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Review Article

The Role of Nuclear Energy in Reducing Greenhouse Gas (GHG) Emissions and Energy Security: A Systematic Review

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The energy sector accounts for about two-thirds of all human-related greenhouse gas (GHG) emissions due to the reliance on fossil-based fuels. This is a significant concern as it can have dire consequences on the survival of humankind and disrupt other natural processes. The research indicated that some mitigation measures to curb GHG emissions are to increase energy from low-carbon sources such as nuclear. However, due to the continuous adverse climate change impact, a comprehensive systematic review of research in this area must be conducted to inform policy practice and future studies. This study attempts to address this gap by mapping the global reflections on the potential of nuclear technology to mitigate GHG through a bibliometric review process. A total of 741 studies were retrieved from the Scopus database and a few from Google Scholar, spanning from 1962 to 2022, and analyzed using a science mapping tool—VOSviewer. The study confirmed that fossil fuels are a significant source of greenhouse gas emissions and contributor to greenhouse emissions. Those authors concluded that promoting clean and alternative energy sources to fossil fuels would help reduce carbon emissions. Although renewable energy has proven to be very efficient among pollution and climate change mitigation sources, nuclear energy is the most dependable option for meeting national and regional CO_2 emission targets while meeting energy supply needs. The bibliometric analysis with VOSviewer suggested that only five African countries, including Ghana, have contributed to the research area with limited collaboration. As a result, it calls for stakeholders to make informed decisions to invest resources in research to address the challenge on the continent. The MESSAGE planning model is recommended for the study.

1. Introduction

Energy security and sustainability of the environment remain a concern to socioeconomic growth and the rapidly accelerating climate change in the world [1–5]. Energy security is one of the significant factors to ensure a country's long-term growth. Global demand for primary energy has doubled in the previous 40 years, increasing at 2%-3% each year [6]. Energy consumption is expanding faster than ever, particularly in developing countries, making energy security an essential component of national security. Energy security is also a significant component and source of interdependence in

international relations [7, 8]. Energy security entails constant access to various energy resources in adequate quantities and at affordable costs, considering environmental and societal factors [9, 10].

Energy security guarantees uninterrupted availability of energy resource supply in a sustainable and timely manner, with energy prices at a level that does not adversely affect the economic performance of the economy [11, 12]. The classical approach to evaluating key energy resource parameters concerning energy security are availability, accessibility, cost, and acceptability [13]. Energy resource availability and affordability are more important in terms of impact on other aspects of energy security [14]. The primary energy security elements typically included in the definition of the term are resource nationalism, diversification of energy sources in the energy mix, and secure supplies of affordable energy resources [15, 16]. Also, other elements considered in the energy security definition are safe transportation (transit) of energy and fuel, as well as the corresponding infrastructure, prospective geopolitical and market changes, and threats that are caused by or have an impact on the energy supply chain [16].

There are about ten main challenges hindering energy security globally. These are decarbonizing the global economy, improving energy efficiency and energy savings in buildings, advancing energy technologies, transitioning to energy systems based on variable renewables, electrifying transportation and some industrial processes, liberalizing and extending energy markets, integrating energy sectors into smart energy systems, making cities and communities smart, and diversifying energy sources [17]. Other security risks are terrorism and fraud in nuclear waste management and generating nuclear power [18].

The focus on ensuring energy security has increased energy generation, consequently increasing CO_2 emissions. Energy-related CO_2 emissions reached a record high of 36.6 billion tonnes in 2021 [19, 20]. An increase in energy demand is unavoidable as the world population grows, economies develop, and people's quality of life improves [6].

Human emissions of carbon dioxide and other greenhouse gases are the leading cause of climate change and one of the most significant challenges confronting the world. This correlation between global temperatures and greenhouse gas concentrations, mainly CO_2, has existed throughout Earth's history [21–23]. The energy industry must drastically reduce greenhouse gas (GHG) emissions to limit climate change. This will necessitate a significant energy sector restructuring, with a transition from fossil to carbon-free energies. Electrification will be a critical enabler of the sustainable energy revolution [6].

Sustainable development of the electricity industry is both a prerequisite and a result of economic progress. It is based on the appropriate management of all risks caused by the uncertainty of the external environment, which is impractical to achieve without ensuring long-term operation [11]. Electricity generation has been a major contributor to global greenhouse gas emissions in the energy sector as its demand is fast rising [24]. The overreliance on rich carbon sources for energy use applications adversely impacts climate change, which is increasing rapidly with only a minimal chance of avoiding the worst environmental and socioeconomic impacts [1]. Concerns about the impact of GHG emissions from electricity generation on climate change have prompted countries worldwide to search for low-carbon energy sources and limit their dependency on conventional fossil fuels [25].

The detrimental effects of climate change have been expressed in international strategic documents such as the Kyoto Protocol and the current Paris Agreement, which most world leaders have adopted as expressions of commitment to a global drive to reduce CO_2 emissions [26, 27]. The Paris Accord prompted the EU to reconsider its aims of decarbonization and energy transformation since energy issues are inextricably related to the climate agenda [26, 28]. The evidence for relating the energy and climate agendas is based on several studies and extensive research by Intergovernmental Panel on Climate Change (IPCC) climatologists. The IPCC cautioned that if CO_2 emission risk does not peak in 2025 and significantly decreases in the next decade, attaining a temperature rise of 1.5°C (compared to preindustrial levels) will be put at risk by the end of the millennium. If no mitigation measures are adopted, the effects of global warming will be exacerbated, some of which will be permanent [21, 22, 26, 29].

The global average surface temperature has risen by around 1.1°C during the preindustrial period of 1850-1900, increasing the frequency and intensity of climate change worldwide [1]. To prevent global temperature rise, the supply of electricity from clean energy sources must double in the next eight years; otherwise, there is a risk that climate change, more extreme weather, and water stress may weaken our energy security and even jeopardize renewable energy supply [30].

Rapid global awareness of the effect of climate change has compelled nations to implement a variety of CO_2 reduction policies and set goals to reduce emissions both locally and globally while optimizing power generation sources [31–35]. To address the challenges of energy security and climate change, the world must transition away from fossil fuels, which requires global CO_2 emissions to peak by 2025 and reach net zero by 2050. If the world is to thrive in the twenty-first century, switching to nuclear and renewable energy sources like solar, wind, and hydropower is essential. With the accelerated rate of climate change and the aim to achieve net zero by 2050, the electricity supply from low-emission sources must be doubled within the next eight years [30].

Unfortunately, the present rate of CO_2 emissions is still incompatible with the Paris Agreement's aims [36]. The empirical studies on 39 European countries from 1980 to 2019 demonstrate that increasing the share of renewable, nuclear, and other nonhydrocarbon energy and promoting energy efficiency could significantly reduce GHG emissions [1]. Furthermore, a study on energy structure and energy security under climate mitigation scenarios in China indicates that the country needs to switch its energy mix from being dominated by fossil fuels to renewable and nuclear sources to reduce greenhouse gas emissions. These structural

changes will increase energy security by increasing energy self-sufficiency. Ultimately, developing low-carbon energy infrastructure improves energy security, enhances the economy, and inadvertently mitigates climate change [37]. The growing concerns about the accelerated rate of climate change and constrained global power supplies have made some policymakers consider nuclear energy, an industry that has struggled for years to attract investment due to concerns about radioactive waste, safety, and the high cost of installing a reactor [38]. To reach carbon neutrality and limit global warming to 1.5°C while addressing energy security risks and sustainability concerns, power sector investment must be increased and directed towards cleaner, more sustainable technologies that promote climate change mitigation and adaptation, especially nuclear energy [39, 40].

Decarbonization of electricity generation has garnered much attention, with nuclear considered an important option to provide a steady electricity supply while curbing greenhouse gas emissions and mitigating climate change [41–43].

Nuclear power is one of the energy sources and technologies currently available to assist in meeting this desire for expansion in a climate-friendly manner. Nuclear power produces only a few grammes of GHGs over its life cycle: a median value of 14.9 g CO_2-eq/kWh was obtained based on more than 200 unique estimates (for light water reactors) reported in the literature. The majority of nuclear-related GHG emissions come from the building phase's cement production, material production, and component manufacture, although emissions are also influenced by the carbon intensity of electricity supply and enrichment technologies in the uranium enrichment phase [44, 45].

The International Energy Agency predicted that by 2050, nuclear power will account for 15% of all annual greenhouse gas reductions. It estimates nuclear power's CO_2 emission coefficient across its life cycle to be 12 tCO_2/GWh, a 40-fold reduction from liquefied natural gas's emission coefficient of 490 tCO_2/GWh, and a 68-fold reduction from coal's emission coefficient of 820 tCO_2/GWh [46]. The International Atomic Energy Agency (IAEA) highlights nuclear power's importance in promoting sustainable development and reducing CO_2 emissions in underdeveloped countries [47]. IAEA expands on nuclear power's contribution to CO_2 reduction by demonstrating that from 1970 to 2013, hydropower prevented 87 $GtCO_2$, nuclear power avoided 66 $GtCO_2$, and other renewables avoided 10 $GtCO_2$ [44, 48].

The World Nuclear Association has asserted that despite the ill fame of the Chernobyl and Fukushima disaster, nuclear power has generated reliable, economical, and carbon-free electricity in the last 60 years [49]. Kim et al.'s research on public risks and environmental hazards of nuclear reactors in Korea concluded that nuclear power plants play a significant role in maintaining a healthy environment, improving air quality, and mitigating climate change aside from their capacity to serve as the baseload for electricity generation [50]. Based on historical data from Sweden and France, it is asserted that replacing fossil fuel electricity with nuclear within four decades is technically viable to achieve the high greenhouse gas reduction targets. At the United Nations Climate Change Conference (COP27) in 2022, nuclear energy was acknowledged to substantially impact climate mitigation by keeping global warming to 1.5°C and reducing temperatures below 2°C [39, 40]. As part of a bigger goal to decarbonize the economy, the United States (US) has already set aside billions of dollars to keep current nuclear power facilities operational and plans to promote new initiatives. Although Russia's invasion of Ukraine's nuclear power plant at Zaporizhzhia has heightened concerns about nuclear safety, according to Rafael Grossi, President of the IAEA, security concerns in Ukraine should not deter countries from constructing nuclear power plants [38].

