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Powering Ghana's future: unraveling the dynamics of electricity generation and the path to sustainable energy

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Abstract

This study investigates powering Ghana's future: unraveling the dynamics of electricity generation and the path to sustainable energy by estimating endogenous parameters and employing an unrestricted Vector Autoregression (VAR) model. The model examines the linear lead–lag relationships between variables in the Ghanaian electricity sector and power consumption, using data from 2002 to 2021. The results reveal structural long-and-short-run headwinds for the unrestricted models and indicate that the growth rate of the Gross Domestic Product (GDP) and electricity from fossil fuels are directly correlated. Granger causality analysis highlights a feedback relationship between GDP growth rate and electricity from fossil fuel sources. The impulse response function reveals that the GDP growth rate is sensitive to exogenous shocks with lasting effects. Variance decomposition results show that renewable energy without hydropower explains a minimal variance due to shocks, while total global greenhouse emissions account for a significant proportion of the variance due to headwinds. Electricity from fossil fuel sources explains a substantial part of the variance due to headwinds, suggesting Ghana's overreliance on conventional energy sources. The study forecasts that installed renewable energy capacity will experience considerable growth by 2036, accounting for most of the energy mix. To promote a sustainable energy future, the study recommends implementing fiscal instruments that incentivize renewable energy consumption, gradually diversifying the energy mix towards natural gas as a medium-term transition fuel for grid electricity generation and shifting entirely to renewables in the long time. This research contributes valuable insights into the dynamics of electricity generation in Ghana and provides policy recommendations for sustainable energy development.

Keywords Sustainable energy, Electricity generation, Vector autoregression (VAR), Ghana's power sector, Renewable energy policy

Introduction

Ghana's electricity generation dynamics disproportionately lean toward traditional sources of energy generation. Conventional sources comprise approximately 68.8% of the generation mix, followed by hydropower at 29.1% and the rest of renewable energy sources (RES) at 2.1%, respectively, Energy Commission of Ghana [1]. The country's overreliance on fossil fuels makes its energy insecure, threatening economic growth and development. Although the country's import bill has been reduced, the government continues to import gas from the West African Gas Pipeline (WGP) to generate electricity [2, 3]. Given this, our study seeks to provide an empirical analysis of the electricity generation dynamics of the Ghanaian power sector with the generation and supply aspects in mind. As things stand, Ghana spends more than a third of its GDP on importing energy to power its economy, which is not sustainable. Hydropower dominated Ghana's

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electricity generation until 2015, when thermal sources overshadowed most of the generation mix. This comes after the power sector deregulation, which saw the formation of independent power producers (IPPs) alongside government-owned power plants in the country. Although the government still controls utility fees, the country has implemented reforms in the power sector that encourage participation from the private sector. This is called the 'unbundling' of the energy sector.

The country's energy consumption is mainly consumed by the industrial and residential sectors, with a per capita consumption of 540 kWh. According to [1], the country's electrification rate was approximately 87% in 2020. In 2019, the total energy supply was 12.52 billion kilowatt-hours (bn kWh). Ghana aims to achieve total electrification capacity by 2030 and installs a 10% deployment of RES. In 2019, the final electricity consumption was 15.5 TWh, and the cumulative carbon dioxide emissions were 18.5 megatons (mt). Furthermore, Ghana's total reliable capacity is 4738.6 MW, an increase of 13% in installations in 2017–2018 [1]. On the other hand, the installed generation capacity connected to the grid was 4990 megawatts (MW) in 2019; 4580 MW are active and running. When integrated supply and solar are added, the total capacity goes up to 4990 megawatts (MW) [4].

In 2020, electricity generation increased to 20,170 gigawatts (GW) [1]. This is due to the increase in demand from about 30.1 million people, with the yearly power demand rising by 10%. The country's gross domestic product (GDP) is approximately 61.6 billion dollars [1]. The country's GDP can grow even faster if there is enough energy to turbocharge growth. An alternative source of reliable energy is renewable energy sources (RES). However, RES continues to form an insignificant part of the generation energy mix. Meanwhile, Ghana is a signatory to the Paris Agreement that seeks to ensure access to cleaner energy sources by 2030 and meet its nationally determined contributions(NDCs) [5, 6].

Consequently, concerning the full electrification program, the government added to the already existing Nationally Determined Contributions (NDCs) to improve and grow access to efficient cooking stoves by 2030 by supplying about two million of those stoves [7]. In addition to bridging the access gap, the country seeks to decrease the electrification rates between urban and rural centers by 87% and 60% by taking steps to reduce the costs of power connection to the national grid because of the low-income levels of the populace and due to places, that are not economically viable to generate or extend power to [7]. Given this, multilateral development institutions, such as the World Bank, are working assiduously to scale up mini-grid solutions to close the access gap via financial backing [4, 7].

Similarly, there were deficits in power supply in the late 2000s, so the government entered into a contract with IPPs to supply power to meet the supply deficit, which led to excess supply costing the state much money on a 'take it or pay it" basis [8, 9]. This surplus capacity led the government to enter into a 43-power agreement to avoid $680 million in annual debt. All this was compounded by high management inefficiencies and operational costs that exacerbated the dire financial situation of the power sector [4]. The energy sector debt will be $12.5 billion by 2030 [4, 11]. To help deal with the deficit in the industry, the government set up the Energy Sector Levy Act Commission (ESLAC), a special purpose vehicle (SPV), as a limited liability company to tackle the debt issue [10]. The Public Utilities Regulatory Commission (PURC) reviews tariffs, and the average user tariffs are 13–15 cents per kWh [4]. Despite these adjustments, the tariff rates in Ghana are among the highest in Africa [11], making the sector unable to raise enough funds to pay for its operating expenses.

Concerning the empirical analysis, the study deploys an unrestricted VAR model that innovates the study by breaking down these parameters to examine their observed outcomes [12, 13]. The VAR approaches the endogenous parameters to their unrestricted functions in a granular way. This article takes a different approach to analysis using an unrestricted VAR model to estimate the linear lead–lag dynamic relationship among GDP growth rate, electricity from renewable sources excluding hydroelectric power, Ghana's total greenhouse gas emissions, the pump price per liter for gasoline, electricity from fossil fuel sources. The reason for using this VAR model is that it allows one to identify shocks and determine their impact on the electricity sector over long and short periods. The contributions of this paper are that it uses unrestricted VAR model to empirically understand shocks and the behavior of these variables, especially energy crises, on the energy generation dynamics and trends, as well as forecasting these variables to determine their tendencies, which makes this paper unique. This offers practical importance for policy formulation and implementation to change the electricity generation situation in Ghana, which is skewed toward thermal sources. Some of these options include macroeconomic and fiscal policies that will incentivize private participation and engender consumption, such as tax rebates and simplifying the licensing process beyond regulatory incentives.

Research objectives

The objectives of this study on the Unraveling the Dynamics of Electricity Generation and the Path to Sustainable Energy are as follows:

1. Examine Ghana's electricity generation sector composition and trends.
2. Identify the impact of shocks on the electricity sector using an unrestricted VAR model.
3. Assess the effectiveness of current energy policies and reforms.
4. Develop evidence-based policy recommendations for a sustainable electricity generation sector.

Contribution to literature

By employing an unrestricted Vector Autoregression (VAR) model, the study offers a unique perspective on the linear lead–lag dynamic relationships among crucial variables such as GDP growth rate, electricity from renewable sources excluding hydroelectric power, total greenhouse gas emissions, pump price per liter for gasoline, and electricity from fossil fuel sources. This detailed analysis helps identify shocks and their impact on the electricity sector over long and short periods.

Also, the study's innovative approach allows for a better understanding of how energy crises and other shocks impact Ghana's energy generation dynamics and trends. This insight can be valuable for policymakers and stakeholders when considering potential responses to concerns or anticipating future challenges.

Third, by analyzing the electricity generation situation in Ghana and its dependence on thermal sources, the study offers practical insights for policy formulation and implementation. This includes suggestions for macroeconomic and fiscal policies that incentivize private participation and promote consumption, such as tax rebates and simplifying the licensing process beyond regulatory incentives.

Fourth, the study highlights the efforts of multilateral development institutions, such as the World Bank, to close the electricity access gap in Ghana through financial backing and support for mini-grid solutions. This aspect emphasizes the importance of international cooperation in addressing energy access disparities.

Finally, by examining the government's initiatives to tackle the energy sector's financial challenges, such as the Energy Sector Levy Act Commission (ESLAC) and tariff adjustments, the study offers a comprehensive overview of the policy landscape in Ghana's electricity generation sector. It also raises awareness about the high tariff rates in the country and the need for further reforms to ensure the sector's sustainability.

Literature review

Countries worldwide are switching their generation mix to newer and cost-competitive energy sources due to environmental concerns, thus the grid modernization. Ghana is not left out of this global drive to modernize the national grid. Ghana's electricity generation sector has attracted considerable attention from scholars. The industry is overly dominated by fossil fuels, making the sector reel with debts and associated problems. This sector reviews the literature on the dynamics of the generation of the power sector. Here, we review the literature on the country's electricity generation and supply aspects.

Recent research has highlighted the significant implications of access to energy for global development and health outcomes. Bekun et al. [14] examined the applicability of the environmental Kuznets curve (EKC) for emerging industrialized economies (E7), considering institutional quality and renewables. The study validates the EKC phenomenon, emphasizing economic expansion over environmental quality, and suggests that policymakers prioritize environmental quality and clean energy transition. Adedoyin et al. [15] investigated the environmental impact of economic complexities in the EU, taking into account Brexit and other crisis events. They reveal that tourism, real GDP per capita, and energy use increase carbon emissions in some regions. Brexit and the Greece bailout crisis have varying effects on emissions, but the EKC hypothesis holds in both scenarios, implying policy directions for post-Brexit EU-UK relations.

