Ghana's Nuclear Power and Its Role in Climate Change

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Abstract

The Ghana Nuclear Power Agenda is a programme laid out by the Ghana Atomic Energy Commission in collaboration with the government of Ghana to guide and facilitate the installation of Ghana's first ever nuclear power plant. The nuclear power plant is expected to generate between 1000 and 12800 MW of electricity from its very first and final installations in a span of 20 years. Ghana's Third National Communication (TNC) Report to the UNFCCC indicates 59 million metric tons of carbon dioxide (MtCO₂e) emission in 2011. Between 1991 and 2011, Greenhouse gas (GHG) emissions grew by 20% as energy intensity of the economy rose alongside with a growing demand in industry, transport and households. If nothing is done to curtail GHG emission from fossil-source power plants, the looming catastrophe of the changing climate will occur faster than we imagine. On the basis of this, advocacy for nuclear power has been intensified in Ghana. Nuclear power is not only environmentally friendly (zero-to-low carbon emission), it is efficient and sustainable source of energy. It offers current and future energy needs without burdening future generations with a broken environment. Using Monte Carlo's model, the current study estimates a cumulative increase (35%) in CO₂ emission between 2016 and 2026 without nuclear power in Ghana's energy mix. With the inclusion of nuclear power in the country's energy mix by 2029, the model estimates CO₂ emission cut by 12.5% between 2029 and 2039. Thus, given the same period of time, the rate of emission of CO₂ was found to be more than twice its reduction.

Highlights Of Study

- Demands for energy (electricity) continues to rise due to industrialization and growth in population;
- Fossil-fueled energy generation plants are a leading greenhouse gas (GHG) emitters which in turn are the leading causes in the global warming phenomenon (climate change);
- Global energy policies can effectively address climate change by reducing dependence on fossil-fueled energy sources;
- Nuclear energy is a sustainable source of electrical power; having low-zero carbon emission potential;
- Ghana is on its way to having its first nuclear power plant; upon completion in 2029, it is expected to generate a 1000 MW power and by 2047 nuclear will be the leading source of electric power with a generation capacity of 12800 MW in Ghana;
- Monte Carlo's model was used to estimate CO₂ emission rates in Ghana;
- The model estimates CO₂ emission cut by 12.5% between 2029 and 2039. Thus, Nuclear power will strategically lead in Ghana's effort of cutting down GHG emission.

Introduction

The 21st century has seen a tremendous surge in industrial activities especially in Europe and North America. Currently, Asia with a lot more developing countries are becoming more and more industrialized

with the aim of bridging the industrial gap and expanding their economies. While industrialization is a necessity for the ever increasing global population coupled with increase in demands for goods and services, there is however, a looming threat on the environment due to excessive pressure on natural resources and release of CO₂ and other greenhouse gases (GHGs) in the atmosphere.

There is a global scientific consensus about utilization of fossil fuel energy being responsible for increased atmospheric CO₂ concentration and the phenomenon of global warming and climate change (Matysek et al. 2006; Denman et al. 2007). Munasinghe et al. 2010, describes climate change as an emerging issue of major global concern for everyone in the universe. It threatens to aggravate the intimidating problems of development we face today like poverty, food security, diseases, and scarcities of water and energy.

Although there are other GHGs such as nitrous oxide (N₂O), methane (CH₄), and chlorofluorocarbons (CFCs) in the atmosphere, CO₂ alone contributes about 50% to global warming making it the biggest culprit of this phenomenon (Niharika et al. 2014). Combustion of fossil fuels for energy generation remains the main human source of GHG emission, however, non-energy emissions (including agriculture and land-use changes) contribute more than a third of the total global GHG emissions (McMichael et al. 2007).

Anthropogenic activities including energy production from fossil-fueled plants, oil and natural gas combustion, cement manufacturing, deforestation etc. have together contributed to the significant rise in the CO₂ concentration in the atmosphere (Le Quere et al. 2011; Scripps et al., 2014). Eighty seven percent (87%) of global anthropogenic CO₂ emissions come from burning coal, natural gas and oil; the remainder are attributed to deforestation, other land use (9%) and manufacturing/ industrial processes (4%) (Denman et al., 2007; Van De Wal et al. 2011).

Anthropogenic sources of CO₂ are much smaller compared to the natural emissions; yet, they have caused an upset in the natural balance that have existed thousands of years ago between the natural sinks that remove CO₂ and the source that produce them (Denman et al. 2007). Until the surge in the CO₂ concentration, emission and washout of CO₂ in the atmosphere have been in a balance and within a safe range. Human activities, however, have disrupted the balance by adding extra CO₂ without means of removing any (Denman et al. 2007).