According to the UN Environment Programme (UNEP), unless immediate and systemic transformation occurs, there are presently no reliable ways to limit global temperature to about 1.5°C and slow global warming, hence a call for serious inclusion of nuclear energy in electricity generation globally. Numerous studies have indicated that global nuclear energy development exhibited nonlinear fluctuating growth, especially after Japan's Fukushima nuclear power plant accident. However, in recent years, as the international situation has changed towards clean, sustainable energy and the call to curb climate change impact, nuclear power may once again become a new energy generation technology heavily encouraged by governments. For instance, in line with the global concern towards energy security and ways to curb greenhouse gas emissions, in February 2022, the European Parliament enacted a new green energy investment programme that includes nuclear power in the green power category, designating qualified nuclear power investments as "green investments" [51]. Also, the US has rejoined the Paris Agreement, bolstering international alliances that are critical to addressing the climate catastrophe on a global scale. The US has set an ambitious domestic goal of reducing greenhouse gas emissions by 50 to 52% from 2005 levels by 2030, pushing governments worldwide to make their firm commitments with nuclear power as one of the primary energy sources to explore [52]. This suggests that the global development of nuclear power will enter a new period of growth.

In the past decade, Ghana has made significant progress in increasing the electricity generation access rate to 84% [53]. However, its environmental performance still needs to be determined. The electricity expansion policy and energy security concerns have shifted from hydro to thermal. In 2021, thermal power accounted for about 65.3% of the country's energy generation, while hydropower contributed 34.1% and other renewable energy made up the percentage [53]. In the quest to reform the country's energy sector to meet its power demand while reducing carbon dioxide emissions, Ghana has taken the initiative to develop its first nuclear power programme to be included in the generation of electricity and to serve a clean baseload energy source to support the nation's industrialization strategy [53–56]. According to the [39, 40] report, Ghana has identified nuclear power as critical to the country's energy transformation plan. It has included it in its electricity generation mix as well as the 2020 National Determined Contribution (NDC) to the UN framework on climate

change [39, 40]. Although insightful and qualitative, the earlier review studies had certain drawbacks. Most review studies have had narrow perspectives, focusing only on country-specific. Furthermore, the review publications have concentrated on countries with nuclear energy, leaving out nuclear-developing countries. Several studies on nuclear activities have been conducted over the last six decades. In the previous six decades, several research has been done on nuclear activities in Ghana [57]; however, since this is Ghana's first nuclear energy power programme, only a few studies on emissions from energy generation and its impact on climate change have been conducted [58].

In an attempt to address the limitations of the previous review studies, this study provides a comprehensive systematic review and bibliometric analysis from the Scopus database and a few from Google Scholar to explore the opportunity offered by nuclear energy technology on energy security and GHG emission reduction for emerging countries on the field of the research work [59, 60].

This study intends to map knowledge on nuclear energy to guide developing countries in energy analysis, planning, management, and policy development towards energy security and decarbonization. The research reduces the knowledge gap between potential emerging nuclear energy countries and countries with nuclear energy. The study adds value to the literature on nuclear energy generation and greenhouse gas emission reduction renaissance by understanding the trends and patterns, identifying main research interests, and links amongst countries, authors, and researchers. To gain a broad understanding of the scope of the work done on nuclear energy for mitigating climate change, the study intends to map the current knowledge on the contribution of nuclear energy in repower greenhouse gas (GHG) emissions from a comprehensive database.

The following objectives guide this research: (1) to identify existing literature on the contribution of nuclear energy in the decarbonization of emissions from the electricity generation sector, (2) to synthesize research knowledge on the contribution of nuclear energy development in the decarbonization of the electricity sector to guide future studies, (3) to evaluate the contribution of researchers to the study, and (4) to identify current research collaborations on the subject among countries the topic under study.

2. Materials and Methods

Considering existing literature and identifying the gap in knowledge that empirical study addresses, various methods such as scoping review, rapid review, narrative review, meta-analysis and mixed studies could be used for the literature review [61]. In this research, a systematic scoping literature review and bibliometric analysis were undertaken by choosing articles indexed by the Scopus database and Google Scholar because of the advantages it offers over the other review methods [62, 63]. Considering a large number of articles, the advanced Boolean search defined the field of interest. This enabled tracking how the research has evolved and altered over the years [64]. The systematic scoping literature review was used to evaluate the potential contribution of nuclear energy in reducing greenhouse gas (GHG) emissions because it can reduce bias in the selection of literature for the review and allow transparency in the approach. The search strategy improves the review's replicability. It is frequently more helpful than the results of a single study as its opportunity allows researchers to know what is already known and what is still unknown about a subject [65]. The approach varies and is typically particular to the type of study, including investigations of effectiveness, qualitative research, economic evaluation, and the prevalence of an activity. The procedure is thorough enough to ensure consistency in research findings and is generalizable across contexts and groups [66].

Unlike the systematic scoping review, rapid reviews are less comprehensive and more prone to bias than systematic and scoping reviews [63]. Also, the advantage of systematic reviews over narrative reviews is that they are based on the results of comprehensive and systematic literature searches in all available resources, with minimal selection bias and no subjective selection bias. In contrast, if written by experts in a specific research area, narrative reviews can provide experts with intuitive, experiential, and explicit perspectives on particular topics [67]. Also, while with systematic review data extraction and synthesis guidelines are based on PRISMA, in narrative review, the overall description of each study focuses mainly on studies that the authors select [68].

Furthermore, the advantage of systematic reviews over narrative reviews is that they are based on the results of comprehensive and systematic literature searches in all available resources, with minimal selection bias and no subjective selection bias. In contrast, if written by experts in a specific research area, narrative reviews can provide experts with intuitive, experiential, and explicit perspectives on particular topics [67]. Also, while with systematic review data extraction and synthesis guidelines are based on PRISMA, in narrative review, the overall description of each study focuses mainly on studies that the authors select [68].

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) was utilized to accomplish study objectives 1 and 2. PRISMA-ScR is a method for synthesizing information that uses a step-by-step process to identify ideas, resources, and knowledge gaps while providing evidence on a research issue [62, 63, 69]. A random sample of review articles published from 1962 to 2022 was used for the analysis; however, conference proceedings were not included. The search was limited to peer-reviewed journal papers written in English. The articles considered had quality content with a nexus among energy, GHG emissions, nuclear power, and climate change.

2.1. Identifying Electronic Databases and Eligibility Criteria. Although the database of these publishers has a strict document indexing process, bibliometric information is easy to retrieve and analyze. Moreover, these databases possess quality, resilience, and a sizable amount of data that can also be found in other databases [70, 71]. For further processing in Microsoft Office Excel, the search results were exported as comma-separated values (.csv) files for analysis. Table 1 provides a summary of the inclusion and exclusion criteria.

Table 1: Document qualification criteria.

Participation necessities
Articles published in English
Selected period 1962 to 2022
The research focused on electricity, nuclear energy, greenhouse gas emissions, and mitigation
Types of documents are articles, conference papers, reviews, and book chapters
Studies focused on the contribution of nuclear energy in reducing GHG emissions from electricity generation
Exemption criteria
Studies that do not relate to nuclear energy development and GHG emissions
Articles without access to the full text
Articles without clear linkage to electricity, greenhouse emissions, and nuclear energy
Duplicate entry
Articles with missing bibliometric data

2.2. Article Screening and Selection. For the preliminary search, the article title, abstract, and keywords in the field of study were used within the advanced search tool of the Scopus database website (http://www.scopus.com/). An exhaustive list of iterative constructed key phrases and words such as electricity, energy, greenhouse gas, emissions, nuclear energy, mitigation, and reduce was coupled employing Boolean logic. The Scopus database was searched using simple and advanced Boolean logic concepts. It was then filtered to obtain as many articles as possible relevant to the research objectives [72]. The search result was filtered according to publication year, subject area, document type, and source type and restricted to English language peer-reviewed journals and articles.

The strings and keywords used for the simple Boolean query and advanced Boolean query search in the Scopus database initially unveiled 1486 articles. The percentage of articles in each category of the search subject area summarized in Figure 1 provides further information on the interest and volume of research contributions to electricity generation sources and their GHG emission. The extracted data were classified into subtitle categories using the document title and abstract to help understand the study trend. The categorization reveals that most publications were in energy, engineering, and environment, with a combined percentage of 73.5%. After limiting the search to energy, engineering, environmental science, and journals in English only, the remaining articles were 741.

2.3. Bibliometric Analysis. For objectives 3 and 4, a bibliometric analysis was utilized to analyze knowledge domains, collaborations, and prospective future research trends. Some tools used for bibliometric analysis include CiteSpace, Sci2, RStudio, BibExcel, and Netdraw. However, the VOSviewer software tool, which is used to assess and illustrate the contributions of scientists to research, was employed to conduct the bibliometric mapping or network analysis [69, 73]. Compared to other bibliometric analyses, the VOSviewer gives special consideration to the graphical portrayal of bibliometric maps, compared to most computer programmes used for bibliometric mapping [74]. The software makes it possible to create, view, and evaluate bibliometric networks for research writers, journals, organizations, and individual publications and generate network diagrams of related keywords gleaned from research paper abstracts and main text. These networks can be viewed using VOSviewer at rates and scales achievable only with manual techniques or antiquated software tools. These mappings are built through citation, bibliographic coupling, cocitation, or coauthorship relationships of journals, researchers, and articles [75]. For the study, the scoping review framework initially developed by Arksey and O'Malley was adopted [76].

3. Results and Discussions

The study's results are presented in this section, and conclusions are drawn to enhance knowledge of the topic using scoping and bibliometric techniques. Also, a systematic review was undertaken to analyze various research findings based on the scoping review data of the study area.

3.1. Scoping Review. The titles and abstracts of the retrieved articles were reviewed, and the area of research was limited to energy, engineering, and environment to ascertain their eligibility before reviewing the published articles' complete content. The search articles were then reduced to 741. The full text of every article that might have qualified was later reviewed, as shown in Figure 2, to determine whether they should be included. In sorting out the required pieces from the bibliometric data, 386 papers were initially excluded. Although the articles were on energy applications and related emissions, they were unrelated to electricity generation. In all, seventy-five articles met the requirement listed in the full-text screening criterion. However, only 19 publications out of the 75 qualified articles were assessed since they had full-text screening.

3.1.1. Data Charting. The following stage of the study involved "charting" relevant data that matched the eligibility criteria [76]. The charting format includes author(s), the article's title, publication year, first author's nation, study objective(s), methodology, and results/findings. Using Microsoft Excel, the data was charted and extrapolated into a data charting format to form the basis for the analysis. The articles studied are summarized in Table 2.