According to Caglar et al. [16], trade openness and economic complexity improve environmental quality, while economic growth, natural resources, and public–private partnerships degrade it. Policymakers are advised to improve environmental quality in BRICS economies. Bekun et al. [17] also, confirm the presence of the EKC phenomenon and tourism-induced emissions and suggest a shift to sustainable tourism development and adoption of polluters pay principles.

Bekun et al. [18] examines the effects of renewable energy, non-renewable energy, economic growth, and investment in the energy sector on CO2 emissions in India. The study finds that renewable energy reduces CO2 emissions, while non-renewable energy and real GDP growth increase them, implying the need for policy direction toward environmental sustainability in the Indian economy.

Acheampong et al. [19] investigates the relationship between energy access and income inequality. They find that access to electricity reduces global income inequality, while access to modern and clean energy increases it. Rural and urban electrification can reduce global income inequality, with urban electrification having a greater impact. The study suggests that access to energy can moderate the impact of economic growth and education to improve global income inequality, with employment, economic growth, education, gender empowerment, industrialization, and health as potential channels through which energy access influences income inequality.

Acheampong et al. [20] examines the impact of access to electricity and clean energy on human development. They find that access to both electricity and clean energy can improve human development, with economic growth, trade openness, foreign direct investment, urbanization, access to credit, and remittance enhancing human development. Employment, industrialization, economic growth, ICT, and gender empowerment are critical channels through which energy accessibility influences human development. However, access to electricity and clean energy worsens human development in South Asia, highlighting the importance of context-specific policy solutions.

Shobande [21] examines the link between electricity use and health in Africa. They find that short- and long-run causalities exist between electricity consumption and health across the panels of seven African countries, with unidirectional causal flow from electricity consumption to mortality. The study recommends the electrification of Africa as a way of averting major public health problems. Related research [22] examines the permanent and transitory effects of electricity and solid fuel use on health in Africa. They find that access to electricity reduces health risks associated with burning solid fuels in Africa.

Furthermore, Shobande [22] find that the levelized cost of Solar Energy (LCOE) of diesel thermal plants is as high as Gh < 351.44 kWh and Solar thermal plants to Ghana. Alemzero et al. and Khah et al. [23, 24] estimated that wind energy costs had fallen by 30% in Africa between 2010 and 2019. [25] find renewable energy to promote economic growth in Ghana and attract foreign direct investment. Energy efficiency is an essential aspect of power generation in Ghana, as Never et al. [26] believed it is vital for the environmental security of Ghana. Also, Adjei-Mantey and Adusah-Poku [27] stated that socio-economic factors in the form of poverty and reduced education levels act as obstacles to the acceptance of light bulbs in Ghana.

In recent years, after the deregulation of the electricity sector in Ghana, the power sector has seen a significant transformation, with IPPs playing an essential role in power generation [28]. Ghana generates enough electricity to power its economy. However, it comes mainly from fossil fuel sources [29]. Although Ghana now has adequate energy and generates enough electricity, household electricity for cooking is very low, with about 20% access to modern cooking solutions [30]. Ghana spends about 27% of its GDP on imported fuels to power its development, regardless of the abundance of local RES. A study by [31] finds that the social cost of owning an internal combustion engine vehicle is greater than 164% and that the generation of RES in the energy mix below 20% harms the environment. This calls for scaling up the deployment of electric vehicles (EVs) and the infrastructure development necessary to enable sector uptake. The study agrees that electric vehicles will drastically reduce emission levels in the country, up to 33%, with a single diesel engine replaced [32].

Furthermore, RES, seen as the panacea to the current energy crisis, sought to determine the degradation of solar photovoltaic (PV) under varied climate conditions in Ghana [33]. This will ensure that the country adopts the most suitable and environmentally benign ones. With the private sector as the right partner to ensure the deployment of RES, such as solar, empirical work supported this assertion. They asked the Government of Ghana to improve its newly designed policy to attract private sector participation and extensively implemented it [34]. They opined that solar energy could bring about off-grid access through PPPs models.

Consequently, as Ghana's emissions levels increased, Jacobson et al. [35] utilized the Stochastic regression to determine the de facto political, economic, and social internalization of Ghana's pollution levels and produced dichotomous results that explained that a negative and positive variation in carbon dioxide emissions, in the long run. In contrast, a negative variation and position variation in political internationalization reduced carbon dioxide emissions. Atanga et al. [36] estimated that about 85% of the aggregate land mass in Ghana is appropriate for solar energy deployment. This potential can meet the energy needs of the country sustainably and over. However, the government has not explored this solar potential to the fullest. In justifying the cost-competitive nature of solar energy for Ghana, Yankey et al.[37] estimated the levelized cost of solar energy (LCOE) and arrived at the cost of \$0.04/k -\$0.15/kWh for utility-scale solar and \$0.73/kWh to \$2.89/kWh for concentrated solar photovoltaic. Results reported [38] suggested that installing photovoltaics in Ghana can generate electricity at lower costs and limit greenhouse gas emissions. A recent analysis by [31] revealed that the Densu river has the technical potential for nine hydroelectric dams to generate approximately 55.7 GWh of yearly electricity. Similarly, Ceballos-Escalera et al. [39] using the theory of social practice, vulnerability, and urban resilience relying on primary data to determine daily energy practice among households and business units in some parts of Accra, discovered that the poor turning to the use of charcoal and the rich resorting to the use of diesel [40] emphasized the importance of seasonality to electricity market trade within the West African Power Pool (WAPP). They used a global hydrological model to multi-region capacity expansion and planning model and discovered that the seasonal transition variation reduced the hydroelectric electricity supply by 40%. Additionally, Afful-Dadzie et al. [41] hypothesized that Ghana faces challenges in electricity generation in the form of costs from renewable energy and that the levels of demand deficit are as high as 18.5%, in line with the scenario of a 10% renewable energy target by 2030. This is a case study analysis regarding Ghana. Kukah et al. [42] proposed using a ranking-type Delphi survey to establish a complete list of critical success factors for private–public partnership projects (PPP) of power projects. They discovered that of the 37 critical success factors (CSFs), nine are very important, while five are ranked highest, such as shared authority, debt guarantee to the private sector to enable them to raise funding from international markets, appropriate risk allocation, and risk sharing. The importance of energy-efficient use has been explored by [43] in their study in which they used fully modified least squares(FMOLS) and Canonical cointegration methods between 1984 and 2014 to evaluate the relevance of technological progress and sectoral development, which have impacted electricity consumption in Ghana, and discovered that technology showed an inverse relationship with energy consumption. Whereas sectoral growth in the services and industry sector directly correlates with energy consumption, depicting energy inefficiency.

In summary, the scholars concluded that Ghana faces an unsustainable energy consumption trajectory, that the trend is costly for electricity generation, and that renewables are the country's best bet to deploy, yet renewables are the least deployed. Therefore, sector restructuring is vital to ensure sustainable economic growth.

Methodology

Model estimation

The study employs Vector autoregression (VAR), a statistical model used in econometrics to capture the interdependence among time series variables. It is widely used in macroeconomics and finance to model the dynamic interactions among economic variables such as output, inflation, interest rates, and stock prices. One of the significant benefits of using VAR models is that they can capture the dynamic relationship between variables, which is vital for understanding how changes in one variable affect the others. VAR models can also help predict future values of the variables in the model, which is crucial for decision-making purposes.

Moreover, VAR models can also be used to analyze the transmission of shocks across different economic sectors and assess policy interventions' effectiveness. VAR models have proven to be a valuable tool in identifying the channels through which monetary policy affects the economy and can also be used to evaluate the effectiveness of fiscal policies. The Vector autoregression regression (VAR) is a multivariate stochastic process of vector generalization of scalar autoregression. It talks about cointegration that implies casualty among variables. Sometimes it is cumbersome to determine which variables to use as the dependent variable when estimating the relationship among variables. More so, economic principles sometimes cannot decide which variables to use as the explained parameter and the exploratory variables. Given this background, the VAR is the appropriate model since all variables are considered endogenous. Similarly, the VAR model was mooted by Sims [34, 44] for the first time and was made famous by [45]. The study is evaluated using statistical software packages such as Stata and EViews.

$$X_{1t} = \beta_0 + \beta_{11}X_{2t} + Q_{11}X_{1t-1} + Q_{12}X_{2t-1} + \epsilon_{1t} \tag{1}$$

$$X_{2t} = \beta_0 + \beta_{22}X_{1t} + Q_{21}X_{2t-1} + Q_{22}X_{2t-1} + \epsilon_{2t} \tag{2}$$

$$X_{3t} = \beta_0 + \beta_{23}X_{2t} + Q_{23}X_{3t-1} + Q_{24}X_{3t-1} + \epsilon_{3t} \tag{3}$$

$$X_{4t} = \beta_0 + \beta_{34}X_{3t} + Q_{44}X_{4t-1} + Q_{34}X_{4t-1} + \epsilon_{4t} \tag{4}$$

$$X_{5t} = \beta_0 + \beta_{45}X_{4t} + Q_{55}X_{5t-1} + Q_{45}X_{5t-1} + \epsilon_{5t} \tag{5}$$

These equations are presented in a matrix as follows.

$$\left[= \begin{pmatrix} 1 & -\beta_{11} \\ -\beta_{12} & 1 \\ 1 & -\beta_{23} \\ -\beta_{34} & 1 \\ 1 & -\beta_{45} \\ -\beta_{55} & 1 \end{pmatrix} + \begin{pmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \\ Q_{23} & Q_{24} \\ Q_{34} & Q_{44} \\ Q_{55} & Q_{45} \\ & \end{pmatrix} + \begin{pmatrix} X_{t-1} \\ Xt_{-3} \\ Xt_{-4} \\ Xt_{-5} \end{pmatrix} + \begin{pmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \\ \epsilon_{4t} \\ \epsilon_{5t} \end{pmatrix} \right] \tag{6}$$

The above equation cannot be regressed directly because the stochastic term is linked to the ϵ_{1t},$\epsilon_{2t}\epsilon_{3t}$, ϵ_{4t} is associated with ϵ_{5t}. Since the regressors in the structural form are linked to the stochastic term, there is likely an endogeneity.

