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Review

Energy development: A global perspective and advances in Ghana

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Abstract: Climate change, population increase, and urbanisation present severe threats to energy security throughout the world. As a result, governments all over the world have made significant investments in diversifying and developing local energy systems, notably in the renewable energy sector. In this light, this review was conducted to analyse the production trends of fossil energy, renewable energy and nuclear energy, as well as the impact of renewable energy production on fossil energy production, between 2000 and 2021. Using correlation and regression analysis, the relationship between these energy sources and the impact of renewable energy on fossil energy production were studied and then measured against similar studies in the literature. The findings showed an increasing trend in fossil energy and renewable energy production and a slightly decreasing trend in nuclear energy production from 2000 to 2021. In addition, there was a significant impact of renewable energy production on fossil energy production in the last two decades. In Ghana, it was found that the addition of solar energy generation to the national grid significantly influenced thermal energy generation. On the whole, renewable energy production has significantly increased over the last decades, and it has the potential to reduce the dependence on fossil energy if effectively developed and managed.

Therefore, future energy development should focus on more research and development in the area of smart and efficient renewable energy technologies.

Keywords: energy; energy development; renewable energy; climate change; nuclear energy; fossil energy; energy security

Abbreviations: AEP: Annual Energy Production; ECG: Energy Commission of Ghana; FE: Fossil Energy; IEA: International Energy Agency; IHA: International Hydropower Association; IRENA:

International Renewable Energy Agency; NE: Nuclear Energy; RE: Renewable Energy; SDG: Sustainable Development Goal; SLR: Systematic Literature Review

1. Introduction

Since the turn of the 21st century, energy has been undeniably the driving force behind world economies. Most economies have transitioned from man-powered and animal-powered agriculture to mechanised agriculture, less-utilised energy industries to high-utilised energy industries and less-intensive energy infrastructure to high-intensive energy infrastructure since the turn of the industrial revolution [1]. Energy is clearly no longer a choice, but rather a must for socio-economic development. In order to fulfil the expanding energy demand, increased energy production has resulted in unprecedented reliance on the exploitation of natural resources such as fossil fuels, nuclear, water, wind and solar, among others [2]. As if the energy burden on natural resources was not enough, the increasing intensity of climate change in recent decades has exacerbated the already erratic supply. Several economies have made new energy development a salient subject in global and local energy discourse in order to address the growing energy demand in the face of climate change [3]. To augment current energy sources, certain economies have already undertaken large energy interventions in the form of renewable energy (RE) development. Climate change mitigation is also a driving force behind the push for new energy development [4–6].

On a global scale, CO_2 emissions have been steadily increasing, reaching 36.6 billion tonnes in 2018 [7–9]. The concentration of greenhouse gases in the atmosphere will continue to rise as long as humans continue to release them. As a result, in order to put a stop to climate change, the concentration of greenhouse gases in the atmosphere must stabilise, but this will require a reduction in global greenhouse gas emissions to net-zero [7]. Energy production is responsible for 87% of all global greenhouse gas emissions [10]. People in impoverished nations have comparatively minimal emissions, according to studies [11,12]. People in the United States of America release more CO_2 in four days than people in poor nations like Ethiopia, Uganda and Malawi emit in a year [11]. The poor have limited access to contemporary energy and technology, which explains why their emissions are low [11]. The energy problem of the poorer half of the world is energy poverty [12,13]. According to Santillan et al. [12], a considerable portion of the population in nations with a GDP per capita of less than $25,000 lacks access to electricity and clean cooking fuels. Lack of access to efficient energy technology is at the root of some of the world's most serious energy challenges. People who do not have access to contemporary energy sources for cooking and heating rely on solid fuel sources such as firewood, dung and agricultural waste. Indoor air pollution, which the WHO considers "the world's biggest single environmental health concern", comes at a huge cost to the health of those living in energy poverty. The Paris Agreement's goal is to keep global average temperatures well below 2 ℃ over pre-industrial levels, as well as pursue efforts to limit temperature rises to 1.5 ℃ [6].

Once again, using wood as a source of energy has a detrimental influence on the ecosystem. Rural communities in developing nations used about 40% of total energy output before the turn of the century, with their energy consumption habits centred on wood-based biomass, notably fuelwood and charcoal [14,15]. Poverty is connected to deforestation because of the dependency on fuelwood. According to the Food and Agriculture Organisation of the United Nations (FAO), the use of wood as a fuel is the single most important source of forest degradation on the African continent [16,17]. In fact, across East, Central and West Africa, fuelwood provides more than half of the total energy [16,17].

As a result of this over-reliance on the forest, the forest's carbon sequestration capability has been diminished, resulting in an increased greenhouse effect. So, where do we go from here? Has there been any progress or policies in the field of RE generation to help mitigate the effects of climate change? The aim of the Paris Agreement is to keep global average temperature increases well below 2 ℃ over pre-industrial levels and to pursue measures to restrict temperature increases to 1.5 ℃. Such bold and ambitious goals need steady development in our energy output. Therefore, what progress has been accomplished in the field of energy so far?

In the last two centuries, more and more people have moved from energy poverty to high CO_2 emission energy sources, particularly fossil fuels [5,18,19]. In many ways, this is a very positive development because economic growth and increased access to modern energy improve people's living conditions. For instance, in rich countries, almost no one dies from indoor air pollution, and living conditions are much better in many ways [20,21]. It also meant that we made headway against the environmental consequences of energy poverty; the relationship between poverty and dependency on fuelwood is one of the main reasons why deforestation decreases as economic expansion accelerates. However, as living standards improved, so did greenhouse gas emissions [20,21]. Perhaps, we require more modern energy sources that are more sustainable.

Electricity is one area where humans have discovered various alternatives to fossil fuels. Nuclear power and RE produce significantly less carbon than fossil fuels and are therefore more environmentally friendly [22]. Nonetheless, in the last three decades, their proportion of worldwide power output has fallen from 36% to 35% [23]. In this regard, some countries have scaled up nuclear power and renewables and are doing much better than the global average. In France, 92% of electricity comes from low carbon sources, whereas, in Sweden, it is 99% [23]. As a result of improving their performance in this area, countries should be closer to the future sustainable energy world. However, the world is still a long way from finding a solution to the globe's energy dilemma, particularly outside of the electricity sector [24].

In Ghana, a greater proportion of total annual energy production is from the residential sector, and this was determined to be about 72% as of 2008 [25]. The bulk of this energy demand in the residential sector is from biomass in the form of firewood and charcoal (wood fuel) for cooking (constituting 76%), followed by petroleum products for transport and cooking/lighting (constituting 17%) and electricity use for lighting and appliances (7%) [25]. Although wood fuel products are themselves renewable, wood fuel combustion can lead to net emissions when there is no reforestation. According to the Energy Commission of Ghana [25], 90% of the wood fuel is obtained directly from natural forests and the annual deforestation rate is 3%. With this rate, the rate of deforestation over the next ten years is expected to be over 30%. The remaining 10% of wood fuel comes from logging and sawmill waste, as well as planted forests. Although RE sources can adapt to changes in weather patterns and long-term climate change, Ghana's rural areas have a higher share of RE sources, making it more sensitive to climate change [26,27]. Due to their sensitivity to the amount, timing and geographical distribution of precipitation, as well as temperature, biomass and hydropower generation are the energy sources most likely to be affected [28,29]. Over the next few decades, the strong reliance on biomass is most likely to either stay the same or perhaps increase [28,30].

Currently, in rural Ghana, it is estimated that about 84% of households use biomass for cooking and a further 13% depend on charcoal, while the remaining 3% include all other sources, such as electricity, kerosene and liquefied petroleum gas (LPG) [25]. Biomass, in the form of firewood and charcoal, provides the majority of Ghana's energy. Petroleum products and electricity, which account for 32% and 9% of total energy output, respectively, contribute to around 59% of total energy production [25]. According to the Energy Commission, an estimated total of 20 million tons of wood fuel and charcoal is consumed annually, and rural production averages the majority. So, given this framework, what advances have been accomplished in Ghana's energy output so far? In light of the foregoing discussions and a general review of the topic, it is necessary to acknowledge that a number of studies on energy have been conducted with regard to sources, climate change impact, emerging technologies, fossil energy (FE), RE and nuclear energy (NE); however, there is a scarcity of information and inconsistencies regarding the trends and interrelationships among the production of FE, RE and NE, as well as the influence of RE production on FE production.

Therefore, the objective of this review was to analyse the trends of FE, RE and NE production, as well as the impact of RE production on FE production between 2000 and 2021 in Ghana and the world at large using a secondary research method. To direct the study, the following questions were formulated: (i) What have been the production trends for FE, RE and NE over the last two decades? (ii) Does the production of RE have an impact on the FE production of the world? (iii) What is the production trend for the various RE sources in Ghana and the world?

The questions were analysed using correlation and regression. The findings showed increasing trends in global FE and RE production and a slightly decreasing trend in global NE production from 2000 to 2021. Although FE production increased, it increased at a decreasing rate. The increased production of RE had a significant influence on FE production, which was observed in the decreasing rate of FE production.

The results of this review represent important information to governments, energy developers, policymakers, climate change activists, the government of Ghana and many other organisations in the energy industry since it brings to the forefront the clear impact of RE interventions on FE development. It also identifies pertinent research areas that could be further studied to address some emerging issues in the energy sector.

2. Materials and methods

2.1. Secondary research method and materials

The main method used in this study is secondary research. Secondary research is a research method that involves using already existing data. The existing data are summarised and collated to increase the overall effectiveness of the research. It includes research materials published in research reports and similar documents that are made available through public libraries, websites, journals, etc. Secondary research is much more cost-effective than primary research, as it makes use of already existing data, unlike primary research where data are collected first-hand by the researcher [31,32].

In this study, the secondary research was implemented as online desk research in the form of statistical data analysis, historical data analysis and the analysis of data contained in the annual reports of international energy organisations. All secondary data collected concern the existing developments in fossil fuel, nuclear and renewable energies in the world, sub-regions and Ghana. Global energy data were obtained from the Our World in Data website (https://ourworldindata.org/), International Hydropower Association (IHA) website (https://www.hydropower.org/), International Energy Agency (IEA) website (https://www.iea.org/) and Renewables 21 website (https://www.ren21.net/). In Ghana, the energy data were obtained from the Energy Commission of Ghana website (https://www.energycom.gov.gh/). From these websites, the global status report on energy and the national energy statistics (Ghana) were downloaded. The downloaded reports included the Renewables 2021 global status report from REN21, national energy statistics 2000–2019 from the Energy Commission of Ghana, Coal 21 and Renewables 21 reports from the IEA, and hydropower status report 2021 from the IHA.

The downloaded reports were then critically read and studied to collect data relevant to the focus of the study. This was followed by the compilation and collation of the data under the following study variables: FE, NE, RE (hydropower, wind, solar, biofuel, geothermal and ocean), installed capacity, primary energy and electricity at the global, regional and local (Ghana) levels. The compilation, collation, data cleaning and analysis were done using Microsoft Excel (Microsoft Office Professional Plus 2016) and IBM SPSS Statistics (v22).

2.2. Systematic review method

The systematic literature review (SLR) method was adopted to conduct a systematic review in which relevant literature with regards to energy development in the world and Ghana were selected. SLRs have long been used in environment and energy studies [33,34]. In contrast with descriptive and narrative reviews, SLRs use an explicit algorithm, as opposed to a heuristic algorithm, to perform a search and critical appraisal of the literature [34]. Systematic reviews improve the quality of the review process and outcome by employing a transparent, reproducible procedure [33–35]. Following the SLR guidelines, the review process for this study consisted of a three-stage protocol: data collection, data curation and data analysis. The analysed data were compared and integrated with the final results for presentation.