3.2. Systematic Literature Review. The fast industrialization and economic expansion of most nations are contributing to increased environmental issues. Economic growth necessitates a greater need for energy primarily from fossil fuels, which impacts greenhouse gas (GHG) emissions [80]—a recent study claimed that emissions depend on the kind of energy sources used and concluded that using renewable energy reduced emissions while using nonrenewable energy for electricity generation increased emissions. Although past studies on the effects of low-carbon energy on environmental quality have been conflicting, the use of fossil fuel production of electricity has been proven to have a detrimental effect on the environment [78, 94, 95]. With the tremendous increase in

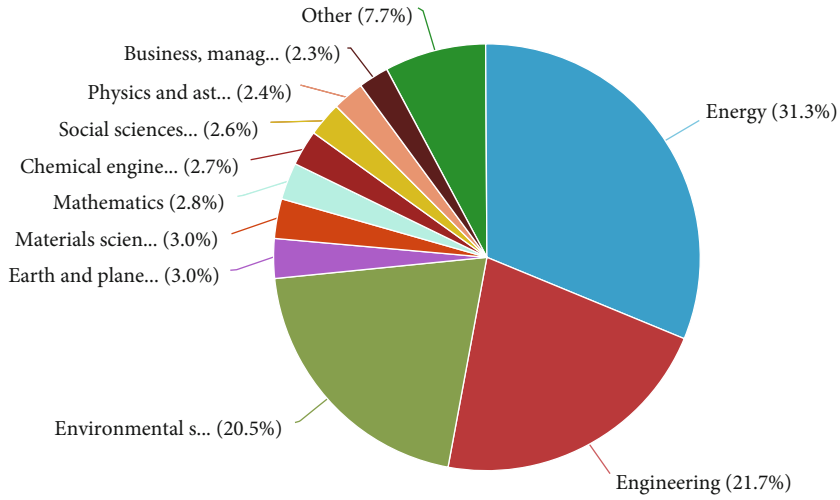

Figure 1: Pie chart on categories of research subject area.

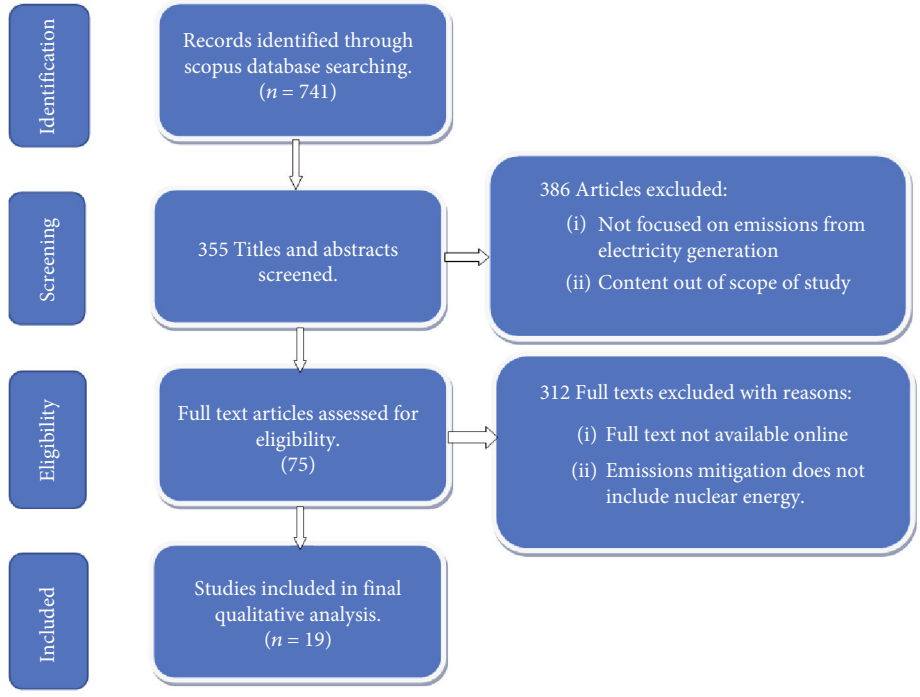

Figure 2: PRISMA-ScR flowchart diagram.

global warming and climate change, economies are shifting to ecofriendly energy alternatives and technologies, which help to mitigate environmental pollution [80].

When evaluating carbon emissions and environmental harm, both the energy generation mix and the carbon intensity of electricity production must be considered [96, 97]. The decision on the choice of energy supply source vis-a-vis their greenhouse gas emissions and decarbonization mitigation impact is crucial for energy planning. Table 2 summarizes the aims and conclusions of the published journals examined in the study. It also depicts some of the models employed in energy planning and informs of scenarios developed in evaluating the impact of nuclear energy as a mitigation source of greenhouse gas emission reduction. Although the researchers used different methods and models in their studies, each research had distinct parameters of interest to analyze, spanning the various energy sources such as fossil fuel, renewables, and nuclear, their greenhouse gas emission level, and their mitigation impact on climate. Various countries and researchers have used models such as LEAP, MESSAGE, MARKAL, EnergyPLAN, MAED, LCA, MoMANI-OSeMOSYS, SIMPACTS, and WASP for energy planning to meet demand while considering greenhouse gas reduction.

3.2.1. Energy Generation and Their GHG Emissions. The energy industry has been one of the primary sources of greenhouse gas (GHG) emissions mainly due to overreliance on fossil fuels [5, 89, 98]. The energy industry causes three-

Table 2: Summarized results of scoping review adapting Arksey and O'Malley's framework.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
1	Jaskólski and Bucko [77]	Modelling Long-Term Transition from Coal-Reliant to Low-Emission Power Grid and District Heating Systems in Poland	Poland	Develop optimization paths of the energy sector to curb the environmental impact of coal-fired power plants in Poland to accomplish long-term strategic goals while reducing the detrimental effect on the consumers' household budget.	The market allocation (MARKAL) modelling framework was used to build and implement energy systems for producing electricity and heat generation network structures. Two scenarios were presented: business as usual (BAU) and withdrawal from coal (WFC).	The modelling indicated the vital role of offshore wind power and nuclear energy in reducing the impact of GHG emissions from electricity generation in Poland. The BAU scenario modelling recommends keeping the coal technologies while adopting carbon capture and storage systems. The WFC scenario recommended the replacement of coal plants with gas-fired power plants to minimize CO_2 emissions.	1
2	Horobet et al. [78]	The role of distinct electricity sources on pollution abatement: Evidence from a comprehensive global panel	Romania	Analyze the impact of nuclear, renewable (hydro, wind, solar, and biofuel), and fossil (oil, coal, and gas) energy sources on pollution using the global average of greenhouse gases (GHGs) from electricity generation in 163 nations.	Two methods were used: the empirical investigation method and the generalized method of moments (GMM). Across a global panel of 163 nations, an empirical study examined alternative energy sources' impact on greenhouse gas emissions from 2000 to 2020. The GMM model was used to evaluate the effects of various energy sources of carbon emission intensity from electricity production.	The GMM estimators substantiate that fossil fuels are significant sources of pollution and a factor in carbon intensity. Furthermore, the use of nuclear and renewable energy reduces pollution on a global scale. Wind energy sources emerged as the most efficient among all energy sources for pollution and climate change mitigation. Furthermore, the study indicated that biofuels increase carbon intensity (CI); however, global carbon trade reduces the CI of electricity production. The findings concluded that the energy forming the energy mix is crucial when reducing GHG carbon intensity.	0

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
3	Naimoğlu [79]	The impact of nuclear energy use, energy prices and energy imports on CO_2 emissions: Evidence from energy importer emerging economies which use nuclear energy	Turkey	The study's objective was to determine how nuclear energy, energy imports, and energy pricing affected CO_2 emissions in 10 developing countries with nuclear energy. Also, the study uses GDP to evaluate the liability of the environmental Kuznets curve (EKC) hypothesis using GDP.	The autoregressive distributed lag (ARDL) approach was employed for the analysis, based on a panel dataset for ten rising economies from 1990 to 2019. The appropriate intermediate estimators PMG, MG, and DFE were applied to achieve the objectives. The robustness of the ARDL results was evaluated using the DOLS and FMOLS estimators.	The study showed that the EKC hypothesis is valid for these countries. Also, from the results, energy prices and nuclear energy generation minimize CO_2 emissions, while emissions increase with rising energy imports. When expressed as a coefficient, a 1% increase in energy costs and the usage of nuclear power results in CO_2 emission reductions of 0.02% and 0.04%, respectively. However, a 1% increase in energy imports causes a 0.09% increase in CO_2 emissions.	1
4	Usman et al. [80]	Do Nuclear Energy, Renewable Energy, and Environmental-Related Technologies Asymmetrically Reduce Ecological Footprint? Evidence from Pakistan	China	The study's objective was to examine the nonlinear relationship between Pakistan's environmental technologies (ERT), renewable and nuclear energies, and environmental pollution from 1990 to 2020, considering the rise in global warming and climate change. To meet this objective, the current study closely examines the asymmetric impacts of nuclear energy, renewable energy, and ERT on Pakistan's ecological footprint.	The nonlinear autoregressive distributive lag (NARDL) approach was used in the current study to assess the asymmetric impacts of nuclear energy, ERT, and renewable energy on Pakistan's environment from 1991 to 2020. To verify the integrated (unit root) order of the various technologies, the augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) model's unit root tests were done.	The NARDL results demonstrated that low adoption of nuclear power, renewable energy, and environmental technology has a more significant long-term and short-term impact on ecological footprints than positive impacts. Except for renewable energy, which demonstrated a negligible short-term asymmetric connection with an ecological footprint, the Wald test revealed that all energy sources showed asymmetric links to the ecological footprint in both the long and short runs. To keep up with the ongoing industrialization trend, Pakistan should develop alternate and clean energy sources.	20

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
5	Nyasapoh et al. [56, 58]	Estimation of CO_2 Emissions of Fossil-Fueled Power Plants in Ghana: Message Analytical Model	Ghana	Due to Ghana's excessive dependence on fossil fuels, its aspirations to become a middle-income country have escalated the energy demand, which inevitably leads to increased GHG emissions. The country intends to develop and implement a long-term, low-carbon, sustainable energy supply strategy to meet the electricity demand.	The Model for Energy Supply Strategy and their General Environmental Effect (MESSAGE) analytical tool was used in this study to conduct a quantitative modelling and simulation of the power generation system and the environmental impacts of various fuel options.	Including low-carbon emission energy conversion technologies, such as nuclear and renewable energy, into the energy mix has proven to be the key to reducing carbon dioxide (CO_2) emissions in Ghana's energy sector.	1
6	Estanislau et al. [81]	Integrated analysis of the Brazilian nuclear energy system	Brazil	The goal of the Brazil National Energy Planning was to create medium- to long-term plans based on a thorough analysis of all available energy sources, restricting alternatives, and identifying trends that would help the energy sector grow while reducing greenhouse gas emissions.	The integration of a nuclear energy programme as a complementary option in Brazil's electricity generation mix from its inception in 1983 until 2050 was examined and evaluated using the MESSAGE modelling tool.	Following the decommissioning of Angra 1 and Angra 2, according to the low and reference scenarios, nuclear energy use will decline from 2019 to 2050. The high scenario demonstrates the possibility of developing new nuclear power plants in the country's energy mix within the same period. According to the report, Brazil has sufficient energy reserves to support the development of nuclear energy as a low-carbon technology, act as a baseload source to supplement renewable energies, and replace fossil fuel thermal plants.	0
7	Kim et al. [82]	Modelling long-term electricity generation planning to reduce carbon dioxide emissions in Nigeria	South Korea	With the production of power relying on fossil fuels to roughly 80%, the study is aimed at suggesting a different energy source mix to satisfy Nigeria's future electrical demand while lowering CO_2 emissions.	The Model for Energy Supply Strategy Alternatives and their General Environmental Effect (MESSAGE) was used to optimize future energy supply systems in Nigeria. The Simple Method to Assessing Electricity Generation's External Costs and Effects (SIMPACTS) code was used to assess the environmental effects and associated costs of damage caused by the various electricity production systems.	As a result of the MESSAGE, it was determined that nuclear power plants (NPPs) and fossil fuels are the best solutions for providing electricity in Nigeria in the future. However, according to the SIMPACTS code, NPP is the technology that is least damaging to the environment and is most ecologically benign. As a result, the NPP is a crucial choice for optimizing future electrical technology to satisfy domestic demand and lower CO_2 emissions.	3