The matching diminished form is given in an expanded form below.

$$X_{1t} = \omega_{01} + \omega_{11}X_{2t} + \omega_{11}X_{1t-1} + \omega_{12}X_{2t-1} + e_{1t} \tag{7}$$

$$X_{2t} = \omega_{02} + \omega_{12}X_{2t} + \omega_{21}X_{1t-1} + \omega_{22}X_{2t-1} + e_{2t} \tag{8}$$

$$X_{3t} = \omega_{03} + \omega_{23}X_{3t} + \omega_{23}X_{2t-1} + \omega_{22}X_{2t-1} + e_{2t} \tag{9}$$

$$X_{4t} = \omega_0 + \omega_{34}X_{4t} + \omega_{44}X_{4t-1} + \omega_{44}X_{2t-1} + e_{4t} \tag{10}$$

Order selection

Since the study estimates the multivariate of the VAR model with orders of 1 to P, it is proper to estimate it. It is interesting to observe the residual of the models. Thus, a more realistic approach is given below. A relevant criterion for the selection of model order for the different variable's extension for the Akaike and Schwarz information criteria is given below.

$$AIC = Log\left|\widehat{\sum\nolimits_P} + 2M^2P\right| TP = 1, ..2, \ldots .P \tag{11}$$

$$SIC = Log\left|\widehat{\sum\nolimits_P} + (log)m^2P\right| TP = 1, \ldots 2, \ldots \ldots P \tag{12}$$

Hence, $|\widehat{\sum_P}$ depicts the causal factor of the residual covariance of the VAR_p model, and T portrays the number of effective observations. This model works best even if the explained vector contains unit roots[41].

Data

The study relies on data from the World Bank Development Indicators (WDI) between 2002 and 2021 to estimate the dynamics linear lead–lag relationship of the variables regarding the electricity generation mix of Ghana. The study uses an unrestricted VAR model to determine how these endogenous parameters work to impact the energy mix. The growth rate of the gross domestic product (GDPGRWT) is one of the endogenous parameters. This will allow the study to understand how GDP impacts the country's electricity generation. Undoubtedly, no country progresses socioeconomically without access to adequate energy.

Similarly, another endogenous parameter is electricity generation from fossil fuel sources (EFOSST). Ghana generates more than 70% of its electricity from conventional energy sources. Electricity from renewable energy sources without hydropower (ELRESXHDY) is equally evaluated to determine the contribution of RES sources to electricity generation in the country. In addition, we have the total greenhouse gas emissions (TGHE) in Ghana. This is also assessed to determine the country's pollution levels (PPGPLIT). Ultimately, PPGPLIT explains the price per liter at the pump of gasoline. Ghana consumes much gasoline in the transport, agriculture, and manufacturing sectors. Hence, the imperative to examine the importance of this variable. Before the analysis, the variables were assumed to be stationary as it is not a necessary precondition to the examination process (Table 1).

The percentage of total electricity production from oil, gas, and coal sources is a critical variable that demonstrates a nation's reliance on fossil fuels for electricity generation. Prior research emphasizes the environmental and economic implications of depending on non-renewable energy sources for electricity production, such as heightened emissions and vulnerability to global market price fluctuations [48] fit, therefore, important consider this in this research. Another vital variable is the percentage of total electricity production from renewable sources, excluding hydroelectric power. This measure reflects the contributions of alternative renewable energy sources, like solar and wind power, to the overall

Table 1 Variable definition. Source: WDI/https://data.worldbank.org/country/GH [47]

Variable	**Definition**	**Source [46]**	**Measurement**
Electricity production from oil, gas, and coal sources (% of total)	Sources of electricity refer to the inputs used to generate electricity. Oil refers to crude oil and petroleum products. Gas refers to natural gas but excludes natural gas liquids	World Development Indicators	Percentages
Production of electricity from renewable sources, excluding hydroelectric (% of total)	Composed of CO2 totals that exclude short-cycle biomass burning (such as agricultural waste burning and savanna burning) but include other biomass burning	World Development Indicators	Percentages
Pump price for gasoline (US$ per liter)	Fuel prices refer to the pump prices of the most widely sold gasoline. Prices have been converted from local currency to US dollars	World Development Indicators	US$ per liter)
GDP growth (annual %)	The annual percentage growth rate of GDP at market prices based on constant local currency	World Development Indicators	Percentages
Total greenhouse gas emissions (% change from 1990)	Total greenhouse gas emissions are composed of total CO2 excluding short-cycle biomass burning (such as agricultural waste burning and savanna burning) but including other biomass burning	World Development Indicators	Percentages

electricity generation. Evaluating progress towards a more sustainable energy mix and the potential to reduce greenhouse gas emissions is crucial for achieving long-term environmental goals [49].

The pump price for gasoline (measured in US$ per liter) is an essential variable representing the consumer-level gasoline cost. This metric is relevant to our study since it affects energy consumption patterns and can influence economic growth and emission levels [50]. Higher fuel prices may encourage the adoption of more energy-efficient technologies and transportation methods [51]. Also, The annual GDP growth rate serves as a measure of a country's economic growth. Including GDP growth is critical since it is frequently correlated with increased energy consumption and emissions. Understanding this relationship is essential for developing effective policies that promote sustainable development [52–54].

Lastly, the percentage change in total greenhouse gas emissions since 1990 is a crucial variable for evaluating the success of current policies and initiatives designed to mitigate climate change. Assessing progress toward national and international emissions reduction targets is vital to ensure long-term environmental sustainability [52].

Table 2 Descriptive statistics. Source: Authors' estimates

	EFOSST_	ELRESXHDY	GDPGRWT	TGHE_	PPGPLIT
Mean	5.743783	0.004014	5.704741	139.4096	0.312500
Median	0.000000	0.000000	5.750002	177.9197	0.000000
Maximum	38.84779	0.030857	14.04712	320.6482	1.060000
Minimum	0.000000	0.000000	0.000000	0.000000	0.000000
Std. Dev	10.62125	0.009880	3.246496	133.4096	0.423256
Skewness	1.914978	2.027200	0.437260	− 0.05264	0.714309
Kurtosis	5.930881	5.234799	3.652748	1.135933	1.683751
Jarque–Bera	19.38219	17.86040	0.992389	2.904857	3.144551
Probability	0.000062	0.000132	0.608843	0.234001	0.207572
Sum	114.8757	0.080273	114.0948	2788.192	6.250000
Sum Sq. Dev	2143.408	0.001855	200.2550	338,164.2	3.403775
Observations	20	20	20	20	20

Results and discussion

Table 2 is the descriptive statistics of the unrestricted VAR model that analyses the dynamics of in-electricity generation of the Ghana power sector. As the table shows, electricity from fossil fuel sources derives the highest mean value. This is so because Ghana generates almost 70% of its electricity from thermal sources. The GDP growth rate is the next variable with the highest mean, showing that Ghana experienced a significant GDP rate in the mid-2000s; the mean was higher. It was seen as the fastest-growing economy in the African continent. Furthermore, electricity from renewable resources, excluding hydropower, has the lowest mean value, as Ghana does not generate much from RES. Ghana's total greenhouse gas has been on a growing trajectory since 2010, when the country began to explore and develop hydrocarbons.

Furthermore, in Table 3, the correlation matrix explains the relationship with the variables. The correlation between RES electricity, excluding hydropower, is significantly related to electricity from fossil sources. This direct correlation implies that there is a need to generate electricity from other renewable sources to replace fossil fuel sources that are very expensive and pollute the environment. Another interesting correlation exists between electricity from renewable sources, excluding hydropower, and total greenhouse gas emissions. The correlation is adverse. This means that as RES consumption increases, emissions decrease. Hence, RES abates greenhouse gas pollution.