Lignite (LNG) also known as brown coal, is a combustible sedimentary rock used for electric power generation with about 70% carbon content and up to 19% ash content. It constitutes a major energy source and has long been used for energy production despite its significant contribution in GHG emissions (Violidakis and Nikolopoulos (2017)). About 27.4% of Germany's electricity originates from lignite power plants whereas in Greece more than 55% of the country's electric energy is derived from lignite (Violidakis and Nikolopoulos (2017)). High moisture content of lignite results in higher CO₂ emissions per unit of energy produced. Lignite is also reported to be responsible for high capital and transport costs as well as technical problems such as reduction in coal friability and difficulties in its blending and pneumatic

transportation (Violidakis and Nikolopoulos (2017)). In ranking, 45% global coal reserves consist of lignite making it the lowest ranking in the coal classification system (Grammelis and Karampinis (2016)). It is readily available natural resource in many countries in Europe and America (Grammelis and Karampinis (2016); Violidakis and Nikolopoulos (2017) and cheaper material for energy generation.

Demands for energy to produce basic human needs such as food, shelter and clothing have increased drastically since the first industrial revolution. The International Energy Agency (IEA) reports that, global demands for electricity rose by 4% in 2018 (IEA 2018), an increase twice as fast as the overall demand for energy. Over the next 20 years, this demand is expected to increase by 43% (IAEA 2009). This expectation offers the opportunity to be proactive in the fight against climate change by reducing reliance on fossil fuel energy sources unto low-to-zero carbon emitting energy sources.

Whilst global energy demand rises, emission of GHGs and other chemical substances detrimental to human health and destruction of the ecosystem rise along. Carbon emission is a major concern due to its light absorbing characteristics causing positive radiative forcing of the climate (Scientific American 2018).

Nii Nelson (2018) cited a strong correlation between energy, the environment and sustainable development. Access to sustainable energy is vital in realizing the developmental goals of developing countries like Ghana (Adam et al. 2013); notwithstanding contribution of the energy sector to climate change (Gyamfi et al. 2015).

Electric power demands in Ghana increased by about 52% between 2006 and 2016. Even though installed generation capacity more than doubled over the same period, there was still a huge deficit in the supply of sustainable power to many parts of the country (GNEP 2010; TNC 2015 and ECG 2016). Despite strides made in generation capacity, the country suffered from persistent power supply challenges due to several reasons including over-reliance on the country's major power generation source – the Akosombo Hydroelectric Power Dam (AHPD). Drastic reduction in the water level of the dam and frequent breakdown of turbines greatly affected the efficiency of the AHPD (Kumi 2017).

In view of these, the State of Ghana have made efforts since the 1980's to diversify its energy generation with the inclusion of thermal and renewable energy sources to its main hydro source. Currently, thermal, hydro and renewables are the three major generation sources with installed capacities of 2786 MW, 1580 MW and 22.6 MW, respectively (ECG 2006; Kumi 2017). Thus, thermal has overtaken hydro as the leading source of electric power since 2017.

The amount of CO₂ produced when fuel is burned is a function of the carbon content of the fuel (UNPD 2019). According to the national energy statistics, the amount of CO₂ emitted from fossil sources in Ghana as at 2016 stood at 14,468,986 tons with an annual average increment of 3.5% (US-EIA 2020). The annual average CO₂ emission in Ghana is ~ 495,166 tons, about 0.04% of the global annual emission.

Growing public concerns over the impacts of anthropogenic carbon emissions; its climatic and economic effects have led to a significant and concerted efforts to reduce carbon emissions through sustainable and efficient energy production (Kennedy and Sgourdis (2011)). In this regard, policies relating to production and utilization of energy are very crucial and should be informed on key issues such as emissions, sustainability and environmental impact. Curtailment of GHG emission through energy policies is not only a worthwhile strategy but the most effective and efficient in mitigating the negative consequences of climate change.

Nuclear power offers that efficient and effective solution to work down on CO₂ emission and save the environment from a looming destruction. It offers a choice to harness our resources to meet our current and later energy needs without burdening future generations with a broken environment with associated health, economic and environmental crises.