The literature review consisted of using Scopus and Google Scholar search engines to find journal articles detailing studies on energy development. This database and search engine were selected on the grounds that they are some of the most powerful databases and search engines in existence [34]. Specifically, Google Scholar provides strong coverage in international research, guaranteeing the highest quality; Scopus, on the other hand, with over 27 million abstracts, is the largest database of scientific literature [34].

To reduce the risk of bias, during the selection phase of the journal articles, articles were searched according to three criteria: (i) use of “energy”, “energy development” and “renewable energy” as keywords, (ii) published between 2000 and 2021 (past 21 years) and (iii) journal articles only.

Within each database, the keywords “energy”, “energy development” and “renewable energy” were used to identify all publications that contained the keywords in its title, keyword list or abstract. After eliminating all of the duplicate documents, a total of over 100 documents were identified over a period between 2000 and 2021. Due to the numerous articles returned, the focus of the study, which included the interlink between FE, RE and NE, was used as a measure to select some of the articles; this entailed skimming through the title of the articles that contained at least one type of target energy among FE, RE and NE. Using this strategy, 70 journal articles were selected for final selection. In the final assessment, all pages of the selected articles were read to identify the ones with the subject matter in alignment with that of the study. Ultimately, 50 journal articles were selected that were directly concerned with energy development in the world and Ghana [36,37]. This process helped to enhance quality control owing to the rigorous peer-review process to which articles published in such journals are subjected prior to publication [36,37].

2.3. Data analysis

The analysis of the data gathered from the annual energy reports, online repository and journal articles was performed to generate meaning or information. Initially, Microsoft Excel was used to organise and sort the data under different variables, including FE, RE and NE. This was followed by the generation of summary descriptive statistics, including the means and percentages of the study variables. In order to facilitate the understanding and identification of trends, bar, pie and line graphs were produced.

Lastly, the data were imported into SPSS to carry out the inferential statistics analysis, including correlation and regression analyses. Correlation analysis was performed to examine the relationship between FE, RE and NE production between 2000 and 2021. Again, time-series regression of the study variables was conducted to identify the cause and effect. The multiple regression analysis was based on the following equation:

$$y = m_1X_1 + m_2X_2 + \cdots + m_nX_n + c + \varepsilon \quad (1)$$

where y = dependent variable, X = independent variable, m = regression coefficient, c = y-intercept and ε = random error term.

The flow chart of the data collection, curation and analysis processes is illustrated in Figure 1.

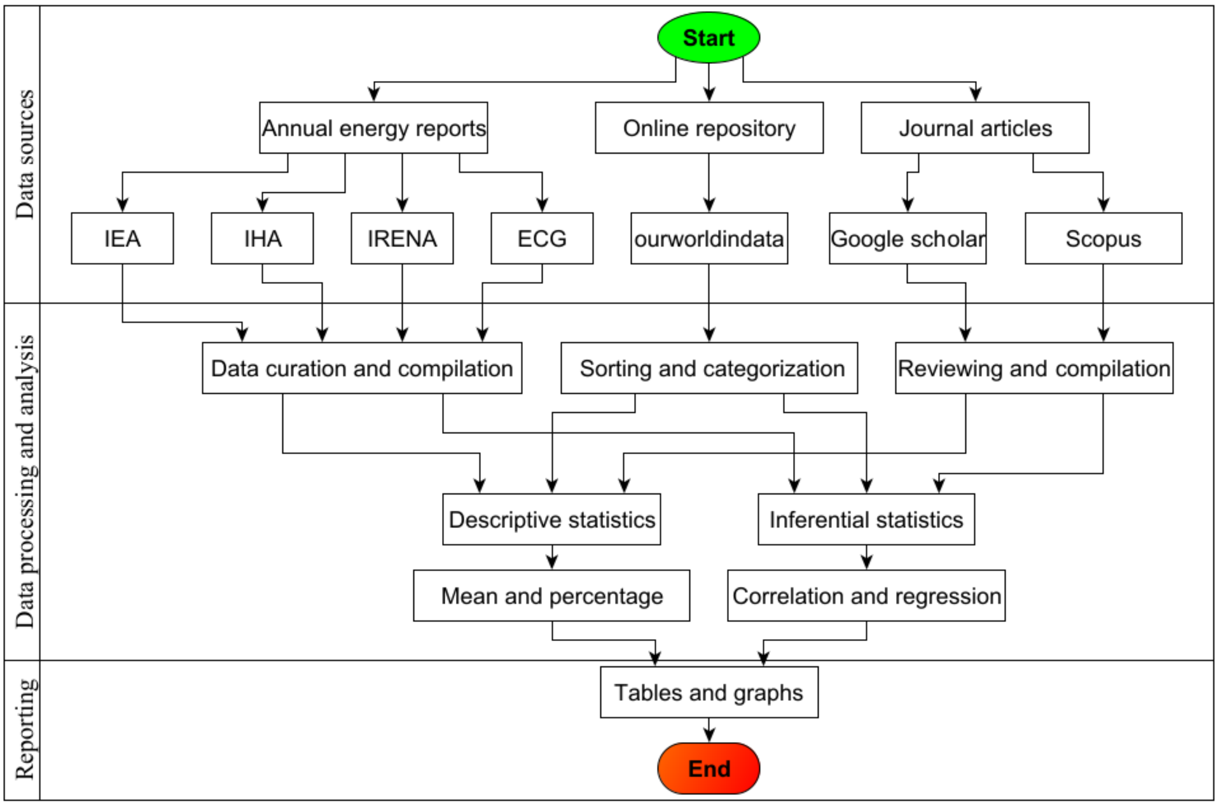

Figure 1. Flow chart of data collection, curation and analysis.

Note: IEA: International Energy Agency; IHA: International Hydropower Association; IRENA: International Renewable Energy Agency; ECG: Energy Commission of Ghana.

3. Results

3.1. Global energy development

Globally, there is an increasing concern regarding new energy development, mostly due to the present status of energy as a driver of the world economy. The recent devastating impact of climate change and the Paris agreement's goal to bring the global average temperature to below 2 ℃ have shifted the global energy focus from high carbon emission energies such as fossil fuels to the development of low carbon emission energies such as RE sources. How have the global and local energy developed in the past two decades (2000–2020), and what are some energy responses to climate change mitigation?

Energy development is concerned with the acquisition of sources of energy from natural resources. The activities involved in energy development include the production of conventional, alternative and renewable sources of energy, and the recovery and reuse of energy that would otherwise be wasted [38]. In fact, identifying means and technologies to reuse and optimise current energy usage will foster energy conservation and efficiency, which in turn would reduce the demand for new energy development in the form of the fresh exploitation of natural resources [39,40].

The share of global energy production according to sources is illustrated in Figure 2. Around the globe, the production of energy comes in varying proportions of the energy mix. The energy mix refers to the combination of the various primary energy sources used to meet energy needs in a given geographic region. It includes fossil fuels (oil, natural gas and coal), NE and the many sources of RE (biomass, hydro, wind, solar, ocean and geothermal) [41,42]. These primary energy sources are used for generating electricity (secondary energy), providing fuel for transportation, cooking, heating and cooling residential and industrial buildings. Therefore, the total energy production in the world represents the sum of the primary and secondary energy production of each country [43]. From Figure 2, it is observed that the global annual energy production steadily increased over the last two decades (2000–2020), peaking in 2019, with the total annual energy production from all sources (fossil fuel, nuclear and renewable) amounting to 153,564.5 TWh and 141,732.43 TWh in 2019 and 2020, respectively. The 2019 to 2020 energy production represented a 7.7% drop in total energy production. This drop could be attributed to the COVID-19 pandemic and its associated lockdowns [44,45]. In reference to an energy source, it is observed that, over the last two decades (2000–2020), the bulk of global energy production was sourced from fossil fuels, with a mean annual energy production of 118,674.4 TWh (91%) (Figure 2a). According to Olabi and Abdelkareem [46], fossil fuel-based thermal plants remained the main sources of primary energy needed for large-sized power plants despite their contribution to climate change because other alternatives, such as solar, wind, biomass and other renewable sources, are not generally competitive and the increasing reliance on hydropower leads to the displacement of people and ecological disturbance.

On the other hand, nuclear and renewable energies constituted a mean annual energy production of 2,583.7 TWh (2%) and 9,045.2 TWh (4%), respectively (Figure 2a). Again, it is depicted that the proportion of global primary energy, which includes cooking, heating and transport, showed no appreciable change for fossil fuel over the last two decades, averaging 86% of annual global production (Figure 2b). Conversely, the primary energy production from renewable sources, including biofuel (bioethanol and biodiesel), wind, hydro, geothermal, solar and ocean, showed an appreciable increase over the last two decades, averaging 9% of annual global energy production (Figure 2b).

According to Ritchie et al. [42], this increase could be linked to the increasing global greenhouse gas emissions associated with the burning of fossil fuels for energy and the goal to reduce CO_2 emissions and local air pollution by shifting towards low-carbon sources of energy. Production from NE, on the other hand, remained slightly constant over the last two decades, averaging 5% of the global annual primary energy production (Figure 3b). This could be due to the sharp dip in nuclear output following the Fukushima tsunami disaster in Japan in 2011, as countries took plants offline due to safety concerns. Nevertheless, nuclear production showed a slight increase in recent years [47].

With reference to global electricity generation, it is observed that, over the last decade (2010–2020), the electricity generation from fossil fuel and NE progressively declined, whereas the generation from renewable sources increased steadily (Figure 2c). The respective shares of electricity generation in 2019 and 2020 were 62.2% and 61.9%, 27.3% and 29.0% and 10.5% and 10.1% in the order of FE, RE and NE. Thus, global electricity generation from RE increased by 1.7% in 2020, whereas the generation from FE and NE decreased by 0.3% and 0.4% in 2020, respectively (Figure 2c). From the perspective of both human health (air pollution) and climate change (greenhouse gas emission), it has become indisputable in recent decades that the world needs to shift from FE production due to its CO_2 emission and pollution, and from NE due to its recent disasters (Chernobyl and Fukushima), to safer and cleaner energy such as renewables. This has resulted in the rise in renewable electricity and the fall in fossil and nuclear electricity [42,47,48]. Renewable electricity includes generation from hydro, wind, solar, geothermal and ocean energies, while fossil electricity includes generation from coal, oil and natural gas [42].

Globally, the shares of primary energy production from FE, RE and NE in 2020 were 84%, 12% and 4%, respectively. Primary production includes the use of these energy sources for cooking, transport, heating, cooling and any other use that does not require the conversion of these energy sources into secondary energy such as electricity. On the contrary, the shares of electricity generation from FE, RE and NE in 2020 were 61%, 29% and 10%, respectively (Figure 3a,b). Comparatively, the shares of primary energy production from FE, RE and NE in 2019 were 84%, 12% and 4%, respectively, and the share of electricity generation from FE, RE and NE in 2019 were 62%, 27% and 11%, respectively (Figure 3c,d). Thus, relatively, there was no change in primary energy production between 2019 and 2020 for any source (FE, RE and NE), but, in 2020, electricity from RE increased by 2% while those from FE and NE decreased by 1%. The change in electricity generation may be linked to the shutting of some coal plants, particularly those in Europe, in order to push towards the goal of the 2015 Paris Climate Accord to bring the global temperature increase to less than 2 ℃. It may also be attributed to the shift towards modern REs. However, primary production remained appreciably unchanged since transport and heating tend to be harder to decarbonise because they are more reliant on oil and gas [23,49].