Similarly, Table 4 shows the results of the VAR model. In the model where the total greenhouse gas (TGHE) is the explained parameter, its second lag is significant with a direct correlation. The significance implies an expansion in emissions levels in the country as the economy grows [55]. The levels of greenhouse gas emissions increased in the 2010s when the nation discovered oil. Similarly, electricity from fossil fuel sources

Table 3 Correlation matrix

	EFOSST_	ELRESXHDY	GDPGRWT	TGHE_	PPGPLIT
EFOSST_	1	0.680652906	0.145820915	− 0.13120634	0.039199212
ELRESXHDY	0.680652906	1	− 0.236258719	− 0.446830915	0.095941759
GDPGRWT	0.145820915	− 0.23625872	1	0.494582915	0.124347108
TGHE_	− 0.13120634	− 0.44683091	0.494582915	1	0.206886986
PPGPLIT	0.039199212	0.095941759	0.124347108	0.206886986	1

Table 4 VAR results. Source: Author's calculations

ppgplit		**The**		**efosst**		**Gdpgrwt**		**Elresxhdy**	
L.ppgplit	− 0.295	L.ppgplit	− 18.5	L.ppgplit	37.42***	L.ppgplit	− 3.035	L.ppgplit	0.0239***
	(− 1.19)		(− 0.30)		− 12.88		(− 1.92)		− 7.72
L2.ppgplit	0.526	L2.ppgplit	− 2.635	L2.ppgplit	35.11***	L2.ppgplit	− 1.386	L2.ppgplit	0.0184***
	− 1.81		(− 0.04)		− 10.34		(− 0.75)		− 5.06
L.tghe	− 0.000271	L.tghe	0.186	L.tghe	− 0.0579***	L.tghe	0.00265	L.tghe	− 0.0000221*
	(− 0.31)		− 0.86		(− 5.74)		− 0.48		(− 2.05)
L2.tghe	− 0.000152	L2.tghe	0.761***	L2.tghe	− 0.0553***	L2.tghe	0.00561	L2.tghe	− 0.0000441***
	(− 0.17)		− 3.41		(− 5.35)		− 1		(− 3.98)
L.efosst	− 0.00341	L.efosst	1.441	L.efosst	0.392***	L.efosst	0.164**	L.efosst	0.000118
	(− 0.39)		− 0.66		− 3.87		− 2.97		− 1.09
L2.efosst	− 0.00731	L2.efosst	− 2.713	L2.efosst	− 0.157	L2.efosst	0.0409	L2.efosst	0.0000125
	(− 0.88)		(− 1.29)		(− 1.61)		− 0.77		− 0.12
L.gdpgrwt	0.0268	L.gdpgrwt	1.116	L.gdpgrwt	− 0.338	L.gdpgrwt	− 0.242	L.gdpgrwt	− 0.000655*
	− 1.21		− 0.2		(− 1.31)		(− 1.72)		(− 2.37)
L2.gdpgrwt	0.0378	L2.gdpgrwt	2.397	L2.gdpgrwt	0.165	L2.gdpgrwt	− 0.158	L2.gdpgrwt	0.000171
	− 1.61		− 0.4		− 0.6		(− 1.06)		− 0.58
L.elresxhdy	20.64	L.elresxhdy	− 3084.2	L.elresxhdy	− 1167.1***	L.elresxhdy	− 350.5***	L.elresxhdy	0.294
	− 1.34		(− 0.79)		(− 6.46)		(− 3.57)		− 1.52
L2.elresxhdy	− 3.678	L2.elresxhdy	9784.0***	L2.elresxhdy	81.51	L2.elresxhdy	380.5***	L2.elresxhdy	− 0.743***
	(− 0.32)		− 3.38		− 0.61		− 5.22		(− 5.19)
_cons	− 0.0607	_cons	− 4.719	_cons	2.138	_cons	7.635***	_cons	0.00339
	(− 0.38)		(− 0.12)		− 1.14		− 7.49		− 1.69
								N	18

(EFOSST) as the dependent variable is significant for the price of gasoline per liter. The magnitude of the correlation is direct, as well. This explains the growing demand for gasoline in downstream transport in the country and for agriculture and other industrial purposes. In this model, the total lag in greenhouse gas emissions is significant for electricity from fossil fuel sources. In addition, electricity from renewable sources, excluding hydropower, is a substantial variable of electricity from fossil energy sources. The direction is negative. The magnitude represents the inverse relationship among the variables. As one increases, the other reduces. This calls for the transition to RES electricity generation, which is cheaper and sustainable [3, 23, 56, 57]. Furthermore, electricity from fossil fuel sources as an independent variable is significant for the gross domestic economy. This implies that electricity consumption impacts economic growth [58].

However, the negative coefficient suggests the decoupling of energy consumption from GDP growth. This is mind-boggling because Ghana has not decoupled its GDP growth rate from its economic development. Perhaps it depicts the future trajectory the economy should take. Furthermore, in the model with electricity from renewable sources as the explained parameter, the price per liter at the gasoline pump is meaningful in the first and second lags. This confirms that the electricity from RES impacts the price Ghanaians pay at the pump for gasoline. However, the negative relationship implies that as one source increases, the other source reduces. This is correct because RES acts as substitutes, not complements, in the energy transition drive. Therefore, if Ghana wants to achieve its 10% RES capacity by 2030 and its NDCs, RES will have to be scaled up in the shortest possible time. This fact is supported by [59, 60] 2022, on the evolving energy landscape of China. The country is behind in achieving 10% RES on its energy mix by 2030. In addition, the price per liter at the pump is significant.

Additionally, total levels of greenhouse gas emissions are significant in the first and second lags of the model, where RES, excluding power, is the dependent variable. This corroborates the scientific facts that RES abates pollution [61]. This was further supported by the correlation where they are negative. As one variable increases, the variable decreases.

Ghana must increase renewable electricity generation if it wants to reduce its emissions levels. Ghana bears the brunt of climate change and its worse consequences

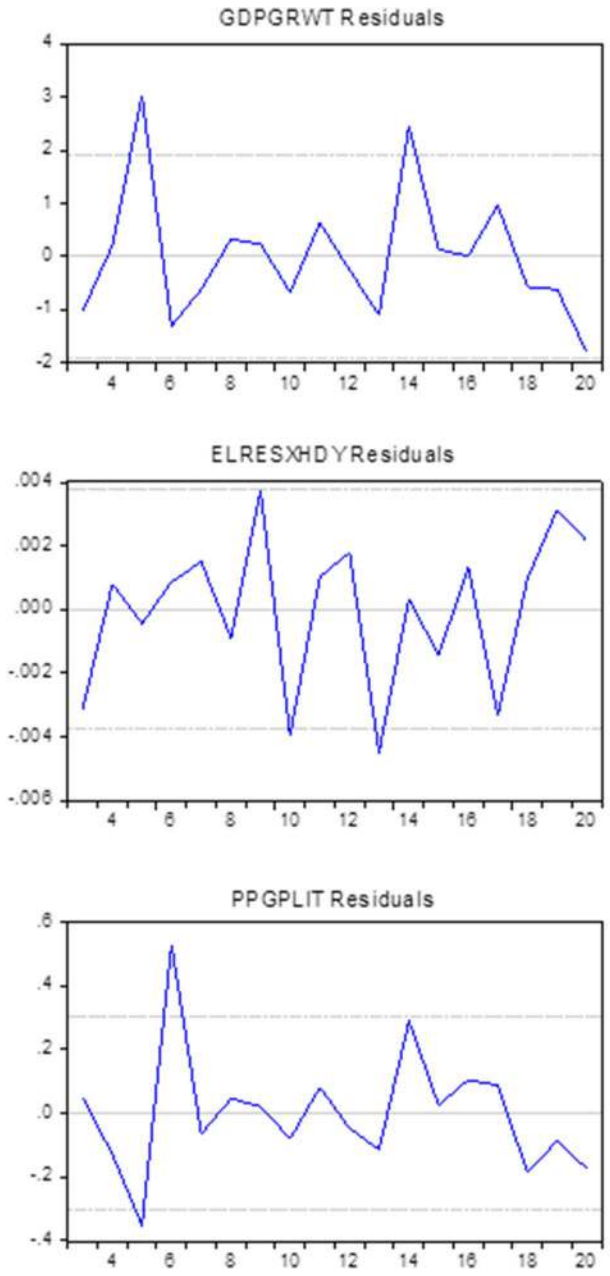

Fig. 1 Residual graphs of the model of the variables. Source: Author's calculations

in Accra in the form of flash floods, changing weather farming seasons in northern Ghana, and many others. As a result, the country must accelerate the deployment of RES in no time. Ultimately, the second lag of renewable energy sources, excluding hydropower, is significant but has an inverse relationship. It explains the relevance of RES in encouraging economic growth in Ghana [61, 62].

Figure 1 shows the residual graphs, using the lag '14' for endogenous parameters. This shows that the stochastic term linked to the variance increases reaches a maximum and then plunges to the end year for the GDP growth rate. The residuals for the electricity from fossil fuel sources are quite steady around the mean divergence away from the stochastic term. All variables vacillate around the mean, which shows the stability of the stochastic term in the analysis. Generally, the matching model is a better time series model.