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
	Zhao et al. [83]	Energy system transformations and carbon emission mitigation for China to achieve global 2°C climate target	China	In order to contribute to climate change mitigation, the objective was to accelerate China's energy structure transition to a low-carbon one and keep the preindustrial level to a maximum global mean temperature rise of 2°C, in fulfilment of the Paris Agreement.	In order to identify the energy demand, carbon emissions, and technology needed at the national and sectoral levels to stay under the 2°C climate target, the project employed a bottom-up national energy technology model C3IAM/NET, a linear optimization model.	Results indicated that China's carbon emission must reach its highest level in 2023 and decline to 3.56 $GtCO_2$ by the middle of the century. The projected limits for the remaining carbon budget are 234 $GtCO_2$. Throughout the planning period of 2020–2050, the power industry was the largest contributor, followed by the industrial, transportation and construction sectors, with a total decrease in emissions of 165.3 $GtCO_2$. The forecasts state that China's primary energy consumption must peak before 2040 and that nonfossil energy sources will comprise 76% of the country's energy structure by the year 2050, with nuclear and renewable sources producing 88.4% of the nation's power.	29
9	Abdel-Hameed et al. [84]	Optimization of electricity generation technologies to reduce carbon dioxide emissions in Egypt	Egypt	Almost 90% of Egypt's power is produced by conventional thermal facilities. In order to minimize greenhouse gas (GHG) emissions in the energy industry and limit the use of natural gas to produce power, the Egyptian government's Vision 2030 energy strategy calls for increasing renewable energy. Based on these three guiding principles, the project must choose future electricity supply options among various power plant technologies. The initiative compared the adverse effects of Egypt's nuclear, hydroelectric, and fossil fuel power facilities on the environment.	The study used two computer models: the simplified method for estimating the environmental impacts of power generation (SIMPACTS) and the model for energy supply strategy options and their general environmental consequences (MESSAGE). The energy supply systems were modelled using MESSAGE to find the best energy supply technology to satisfy future demands. SIMPACTS analyzed the damage costs and environmental effects of producing power.	The results demonstrated that gas and nuclear power plants are dependable long-term suppliers of electricity. While operating normally, nuclear power plants (NPPs) have less influence on the environment and incur lower expenses for external damage. According to the project's findings, NPPs are Egypt's best long-term solution for generating power to fulfil future demand.	3

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
10	Andani et al. [85]	Decarbonizing the electricity system in the Sumatra region using nuclear and renewable energy-based power generation	Indonesia	According to Indonesia's national energy strategy, new and renewable energy will make up 23% and 31% of the country's energy mix in 2025 and 2050, respectively. The goal is to ensure that the nation fulfils its obligation to take part in initiatives to mitigate global climate change within the time.	The PLN energy model was used to examine decarbonization and determine the long-term supply and demand for power. To create scenarios that considered population and gross regional domestic product (GRDP) development, the energy demand was forecast using an econometric technique based on historical data on power demand.	According to the study's findings, the Sumatra region of Indonesia has the potential to achieve 100% decarbonization by 2050 using nuclear power plants. The 21.3 GW hydropower plant can cut emissions by 79.2%, while the 7.4 GW geothermal power plant can also minimize emissions by 27.4% within the same period. However, the decarbonization of the energy grid in the Sumatra area depends on the combination of these three power generation facilities.	0
11	Bamshad and Safarzadeh [86]	Effects of the move towards Gen IV reactors in capacity expansion planning by total generation cost and environmental impact optimization	Iran	Considering the rising energy demand, the objective is to accelerate the construction of a cost-effective and low-emission new electricity generation power plant in Iran. This aims to introduce a combined cycle of a thermal and nuclear power plant in Iran's traditional thermal energy mix.	The WASP software was employed for the energy expansion planning in Iran to investigate the impact of the inclusion of Gen reactors on operating costs and emissions.	The review introduced a correlation between the long-term point of view on the future with the improvement of nuclear energy stations and the assortment of atomic reactors in Iran's energy blend. The outcomes demonstrated that the Gen IV reactors have the most innovation among different force plants to lessen the working expenses and emanations when presented in Iran's customary nuclear power blend. The findings showed that Gen IV reactors and combined cycle thermal power plants cut costs and emissions by 72% and 16%, respectively, compared to Gen II NPPs and traditional thermal power plants.	6

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
12	Hassan et al. [87]	Is nuclear energy a better alternative for mitigating CO_2 emissions in BRICS countries? An empirical analysis	China	Numerous studies have shown in recent times inconclusive results on the nuclear energy and carbon dioxide (CO_2) emission nexus. To better understand the nuclear energy pollution nexuses, this study examines how nuclear energy affects the decrease of pollution for the BRICS nations using data from 1993 to 2017.	Based on empirical estimation, this study utilized the advanced panel data techniques of continuously updated fully modified (CUP-FM) and continuously updated bias-corrected (CUP-BC). The BRICS' CO_2 emissions, income per capita, and energy consumption during the study period were considered when determining the impact of nuclear and renewable energy per capita GDP on CO_2 emissions.	The findings showed that (i) the cross-sectional dependence test demonstrated that the sample countries depend on one another, (ii) the LM bootstrap cointegration demonstrated that the variables under consideration are somehow connected, and (iii) according to the CUP-FM and CUP-BC estimation results, nuclear energy consumption reduces CO_2 emissions and significantly impacts climate change mitigation.	59
13	Debrah et al. [55]	Drivers for Nuclear Energy Inclusion in Ghana's Energy Mix	Ghana	Ghana intends to incorporate nuclear energy into its energy mix to achieve a cost-effective, dependable, and sustainable energy supply in a safe environment. The main factors that led to including nuclear energy in the energy mix are discussed.	The motivations behind including nuclear energy in the country's energy mix were identified through an empirical study and a systematic review of the relevant literature.	The fossil fuels used to power thermal power plants are depleting and may run out by early 2030, while undeveloped hydro supplies are equally limited and unreliable. Although renewable resources are numerous, they are unreliable, are intermittently available, and do not provide a baseload option. The research concludes that there is a need for an update of the country's policy framework and diversification of its energy mix to include nuclear energy and other low-carbon energy sources.	4
14	Sarjiya et al. [88]	Achieving New and Renewable Energy Target: A Case Study of Java-Bali Power System, Indonesia	Indonesia	To reduce its reliance on fossil fuels in the power sector, Indonesia plans to use new and renewable energy (N&RE) as an alternative energy source. According to the nation's National Energy Policy (NEP), N&RE should reach 23% in 2025 and 31% in 2050. By considering alternative approaches to achieve its goal in Indonesia's Java-Bali power system, a strategy for generation expansion planning (GEP) needs to be developed.	As a model for generation expansion planning (GEP), this study employed MoMANI-OSeMOSYS. The "business as usual," "renewable energy," and "new and renewable energy" scenarios were developed. Optimization results based on the least-cost objective function were analyzed to determine the appropriate energy mix.	The outcome demonstrates that implementing the N&RE objective increases generation costs while decreasing CO_2 emissions. Nuclear energy is required for Indonesia's National Energy Policy (NEP) to meet its new and renewable energy targets of 23% in 2025 and 31% in 2050.	4

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
15	Wang et al. [89]	A comparative life-cycle assessment of hydro-, nuclear and wind power: A China study	China	The energy sector has been identified as one of the major producers of greenhouse gas (GHG) emissions. China's top three clean energy technologies are hydropower, nuclear, and wind power. Environmental impact assessments of various technologies are evaluated based on their life cycle analysis to ascertain their overall significance to climate change.	In this project, the potential environmental effects of the three power generation technologies were assessed using the CML 2001 method developed by the Semipros LCA software. In the research, five kinds of emission impacts were evaluated. These were human toxicity potential (HTP), eutrophication potential (EP), photochemical ozone production potential (POCP), and global warming potential (GWP100).	The study finds that wind power technology has the most environmental effects compared to other renewable energy sources. The importance of nuclear power is second only to hydropower in importance. For instance, compared to nuclear power (12.4 ± 1.5 g CO_2-eq/kWh) and hydropower (3.5 ± 0.4 g CO_2-eq/kWh), wind power has a greater life cycle global warming potential (GWP) of 28.6 ± 3.2 g CO_2-eq/kWh of GWP100.	57
16	Siqueira et al. [90]	Current perspectives on nuclear energy as a global climate change mitigation option	Brazil	Fossil fuel accounts for about 66% of electricity generation globally and is a high source of GHG emissions. Nuclear energy is classified as one of the effective technologies for climate change mitigation. The study evaluated the amount of carbon dioxide (CO_2) emissions that might be avoided if coal plants were utilized for power generation and conducted a systematic review of the potential of nuclear energy development as a strategic choice to address climate change.	For the analysis, it was assumed that nuclear power facilities provide an equivalent quantity of electricity to a coal-fired power station. The equation used to determine the quantity of annual emissions of CO_2 ($m_{avoidCO2}$), which nuclear generation could avoid, was $m_{avoidCO2} = EFR_{coal} \times GE_{nuclear}$, where EFR_{coal} represents the emission factor rate to coal-fired power plants and $GE_{nuclear}$ is the annual nuclear energy generation.	The study indicated that global perception shows that low investment in nuclear energy results in the avoidance of equivalent CO_2 emission share in future as that of today. However, significant investment in nuclear power facilities might contribute more efficiently to non-CO_2 emissions.	16
17	Liya and Jianfeng [91]	Scenario analysis of CO_2 emission abatement effect based on LEAP	China	The study aims to develop different electricity generation mix options in line with the energy planning policy of China to optimize the energy mix aimed at improving the country's environment and economy between 2012 and 2050.	China's medium- and long-term energy planning from 2012 to 2050 was analyzed using the LEAP-China-Power model (bottom-up model), with 2012 serving as the base year. Developed scenarios of the electricity demand, energy structure, carbon dioxide emissions, and overall costs were simulated. A baseline scenario, a CCS scenario, and a nuclear and natural gas combined cycle (N&N) scenario were all created.	Using the LEAP-China-Power model in the research, the economic and environmental impacts of thermal power, renewable energy, and nuclear energy, technologies were assessed considering their life cycles. According to the findings, the carbon capture and storage CCS scenario is not as good an option as the nuclear and natural gas combined cycle (N&N) scenario.	8

Table 2: Continued.