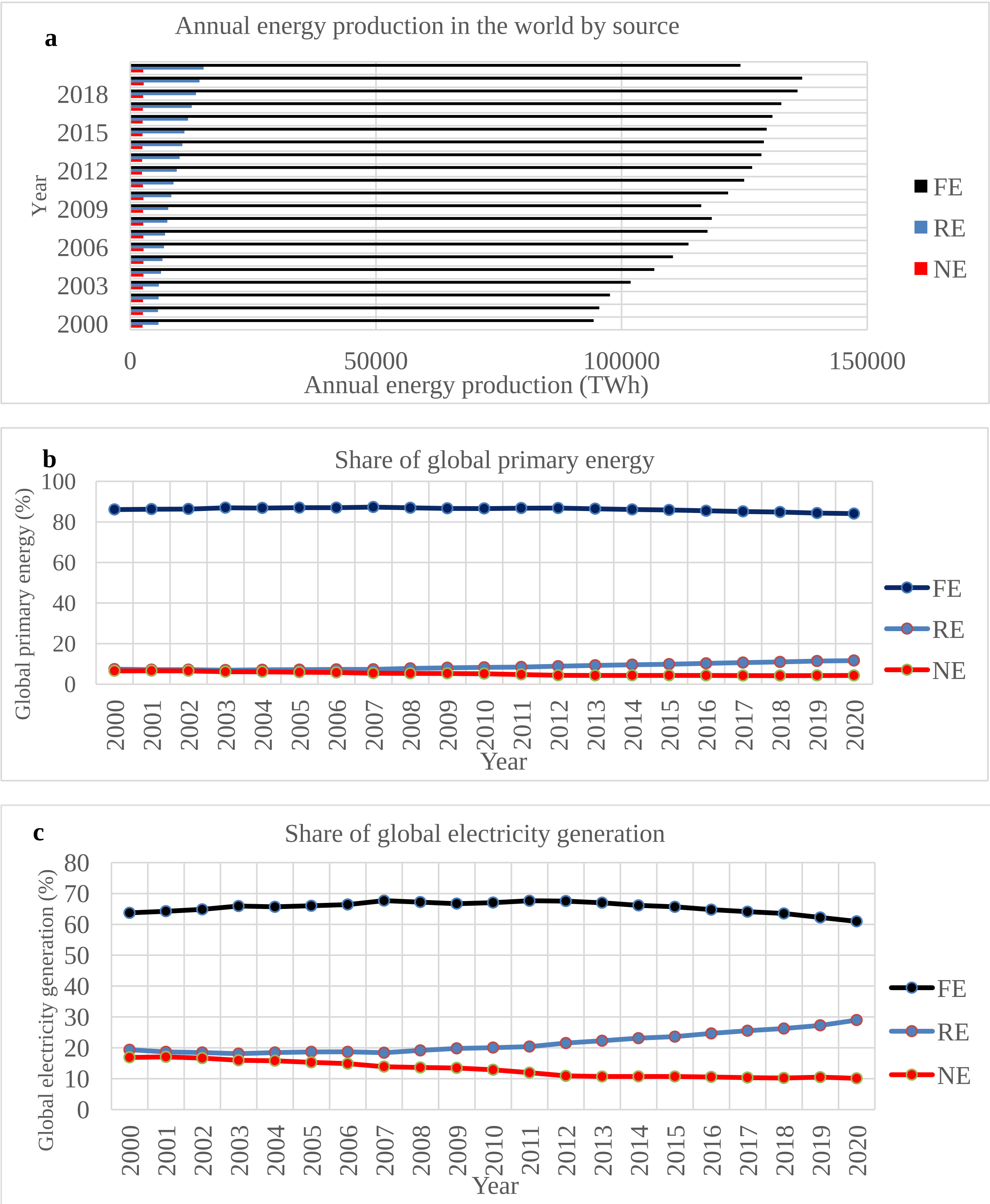

Figure 2. Shares of global energy production by source. Source: direct analysis based on Our World in Data [42]; REN21 [50] and IEA [51] Reports.

Note: FE: fossil energy; RE: renewable energy; NE: nuclear energy.

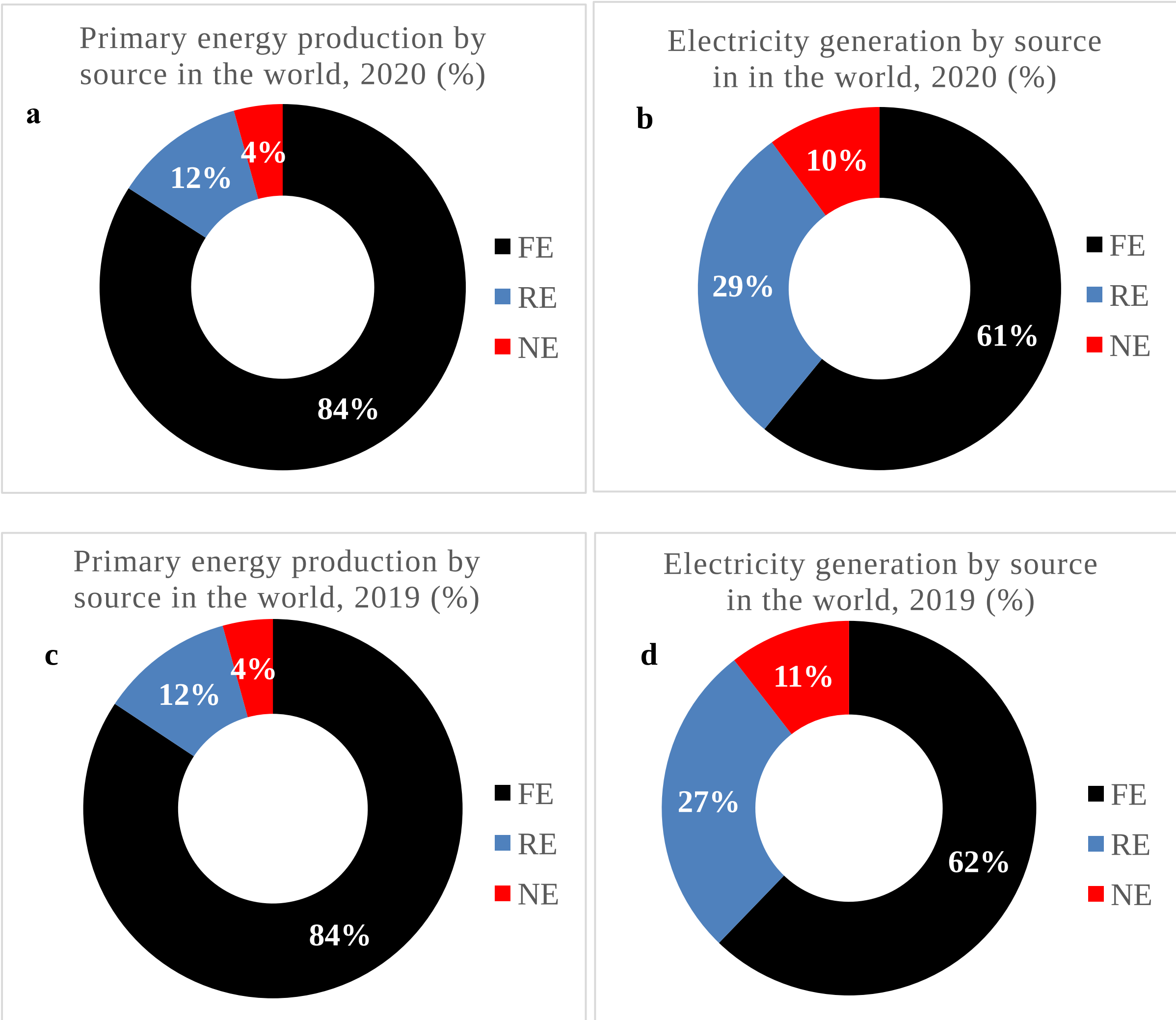

Figure 3. Global proportions of annual energy production and electricity generation by source. Source: direct analysis based on Our World in Data [42]; IRENA [48]; REN21 [50] and IEA [51] Reports.

The developments in FE, RE and NE production in the world were analysed using correlation and regression analysis. The Pearson correlation analysis for FE, NE and RE production is presented in Table 1. It is observed that there was a highly positive correlation and statistical significance ($r = 0.86$, $p < 0.001$) between RE and FE production globally over the last two decades. However, the correlation between NE and FE, as well as NE and RE, was found to be poorly negative and statistically insignificant ($r < -0.15$, $p > 0.01$). This means that the production of FE and RE increased over the last two decades (2000–2021) and the production of NE decreased.

Again, the ordinary least regression results for NE and RE production (independent variables) with respect to FE production (dependent variable) are presented in Table 2. Here, the response variable FE was regressed on the predicting variable RE, with NE as the control variable. It is observed that, over the last two decades, the production of NE had no significant impact on FE production ($p > 0.01$), but the production of RE had a significant influence on FE production, $p < 0.01$. The combination of RE and NE production showed a significant impact on FE production, $F(2, 18) = 26.12$, $p < 0.01$, with an adjusted R^2 of 0.72. This shows that there was a significant influence of RE production on FE production. Therefore, the unit production in RE is more likely to cause a significant change ($B = 3.83$, $p < 0.01$) in FE production than a change in FE production by NE ($B = −4.56$, $p > 0.01$).

Table 1. Correlation analysis for global FE, NE and RE production.

	FE	NE	RE
FE	1.00		
NE	−0.13	1.00	
RE	0.86**	−0.11	1.00

**Correlation is significant at the 0.01 level (2-tailed).

Table 2. Regression analysis for global NE and RE on FE production.

Regression	Predictor	B	t-value	P(t)	Adjusted R^2	F-value	p(F)
FE~NE+RE	NE	−4.56	−0.27	0.79	0.72	26.12	0.00
	RE	3.83	7.15	0.00			

Note: B: unstandardized coefficients.

3.2. Global renewable energy development

Since the Industrial Revolution, the energy mix of most countries across the world has been dominated by fossil fuels. This has major implications for the global climate, as well as for human health. The combustion of fossil fuels contributes to 75% of global greenhouse gas emissions [49]. Besides, the burning of fossil fuels leads to a huge amount of regional air pollution, which causes major health problems [49]. Therefore, in order to mitigate CO_2 emissions and regional air pollution, there has been increasing interest in quickly shifting towards RE generation.

Globally, RE is perceived to be capable of decarbonising the global energy system in the years ahead. However, the impact of RE on current global energy is not well established.

From Figure 4e, it is observed that the global energy generation from renewable sources consistently increased over the last two decades (2000–2020). Over the two decades, it is observed that hydropower contributed the largest share of average annual energy generation (3,391 TWh, 72%) (Figure 4b). The contribution from hydropower was largely for the generation of electricity. Other shares of renewable generation came from biofuel (607 TWh, 13%), wind (526 TWh, 11%) and solar (177, 4%), representing the average annual generation over two decades (2000–2020) (Figure 4b). Biofuel (biodiesel and bioethanol) was largely used for transport. In 2019, the share of RE generation was in the order of hydro (4,261 TWh, 57%,), wind (1,417 TWh, 19%), biofuel (1,110 TWh, 15%) and solar (704 TWh, 19%) (Figure 4c). This order was maintained in 2020, with slight changes in hydro (4,355 TWh, 56%,), wind (1,590 TWh, 20%), biofuel (1,043 TWh, 13%) and solar (844 TWh, 11%) (Figure 4d). Thus, hydro, biofuel and solar generation dropped by 1%, 2% and 8% from 2019 to 2020, respectively. On the contrary, wind generation increased from 2019 to 2020 by 1%. The fall in hydro, biofuel and solar generation may be attributed to COVID-19 lockdowns delaying the commissioning of new plants, while the rise in the wind is ascribed to the connection of offshore wind power segments in five countries in Europe and two in Asia, as well as the United States of America, amounting to 6.1 GW in 2020 and a cumulative global offshore capacity of more than 35.3 GW [44,48,50].