Figure 2 is the endogenous graphs for the analysis. Endogenous parameters show that the GDP growth rate started on an increasing path, peaked in the 2010s, then

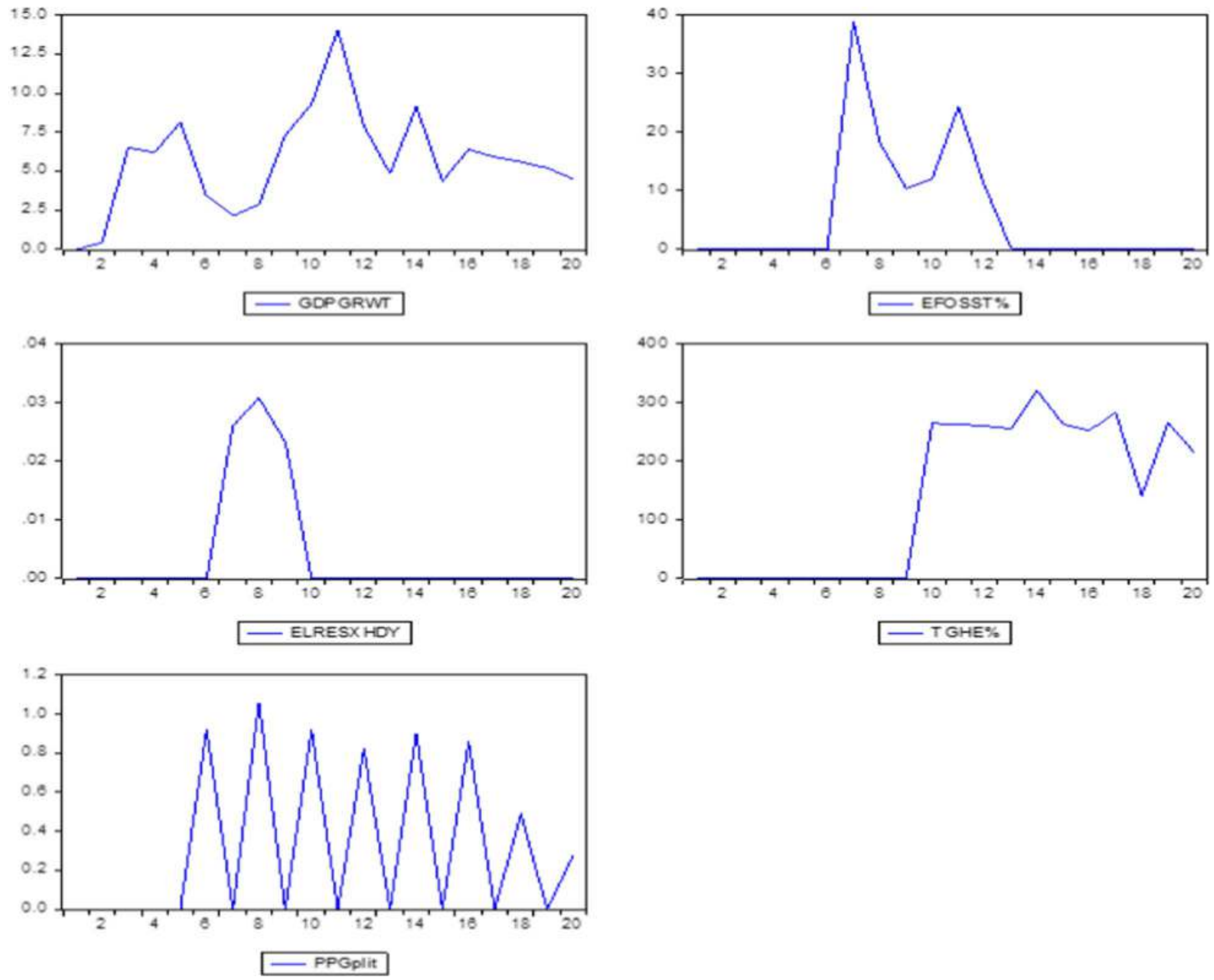

Fig. 2 Endogenous graphs of the variables

went into a trough and continued on a steady path. 2012 and 2013 saw Ghana as one of the fastest-growing economies in the world, with a 14% GDP growth rate, as shown in the diagram. Furthermore, electric generation peaked in 2006 and decreased in 2009 and 2014. Similarly, as the graphs show, Ghana's total greenhouse emissions peaked in 2010 and have been on a trajectory due to the uptake of the upstream petroleum sector in the country. According to [31, 34], globalization has increased Ghana's emissions levels. The price per litre at the pump is growing zigzag, representing the increase and decrease pathways. Additionally, RES generation without hydropower peaked midway and has remained flat.

Table 4 presents eight complex roots of 0.846586−0.215968i; 0.846586 + 0.215968i with an equal modulus of 0.873699 0. Also, 488,625−0.671621i;

Table 5 Lag structure

Root	Modulus
− 0.915743	0.915743
0.846586−0.215968i	0.873699
0.846586 + 0.215968i	0.873699
0.488625−0.671621i	0.830560
0.488625 + 0.671621i	0.830560
0.033735−0.721956i	0.722744
0.033735 + 0.721956i	0.722744
− 0.717079	0.717079
− 0.385059−0.096138i	0.396879
− 0.385059 + 0.096138i	0.396879

No root lies outside the unit circle

The VAR satisfies the stability condition

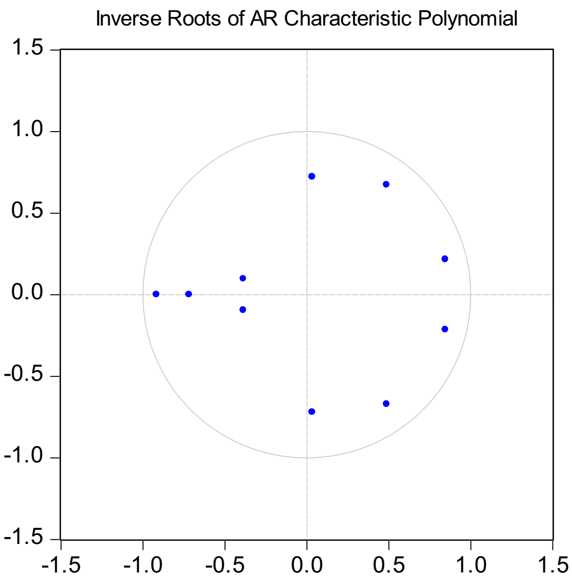

Fig. 3 AR root graph. Source: Author's construct

0.488625 + 0.671621i have an equal modulus of 0.830560 and 0.033735−0.721956i; 0.033735 + 0.721956i achieve an equal modulus of 0.722744. Finally, − 0.385059−0.096138i and − 0.385059 + 0.096138i derive an equal modulus of 0.396879. All these confirm that the model is accurate and satisfies the stability condition (Table 5).

Subsequently, Fig. 3 presents the eight roots of the VAR model, corroborated by the fact that the model is stable and graphs the roots using a complex coordinate system. As shown in the graph, all the coordinates lie inside the circle, signifying the stability condition. Therefore, it is appropriate to analyze the dynamic electricity situation in Ghana [63].

From Table 6, the Granger causality test is performed to determine the relationship among the variables. Determine which variable causes the other. The connection is based on the null hypothesis that an endogenous variable does not cause the other variables. Given this, the GDP growth rate (GDPGRWT) has a chi-square of 25.00574 and a *P*-value of 0.000; therefore, the null hypothesis is rejected, and GDPGRWT does cause EFFOSST, which has a chi-square of 132.3742 and a *p*-value of 0.000. Furthermore, the model of ELRESXHDY, EFFOSST, significantly granger causes total greenhouse gas emissions (GHE) and price per litre at the pump (PPGPLT). Therefore, it is concluded that there is a feedback relationship between the GDP growth rate, EFOSST, and ELRESXHDY. This is apt since GDP growth requires energy to bring about change. No meaningful development can take place without adequate and sustainable energy.

Table 6 VAR granger test/wald test. Source: Author's calculations

Dependent variable: GDPGRWT			
Excluded	Chi-sq	df	Prob
EFOSST_	3.964188	2	0.1378
ELRESXHDY	12.25615	2	0.0022
TGHE_	1.160525	2	0.5598
PPGPLIT	2.896414	2	0.2350
All	25.00574	8	0.0016
Dependent variable: EFOSST_			
Excluded	Chi-sq	df	Prob
GDPGRWT	0.757173	2	0.6848
ELRESXHDY	17.05571	2	0.0002
TGHE_	63.48471	2	0.0000
PPGPLIT	66.06707	2	0.0000
All	132.3742	8	0.0000
Dependent variable: ELRESXHDY			
Excluded	Chi-sq	df	Prob
GDPGRWT	2.241062	2	0.3261
EFOSST_	0.492105	2	0.7819
TGHE_	19.23845	2	0.0001
PPGPLIT	27.99978	2	0.0000
All	52.51906	8	0.0000
Dependent variable: TGHE_			
Excluded	Chi-sq	df	Prob
GDPGRWT	0.085927	2	0.9579
EFOSST_	0.744941	2	0.6890
ELRESXHDY	4.481621	2	0.1064
PPGPLIT	0.117292	2	0.9430
All	9.543200	8	0.2986
Dependent variable: PPGPLIT			
Excluded	Chi-sq	df	Prob
GDPGRWT	1.735052	2	0.4200
EFOSST_	0.400585	2	0.8185
ELRESXHDY	0.697107	2	0.7057
TGHE_	0.124586	2	0.9396
All	2.688177	8	0.9524

Additionally, from Table 7. The lag order selection of five lags is adequate, which are chosen by the model, which is in tandem with the model mentioned above, according to the SC statistic. Hence, the VAR is evaluated with a lag interval of '16'.

