum, 2% lower than the demand growth rate projection of the Ghana grid company (GRIDCo) [79]. This is accounted for by the tolerance given in the GRIDCo projections for other sectors of demand whereas this study is based on available data for the four primary demand sectors from the Energy Commission. The residential and street lighting growth rate is expected to be at 8% whilst non-residential and special load sectors increase by 9% per annum. The dips in the demand growth curves were because of the load shedding exercises. The load shedding exercise was because of supply unable to meet demand. A schedule was then created to cut supply at certain times to create a balance. Most often though, these power cuts were random. Most industries, therefore, resulted in independent power plants to continue production and for the safety of their equipment's according to Nduhuura et al. [80]. This shifted the demand for electricity from the national grid to private diesel generators.

Supply business-as-usual (BAU) scenario

Electricity generation capacity in the business scenario is more than 1,000 GWh as shown in Fig. SM 2. This shows that Ghana has more than enough installed generation capacity to meet demand. Ghana's inability to meet demand is, therefore, a challenge of finances prioritizing of crude oil purchasing. A study from Tweneboah and Adam [81] argues that monetary policy has lessened negative growth consequences of oil price shocks, at the cost of higher inflation. Therefore, policymakers are torn between higher inflation or negative growth. From 2016, generation capacity increased substantially with an increase in generation from Tema thermal plant 2, Trojan, Kar power, and BXC solar. Except for BXC solar, all plants required crude oil for a generation. Kar power started generation in 2015 but increased generation from 64 GWh to 1822 GWh by 2016. However, the Takoradi T3 and my reserve plants were decommissioned in 2016 and 2017, respectively. The AKSA plant started generation in 2017 as shown in Fig. 3. Genser, Meinergy and Safisana Biogas plants also started generation in 2018. 34.6% of generation capacity would come from the Akosombo, Bui Hydro, and Kpone power plants with thermal production accounting for 66.8% of projected national generation by 2030. Solar energy should however contribute 12.4% of generation by 2030 in the BAU scenario.

Solar transition scenarios

This explains the three main scenarios considered: Low, moderate, and visionary transition scenarios. In the low transition scenario, the total solar installed generation was projected to increase by 5% as shown in Fig. SM 3. Therefore, the generation increases from 70 MW in 2020 to 270 MW in 2030. This would contribute to 1% of the projected demand in 2030. The residential and non-residential sectors contribute 42% and 13% (highest and lowest) demand sectors in 2030. Solar generation could contribute 2.6% of residential demand or 8.7% to non-residential demand in 2030. Averagely, 2.3% of total demand could be met in the low transition scenario. This would leave a deficit of 1093.63 MW by 2030 of the 1363.63 MW targets of the REMP.

In the moderate transition scenario, shown in Fig. SM 4 solar transition was projected to increase by 10% in line with the target in the renewable energy Act. The solar installed generation could, then, contribute 5.2% of residential demand or 17.1% to non-residential demand in 2030. This could also contribute to 482.46 thousand GW of solar energy by 2030.

For the visionary scenario shown in Fig. SM 5, the solar transition was projected to increase by 15%. Solar generation could contribute 8.1% of residential demand or 26.8% to non-residential demand in 2030. Approximately 784.13 thousand GW of solar energy could be contributed by 2030. As island communities are the main targets of solar off-grid systems, the visionary scenario could help Ghana attain the 100% electrification rate by the 2030 target.

Strategies such as mobilizing funds domestically (e.g., bonds, shares, etc.). Investments such as the provision of government on-lending facilities/loans to solar projects. The success story of South Asia according to a study by Palit [82] could be emulated. Competitive procurement could be institutionalized to achieve price reduction in solar tariffs. Also, upgrading of the National Interconnected Transmission System [83] to make the grid robust for solar integration (system control center, weather forecasting systems, etc.), driving developments onto lands that does not compete with other uses (e.g. abandoned mineral mine sites) and encouraging the contribution of land as equity in solar projects should be encouraged.

The government can also continue providing incentives through the energy levy, intensify awareness creation, and capacity development for stakeholders.

Carbon emissions

Carbon emissions associated with generation were the same until the introduction of the solar transition scenarios as seen in Fig. SM 6. The maximum emissions occurred in the Business-As-Usual (BAU) supply scenario. The least emission, however, was from the visionary supply scenario although the maximum solar generation was from this scenario confirming the globally accepted fact that solar energy utilization does not add any carbon dioxide to the atmosphere. The BAU supply scenario emits 80.8% more carbon dioxides compared to the visionary scenario. Increasing solar energy will therefore reduce the carbon emissions from electricity generation significantly. The moderate and low supply scenarios follow, respectively. Fig.SM 7 shows the avoided carbon power production. By 2030, 3.31 million metric tonnes, 9.33 million metric tonnes, and 13.66 million metric tonnes CO_2 would be avoided in the Business-as-usual, low, moderate, and visionary scenarios. This shows that the highest amount of emission avoided would be in the visionary supply scenario. If this effort coupled with similar avoided emissions from biogenetic emissions from power generation would reduce drastically according to a study by Kemausuor et al. [76]. This would help the country reduce its carbon emissions as part of its efforts to reducing global warming in line with the Intergovernmental Panel on Climate Change (IPCC) protocols [84].

Conclusion and policy implications

Three main solar energy transition scenarios were designed including demand projections, supply, the demand projections indicated that residential demand is projected to increase substantially followed by special load tariff, non-residential, and street lighting respectively. The residential growth however experienced a sharper growth rate in comparison to the other 3 sectors. Solar energy for the residential sector is therefore recommended to help meet demand.

Four main supply scenarios were designed using LEAP. The business-as-usual supply scenario was designed based on the current supply rate which cannot meet the target set in the renewable energy master plan. The low transition, moderate and visionary scenarios increased solar transition by 5%, 10%, and 15%, respectively. Appreciable gains were made in the low and moderate transition scenarios. However, the visionary supply scenario can meet the renewable energy target by 2030 with solar energy. Implementation strategies such as tax incentives, solar subsidies, promotion of local manufacture of solar systems, prioritizing solar thermal power generation, and crop drying. Also strengthening the national grid to encourage grid interconnection, net metering incentives, and investment in the solar generation sector is recommended.

In line with environmental concerns with power generation, solar energy reduces carbon emissions compared to thermal power generation. Most importantly the visionary supply emission scenario produces 80.8% fewer carbon emissions whiles generating 15% more solar power. In Comparison to the Business-as-usual supply scenario with the visionary scenario over 13 million metric tonnes of CO_2 will be offset by 2030. This will help the country attain its contribution to keeping global temperature increase below 2°C – Sustainable Development Goal 13. Sustainable Development Goal 7 – clean energy targets could also be implemented through the promotion of solar energy. As Ghana prioritized energy in its Intentionally nationally determined contributions (INDCs) with a target of 100% electricity access by 2030, an increase in solar energy generation can also aid in the earlier achievement of this target. The framing of solar energy deployment as a strategy for sustainable economic growth is strongly recommended.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2022.e01162.

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