S/N	Author(s)	Title	Country of the first author	Objectives	Methods	Key findings	Cite
18	AlFarra and Abu-Hijleh [92]	The potential role of nuclear energy in mitigating CO_2 emissions in the United Arab Emirates	UAE	The yearly CO_2 emissions in the UAE have increased tremendously since 1990 due to the use of fossil fuels for electricity generation. This research assesses the impact of the UAE's proposed inclusion of nuclear energy in their energy mix in reducing CO_2 emissions from the development stage up to the year 2050 in accordance with the Kyoto Protocol.	The electricity demand and greenhouse gas in the UAE up to 2050 were evaluated using the MESSAGE model. Some energy supply/fuel scenarios, including business as usual (BAU), the UAE's proposed nuclear strategy (APR1400), and the clean energy era (CEE) proposed scenarios, were developed and simulated.	Nuclear energy was realized to be the most reliable choice in curbing CO_2 emissions than carbon capture and renewable energy. Also, nuclear energy was more economically viable than electricity generation from fossil fuels in the UAE. Nuclear energy was shown to be cheaper to create power than fossil fuels, with a cost per kWh of only 3.2 cents compared to 8.15 cents for conventional fuels.	57
19	Liu et al. [93]	New power generation technology options under the greenhouse gas mitigation scenario in China	China	The power generation sector is a major contributor to GHG emissions in China. The country is aimed at adopting policies and strategies to minimize GHG emissions. More energy-efficient and less carbon emission energy technologies have been identified as having significant potential for GHG mitigation. The study's primary objective was to evaluate the development of various energy generation technologies and their impact on GHG emissions in China.	The study analyzed the development of new electricity-generating technologies and their impacts on GHG emission reduction in China using the energy technology model MESSAGE. The baseline and the mitigation scenarios were developed to study the new electricity generation technology options under various situations.	The study indicated that high-efficiency coal power plants, conventional renewable technologies, and nuclear power would contribute significantly to the reduction of GHG in the short term. However, renewable energy and carbon capture storage (CCS) will be increasingly significant in the medium and long term.	44

quarters of all anthropogenic greenhouse gas emissions worldwide. Since 1990, the energy supply, industrial, and transportation sectors have contributed the most to emission growth. In 2020, the energy supply sector emissions were estimated at 20 $GtCO_2e$, representing 37% of global emissions. This includes electricity and heat production, which contributed 14 $GtCO_2e$ in 2020 and accounted for 25% of the emissions [99]. Carbon dioxide (CO_2) emissions from the combustion of fossil fuels reach around 34 billion tonnes (Gt) per year worldwide. About 45% comes from coal, 35% from oil, and 20% from gas [100]. Although electricity accounts for only 20% of total energy use, it accounts for 40% of all energy-related emissions. Hence, achieving net zero emissions will require a fundamental overhaul [39, 40, 100].

Both fossil fuel and nonfossil fuel power systems produce greenhouse gas emissions during their life cycle, mainly due to the energy needed for their manufacture, construction, and operation, as well as upstream CH_4 emissions [101]. Approximately 60% of the electricity supply in the US is generated from fossil fuels, primarily natural gas and coal. Hence, electricity generates the country's second-largest share of GHG emissions [102]. Although electricity generation technologies produce GHG at some point in their life cycle electricity industry, it is the most readily decarbonized sector. Introducing nonfossil, low-carbon energy sources such as hydro, nuclear, wind, solar, and other renewables in the power generation mix provide the means to decarbonize the electricity industry [100].

To evaluate the climate change mitigation potential of power generation technology, comparing total (direct and indirect) GHG emissions per unit of electricity produced is critical. Due to higher direct combustion emissions, such as CH_4 from fossil fuel extraction and indirect land-use change emissions, coal, gas, bioenergy, and hydropower generate significantly more specific GHG emissions than nuclear, wind, and solar power [102].

As the global impact of climate change becomes more apparent, the message that greenhouse gas emissions must be reduced is unequivocal. Nonetheless, the Emissions Gap Report (EGR) 2022: The Closing Window - Climate Crisis Calls for Rapid Transformation of Societies shows that the world community is falling well short of the Paris goals, with no realistic pathway to 1.5°C in place. Only an immediate system-wide shift can avert climate devastation [99].

3.2.2. Impact of Greenhouse Gas Emissions on Climate Change. The world has been experiencing environmental degradation for decades as a result of an increase in greenhouse gas emissions (GHG) primarily from the fuel and technology used for power generation [58, 103] which has led to temperature rise [104] and changes in national and region climates [105]. Studies over the decades have shown that although all nations have high pollution levels, the more industrialized and densely populated nations produce most of the world's pollutants [106]. Despite the economic downturn in many sectors due to the coronavirus pandemic, global emissions in 2020 exceeded 34 billion tonnes and had recovered to levels that were nearly prepandemic by the end of 2022 [78]. However, greenhouse gas emissions from one country may contribute to pollution and global warming and negatively impact economic growth in other nations [107]. The study confirmed that fossil fuel is a major source of greenhouse gas emissions and a driver of carbon intensity [58, 78]. Most authors concluded that promoting clean and alternative energy sources as an alternative to fossil fuels reduces carbon emissions [80, 85, 89].

3.2.3. Nexus between Nuclear Energy Generation and the Environment. Among all the low-carbon energy sources, nuclear energy has been the most contentious; its deployment has sparked much debate in the literature. Numerous conflicting pieces of evidence have been documented on the impact of nuclear energy and environmental degradation [80]. For instance, some countries, including Germany and Italy, have shut down all nuclear power plants and now depend on renewable energy sources, asserting that the risks of nuclear power are uncontrollable. Hence, nuclear phase-out keeps their countries safer and avoids more nuclear waste. Meanwhile, nuclear power is experiencing a renaissance in China, Russia, and India to augment their energy supply since it is considered clean and safe [108].

Research previously done by Usman et al. [109], Sarkodie and Adams [110], and Mahmood et al. [111] has demonstrated the negative consequences of nuclear energy on environmental deterioration. Most research conducted on the GHG emission reduction practices of the BRICS nations between 1993 and 2017 indicated that despite being effective at reducing emissions, nuclear energy is suboptimal to renewable energy for promoting pollution reductions [112]. Also, some research has proven that nuclear energy has a negligible impact on the world's top five most polluted nations (i.e., the United States, China, India, South Korea, and Japan) despite the efforts to reduce environmental pollution considering the impact of renewable energy development [78, 112, 113]. Similar results were published by Iwata et al. [114] for 11 OECD nations, wherein only Finland, Japan, Korea, and Spain showed that nuclear power had a beneficial effect on carbon dioxide emissions [87]. Furthermore, some academics, politicians, media, and nongovernmental agencies emphasized the adverse effects of nuclear energy. These drawbacks include the threat posed by nuclear waste disposal to the environment and human health, operational risks such as the explosion that can have lethal consequences, or the huge investments and operational expenses to establish and operate nuclear reactors [115]. Saidi and Omri [116], Baek and Pride [117], and Ulucak and Erdogan [118] are some of the known studies that have discovered a negative association between nuclear energy and environmental deterioration.

However, recent research has produced findings demonstrating nuclear energy's efficiency in reducing emissions. Hence, nuclear energy is projected to replace conventional fossil fuel energy for electricity generation, which discharges much CO_2. Hassan et al. [119] investigated the impact of nuclear power and technical innovation on environmental pollutants. According to the ARDL analysis, nuclear power is a clean energy source, and technological progress can also assist in reducing environmental damage.

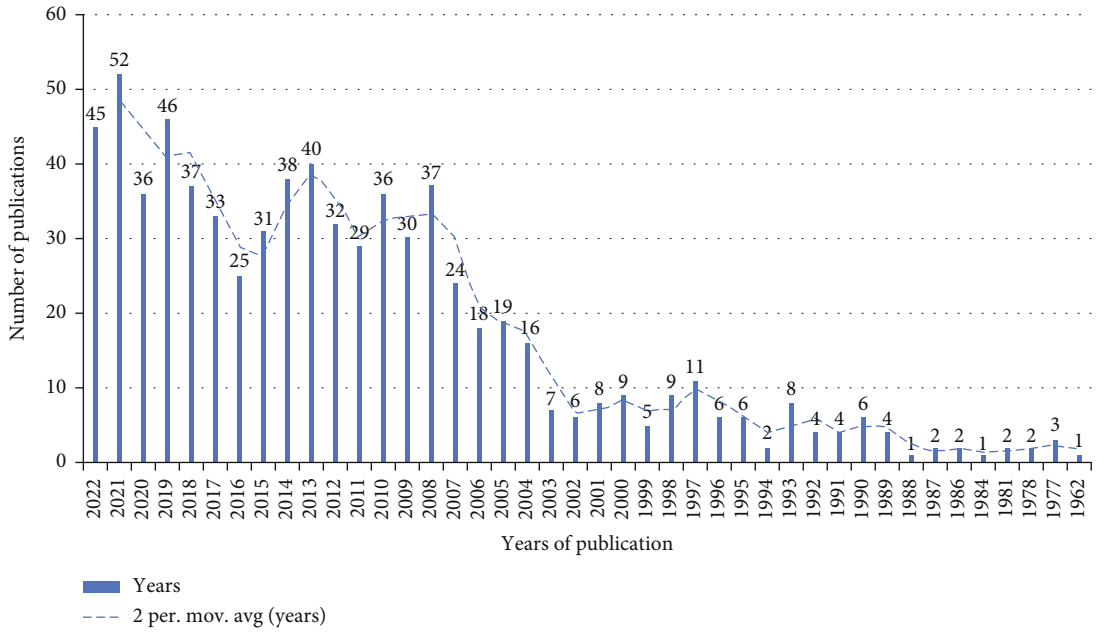

Figure 3: Yearly distribution of the publications reviewed.

According to the IAEA report, in comparison to other sources of energy, nuclear power produces one of the fewest amounts of greenhouse gases (GHGs) per unit of electricity produced [120]. Also, some empirical findings indicate that nuclear energy aids environmental sustainability [121]. Furthermore, empirical results also show that nuclear energy consumption improves air quality, recommending a quick adoption of nuclear energy in India's energy mix [122].