Figure 4 presents the correlogram of the VAR model alongside the endogenous variables with a lag interval of '16'. Presents five graphs of the endogenous parameter, which depict that one or two of the autocorrelations of the corresponding study unit are meaningful. Their significance confirms the importance of these variables

Table 7 Lag order selection

Lag	Lo		lo LR FPO	AIC	SC	HQ
0	− 174.4750	NA	110.2998	18.89210	19.14064	18.93416
1	− 128.6505	62.70721*	13.76872*	16.70005*	18.19127*	16.95242*

LR sequential modified LR test statistic (each test at 5% level)

FPE Final prediction error

AIC Akaike information criterion

SC Schwarz information criterion

*indicates the lag order selected by the criterion

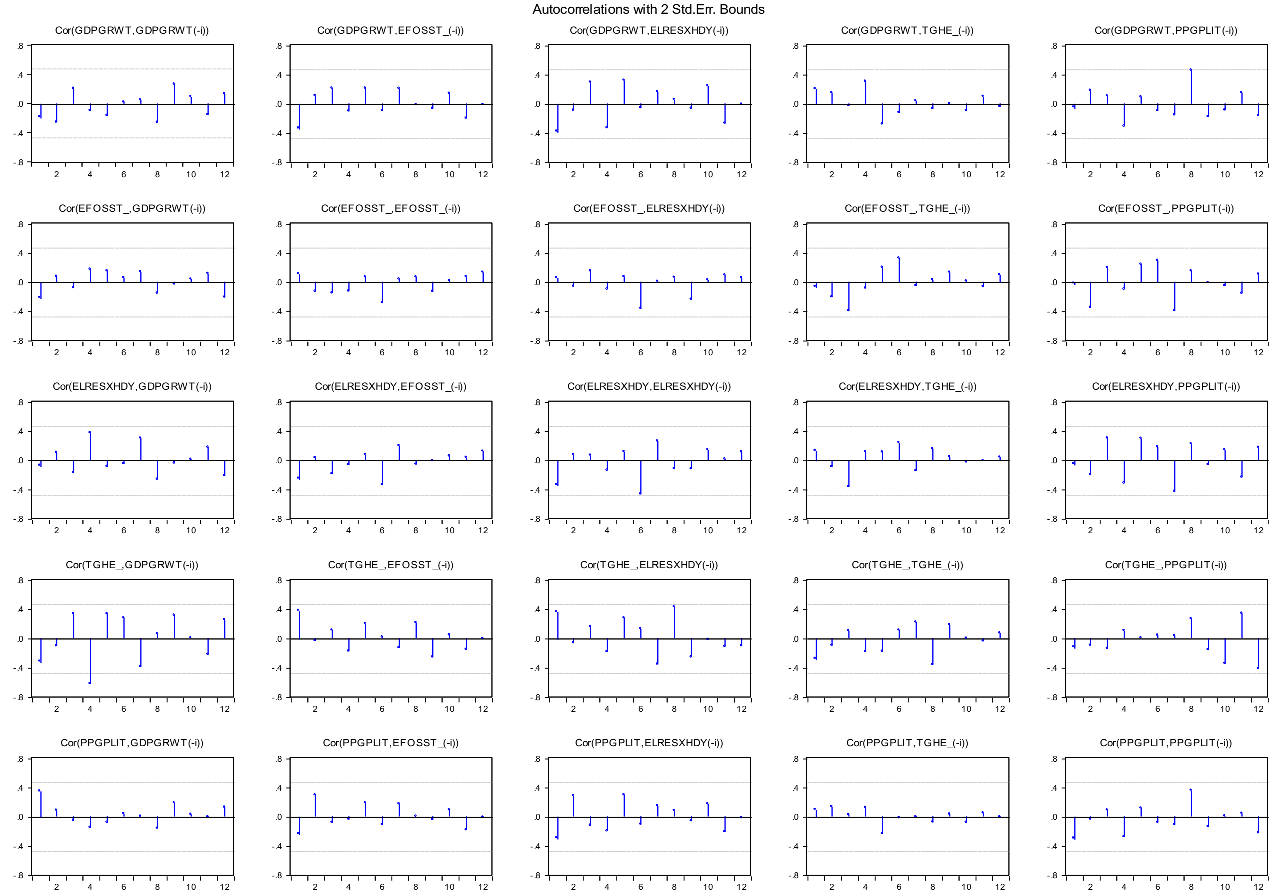

Fig. 4 Residual correlogram of the VAR model. Source: Author's construct

in explaining the Ghanaian dynamics in the electricity generation mix. Some graphs show that autocorrelations are outside the interval with two standard error bounds. The other graphs show that some of the autocorrelations are outside the interval.

From Table 8, the VAR normality test is performed to determine the distribution of the stochastic variables. It employs the Jacque Bera residual normality test testing with the null hypothesis that the residuals are normally distributed and the alternative hypothesis that the residuals are not normally distributed. Bearing the residuals of the components and their *P*-values, it is concluded that they are normally distributed since they are generally not significant or more than 0.5%.

Table 8 VAR residual normality test. Source: Author's calculations

Component	Skewness	Chi-sq	Df	Prob
1	1.053272	3.328143	1	0.0681
2	0.259359	0.201801	1	0.6533
3	0.417071	0.521844	1	0.4701
4	− 0.07361	0.016254	1	0.8986
5	− 0.50182	0.755466	1	0.3848
Joint		4.823508	5	0.4378
Component	Kurtosis	Chi-sq	df	Prob
1	3.791337	0.469661	1	0.4931
2	2.319899	0.346903	1	0.5559
3	2.072214	0.64559	1	0.4217
4	2.98298	0.000217	1	0.9882
5	3.935924	0.656966	1	0.4176
Joint		2.119336	5	0.8324
Component	Jarque–Bera	df	Prob	
1	3.797804	2	0.1497	
2	0.548704	2	0.7601	
3	1.167434	2	0.5578	
4	0.016471	2	0.9918	
5	1.412432	2	0.4935	
Joint	6.942844	10	0.7308	

Figure 8 shows the impulse response of the endogenous variables to shocks from ϵ_t. These shocks are macroeconomic and could be constructed to make a positive contribution to the electricity sector in Ghana. The response of TGHE to shocks from RES electricity, excluding hydropower, started from a negative point initially, dipped in the third quarter, and went on an increasing trajectory for the rest of time. The RES capacity is projected to increase when all projects are available. Also, the reaction of the GDP growth rate from shocks from itself leads to an initial expansion in growth, plunges in quarter two, and continues on a steady path. The response of the GDP growth rate to total greenhouse gas emissions started on a positive direction, peaked around quarter four, and continued on an upward trajectory. As the economy grows and relies heavily on fossil fuel sources, emissions levels will increase. A similar situation is observed concerning the price at the pump gasoline per litre. It responded to shocks by taking off on a higher trajectory, nosediving, and continuing steadily.

Generally, endogenous variables respond directly to shocks, which attain a permanent effect that advances to a new steady state in the long run. The dynamic reactions