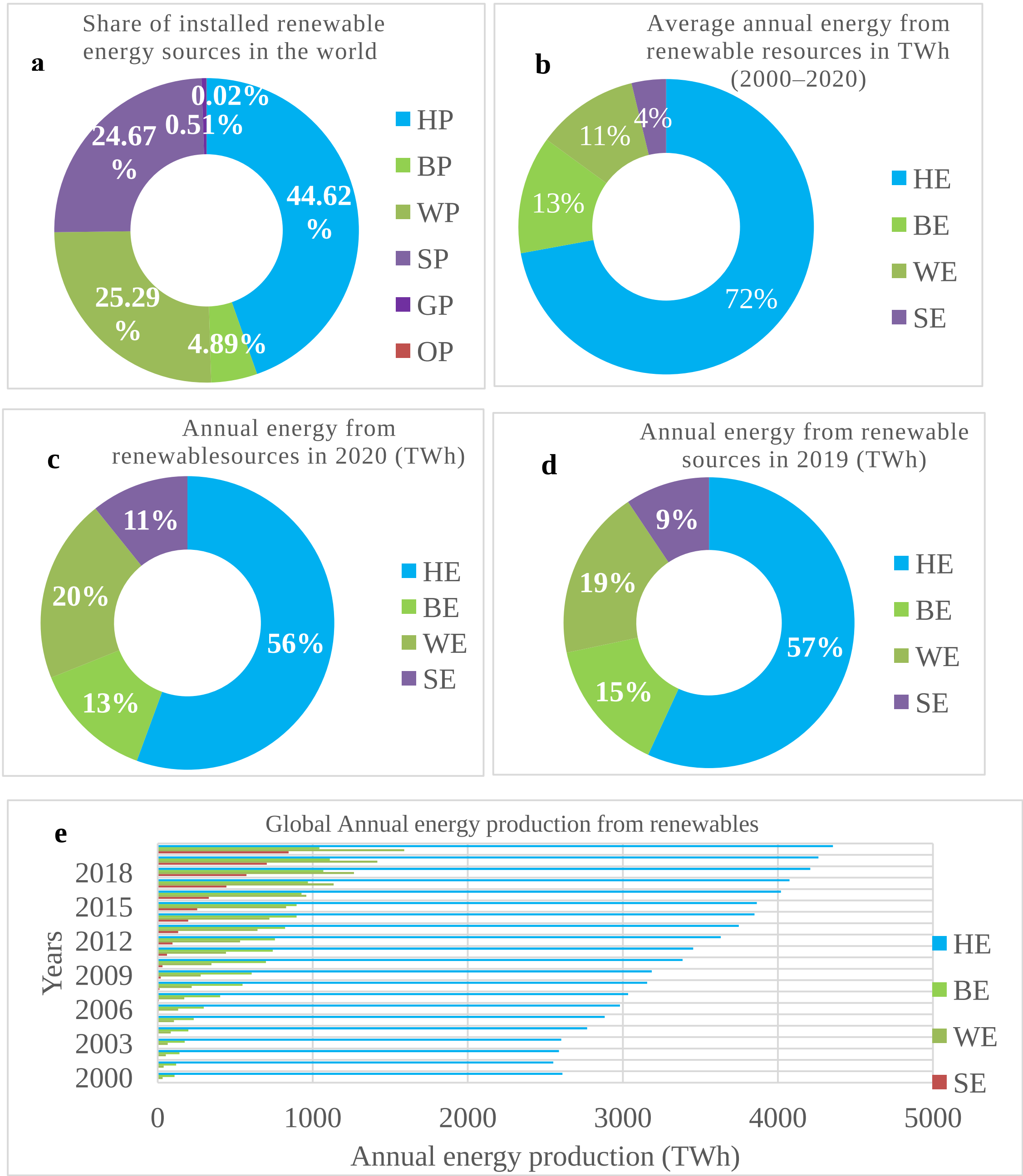

Figure 4. Global installed capacity and annual energy generation from renewable sources. Source: direct analysis based on Our World in Data Report [42]; IRENA [48]; REN21 [50] and IEA [51] Reports.

Note: HP: hydropower; BP: biopower; WP: wind power; SP: solar power; GP: geothermal power; OP: ocean power; HE: hydro energy; BE: bioenergy; SE: solar energy; WE: wind energy.

In terms of the global installed capacity of RE, it was determined that, as of 2020, hydropower constituted the greatest share of global installed RE capacity, with an installed capacity of 1,324 GW, representing 45% of the overall installed capacity. The remaining shares of total installed capacity were in the order of wind (750 GW, 25%), solar (732 GW, 25%), biofuel (145 GW, 5%), geothermal (15.07, 0%) and ocean (0.53 GW, 0%) (Figure 4a). Hydropower has remained the main source of RE needed for large-sized power plants because other renewable alternatives, such as solar, wind, biomass, geothermal and ocean, are not presently competitive, except in remote areas, hence its greatest share in renewables [29,52].

The Pearson correlation (r) between hydro energy (HE) and bioenergy (BE), solar energy (SE) and wind energy (WE) production was found to be highly positive and statistically significant ($r \geq 0.85$, $p < 0.01$). Again, a highly positive correlation and statistical significance exist between BE and SE, WE and BE, as well as WE and SE production ($r \geq 0.79$, $p < 0.01$). These results show that the production of HE, BE, SE and WE increased over the past two decades. A summary of these findings is shown in Table 3.

The results of multiple regression analysis of BE, SE and WE on HE generation in the world are presented in Table 4. The response variable HE was regressed on the predicting variables SE and WE, using BE as the control variable. The results show that the exclusive production of SE and WE had a significant influence on HE production ($p(t) < 0.05$). Again, when the production of SE and WE was combined with BE production, there was a significant impact on HE production, $F(3, 17) = 678.47$, $p < 0.0$, with an adjusted R^2 of 0.99. This means that the increased production of SE and WE were capable of influencing the HE production with or without BE production.

Table 3. Correlation analysis for global HE and alternative RE production.

	BE	SE	WE	HE
BE	1.00			
SE	0.79**	1.00		
WE	0.91**	0.96**	1.00	
HE	0.99**	0.85**	0.96**	1.00

**Correlation is significant at the 0.01 level (2-tailed).

Table 4. Regression analysis of global HE on other RE production.

Regression	Predictors	B	t-value	p(t)	Adjusted R^2	F-value	p(F)
HE~BE+SE+WE	BE	0.69	3.17	0.00	0.99	678.47	0.00
	SE	−1.13	−2.44	0.03			
	WE	1.29	3.53	0.00			

3.3. Regional energy development

The production of energy varies geographically based on a number of factors, such as the population size, nature of the economy, extent of industrialization, energy policy and resource availability. In this regard, this section compares and discusses the production of energy at the regional and local levels. The regions of consideration are Europe, North America, Asia Pacific and Africa.

3.3.1. Energy production by region

In order to meet the growing energy demand in the various sectors of the economy, regions around the world in the past decades have made major efforts to integrate different energy sources into their energy mix. But, to what extent have these energy sources developed over the past decade (2010–2019)?

The production of FE for primary purposes such as transport, cooking, heating and cooling and electricity generation, as well as the electricity generation from nuclear and renewable sources is illustrated in Figure 5. The renewable electricity mix is the sum of electricity generation from hydro, wind, solar, geothermal and ocean power. It is observed that the production of fossil fuel over the past decade (2010–2019) has steadily declined in Europe, with an average annual production of 19,959.6 TWh. However, on the African continent, fossil production has seen a gradual increase over the past decade, with an average annual production of 4,510.8 TWh. The production in North America fluctuated over the past decade, with an average annual production of 26,179.8 TWh (Figure 5a). Thus, comparatively, among the three continents, Africa produces a little over 9% of the fossil fuel, whereas North America and Europe produce 4% and 37%, respectively. This is espoused by the IEA [43], which states that Africa still has a relatively low installed capacity; hence, there is low energy production and access; again, Africa has low access to thermal technology.

With regards to the electricity generated from NE, it is seen that Europe has shown a steady decline in nuclear electricity generation, with an average annual generation of 977 TWh. On the contrary, nuclear electricity generation in the Asia Pacific progressively increased over the past decade, with an average annual generation of 478 TWh. However, nuclear generation in North America remained steadily constant, with an average annual generation of 948 TWh. In Africa, nuclear electricity generation remained relatively low over the past decades, with an average annual generation of 14 TWh (Figure 5b). Thus, comparatively, Africa generated 1% of the total nuclear electricity from Europe, North America, Asia Pacific and Africa. Among these continents, Europe (40%) had the greatest share of nuclear electricity generation, followed by North America (39%) and the Asia Pacific (20%). According to Jiang et al. [45], the decline in NE in Europe is partly associated with the Chernobyl and Fukushima disasters and the growing interest of most European countries in RE sources. Africa, on the other hand, lags behind in nuclear generation due to low installed capacity and limited technology [43].

Regarding the electricity generated from renewable sources over the past decade, it was observed that renewable electricity generation consistently increased over the past decade (2010–2019) in Europe, North America, the Asia Pacific and Africa (Figure 5c). The contribution of renewable electricity to the electricity mix in Europe, North America, the Asia Pacific and Africa in 2019 were 36.8%, 23.1%, 23.1% and 20.4%, respectively. These represented 2.3%, 0.6%, 1.2% and 1.2% rise in renewable electricity from the previous year (2018) in the order of Europe, North America, the Asia Pacific and Africa. The rise in renewable electricity generation across these regions is linked to the decarbonisation of the global energy system to meet the Paris Climate Accord requirement for climate mitigation [48,51].