Most research articles asserted that nuclear energy is the most reliable option for achieving national and regional CO_2 emission mitigation targets while meeting the energy supply need [81, 82, 84, 88, 89]. Furthermore, along with the rapid increase of emerging industrialized countries, the global geography of the development of nuclear energy is undergoing a spatial reconfiguration phenomenon, as indicated by studies on research and collaboration among nations. However, in response to the call on climate change mitigation and energy challenges confronting the Middle East and Africa, some countries in these geographical regions are incorporating nuclear solutions into their energy and environmental planning strategies, evidenced by the number of requests for Integrated Nuclear Infrastructure Reviews from IAEA Member States (INIR) [39, 40].

Although wind energy has proven to be very efficient among sources for pollution and climate change mitigation [78, 88], comparatively, nuclear and other renewable energy sources have lower global pollution levels [84, 88–90, 92]. Studies conducted by Apergis et al. [123] on data from 19 industrialized and developing countries between 1984 and 2007 showed that using nuclear energy significantly minimizes CO_2 emissions [117]. Based on a panel cointegration analysis of 12 major nuclear generating nations to determine the impact of nuclear power, energy supply, and income on CO_2 emissions, it was concluded that nuclear energy reduces CO_2 emissions [124]. Other researchers have asserted that including nuclear power in the energy mix is essential for achieving GHG emissions and carbon intensity targets while ensuring adequate energy security [78, 81, 85]. According to a study on Egypt's energy mix, nuclear power plants (NPPs) have low external damage costs and minimal environmental impact during normal operation. This makes nuclear power plants one of the long-term electricity generation choices for the country to satisfy future electricity demands while contributing to combating climate change [84].

Although Ghana has some renewable resources, they are unreliable since their supply is sporadic and cannot be depended on as a baseload technology. Nuclear energy must be included in its energy mix diversification options to meet the country's long-term energy need and the nationally determined contribution (NDC) of greenhouse gas emission mitigation target. In view of this, Ghana has initiated developing a nuclear power plant to address future energy security and contribute towards reducing greenhouse gas emissions [55, 58].

3.3. The Trend of Publications and Citation. A graph of yearly publications on power generation and emissions is shown in Figure 3. The graph shows that there were no substantial publications on the subject between 1962 and 2003. However, the Scopus bibliometric analysis data gathered on the contribution of nuclear energy towards global decarbonization indicated that the published articles increased from sixteen to forty-five between 2004 and 2022, with the highest number of fifty-two publications in 2021. Overall, an annual average of thirty-three articles were published within the period.

3.4. Research Contributions and Collaborations among Countries. The coauthorship network of countries on emissions from electricity generation and the contribution of nuclear energy in GHG mitigation are depicted in Figure 4.

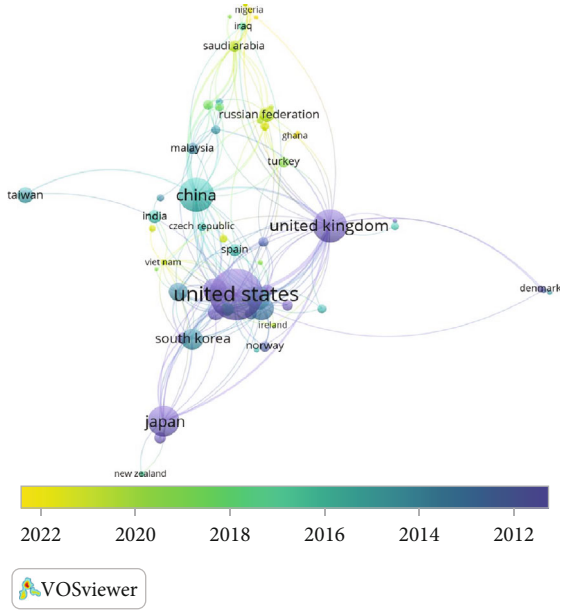

Figure 4: Network of coauthorship countries.

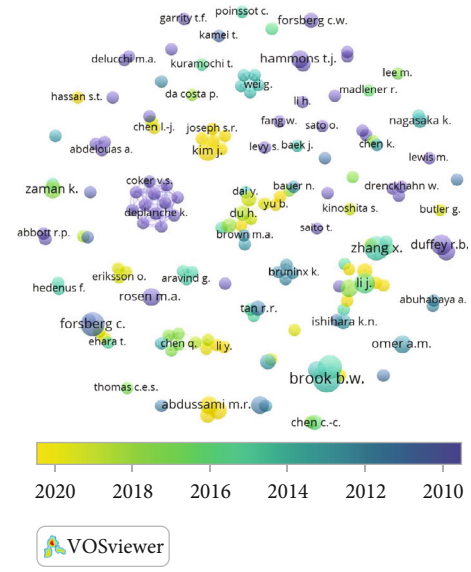

Figure 5: Network of prolific researchers in the study field.

The Scopus research data were exported to Excel CVS and analyzed using VOSviewer. In all, 741 cited published papers were subjected to a threshold of two in the VOSviewer analysis, with contributions from 88 different countries. Among all the nations, the United States was the most prolific contributor with a contribution of 179 documents, 3908 citations, and a total link strength of 73 with other countries. Other major contributing countries to the research are the United Kingdom, China, France, Canada, Germany, India, South Korea, Russia, and Taiwan. Few African countries, such as Egypt, South Africa, Tunisia, Nigeria, and Ghana, have contributed with limited collaboration to the research. The continent's contribution to knowledge on energy and emission management is limited.

The studies show that research on the impact of nuclear in reducing GHG emissions has generally concentrated on single or several nations, and the research methodologies are mostly life cycle evaluation and case studies. However, few researchers have investigated the global spatial distribution of nuclear power generation and the impact of the geographical distribution of nuclear on global GHG emissions.

3.5. Network of Coauthorship among Researchers. The Scopus data processed in VOSviewer indicates that Ghanaians authored three documents, made eighty-five citations, and collaborated with only the UK, Russia, and Turkey between 2020 and 2022. The VOSviewer analysis in Figure 5 shows that the most prolific publications were from 2010 to 2022. Among several researchers, B.W. Brook has made the most significant contribution with ten publications, 445 citations, and a link strength of 10 with seven international affiliates. S. Hoon has produced 7 documents, received 230 references, and had a link strength of 7 with the other 7 nations, as shown in Figure 6.

3.6. Cooccurrence of Author's Keyword Analysis. The researcher's most occurrence keywords in a published paper provide valuable information on the research area of interest. The author's keywords indicate their research interests and priorities in their chosen field [125]. The keyword analysis was essential to the study because it enhanced the article's search, increased its citation, and confirmed the dataset extracted concerning the objectives.

In this systematic review, the number of occurrences of a keyword considered by the VOSviewer network for this analysis was a minimum threshold of five times. In all, 1583 keywords were identified, of which forty-three met the threshold limit. A network of the cooccurrence keywords frequently used is illustrated in Figure 7. The cooccurrence network diagram generated has keywords such as nuclear power, nuclear energy, renewable energy, GHG, emissions, climate change, electricity generation, energy policy, carbon emission, carbon dioxide, and decarbonization. The quest to mitigate climate change has increased the interest of researchers through the cooccurrence of the keywords.

The high interest in using the technology for climate change mitigation has received a fair research effort from researchers by the cooccurrence of the keywords such as nuclear power, nuclear energy, greenhouse gas emissions, climate change, electricity generation, and carbon generation dioxide, found in its cluster. The benefits of the technology are included in the studies of scholars as suggested by keywords such as climate change mitigation and decarbonization. The cooccurrence network diagram inferences further support the authors' earlier categorization of documents. The network diagram indicates a gap in research and interest among countries which are yet to develop some nuclear plants.

3.7. Overview of Energy System Planning Tools and GHG Emission Models. Most recent global and national accords on energy and environmental nexus necessitate energy planning models (EPM) [126] in the sector's development at the regional, national, and international levels to influence

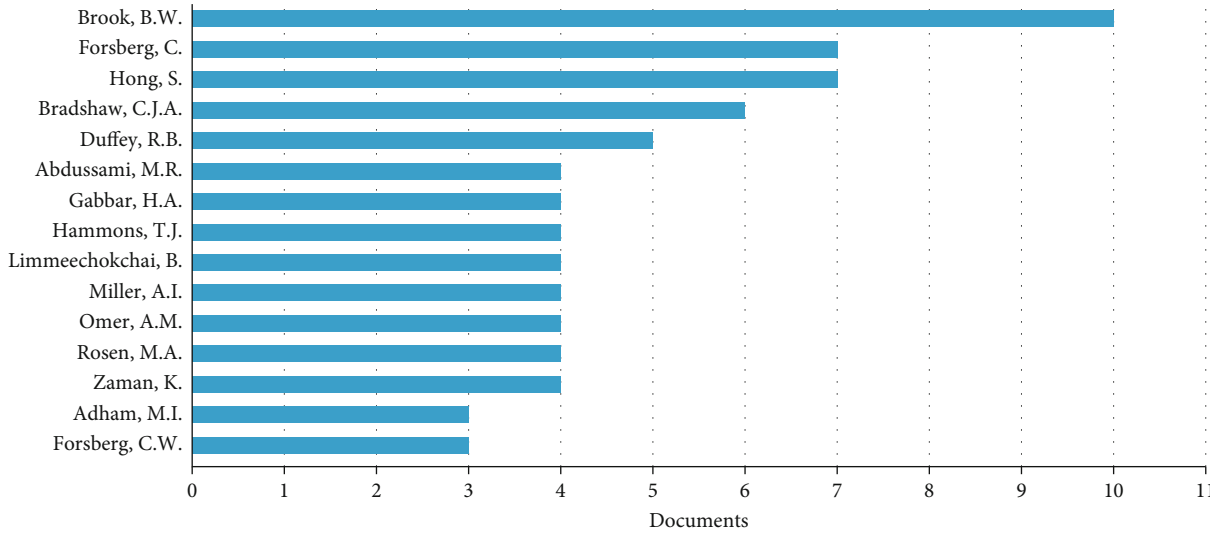

Figure 6: Comparison of the most prolific 15 authors in the study area.