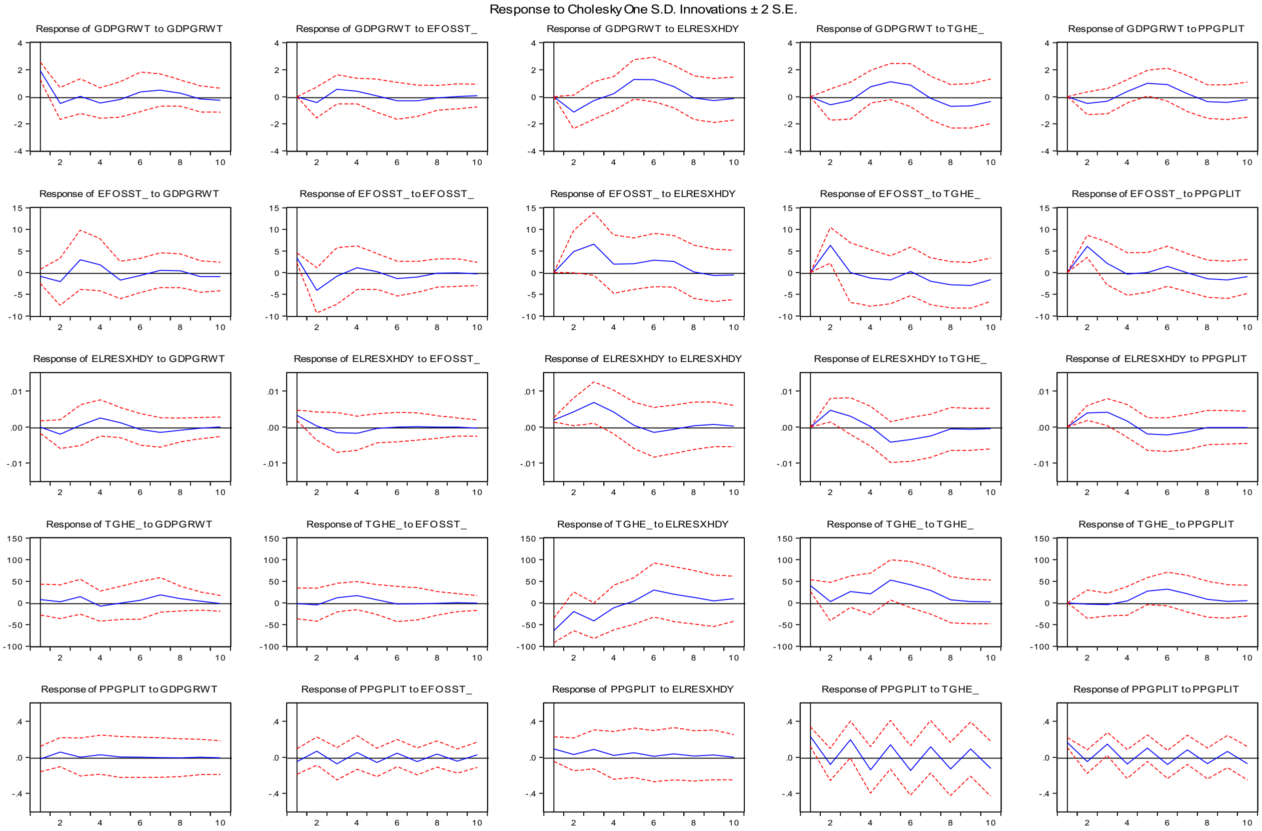

Fig. 5 Impulse response function (IRF). Source: Author's estimation

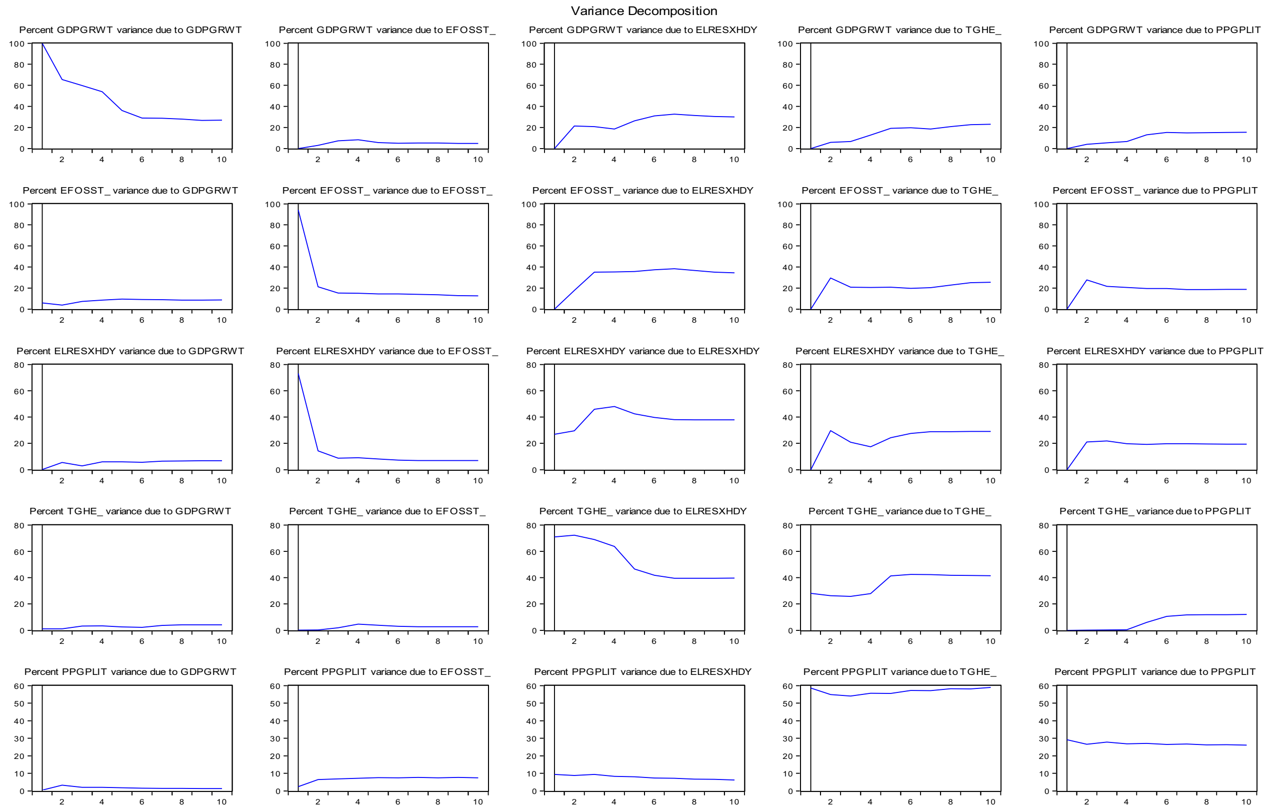

Fig. 6 Variance decomposition graphs. Source: Author's construct

of most endogenous parameters are varied. However, this is reassuring since they increase Ghana's electricity generation mix and advocate for reversing adverse reactions that do not affect economic development. Endogenous parameters, such as total greenhouse emissions and high-growing fossil fuel consumption, must be curbed since they are not sustainable generation sources. It is worth mentioning that some of these shocks are permeant and not transitionary. The reaction of the GDP growth rate to shocks from global oil markets and the current energy crisis (Russian—Ukraine conflict) permanently affects the economy's economic growth of the economy from the short to the long term (Fig. 5).

Figure 6 shows the variance decomposition results for the analysis (VD). VD explains the amount of variance ignited by a variable's reaction to shocks from other variables and itself. The variance of GDP rate to itself from shocks explains a greater percentage rate of all the variance of 100% and declines to around 10%. Therefore, the growth rate is susceptible to shocks since these shocks are exogenous and directly impact the economy. Similarly, the variance of GDP to shocks from other endogenous parameters started at less than 1%. It increased a bit to about 10% or more.

In the same way, the variance explained by EFOSST due to shocks from different endogenous variables is more than 20% and, in some instances, more than 70%. EFOSST explains a more significant proportion of the variance due to electric generation dynamics shocks. Additionally, the variance explained by total greenhouse gas emissions (TGHE) to itself and to different variables varied from less than 1% to nearly 70% in some cases. This also represents the levels of greenhouse gas emissions in the country. Ghana's THE peaked around 2010 when the country began exploring oil and gas.

Variance connotes the headwinds of the importance of the supply aspect that accounts for the greater part of the generation of variance in electricity within the economy. The chart dramatically explains the narratives regarding the headwinds and the amounts of variances caused by the variable itself or different variables.

Figure 7 Below defines the cumulative electricity from oil and gas, and coal sources, which is forecast to increase to 8.8% from 2036 and beyond, and installed renewable energy generation capacity for the same period. This implies that the country still relies on conventional energy sources.

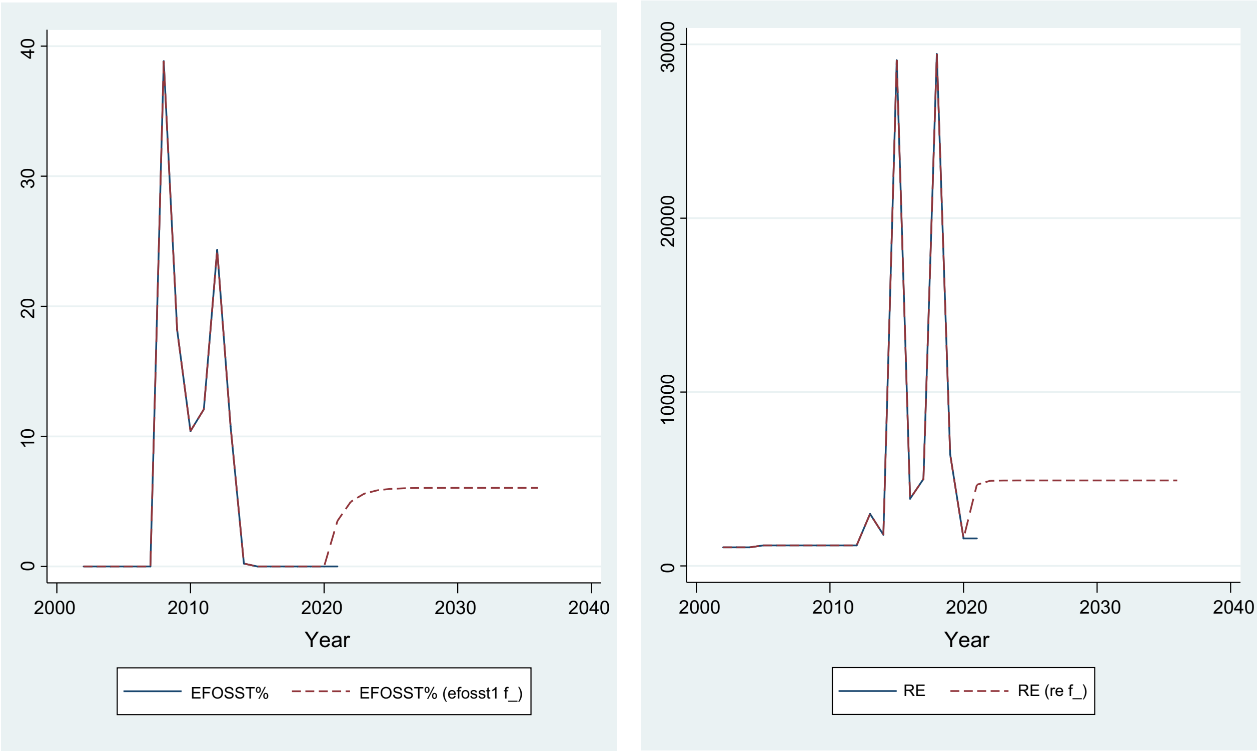

Fig. 7 Forecast of the installed generation capacity of EFOSST and RE. Source: Author's construct

On the other hand, the figure shows that Ghana's installed RE generation capacity will continue to grow despite reaching 6000 MW or more. Hydropower is a more significant part of the growth, with wind and solar coming next. This forecast is on point since when pipeline projects come on stream. This implies that the installed total capacity for renewable energy will have increased by about 57.8% by 2036.

Figure 8 shows the electricity generation sources in Ghana. The country has been generating a lot from conventional energy sources such as natural gas, bioenergy, hydropower, and to a lesser extent emerging RES. The data period depicted on the tree map is 2000–2019.