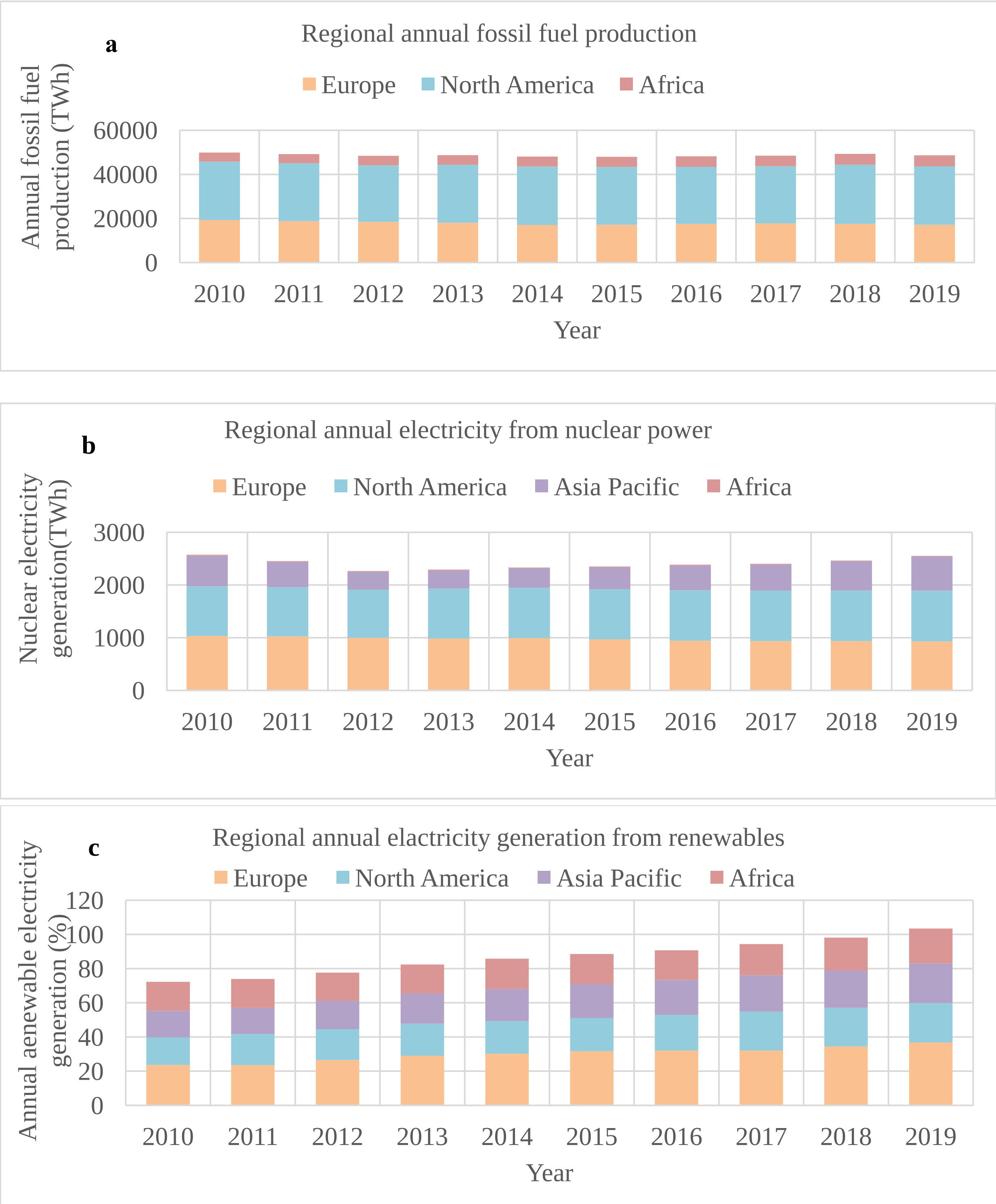

Figure 5. Renewable energy production. Source: direct analysis based on Our World in Data [42]; IRENA [48]; REN21 [50] and IEA [51] Reports.

3.3.2. Energy production by top five countries

In order to assess the countries that are making the most efforts to develop their total energy mix, a review was conducted to identify the top five countries in fossil fuel consumption, nuclear electricity generation and renewable electricity generation. It was identified that, in terms of fossil fuel consumption, China and the USA constantly remained the two highest consumers over the past decade, with average annual consumptions of 30,096 TWh and 21,700 TWh, respectively. India, Russia and Japan made up the remaining top five consumers, with average annual consumptions of 7,095 TWh, 7,048 TWh and 4,829 TWh, respectively (Figure 6a). According to Gunnarsdottir et al. [38], generation in these countries is still relatively high due to the already existing large installed capacity and the low prices of fossil fuels like oil and coal, which undermines the incentives for clean energy deployment.

Regarding the electricity generation from NE, the top five countries were in the order of USA, China, France, Russia and South Korea. In 2020, the USA produced 790 TWh of electricity from NE compared to the 366 TWh produced by China. From 2019 to 2020, the production in the USA dropped by 2.1%, while that of China increased by 5%. As indicated in Figure 6b, China consistently increased its nuclear generation from 2010 to 2019. Again, it is observed that, from 2019 to 2020, the nuclear generation in France dropped by 11%, while that of Russia and South Korea increased by 3.1% and 10.1%, respectively. Just like China, nuclear generation in Russia and South Korea progressively increased over the last decade, but France's production steadily decreased over the same period. According to Carayannis et al. [53], the reduction in France's nuclear electricity is in line with the French government policy to reduce the nuclear share of electricity from 75% to 50% by 2025 in an effort to diversify France's energy production as the country adopts new targets for cutting greenhouse gas emissions with a focus on RE. Again, according to Hazboun et al. [54], the decrease in the USA's nuclear power generating capacity is a result of historically low natural gas prices, limited growth in electricity demand and increasing competition from RE. According to Michaelides et al. and He et al. [23,47], the increases in nuclear electricity generation in China, Russia and South Korea are due to the national governments' commitment to subsidising nuclear power for domestic electricity generation and exporting reactor technology abroad. Again, government officials in these countries have argued that increasing and maintaining nuclear power is necessary to meet national and international goals for reducing carbon emissions that contribute to climate change.

In reference to renewable electricity generation, the top five countries with the highest shares of renewable electricity in their electricity mix in 2020 were Costa Rica, Norway, Uruguay, Tajikistan and Brazil. From Figure 6c, the shares of renewable electricity were in the order of Costa Rica (99.8%), Norway (98.8%), Uruguay (94.1%), Tajikistan (92.9%) and Brazil (84.2%). It was found that these countries increased their shares of renewable electricity generation in 2020, except Uruguay and Tajikistan, which dropped by 4.2% and 0.2%, respectively. According to Enerdata [41], these countries maintained their high standing in the share of renewable electricity in their electricity grid due to the long history of sourcing most of their electricity from hydropower. In the order of hydropower shares of the electricity mix, there are Tajikistan (98%), Norway (97%), Costa Rica (67.5%), Brazil (66%) and Uruguay (60%). Despite their shares of hydropower, the governments of these countries have consistently made ambitious efforts to harvest modern renewables such as wind, solar and geothermal energies to integrate into their energy mix.

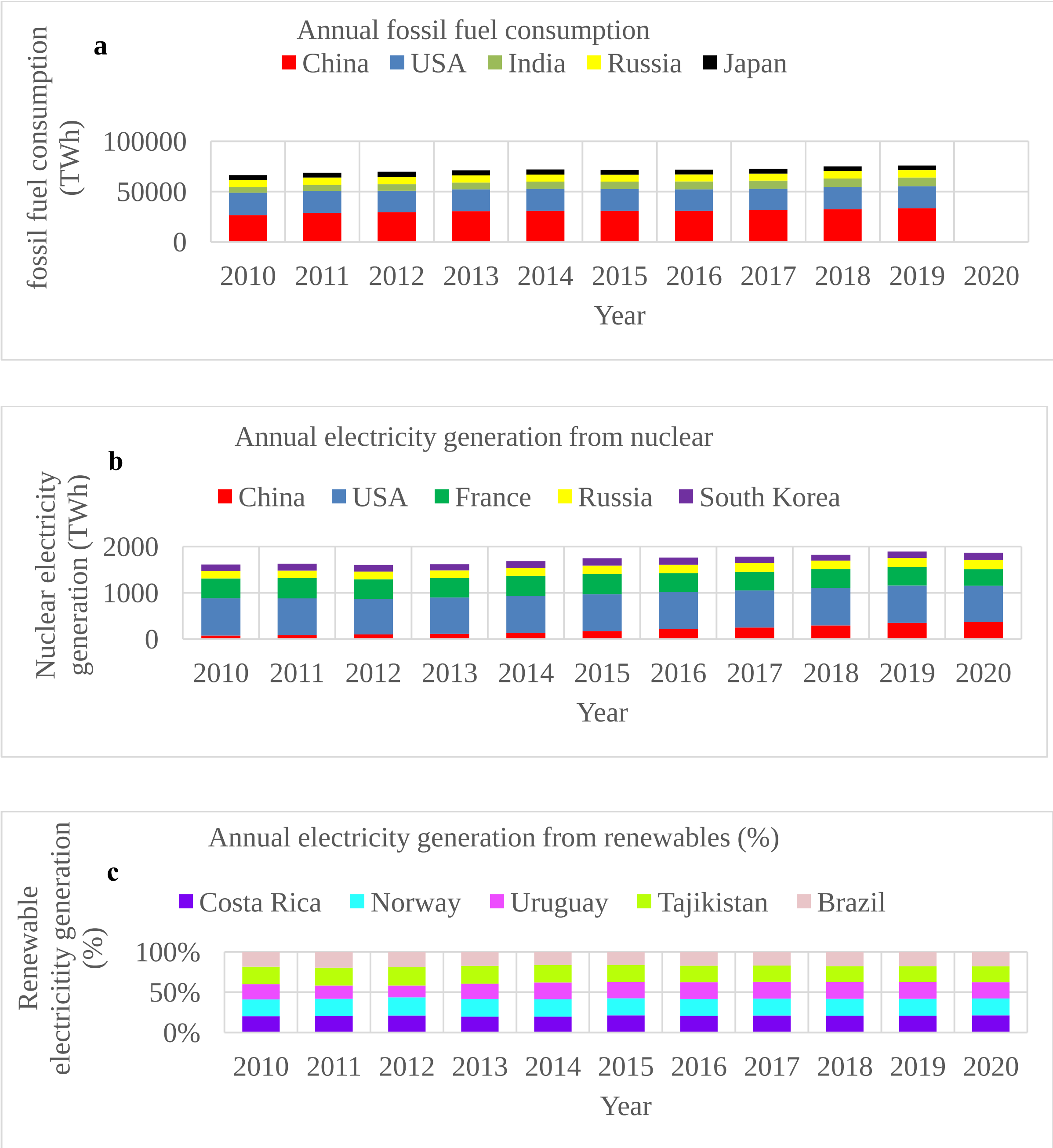

Figure 6. Energy production and consumption for the top five countries. Source: direct analysis based on Our World in Data [42]; IRENA [48]; REN21 [50] and IEA [51] Reports.

3.3.3. Renewable energy generation by top five countries and regions

With the rise in droughts, floods, wildfires, pestilences and other associated impacts of climate change becoming more and more intense, many countries have mapped up strategies to decarbonise their energy system by shifting towards low carbon emission energy sources. Besides, in order to meet the Paris climate agreement and Glasgow COP26's goal of bringing the global temperature increase to 1.5 ℃, RE sources have gained prominence in international and national discourses in matters concerning climate change mitigation and decarbonisation. On this note, it is crucial to analyse the development of RE over the years and the current state of RE generation.

Globally, hydro, wind, solar, geothermal, biomass and ocean power have been harnessed for energy or electricity generation. In fact, as of 2020, the total installed capacities of RE in the world were in the order of hydro (1,324 GW), wind (750 GW), solar (732 GW,), biofuel (145 GW), geothermal (15.07 GW) and ocean (0.53 GW). According to IRENA [48], the large share of hydropower in RE capacity is related to the fact that it is the oldest source of RE technology, whereas technologies from other renewable sources are still developing. Again, it continues to dominate the renewable sector because hydroelectric power is the most preferred source for energy production among all RE sources due to its constant and reliable energy production throughout all seasons, and its precise control over the demand and load. However, hydropower projects have become controversial in recent years due to the environmental and social impacts related to bio-diversity and human resettlement; hence, the increasing shift to other renewable sources.

On the regional front, Asia tops the total installed RE capacity with a cumulative installed capacity of 1,340.41 GW, followed by Europe with a cumulative installed capacity of 647.66 GW. The cumulative installed capacities of other regions were in the order of North America (409.73 GW), Central and South America (240.70 GW), Africa (57.38 GW), Australia (42.01 GW) and the Middle East (19.07 GW) (Figure 7a).