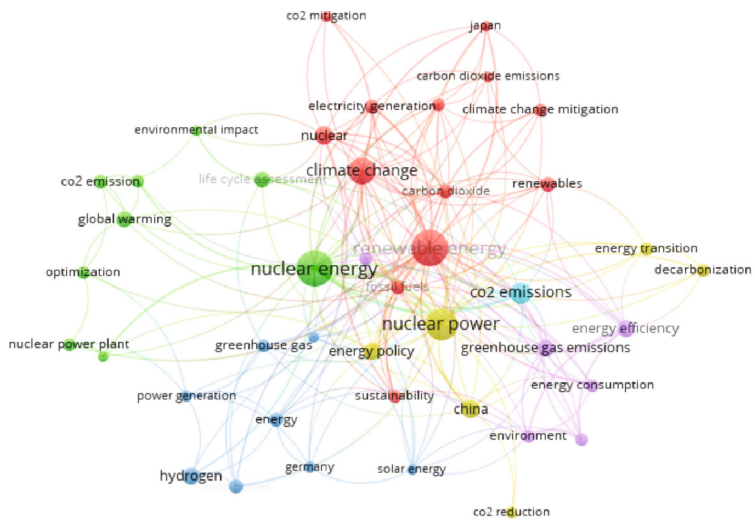

Figure 7: Network of cooccurrence keywords.

policymaking and implementation [127, 128]. Energy planning models are key to energy security and decarbonization of the sector [126], allowing multicriteria analyses of the effects of energy policies on the economy and environment. Scenario analysis is commonly employed in modelling tools to evaluate various assumptions about technology, environment, and economic variables. Among their likely deliverable outcomes are the system viability, natural resource utilization, total financial costs, greenhouse gas emissions, and energy efficiency of the system analyzed [129].

Effective long-term energy planning and the penetration of clean energy technologies towards decarbonization [130] necessitate incorporating advanced computational techniques and model software. Many available tools and model software for energy planning include LEAP, MESSAGE, MARKAL/TIMES, EnergyPLAN, RETScreen, NEM, and OSeMOSYS [131]. Incorporating multiple models into multipurpose energy modelling improves its functionality under centralized decision-making [132]. The multicriteria assessment (MCA) approach can deal with a wide variety of uncertainties and input data, as shown by energy assessment studies [126, 133, 134]. However, to evaluate the effectiveness of GHG mitigation objectives and other decarbonization policies such as sustainable development UNEP Balancing Energy and climate change policies, many countries have adopted models such as LEAP, MESSAGE, MARKAL, and AIM among others [135]. The applications and results of the modelling tools differ due to underlying constraints, gaps in the energy industry, and the model's categorization.

According to the research, there are numerous and varied ways to describe energy system models, but very few, if any, models fall into a single clear category. However, Hourcade et al. [136] determine three key differences among energy models, including the models' goals, structures, and external or input assumptions. In order to categorize energy

models, Grubb et al. [137] mentioned that there are six classifications of energy-economy models. These are "top-down" and "bottom-up," "time horizon," "optimization and simulation techniques," "level of aggregation," "sectorial coverage (energy and economy)," and, finally, "geographic coverage, trade, and leakage." Other researchers also categorized energy models into seven classifications, which are as follows: simulation, scenario, equilibrium, bottom-up, top-down, investment optimization, and operation optimization modelling tools [138–142]. Some other classification methods are based on mathematical techniques, the amount of data required, the models' complexity, and the models' flexibility [143]. Moreover, planning models can be classified into the following categories: energy planning models, forecasting models, energy supply-demand models, renewable energy models, optimization models, and emission reduction models [144]. Table 3 depicts the classification of the energy system models according to their analytical approach, type, mathematical approach, time horizon, coverage and spatial application, sector and scope, and interactive user features and accessibility.

Energy system models can be designed to have a broad spectrum of applications and scopes, such as international, regional, national, municipal, or stand-alone. Most countries develop or use a number of energy models for their energy planning and policy development [150]. For instance, modelling was used to analyze the long-, medium-, and short-term CO_2 emission reductions in the United Kingdom [128, 151], Asia, and South and North America and emerging economies like Africa [139, 144, 152, 153].

Energy models have gained significant attention in all countries; however, each country either develops its own or adapts one or more models, as depicted by Table 4, depending on factors such as energy sustainability, planning policy, or environmental treaties. In Colombia, the LEAP was used to forecast the country's energy need from 2030 to 2050, considering climatic change, technological advancement, and demand for clean energy [154]. The effect of power conservation and emission reduction on the transport sector in China was evaluated using the Long-range Energy Alternatives Planning (LEAP) tool [98, 155]. The electricity demand and supply forecasts, environmental impacts, and costs in Nigeria were determined using the LEAP modelling tool [157] and also for the energy planning in Kenya to analyze the electricity demand, potential atmospheric pollutants, technology stocks, and greenhouse gas (GHG) emissions from 2010 to 2040 under various scenarios [157]. As part of measures to mitigate against the impact of greenhouse gas (GHG) emissions from Iran's electricity generation sector, the LEAP software was employed to analyze the electricity demand, generation costs, and the volume of carbon dioxide emissions from its thermal power plants between 2011 and 2030 [98]. To develop an optimal energy generation plan from 2010 to 2040 for Ghana, the Open Source Energy Modelling System (OSeMOSYS) was integrated into LEAP to analyze the economic, technological, and environmental ramifications of the country's renewable energy policies [158]. Also, the OSeMOSYS and the LEAP were utilized to optimize energy generation to curtail the impact of greenhouse gases [32].

In China, eight renewable-based scenarios for the effectiveness of intended nationally determined contributions (INDCs) were developed with the EnergyPLAN model [182]. This software was employed in modelling Tanzania's energy sector planning [179] and Malaysia's 2010 to 2050 energy sector development [183]. Moreover, the EnergyPLAN was used to model the Irish energy system [131] as well as for researching Latvia's long-term ambitions for domestic energy production [184].

Franco and Salza [185] investigated Italy's technooperational goals for the optimal penetration of inconsistent renewable energy sources in intricate energy networks using ENPEP-BALANCE. Also, the potential renewable electricity to reduce greenhouse gas emissions in Macedonia [186] and Portugal [187] was evaluated using ENPEP-BALANCE.

The MESSAGE, an energy optimization bottom-up planning tool, is used to determine the efficient and economical investment for energy generation [140, 188]. Syria's long-term energy supply optimization strategy to minimize the cost of energy generation and supply from 2003 to 2030 was developed with MESSAGE [189]. Malaysia applied the model to its financial analysis of energy growth and the related carbon emissions between 2009 and 2030 [172, 190]. Moreover, MESSAGE was used to develop the world energy transition GHG emission scenarios for the World Energy Council and the Intergovernmental Panel on Climate Change [131]. In Indonesia, it has been applied to evaluate the contribution of nuclear power and other alternative electricity generation sources to mitigate greenhouse gas emissions [191]. Using the MESSAGE model, the energy supply, demand, and associated environmental factors from the various energy sources in India were analyzed [192]. The MESSAGE model was used to assess how Brazil might expand its electricity supply system while minimizing greenhouse gas emissions [81].

The International Atomic Energy Agency (IAEA) has offered training to most countries in Latin America, the Caribbean, and Africa on using MESSAGE for energy planning. Some Latin American and the Caribbean countries that have used MESSAGE for energy planning are Argentina, Brazil, Nicaragua, Paraguay, Uruguay, and the Dominican Republic [176]. For instance, an energy study carried out in Brazil employed a combination of MAED and LEAP for demand side modelling and MESSAGE model for supply optimization to identify the most cost-effective solution for the projected climate change target by the country's electricity generation sector from 2005 to 2035 [164]. The International Renewable Energy Agency (IRENA) assisted the five African power pool regions (West, Southern, Eastern, Central, and North) in developing specific country scenarios for the analysis of renewable energy prospects using MESSAGE [193].

MESSAGE is a bottom-up methodology used by government energy planners worldwide to determine the cost-optimal supply mix and accompanying investment requirements [193]. In partnership with the World Energy Council (WEC) and the Intergovernmental Panel on Climate Change (IPCC), MESSAGE has been used to create pathways for global energy transition, focusing on preserving the climate.

Table 3: Energy system model classification.

Name/ representative model	Developer	Analytical approach	Methodology approach	Time horizon	Geographical coverage and spatial application	Sector/scope	User interactive features/ accessibility	Reference
MESSAGE	IAEA	Bottom-up	Optimization, scenario operational approach, optimization	Long term	Local, country, regional, and global	Energy demand projections-economic-environmental analysis	High user friendliness, commercial/free to IAEA member state commercial	[92]
LEAP	SEI	Top-down Bottom-up	Simulation, optimization, scenario operational approach	Long term	Local, country, regional, and global	Energy planning-environmental impact assessment and economic or accounting and cost analysis nexus	High user friendliness, free for academics and developing countries Not open source Commercial	[31]
MARKAL/ TIMES	ETSAP	Top-down Bottom-up Equilibrium	Scenario operational approach, optimization	Medium term	Local, country, regional, and global	Energy, environment nexus Energy, environment, and economic analysis	High user friendliness	[31]
Mixed Integer Linear Program (MILP)	Bolivia	Bottom-up	Simulation, optimization	Medium term	Local	Energy-environment-economics		[145]
EFOM		Bottom-up	Scenario operational approach	Long term	Global	Energy, environment, and economic analysis		[146]
AIM		Top-down	Simulation	Long term	Regional, global	Energy, environment, and economic analysis		[147]
EnergyPLAN	Aalborg Univ., Denmark	Bottom-up	Simulation/ optimization, operational planning	Long-term operational	Local, country, regional, and global	Energy planning, environmental cost, economic assessment	High user friendliness, not open source	[126]
ENPEP-BALANCE	USA Argon National Lab	Top-down	Market simulation	Long term	Global/sectoral	Energy and environment nexus use for GHG scenario analysis	High user friendliness	[126]
MAED	IAEA	Bottom-up	Simulation and accounting	Long term	Local, country, and regional levels	Energy and environmental nexus	User friendly commercial/ free to IAEA member state commercial	[148]
OSeMOSYS	KTH, SEI	Top down Bottom-up	Optimization, scenario operational approach	Medium- to long-term planning	Local, country, regional, and global	Energy planning, cost optimization	User friendly	

Table 3: Continued.

Name/ representative model	Developer	Analytical approach	Methodology approach	Time horizon	Geographical coverage and spatial application	Sector/scope	User interactive features/ accessibility	Reference
SUPER	OLADE		Simulation and optimization			Analysis of financial situation, environmental impact, and energy demand	User friendly	[126]
Rogeaulito	The Shift Project, Europe	Bottom-up	Physical accounting	Long term	Global	Energy sectors and the environment		[149]
CO_2DB	Austria IIASA		Data inventory			Information on energy technologies and their amounts of carbon emissions	User friendly	[126]
RETScreen	Canadian Natural Resources		Simulation and accounting		Local, country, regional	RE technologies, energy efficiency assessment cost, and emission analysis	User friendly, Free to download	[126]

Table 4: Some countries and the energy planning models they used.