Despite being sustainable and efficient source of energy, nuclear power plants (NPP) continue to face issues relating to safety, security, technical risk and disposal of its spent fuel (nuclear waste) (Haas et al. 2019). Increasing cost and duration of construction have worsen the plights of NPP vendors. The French vendor AREVA and the US-based Westinghouse both declared bankruptcy in 2017.

Furthermore, the three major accidents that occurred in the history of nuclear power: the 1977 Three Mile Island in the USA; the 1986 Chernobyl in Ukraine and the 2011 Fukushima in Japan have caused a major set back in the industry, increasing the disquietness of the public about its safety (Haas et al. 2019).

It is important to note that, no industry is completely immune from accidents; and when they occur, they become a cause for improved safeguards and regulations. Safeguards in the nuclear industry focuses on restraining activities that could lead to acquisition and/or development of nuclear weapons (IAEA 2018; WNA 2021). Safety on the other hand relates to measures and activities that mitigate radiation hazards as a result of radiological accidents and/or incidents (IAEA 2019; WNA 2021).

It is actually evident in the last 60 years of NPP operations across the globe that, it is a safe means of generating electricity; its risk of accident and the consequences thereof is minimal compared to other acceptable risks (WNA 2021). Furthermore, the IAEA provides recommendations and guidance on the use of deterministic safety analysis and its application to nuclear power plants in compliance with established requirements of the IAEA's Safety Standards Series (IAEA-SSG-54 2019; IAEA-SSG-2 2019), Safety of Nuclear Power Plants: Design (IAEA 2016), and Safety Assessment for Facilities and Activities (IAEA-SSR-2/1, 2016; IAEA-GSR Part 4, 2016) all of which contribute to the sustained safety and security of the industry and assurance of same with much improved technologies.

The government of Ghana in the last decade have intensified its efforts to include nuclear power in the energy mix of the country. Whilst this is regarded as a prudent move towards curtailing GHG emissions and restoring our depleting environment, it will go a long way in sustaining the energy needs of the country for its accelerated developmental goal. There is also the need to build a high quality human resource as well as logistical framework that can effectively deal with all the nuclear security and safety

issues including use, transport, theft, threat and risks associated with nuclear materials and emergency response. In this regard, the Ghana Atomic Energy Commission (GAEC) and other local and international agencies are working together to achieve the ultimate goal of establishing Ghana's first nuclear power plant.

Methodology

The GAEC main site (Fig. 1) currently operates a light water nuclear research reactor also known by design as Miniature Neutron Source Reactor (MNSR) located at Kwabenya in the Ga East District of the Greater Accra. All research laboratories and auxiliary units of the Commission are located within range: latitude $5^{\circ} 6'7''$ N to $5^{\circ} 6'9''$ N, longitude $0^{\circ} 21'$ W to $0^{\circ} 26'$ W, and elevation of 64 m.

The Nuclear Power Agenda

The Ghana Nuclear Power Agenda is a national agenda with the involvement of major stake holders such as the Nuclear Power Institute (NPI) of GAEC, the Volta River Authority (VRA), the Bui Power Authority (BPA), the Ghana Grid Company Limited (GRIDCo) and the newly formed Nuclear Power Ghana Limited (NPG) to promulgate the actualization of Ghana's first nuclear power.

Source of data

Data from various local and international sources on energy, carbon emission, and climate change have been reviewed to inform Ghana's nuclear power infrastructure programme. The data were compiled from various studies and reports from reliable sources locally and internationally. Both regulatory and technical documents from resource organizations including the International Atomic Energy Agency (IAEA), International Energy Agency (IEA), United States Department of Energy (US DoE), Nuclear Regulatory Commission of the United State (US NRC) and Nuclear Energy Institute (NEI) were sought as manual guide for developing Ghana's nuclear power charter document.

Documentations for the study were categorized with preferences based on country needs informed by geological, meteorological and economical considerations. Finally, data obtained were used in drafting Ghana's nuclear charter document for major thematic areas such as siting and environment, meteorology and atmospheric.

The current study focuses on CO₂ emission and how nuclear power will help cut down on its emission whilst at the same time supply sustainable and efficient energy for the accelerated growth of Ghana.

Evaluation and simulation of data

Data of CO₂ emission from the major sources in Ghana such as transport, electric power generation, industrial combustion, noncombustion and building were obtained and simulated using Monte Carlo method. By this approach, ten year estimation of CO₂ emission sector-by-sector were simulated. The

same model was used to estimate contribution of nuclear in cutting down CO₂ emission in the first ten years (2029–2039) of nuclear power plant operation in Ghana .