On the national front, the top five countries by total installed capacity as of 2020 in hydropower generation were China (370 GW), Brazil (109 GW), the USA (102 GW), Canada (82 GW) and India (51 GW) (Figure 7b). Again, the top five countries by installed capacity as of 2020 in wind power generation were China (282 GW), the USA (118 GW), Germany (62 GW), India (39 GW) and Spain (27 GW) (Figure 7c). Again, the total installed capacity according to solar power generation was in the order of China (254 GW), the USA (74 GW), Japan (67 GW), Germany (54 GW) and India (39 GW) (Figure 7d). With respect to geothermal power generation, the total installed capacities as of 2020 were in the order of the USA (2.6 GW), Indonesia (2.1 GW), the Philippines (1.9 GW), Turkey (1.6 GW) and New Zealand (1.0 GW) (Figure 6e). According to the IEA and Zhao et al. [5,51], in the past decade, Asia has evolved to be a major player in RE installation, and China has been a leader in the market expansion of RE; again, its openness to foreign investments regarding importing foreign renewable technology continues to evolve.

The above discussion shows that many countries have made efforts to integrate different sources of RE into their energy mix. However, regions like Africa, Australia and the Middle East are still lagging in RE generation compared to regions like Asia, Europe and North America. The low exploitation of RE in these regions may be attributed to less access to RE technologies and limited capital investment [13,18,51,55]. In fact, according to Duah et al. [56], Africa has the human capacity to develop its RE sector, but limited access to RE technologies makes the course difficult. Again, Duah et al. [56] attributed low development in the RE sector to finance and lack of political will to develop the RE sector.

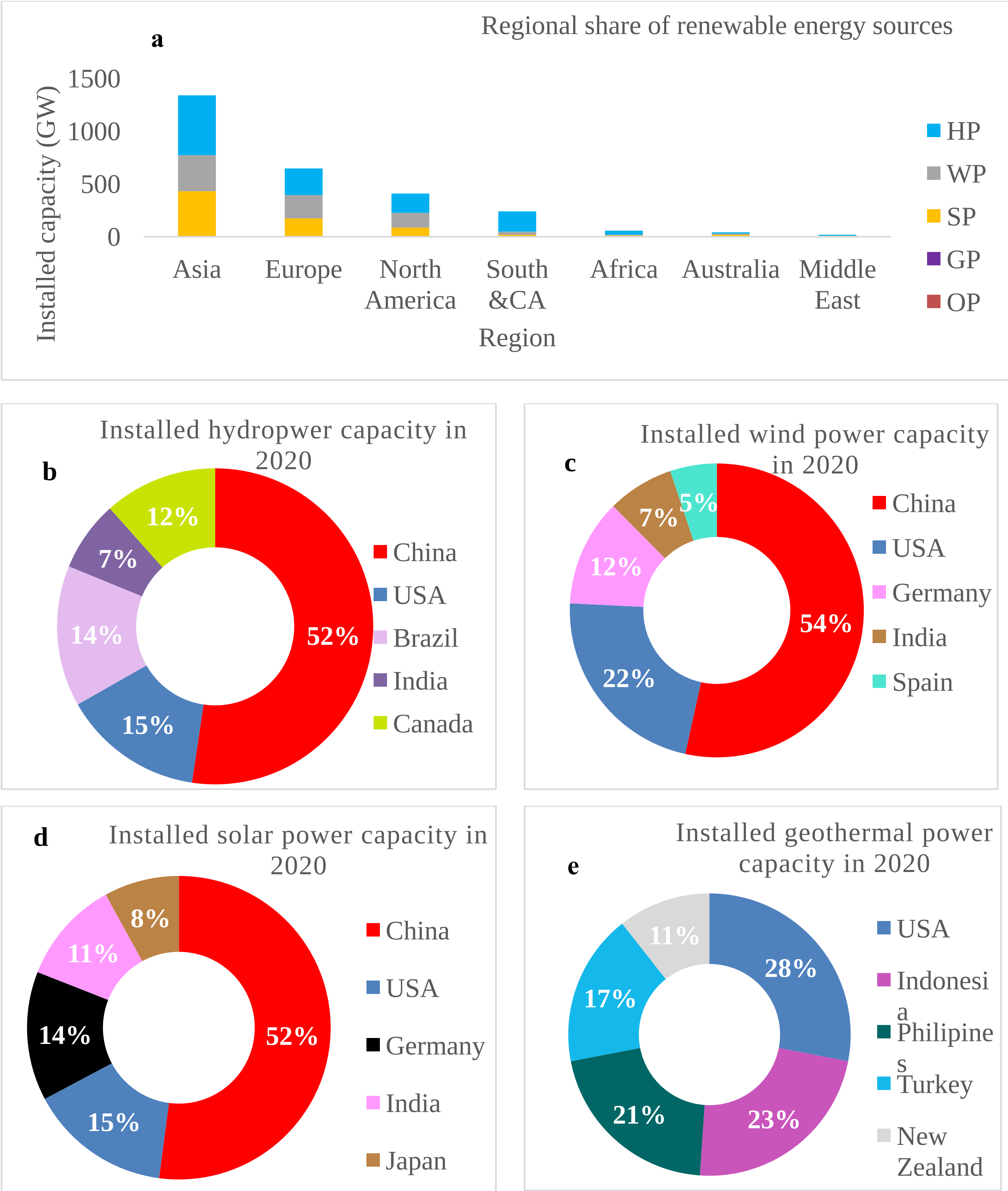

Figure 7. Renewable energy installed capacity for top five countries and regions. Source: direct analysis based on Our World in Data Report [42]; IRENA [48]; REN21 [50]; IHA [52] and IEA [51] Reports.

Note: CA: Central America

3.4. Energy development in Ghana

The energy mix of Ghana continues to be dominated by thermal energy fueled by crude oil, natural gas and diesel, hydroelectricity and solar power. To meet its energy demand, Ghana also imports from Cote D'Ivoire. However, Ghana also exports power to Togo, Benin and Burkina Faso. Ongoing grid expansions would allow further exports to other neighbouring countries in the sub-region [25]. Ghana has a vibrant power generation terrain, with players from both the public and private sectors. Reforms in the power sector in the 1980s gradually removed barriers and created a level playing field for the participation of independent power producers in an area that, hitherto, had only public sector participants.

The total installed capacity for existing plants in Ghana as of 2020 was 5,178.1 MW, consisting of 69% thermal power (3,549 MW), 30% hydropower (1,580 MW) and a little less than 1% solar power (49.1 MW) (Figure 8). The thermal power capacity is made up of 340 MW from Takoradi International Company (TICO), 330 MW from Takoradi Power Company (TAPCO), 110 MW from Tema Thermal 1 Power Plant (TT1PP), 110 MW from Cenit Energy, Ltd., 560 MW from Sunon Asogli Power Ghana, Ltd., 87 MW from Tema Thermal 2 Power Plant (TT2PP), 220 MW from Kpone Thermal Power Plant, 470 MW from Karpowership, 250 MW from Ameri Plant, 44 MW from Trojan, 95 MW from Genser, 203 MW from Amandi, 370 MW from AKSA and 360 MW from Cenpower. The hydropower capacity is made up of 1,020 MW from the Akosombo hydropower station, 400 MW from the Bui hydropower station and 160 MW from the Kpong hydropower plant. The solar power capacity is made up of a 2.5-MW Navrongo solar power station, 20-MW Gomoa Onyaadze solar station, 20-MW BXC solar power station, 6.5-MW Lawra solar plant and 0.1-MW Safisana Biogas facility (Table 5).

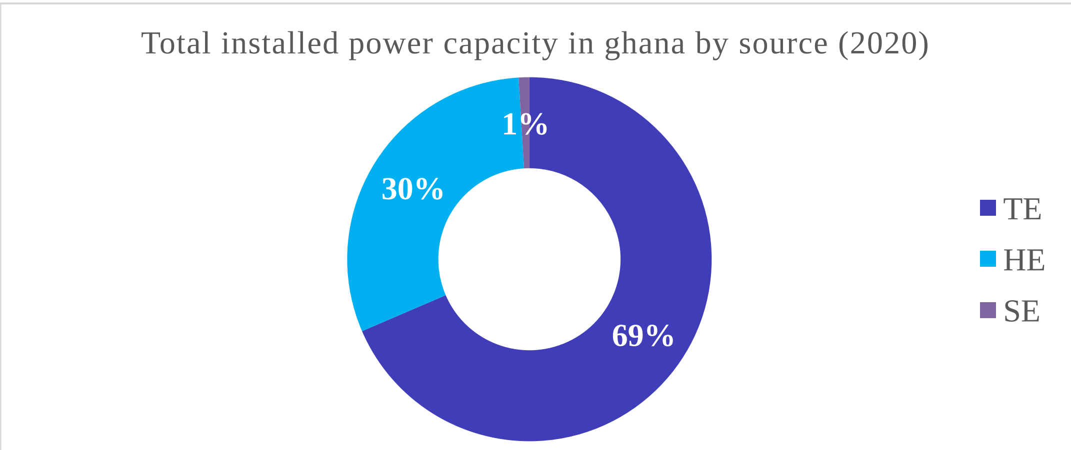

Figure 8. Installed power capacity in Ghana. Source: direct analysis based on National Energy Statistics [25]; Our World in Data [42] and IEA Reports [5].

Table 5. Installed and dependable capacities of power stations in Ghana.

TP plants	Installed capacity (MW)	Dependable capacity (MW)
Takoradi Power Company (TAPCO)	330	300
Takoradi International Company (TICO)	340	320
Tema Thermal 1 Power Plant (TT1PP)	110	100
Cenit Energy Ltd	110	100
Sunon Asogli Power (Ghana) Limited	560	520
Tema Thermal 2 Power Plant (TT2PP)	87	71.5
Kpone Thermal Power Plant	220	200
Karpowership	470	450
Ameri Plant	250	230
Trojan	44	39.6
Genser	95	85
Amandi	203	190
AKSA	370	350
Cenpower	360	340
Total	3549	3296.1
HP plants		
Akosombo	1020	900
Bui hydrolectric power station	400	360
Kpong hydroelectric station	160	105
Total	1580	1365
SP plants		
BXC solar power station	20	16
Gomoa Onyaadze solar stat	20	16
Navrongo solar power station	2.5	2
Lawra solar plant	6.5	6.5
Safisana Biogas	0.1	0.1
Total	49.1	40.6

Source: direct analysis based on National Energy Statistics by Energy Commission of Ghana [25].

Note: TP: Thermal power; HP: Hydropower; SP Solar power.