Country	Model												Reference
	MESSAGE	LEAP	MARKAL	MAED	ENPEP	RETScreen	AIM	WASP	EnergyPLAN	MILP	TIMES	EFOM	
China	✓	✓	✓				✓						[91, 159–161]
Bangkok		✓											[162]
UK			✓										[146]
Germany									✓				[163]
Brazil	✓			✓									[164]
Ireland									✓				[165]
Iran	✓							✓					[86, 166, 167]
Nigeria						✓							[168]
Greece										✓			[169]
Norway									✓				[165]
Cote d'Ivoire											✓		[170]
Italy												✓	[147]
Pakistan		✓										✓	[171]
Namibia		✓											[172]
Ghana		✓		✓									[31]
Denmark									✓				[131]
India			✓		✓		✓						[160, 173, 174] [175] [176]
Thailand							✓						[177]
Colombia		✓											[103]
South Korea	✓										✓		[177]
Portugal									✓				[103]
Switzerland											✓		[178]
UAE	✓												[92]
Tanzania	✓												[179]
Quebec			✓										[180]
Argentina	✓	✓						✓					[176]
Mexico		✓											[176]
Uruguay	✓			✓				✓					[176]
Southeast Asia							✓						[160]
Lithuania	✓												[181]
Poland			✓										
Egypt	✓												[84]

MESSAGE can be used to model all the energy sources such as renewable energy, thermal generation, nuclear and carbon sequestration, GHGs, and other radiative materials intended to stabilize future CO_2-equivalent concentrations [194].

The extensive use of the MESSAGE software globally has proven that the model could be used to study energy and its climate change impact in Ghana.

4. Conclusion

The increasing concern over the potential adverse effects of climate change on the world's environment makes energy a key part of sustainable development. Since carbon emissions from fossil fuels for electricity generation are the primary sources of GHGs, research on carbon neutral development path is critical to mitigating the possible consequences of this issue in the following decades. Existing studies have debated whether nuclear power can reduce GHG emissions. Meanwhile, numerous studies have revealed the relevance of nuclear energy in reducing GHG emissions. However, few researchers have investigated the global spatial distribution of nuclear power generation and the impact of the geographical distribution of the nuclear on global GHG emissions.

Research by Jaskólski and Bucko indicated that energy systems require technological innovations to achieve climate neutrality. In Poland, where obsolete coal-fired power plants dominate the electricity system, efforts to reduce environmental effects are coupled with substantial expenditures. As a result, optimal energy sector development paths were to be identified to achieve ambitious long-term strategic goals while minimizing the negative impact on climate change and consumers' household budgets. A methodology and a model for developing the electricity and heat generation structure were developed and implemented in the market allocation (MARKAL) modelling framework. Two scenarios were presented: baseline (BAU) and withdrawal from coal (WFC). The research revealed that nuclear energy and offshore wind power play a substantial role in achieving climate neutrality in electricity generation. The projected development paths ensure a significant reduction in greenhouse gases and industrial emissions [77].

Also, Naimoğlu investigated the effects of nuclear energy, energy pricing, and energy imports on CO_2 emissions in the short and long term for ten energy-importing rising economies that employ nuclear energy using the autoregressive distributed lag (ARDL) technique. The study's key finding was that the EKC hypothesis is valid for these economies. Hence, nuclear energy consumption and energy pricing minimize CO_2 emissions. However, energy imports raise CO_2 emissions. When measured as a coefficient, a 1% rise in nuclear energy utilization and energy pricing reduces CO_2 emissions by 0.04% and 0.02%, respectively. However, a 1% increase in energy imports raises CO_2 emissions by 0.09% [79].

Based on Egypt's sustainable development policy, the country's Vision 2030 was unveiled by the Egyptian government in 2016, with energy being a critical component of this vision. Renewable energy was given in the country's 2030 as the best alternative for reducing greenhouse gas emissions (GHGs) in the energy sector. However, the country depends on natural gas for its electricity generation. The country planned to expand its reliance on renewable energies, cut CO_2 emissions, and limit power production from natural gas. The research was carried out on the environmental consequences and external costs of Egypt's fossil, hydro, and nuclear power plants to provide a complete picture using MESSAGE and SIMPACTS models. Nuclear and gas power plants were shown to be long-term electricity suppliers. However, the research concluded that nuclear power plants are the best long-term alternative source of electricity generation for Egypt to fulfil future demand [84].

As part of Nigeria's policy to cut emissions to meet the Paris Agreement's aim of limiting global mean temperature rise to 1.5 degrees Celsius, research was conducted to determine the alternative optimal energy mix required by the country to meet its long-term sustainable electricity demand and reduce CO_2 emissions. The MESSAGE and SIMPACTS models were used in this study to evaluate two case scenarios of Nigerian energy supply systems in order to determine the optimal energy supply technology to satisfy future demand and estimate the environmental impacts and resulting damage costs during the normal operation of various electricity generation systems. The MESSAGE results show that fossil fuels and nuclear power plants are the best electricity generation technology for meeting Nigeria's projected energy needs. The SIMPACTS code results show that nuclear power plants have the lowest damage costs due to their negligible environmental impact during normal operation. As a result, nuclear power plant technology is the most environmentally friendly and best alternative for optimizing future electrical technology to fulfil demand. The findings of this study will be used as a reference source in modelling long-term energy mix, lowering CO_2 emissions in Nigeria (J. [82]).

According to the World Nuclear Association's August 2023 report, nuclear energy accounts for around 10% of global electricity generation, with approximately 440 power reactors. Nuclear power is the world's second-largest low-carbon energy source, accounting for 26% of total output in 2020. Nuclear energy is used in almost 220 research reactors in over 50 nations. Nuclear energy is used in around 220 research reactors in over 50 nations. Thirteen countries produced at least one-quarter of their electricity from nuclear in 2021. Nuclear energy provides around 70% of France's electricity, while Ukraine, Slovakia, Belgium, and Hungary receive approximately half of their electricity from nuclear sources [195].

Like many other African countries, Ghana formulated developmental and energy policies guided by international agreements such as the 2015 Paris Agreement on climate change. Although Ghana is endowed with fossil fuel, hydro, and renewable resources to drive its industrial ambitions, the indigenous gas fields feeding some thermal plants for electricity production are decreasing. They could run out by early 2030 unless new fields are discovered, and price volatility may also affect them. The untapped hydro resources are also small and unreliable if the country seeks to become a middle-income country. Despite the abundant renewable resources, they are intermittent and do not present a

baseload option. To safeguard Ghana's energy security and reduce CO_2 emissions, the country seeks to include nuclear energy into its energy mix [55].

In line with the 2015 Paris Agreement, all Parties to the United Nations Framework Convention on Climate Change (UNFCCC), including Ghana, have concerted to formulate nationally determined contributions (NDCs) to reduce GHG emissions to keep the increasing world's mean surface temperature below 2°C by the end of the century [39, 40]. The IAEA 2022 report indicates that Ghana has initiated the development of nuclear power emerging nuclear programme to be included in its energy mix since nuclear energy is crucial to the country's energy transformation plan as well as working towards the realization of its nationally determined contribution (NDC) to the UN framework on climate change.

The study used Scopus data for bibliometric analysis and systematic review to investigate the role of nuclear energy in curbing greenhouse gas (GHG) emissions from electricity generation and the extent of research on the subject area. This review has highlighted that the development of nuclear energy has fewer adverse effects on the environment during regular operation and is also one of the significant sources for optimizing energy demand.

Furthermore, along with the rapid increase of emerging industrialized countries, the global geography of the development of nuclear energy is undergoing a spatial reconfiguration phenomenon, as indicated by studies on research and collaboration among countries. The bibliometric analysis showed that developed countries such as the USA, UK, and China endowed with nuclear energy had significantly contributed to the research area. In contrast, only a few African countries, including Ghana, have contributed to the research and have had limited collaboration with other countries. The scoping review indicates the continent's limited contribution to energy and emission management knowledge.

The feasibility of future energy systems is a complex undertaking that can be accomplished using energy models based on the system approach. The studies looked at the classification of various energy models developed or used by some countries for energy planning and analysis of greenhouse gas emissions to assist policymakers with climate change mitigation-related energy concerns. Effective GHG reduction measures can be found within the many components of energy systems. The energy models can analyze the effectiveness and impact of technologies, energy sources, and other input data parameters of the developed scenarios. The energy models provide insight into the viability of the life cycle analysis of several energy sources. There are numerous models for adopting low-carbon energy technologies and resources for planning to achieve energy security and curb GHG emissions. However, the MESSAGE model will be used for energy planning in this study.

Although the systematic review indicates that numerous research studies have been carried out on the impact of nuclear energy on CO_2 emissions, there are some limitations with these studies as a result of the available data, the period of the research, the data utilized, the weaknesses in modelling approaches, and the variables used in the models [78, 124]. Further, another limitation was the assessment of numerous publications from one database since publications not indexed in the Scopus database may not be considered in the review [196].

The findings of this research on nuclear energy are crucial for directing Ghana's energy policy and planning to achieve its objectives on energy supply and the aim to reduce greenhouse gas emissions, which adversely impact climate change. Additionally, these studies on nuclear energy may not only offer a solution to Ghana's electricity shortages but could also aid in a smooth transition away from carbon-based technology to clean energy and less environmentally harmful power generation sources [197]. Furthermore, the research avails Ghana the opportunity to comprehend the gains it stands to make in the development of its nuclear power programme in energy security and the mitigation of greenhouse gas emissions.

The main objective of this study is to contribute to the knowledge of nuclear energy and the environment with an enhanced model and variables. For Ghana to be able to work towards the feasible achievement of energy security and a sustainable environment, there is the need to fulfil these requirements:

(i) Understand the current state of the energy system to identify the potential capacity of the nuclear energy required to meet the future electricity demand and estimate their impact on GHG emission reduction in Ghana

(ii) Establish quantitative targets for GHG emission reductions in the future to meet the country's NDC target

(iii) Develop alternative optimization scenarios considering the introduction of different capacities of the nuclear power plants within a scheduled time in correspondence with demand

The transition to a modern, cleaner energy pathway has recently received global attention. Although nuclear energy has emerged as a cleaner alternative energy source and is garnering significant policy attention, the impact of nuclear energy on greenhouse gas emission mitigation remains inconclusive in the existing literature. As a result, this study examines the dynamic linkages between GHG emissions from electricity generation and the mitigation with the introduction of nuclear energy in Ghana's energy mix in the long term. With the stated limitations and Ghana's status as an emerging nuclear country and the need to fulfill these requirements, there is a need for further research on the nuclear power programme to enhance the knowledge level on the policy implementation and the contribution of the country to climate change mitigation.

Although good research has been done on energy resources, climate change, and the impact of nuclear energy, considering the current level and rate of technology progress in the energy sector and the global concerns on the slow pace of countries' transitions towards decarbonization policy

implementations, complete climate neutrality is questionable. Therefore, further research is needed to achieve global net zero decarbonization by 2050.

Data Availability

Data on the study was mainly sourced from the Internet and this has been duly referenced in the paper.

Conflicts of Interest

The authors disclosed that they have no conflict of interest.

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