Descriptive statistics such as the mean, minimum and maximum CO₂ emissions from the major sources in Ghana between 1996 and 2016 were computed using SPSS. The mean CO₂ value was then used as the primary datum to generate random variables for each of the sectors stated above by the Monte Carlo model.

The model is an excel-base software in which a cell is selected and defined as the ‘input variable’ and another cell defined as the ‘forecast’ or ‘output variable’. Uncertainties associated with the input variable is offset by the probabilistic simulation approach of the model.

In the simulation process, the input variable is the mean CO₂ emission from each of the five sectors. For each input, 1000 iterations/ simulation trials were inputted into the model and ran to generate a forecast/an output. Summary of the methodology is given in Fig. 2.

Results And Discussion

3.1. GHG emissions in Ghana

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Ghana deems it a great importance in the effort to stabilize the global GHG emissions. Ghana emitted 59 million metric tons (MtCO₂e) of GHG in 2011, with 53% of emissions coming from Land-Use Change and Forestry (LUCF) sector. Figure 3 shows the CO₂ emissions between 1980 and 2016 along with the 3 leading CO₂ emission sources in Ghana.

Greenhouse gas emissions grew 20% between 1991 and 2011 with a rising energy demand in industry, transport and households (ECG 2009; Oduro et al. 2020). The World Resources Institute and Climate Analysis Indicator Tool (WRT CAIT 2015) gives indication about the main drivers of GHG emission in Ghana. According to the the tool, the dominance of LUCF in Ghana’s GHG profile is mainly as a result of changes in forest land – deforestation and civil constructions. Energy is the second largest emitter, contributing 25%; of which 39% is due to transportation, 29% to other fuel combustion and 19% to electricity and heat. Agriculture forms the third largest emitter, accounting for 15%, of which burning savanna is responsible for 45% (GNEP 210; Nii Nelson 2018).

3.1.1. CO₂ emission – source by source

The annual average emission rate of CO₂ in Ghana between 1996 and 2016 stands at 3.54%; ~ 495,166 tons of CO₂ per annum. Given in Table 1 is a Ghana versus global – sector by sector CO₂ emissions between 1996 and 2016. With a projected population of 30 million, estimated CO₂ emission per capita was equivalent to 0.48 tons per person. The current study further simulated CO₂ emission for the next ten

years (2016–2026) of non-nuclear power regime; and ten years into the nuclear power regime (2029–2039) using Monte Carlo’s probability model. Result of the model (Fig. 4) estimates an annual CO₂ emission rate of 3.5% or cumulatively 35% for the period 2029–2039. The model further estimates an annual CO₂ emission cut of 1.25% from the major emission sources under consideration during the first ten years of the nuclear power regime. Cumulatively, CO₂ emission is reduced by 12.5% of for the period between 2029 and 2039. Thus, given the same period of time, emission rate is more than twice the reduction rate.

Table 1
Ghana versus global sector by sector CO₂ emissions

	CO ₂ Ghana (tons)	CO ₂ Global (tons)	%CO ₂ Ghana	%CO ₂ Global	Ghana’s Annual rate (tons)	Ghana’s Annual average (tons)
Transport	7.31x10 ⁶	7.47x10 ⁹	50.5	20.9	2.56x10 ⁵	8.87x10 ⁶
Electric power (Fossil)	2.63x10 ⁶	1.38x10 ¹⁰	18.2	38.5	9.22x10 ⁴	3.20x10 ⁶
Industrial combustion	1.91x10 ⁶	7.58x10 ⁹	13.2	21.2	6.69x10 ⁴	2.32x10 ⁶
Non- combustion	1.45x10 ⁶	3.58x10 ⁹	10	10	5.06x10 ⁴	1.76x10 ⁶
Building	1.17x10 ⁶	3.36x10 ⁹	8.1	9.4	4.10x10 ⁴	1.42x10 ⁶

3.2. Impact of climate change on power generation in Ghana

Climate change has had grave consequence on Ghana’s energy generation as hydro continues to be the leading source of power. Hydro-power currently produces about 1500 MW power (42%), followed closely by domestic gas, contributing 41% of the country’s energy mix. Specific effects of the climate such as rise in average temperature, variability in rain fall (reduced rainfall), changes in the intensity and pattern of extreme weather events, rise in sea level and droughts especially in 1983/1984, 1997/1998 and 2006/2007 have affected electricity generation and supply from the hydropower systems (TNC 2015; Kumi 2017) which in turn affected industrial production leading to job losses and economic instability of the country.