Conclusions and policy recommendations

The study uses data from WDI from 2002 to 2021 to study the electricity dynamics of Ghana. An unrestricted VAR model was deployed in the analysis. After the analysis, it is evident that Ghana's electricity sector is characterized by fossil fuel consumption that exposed the country to external shocks that impacted the macroeconomic stability of the country in short to long term, eroding the gains made in building the economy. The current shocks that brought untold economic hardships were the Covid pandemic and the ongoing Russian–Ukraine aggression that caused acute energy shortages in Ghana, reverberating throughout the economy. This shock will not affect the country's GDP growth rate. The analysis revealed that the variance in the GDP growth rate was explained by more than 100% in reactions to shocks.

Additionally, electricity from fossil fuel sources also explained significant variance in the variance decomposition and was substantial in the VAR model. This shows the importance of fossil fuels to the in-electricity generation dynamics of the country. This is a supply shock that directly impacts the generation of electricity. In addition, the price per liter at the pump explained approximately 96% of the variance in reaction to shocks. This is right, as the current energy crisis has queues at the filling stations in Ghana.

Furthermore, the analysis reveals that Ghana's renewable energy sources without hydropower are minimally used. It explains the low variance in shock reactions that depicts the low levels of RES generation in the country, emerging energy sources per se, without traditional hydropower. Furthermore, the Granger causality analysis shows a feedback relationship between fossil fuel electricity generation and the country's GDP growth rate. Thus, both grangers cause each other and are significant. The impulse response (IRFS) analysis shows that the

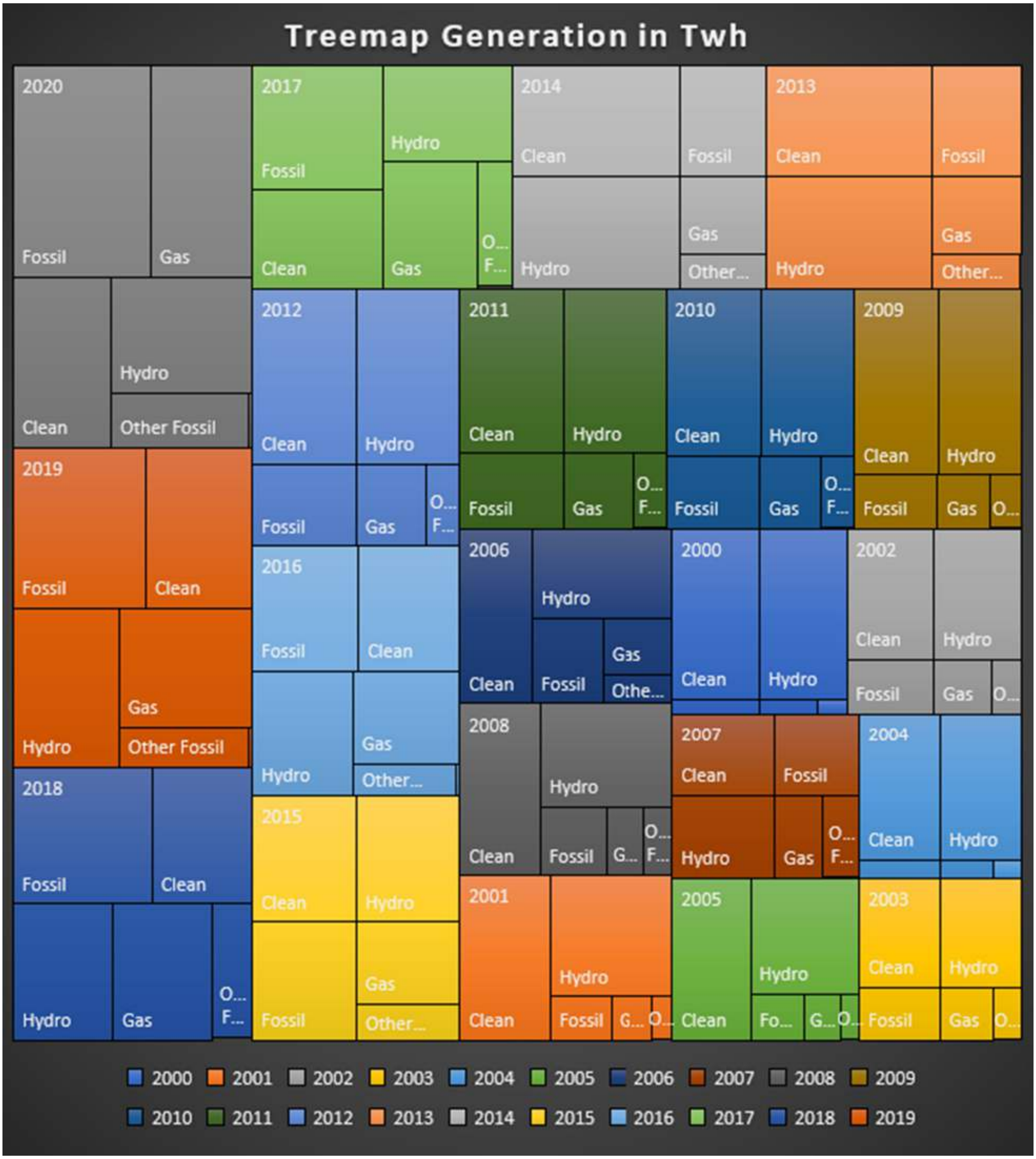

Fig. 8 Sources of Ghana

parameters reacted positively to short- and long-term shocks, keeping a steady trajectory going forward, with only one nosedived to a negative trajectory. Overall, the variables are increasing, reassuring their importance to the electricity generation dynamics of the country. The results also determine that Ghana is energy secure but that its energy consumption comes from fossil fuel sources that are not sustainable—export power to its neighbors. The inverse root AR characteristic polynomial analysis confirms the robustness of the model in the analysis since all coordinates lie within the circle, satisfying the stability condition of the analysis.

The study's findings highlight the need for significant policy changes to ensure sustainable energy consumption in Ghana. The following recommendations aim to address the challenges identified in the study while promoting a sustainable and resilient energy sector:

- Scale up renewable energy source (RES) deployment and diversify the energy mix: The government should prioritize expanding renewable energy sources, such as solar, wind, and biomass, while diversifying the energy mix to reduce dependence on fossil fuels. Targeted investments, public–private partnerships, and policy initiatives supporting various renewable technologies and energy efficiency measures should be implemented to achieve this. A diversified energy mix will contribute to greater energy security, environmental sustainability, and economic resilience.
- Reduce indebtedness to Independent Power Producers (IPPs): To alleviate the energy sector's financial burden, the government should renegotiate contracts with IPPs, establish transparent procurement processes, and create regulatory frameworks that foster fair competition. This approach will ensure that contracts are economically viable, aligned with renewable energy goals, and promote public–private partnerships to share risks and financial responsibilities.
- Implement a negative bidding process for conventional power generation: Introducing a negative bidding process, where power producers pay the state for the electricity they generate, can encourage efficiency and cost reduction among conventional power generators. This system incentivizes lower costs to remain competitive, ultimately leading to reduced consumer electricity prices and a more financially stable energy sector.
- Address institutional complexity and promote private sector participation: Simplifying institutional structures and processes in the public sector can reduce red tape, streamline decision-making, and facilitate private sector involvement in renewable energy deployment. Providing financing policy instruments, such as grants, low-interest loans, and tax incentives, will further incentivize private sector investment in the renewable energy sector.
- Secure special funding for renewable energy entrepreneurs: The government should collaborate with multilateral development institutions to establish funding programs specifically supporting renewable energy supply chain entrepreneurs. This initiative will stimulate innovation, create job opportunities, and contribute to the growth of a sustainable energy sector.
- Retrofit diesel power plants with natural gas: As a medium-term solution, Ghana should consider converting diesel-based power plants to run on natural gas, which emits fewer greenhouse gases. This transition will help reduce generation costs, limit environmental pollution, and buy time for the country to scale up its renewable energy infrastructure.
- Establish a robust regulatory environment and form pressure groups: A strong regulatory environment is essential for transforming Ghana's electricity generation dynamics. The government should introduce policies and regulations that promote renewable energy deployment, ensure fair competition, and protect consumers. The formation of pressure groups, such as "The Ghana RES Association," can advocate for renewable energy expansion, hold the government accountable, and protect the country from external shocks while promoting sustainable economic development.

While the study provides valuable insights, it is crucial to acknowledge several limitations that may impact the accuracy and generalizability of the findings. Data availability poses a constraint as the study relies on data from the World Development Indicators (WDI) for the period between 2002 and 2021. Consequently, some variables may have limited data points, which could affect the robustness of the results. To address this limitation, future research could consider incorporating additional data sources and extending the analysis period to capture a broader range of factors and trends in Ghana's electricity sector.

Also, the choice of the unrestricted Vector Autoregression (VAR) model for the analysis may introduce sensitivity to the results due to the model's underlying assumptions. To strengthen the robustness of the findings, future studies could explore alternative models and methodologies, such as dynamic panel data models or machine learning approaches. These complementary methodologies might provide a more comprehensive understanding of the electricity generation dynamics in Ghana.

Lastly, the analysis focuses primarily on macro-level factors, excluding micro-level factors such as regional differences, local policies, and individual consumer behavior. Investigating these micro-level factors can contribute to a more nuanced understanding of the electricity generation dynamics in Ghana. Future research should, therefore, consider examining these factors to provide a more holistic perspective on the electricity sector.

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Author contributions
SAA and QXS are the authors of this manuscript. SAA prepared the concept of the study and participated in the collection, analysis, and interpretation of the data. QXS completed manuscript editing and supervision. All authors read and approved the final manuscript.

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Declarations

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Competing interests
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