The grid electricity generation in Ghana has been mainly sourced from hydropower, but thermal power took the lead in Ghana's electricity generation starting in 2015 (Figure 9a and Table 6). Since 2015, the gap in electricity generation between hydropower and thermal power in Ghana has been widening, except between 2019 and 2018 (Figure 9b and Table 7). In fact, in 2019, the annual energy production (AEP) from thermal power and hydropower were 10,885 GWh and 7,252 GWh, respectively. Comparatively, in 2018, the generations were 10,195 GWh and 6,017 GWh, respectively. Thus, while AEP from thermal power increased by 7%, the AEP from hydropower increased by 21%. The recent narrowing of the gap between hydropower and thermal power generation can be attributed to rising energy demand and a recent power outage crisis that forced many factories to shut down; thus, thermal power, such as the 470 MW floating powership natural gas-powered plant from Karpowership, was seen as the quickest way to address the power crisis

In 2013, Ghana integrated electricity generation from solar power into its national electricity grid. In that year, the total installed capacity and AEP from solar power were 2.5 MW and 3 GWh, respectively. Since then, the total installed capacity and AEP from solar power gradually increased to up to 49.1 MW and 52 GWh in 2020, respectively, with the most recent installation coming from the 6.5-MW VRA Lawra solar plant in 2020 (Figure 9a,b). Thus, there is an indication that Ghana is making good progress in RE development. However, compared to thermal and hydro generation, Ghana needs to hugely expand its solar generation if it has any ambition of phasing out fossil fuel generation or achieving net-zero emissions. Perhaps, this goal can be achieved if Ghana would consider other renewable options such as wind and ocean energies. As a matter of fact, according to Baffoe et al. [57], Ghana has a technical potential for wind energy of 82.8 TWh yearly, and a total final electricity production of 6.9 TWh a year.

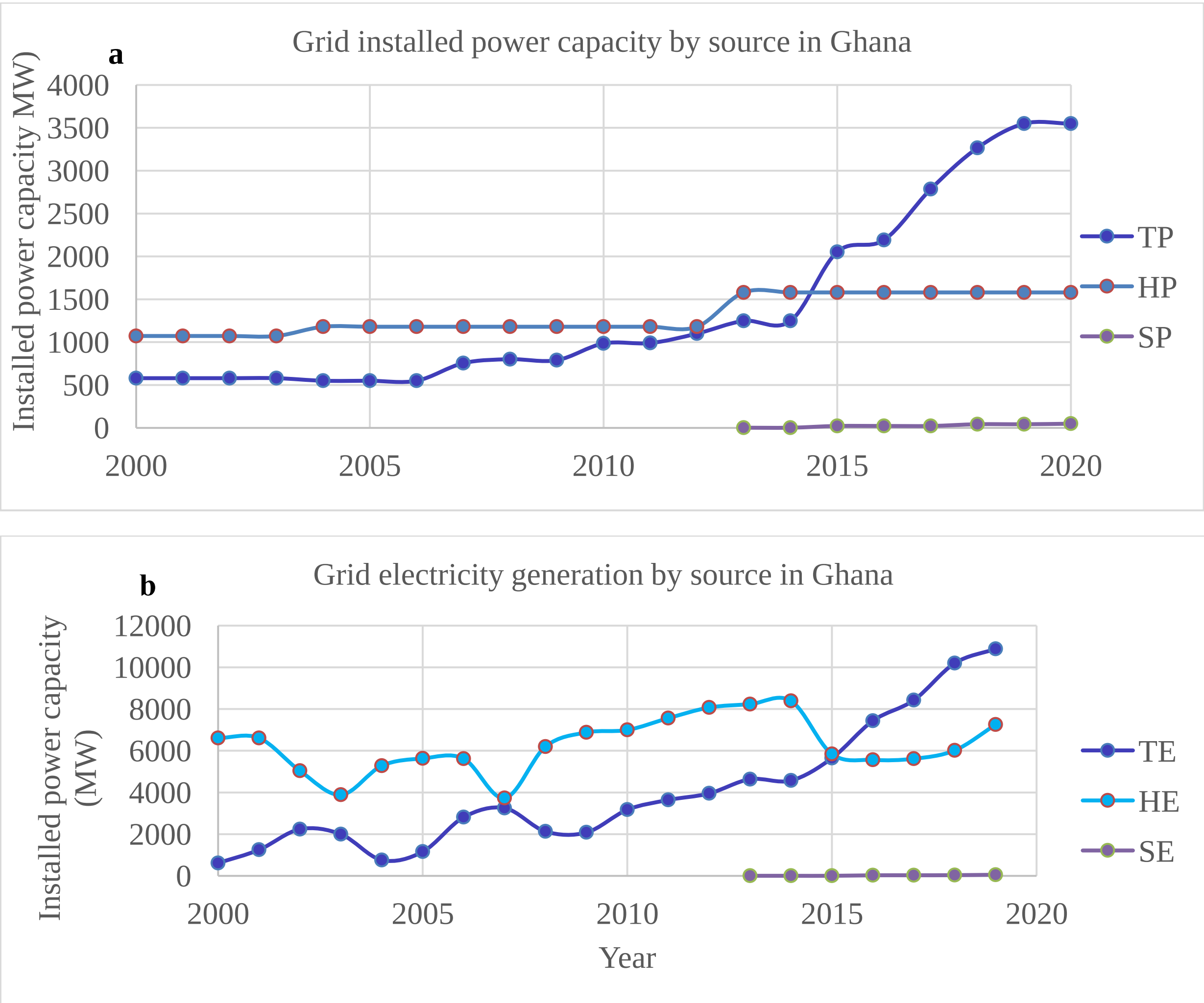

Figure 9. Trends of installed power capacity and AEP in Ghana. Source: direct analysis based on National Energy Statistics [25]; Our World in Data [42] and IEA Reports [5].

Ghana published a Renewable Energy Master Plan in 2019 with the aim to achieve the following by 2030: increase the proportion of RE in the national energy generation mix from 42.5 MW to 1,363.63 MW (with grid-connected systems totalling 1,094.63 MW), reduce dependence on biomass as the main fuel for thermal energy applications, provide RE-based decentralised electrification options for 1,000 off-grid communities and promote local content and local participation in the RE industry [30].

Table 6. Trends of installed and dependable capacities of energy sources in Ghana.

Installed Capacity (MW)					Dependable Capacity (MW)			
Year	HP	TP	SP	Total	HP	TP	SP	Total
2000	1072.00	580.00	0.00	1652.00	928.00	430.00	0.00	1358.00
2001	1072.00	580.00	0.00	1652.00	951.00	530.00	0.00	1481.00
2002	1072.00	580.00	0.00	1652.00	974.00	530.00	0.00	1504.00
2003	1072.00	580.00	0.00	1652.00	982.00	530.00	0.00	1512.00
2004	1180.00	550.00	0.00	1730.00	1040.00	500.00	0.00	1540.00
2005	1180.00	550.00	0.00	1730.00	1040.00	500.00	0.00	1540.00
2006	1180.00	550.00	0.00	1730.00	1040.00	500.00	0.00	1540.00
2007	1180.00	755.00	0.00	1935.00	1040.00	670.00	0.00	1710.00
2008	1180.00	801.00	0.00	1981.00	1040.00	695.00	0.00	1735.00
2009	1180.00	790.00	0.00	1970.00	1040.00	725.00	0.00	1765.00
2010	1180.00	985.00	0.00	2165.00	1040.00	900.00	0.00	1940.00
2011	1180.00	990.00	0.00	2170.00	1040.00	905.00	0.00	1945.00
2012	1180.00	1100.00	0.00	2280.00	1040.00	1005.00	0.00	2045.00
2013	1580.00	1248.00	2.50	2830.50	1380.00	1105.00	2.00	2487.00
2014	1580.00	1248.00	2.50	2830.50	1380.00	1187.00	2.00	2569.00
2015	1580.00	2053.00	22.50	3655.50	1380.00	1957.00	22.00	3359.00
2016	1580.00	2192.00	22.60	3794.60	1380.00	2119.00	22.00	3521.00
2017	1580.00	2785.00	22.60	4387.60	1380.00	2568.00	18.00	3966.00
2018	1580.00	3266.00	42.60	4888.60	1380.00	3058.00	34.00	4472.00
2019	1580.00	3549.00	42.60	5171.60	1365.00	3296.00	34.00	4695.00
2020	1580.00	3549.00	49.00	5178.00	1365.00	3296.00	41.50	4702.50

Source: direct analysis based on National Energy Statistics report by Energy Commission of Ghana [25].

Table 7. Trend of grid electricity generation by source in Ghana.

	Grid Electricity Generation (GWh)				Grid Electricity Generation (%)			
Year	HE	TE	SE	Total	HE	TE	SE	Total
2000	6610.00	614.00	0.00	7224.00	91.50	8.50	0.00	100.00
2001	6609.00	1250.00	0.00	7859.00	84.09	15.91	0.00	100.00
2002	5036.00	2237.00	0.00	7273.00	69.24	30.76	0.00	100.00
2003	3885.00	1996.00	0.00	5881.00	66.06	33.94	0.00	100.00
2004	5280.00	758.00	0.00	6038.00	87.45	12.55	0.00	100.00
2005	5629.00	1159.00	0.00	6788.00	82.93	17.07	0.00	100.00
2006	5619.00	2811.00	0.00	8430.00	66.65	33.35	0.00	100.00
2007	3727.00	3251.00	0.00	6978.00	53.41	46.59	0.00	100.00
2008	6196.00	2129.00	0.00	8325.00	74.43	25.57	0.00	100.00
2009	6877.00	2081.00	0.00	8958.00	76.77	23.23	0.00	100.00
2010	6995.00	3171.00	0.00	10166.00	68.81	31.19	0.00	100.00

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	Grid Electricity Generation (GWh)				Grid Electricity Generation (%)			
2011	7561.00	3639.00	0.00	11200.00	67.51	32.49	0.00	100.00
2012	8071.00	3953.00	0.00	12024.00	67.12	32.88	0.00	100.00
2013	8233.00	4635.00	3.00	12871.00	63.97	36.01	0.02	100.00
2014	8387.00	4572.00	4.00	12963.00	64.70	35.27	0.03	100.00
2015	5844.00	5644.00	3.00	11491.00	50.86	49.12	0.03	100.00
2016	5561.00	7435.00	27.00	13023.00	42.70	57.09	0.21	100.00
2017	5616.00	8424.00	28.00	14068.00	39.92	59.88	0.20	100.00
2018	6017.00	10195.00	33.00	16245.00	37.04	62.76	0.20	100.00
2019	7252.00	10885.00	52.00	18189.00	39.87	59.84	0.29	100.00

Source: direct analysis based on National Energy Statistics report by Energy Commission of Ghana [25] and Our World in Data [42].

Ghana depends on three main sources of energy for power generation: thermal energy (TE), HE and SE. All of the thermal plants in Ghana are either coal-powered or gas-powered, which poses a serious burden on the environment. In light of this, the study assesses whether the developments in HE and SE in the last two decades had any impact on TE production. The correlation (r) results among these three variables are summarised in Table 8, while the regression results are summarised in Table 9.

The results show a very high positive correlation and statistical significance between TE and SE generation ($r = 0.91$, $p < 0.01$). This indicates that there was a significant increase in SE production with respect to the increase in TE production over the past two decades. Conversely, the correlation between HE and TE was poorly positive and statistically not significant ($r = 0.16$, $p > 0.01$). This also indicates that the increase in HE production with respect to the increase in TE production in the past two decades was not significant. Again, there was a very low positive correlation and no statistical significance between HE and SE ($r = 0.06$, $p > 0.01$). This also means that the increase in SE with respect to the increase in HE in the last two decades was not significant. Thus, on the whole, Ghana added more TE to the national grid than the addition of SE and HE generation in the last two decades.

The regression results for SE with respect to TE generation, and with HE as a control variable, are presented in Table 9. It was observed that, in the past two decades, the development of HE generation had no significant influence on TE generation ($p > 0.05$), but the development in SE generation had a significant influence on TE generation ($p < 0.01$). The combination of SE and HE generation had a significant impact on TE production, i.e., $F(2, 18) = 44.40$, $p < 0.01$, with an adjusted R^2 of 0.82. These results show that the increased SE generation in the last two decades had a significant influence on TE production.