3.3. Mitigation plan for GHG emission

Ghana’s Intended Nationally Determined Contribution (INDC) identifies emission reduction actions to be undertaken between 2020 and 2030 in the energy, transportation, agriculture, forestry and land use, waste, and industry sectors. Ghana aims to reduce GHG emissions by 15% in 2030 through actions

including a 20% improvement in energy efficiency of industrial facilities, replacement of light crude oil with natural gas in electricity generation plants, and the reforestation and afforestation of 10,000 hectares of degraded lands annually (ECG 2009; SNC 2011).

In the last two decades, the government of Ghana through the Ministry of Energy, the Energy Commission and other stakeholders in the energy sector have implemented various measures to ultimately ensure energy sufficiency, sustainability and reduction in CO₂ emissions. Measures such as replacement of high energy consumption bulbs to low ones; effacement of CFC refrigerants and diversification of the energy source of the country contributed greatly, however, not sustainably. The greatest challenges have always been cost recovery, wastage and illegal power connections all of which hamper expansion of the energy infrastructure of the country. As a result of these, the energy sector and the power sub-sector in particular have not improved sufficiently to become economically independent; implement all the measures relating to sustainable energy and reduction in CO₂ emissions.

3.4. Contribution of nuclear power in resolving climate change

Nuclear energy is a sustainable, cost-effective and low-to-zero carbon emission source of power. Owing to Ghana's commitment to the UNFCCC, the country remains focused on its bid to integrate nuclear power into its power generation mix. The Ghana Nuclear Power Agenda has thus been formed with the involvement of major stakeholders in the energy sector to work together to achieve the ultimate goal of establishing the country's first nuclear power plant. There is a steady progression as the Ministry of Energy sets up a target to fully activate the second phase of the project by the end of the first quarter of 2019. The first phase, which was primarily about making the decision to use nuclear power and meeting all the 19 infrastructural needs outlined by the International Atomic Energy Agency (IAEA 2007), was fully addressed by the country as at April 2017.

Phase II, which includes implementation of the decisions made in phase I has been activated and expected to take four years to complete. Phase III, which deals with the construction of the plants will take between five and six years to complete (NPI 2018).

Ghana's first nuclear power plant of 1000 MW capacity is expected to come onboard by 2029; the capacity will rise to 3000 MW by 2033 and by 2047 the country's nuclear power capacity would have risen to 12800 MW. Figure 5 illustrates the progression of Ghana's nuclear power from 2029 to 2047. The progression of nuclear power generation compared with other major power sources have also been illustrated in Fig. 6. Nuclear power generation capacity increases progressively from its inception in 2029 through to 2047 when it becomes the largest source of power only after lignite. During the same period, generation capacity of lignite increases marginally whilst hydro generation decreases sequentially.

Conclusion

Available data in the literature shows that GHGs remain the major contributors to the changing global climate whilst fossil-fueled power plants for energy production are the leading sources of GHGs. Energy utilization has also been cited as key contributor of GHGs in the atmosphere. Lignite emits the highest GHG on a lifecycle basis followed by coal-fueled power plants, oil and natural gas in that order.

In Ghana, transport, fossil source electric power and industrial combustion are the three leading CO₂ emission sources. Other sources include non-combustion and building. Curtailment CO₂ emission is deemed effective approach to dealing with the climate change problem, and this depends much on sustainable energy policy.

Ghana's first nuclear power plant to be installed by the year 2029 with a starting generating capacity of 1000 MW. By the year 2047, generation and installed capacities for nuclear power would have reached 35% and 26%, respectively – being the highest energy generation in the country. Carbon dioxide emission without nuclear power in Ghana will cumulatively increase by 35% based on the current emission rate by the year 2039. However, with nuclear power in operation, CO₂ emission cuts by 12.5% by the year 2039.

Declarations

Conflict of Interest

There are no conflicts of interest to declare

Data availability statement

The manuscript has no associated data to provide. However, additional information have been provided as supplementary material.

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Figures

Figure 1

Main site of Ghana Atomic Energy Commission. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Summary of methodology

Figure 3

Outlook of GHG emission in Ghana

Figure 4

Ghana's projected CO2 emission with and without nuclear power

Figure 5

Nuclear power projection

Ghana's electric power generation in the next 30 years: nuclear vs. other major sources

Figure 6

Projection of nuclear power against other major sources in Ghana

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