Table 8. Correlation analysis for TE and HE and SE production in Ghana.

	TE	SE	HE
TE	1.00		
SE	0.91**	1.00	
HE	0.16	0.06	1.00

**Correlation is significant at the 0.01 level (2-tailed).

Table 9. Regression analysis results for HE and SE with respect to TE production in Ghana.

Regression	Predictors	B	t	P(t)	Adjusted R^2	F	p(F)
	HE	0.25	1.11	0.28			
TE~HE+SE					0.82	44.40	0.00
	SE	184.22	9.28	0.00			

4. Discussion

4.1. Relationship between fossil, nuclear and renewable energy production in the world

The current study involved reviewing and analysing the correlations between developments in FE, NE and RE production in the world over the past two decades. Again, it involves the analysis of the impact of developments in RE production on FE production. In the last two decades, the correlation results revealed a highly positive and significant relationship between FE and RE production. There was also a significant impact of the production of RE on FE production.

These findings are consistent with similar studies conducted by Jackson et al. [58] and Kober et al. [59]. According to Jackson et al. [58], global FE and RE production have increased over the years, but FE production is increasing at a decreasing rate. The same assertion was made by [59], where it was also indicated that the increased development in RE production is responsible for the decreasing rate of FE production. This means that, in this era where climate change is posing a serious threat to the environment and human livelihood, the consistent increase in RE generation is one of the most powerful tools to mitigate climate change. As a matter of fact, countries such as France, Norway and Germany have recognised this fact; hence, they are currently utilizing about 98%, 84% and 80% of their hydropower potential, respectively, and shutting down some of their fossil-powered plants [60]. Again, the analysis revealed that an exclusive development in RE generation is sufficient to cause a significant impact on FE production. This is also true in the light of a study by Hook et al. [61], who determined that alternative energy sources such as RE have the potential to substitute FE production; however, it is going to require time and persistent increases in RE.

These findings represent important information, especially to the global energy forum, with regard to the scepticism surrounding the true impact of RE development on shaping the world's energy system [62]. According to Vliet et al. [62], many countries in Central and South Asia and the Asia Pacific, including China, have recognized this importance and are, therefore, seeking to replace fossil production with RE and synfuels by 2040. However, their study indicated that these regions need to supplement FE generation with carbon capture and sequestration technology in the short run.

The study has shown that it is feasible to transition from FE dependence to a clean and RE dependence. However, the acceleration of such a transition is slow due to a number of factors. According to Karatayev et al. [63], countries with huge reserves of fossil fuel are reluctant to commit to the carbon neutrality goal because it is a major backbone of their nation's economy. The study also argued that regional geopolitics and limited education on RE and its benefits to the environment were also contributory factors to slow RE penetration. Moreover, there is the fear that high dependence on RE could jeopardize energy security due to climate variability and other factors. Consequently, many have proposed the integration of a triple-energy system in which FE, RE and NE are jointly produced and consumed at the same time [64]. According to Lund et al. [65], FE production still dominates our energy system because there are still some technological gaps in RE generation that need to be improved in order to fully exploit the global RE potential. This was also espoused by Aized et al. [66], who indicated that improved and new RE technologies are the only way for RE to gain a competitive advantage over FE dependence. In a study by Chu et al. [67], the motivation for the continuous rise in RE is mainly the climate change impact; therefore, if climate change mitigation policies are properly designed and enforced, it will prompt many countries to quickly transition to RE. In support of this argument, it was pointed out that regions like Africa and South America have relatively low RE penetration in their energy system due to the fact that they contribute less to global warming in terms of greenhouse gas emissions [68]. This supports the findings of the present study, which revealed that Africa has the least penetration of RE.

In this regard, a collaboration between developed and developing countries is required to accelerate RE development. This is also encouraged to facilitate the accelerated attainment of climate change mitigation goals, such as the Paris climate agreement [69]. Regarding Europe, Connolly et al. [70] indicated that RE production is gaining more momentum due to the increasing threat of climate change and the dangers associated with nuclear radiation. It was also indicated that countries like France and Germany have decommissioned some of their nuclear power plants and compensated them with new solar systems and wind farms [71]. These support the study's findings that NE development decreased over the years as RE production steadily increased.

4.2. Relationships among sources of renewable energy production in the world

The present study also examined the inter-relationships among the various sources of RE development (BE, SE, WE and HE) and the impact of BE, SE and WE on HE generation in the world. The study found highly positive correlations between these energy sources. It also showed that the continued increase in BE, SE and WE generation in the past two decades had a significant impact on the development of hydropower generation.

These results are also consistent with similar studies in the literature. For instance, according to Owusu et al. [73], there has been consistent development in RE sources over the years, including BE, SE, WE and HE. The study further identified that the rate of SE and WE installation is increasing at a faster rate than HE development. This is attributed to the fact that most countries have already utilised their hydropower potential, coupled with the persistent decline in streamflow as a result of climate change [74]. Consequently, many countries are now finding BE, SE and WE more reliable and sustainable than HE. In fact, countries such as the USA and China have made it a major energy policy goal to expand their installed RE capacity by persistently increasing their solar and wind power capacity.

Currently, the USA and China make up 60% of the global installed wind power capacity. Similarly, major countries in Europe, such as Germany, Italy and Spain, are making significant increases in their photovoltaic (PV) solar installed capacity [74]. Moreover, Zhao et al. [75] indicated that the increased development in RE, excluding HE, is a sure way to alleviate energy poverty, especially in rural communities. The study indicated that, since hydropower development often requires water impoundment, it usually results in the displacement of people. Consequently, energy developers are now shifting more attention onto SE, WE and BE, which do not cause the displacement of people. This is also espoused by Mukeshimana et al. [77], who found that RE development, excluding HE, has a relatively low negative impact on the environment. These findings are very crucial to the push for the RE agenda to transform the energy system. As a matter of fact, Owusu et al. [73], revealed that the world is vastly underutilising its RE potential, with technological inefficiency cited as the major problem. In a similar study, Mukeshimana et al. [77] also identified financial constraints and sociocultural and political unwillingness as factors militating against RE penetration. According to Zhao et al. [75], addressing these problems represents a great opportunity to expand RE capacity.

The significant influence of BE, WE and SE on HE generation also means that the last two decades have seen a major improvement in the RE energy sector, excluding hydropower [78]. According to Tripathi et al. [78], RE, excluding hydropower, is becoming more prominent in India to curb greenhouse gas emissions and mitigate climate change. Likewise, Strachan et al. [79] indicated that RE sources are seen as effective tools to accelerate economic development, particularly in rural communities. In this line, Li et al. [80] proposed improvements in RE technologies and the mapping out of RE potential sites to facilitate a rapid transition to RE [81]. The above discussions show that the global energy system is progressively shifting in favour of RE. This is true in light of a study by Xu et al. [82], who projected a significant increase in RE generation in China.

4.3. Relationships among thermal, hydropower and solar energy production in Ghana

Thermal, hydropower and solar power plants are the three main power systems that supply the increasing energy needs of the growing Ghanaian population. Hence, the correlations between the generation from these energy sources were analyzed. Again, the impact of SE and HE generation on TE generation in the past two decades was also investigated.

The correlation analysis revealed a positively strong and significant link between TE and SE generation. The relationship between TE and HE was determined to be positively weak. Similarly, the relationship between SE and HE was found to be positively weak. Again, it was found that the exclusive production of HE had no significant influence on TE production, but when the production of HE was combined with SE, there was a significant effect on TE generation. These findings were consistent with extant literature, which also found a significant effect of HE and SE generation on TE generation in Ghana. According to a study by Boadi et al. [86], the weak correlation between HE and TE generation over the years was because of the persistent fall in the water level of the Aksosombo reservoir due to climate variability impact. The study ascertained a significant impact of climate change on HE generation from the Akosombo hydroelectric station. This was attributed to erratic and decreased rainfall in the Volta Basin. On the other hand, in a study by Boadi et al. [86], it was determined that TE generation in Ghana has consistently increased over the years, and it is projected to continue owing to the recent exploitation of natural gas in Ghana. The same study also supported the strong positive correlation between TE and SE generation in Ghana. It indicated that there has been a progressive increase in SE generation in the last decade. This finding was also espoused by Aboagye et al. [87], who indicated an improvement in Ghana's SE production over the years.

However, the study revealed that this improvement is below expectation; therefore, the government of Ghana has formulated a new RE policy to increase its SE capacity to 1363.63 MW by 2030. Even though the SE generation is below expectation, it is still crucial in the sense that it offers a great opportunity for Ghana to contribute its quota to climate change mitigation [88]. The significant impact of HE and SE generation on TE generation in Ghana also suggests the feasibility to substitute TE with RE in order to meet the sustainable development goal 7 (SDG7), which targets "clean and affordable energy for all". In order to attain this goal, Kuamoah [89] recommended a total revision of the energy policy of Ghana in order to extend subsidies to cover RE development. This recommendation was also backed by Mensah et al. [90], who proposed an effective implementation of Ghana's RE policy and the integration of RE into the energy system. Moreover, they found that the exclusive development of SE has a significant impact on TE generation. This also means that Ghana can effectively rely on SE development to achieve its rural electrification project, which aims at electricity access to all rural communities [91].

Again, Ghana can increase its energy capacity HP, SP and wind power. According to Arthur et al. [29], the Pra river has a high hydropower potential that can be exploited to increase the country's energy supply. From these, it can be inferred that the increase in the country's TE generation is not because Ghana lacks RE capacity, but because there is a lack of commitment to developing RE, coupled with many other factors. According to Merem et al. [92], some of these militating factors to RE development include poor infrastructure, low RE technology and partial implementation of RE policies. According to Danso et al. [93], Ghana has a high SE and WE potential that is adequate to halt the persistent power outages in Ghana if developed. This means that the significant influence of the RE sources on TE generation could be expanded in the future.

5. Conclusions

Energy is an essential commodity that affects the lives of everybody worldwide. For this reason, SDG7 emphasises clean and affordable energy for all. Hence, governments across the globe have implemented a variety of energy interventions to satisfy rising energy demand as a result of increased population, urbanisation and industrialisation.

According to the findings of the current study, the overall energy output in Ghana, and across the globe as a whole, have grown during the previous two decades. There was an upward trend in fossil and RE production and a slight downward trend in NE production in the world. Although FE output has grown over the previous two decades, it has increased at a decreasing rate. The increased RE production has had a significant influence on FE output, notably, electricity generation from fossil fuel-powered plants. In contrast to the declining rate of FE production, there was an increase in the production of HE and modern RE sources such as wind, solar, geothermal, and biofuels.

These findings should serve as a major motivator for world governments, RE organisations and climate change activists to fight for the growth of RE as a means of achieving clean energy systems and mitigating climate change. The integration of SE generation into Ghana's national grid has had a substantial impact on TE generation. In the recent decade, this has been seen in the growing output of SE. This information demonstrates the potential of SE to be a dependable energy source that might be exploited to improve electricity access in Ghana's rural areas.

Therefore, the following research topics might be investigated in light of future energy development in Ghana and the world as a whole. First, investigate the viability and sustainability of a clean energy system based on different RE sources and identify key vulnerabilities. Second, assess the potential for RE development and determine implementation strategies that would supplement or replace existing FE production. Third, appraise the RE potential (solar, wind, ocean, biofuel) of Ghana, map out prospective locations and identify implementation obstacles. Finally, investigate and recommend efficient RE technologies for solar, wind, ocean and bioenergy production for increasing RE output.

Conflict of interest

The author declares no conflict of interest in this study.

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