

Modeling the Electricity Generation Dynamics of Ghana. A Structural Vector Autoregression Regression Approach

This study estimates endogenous parameters to ascertain the dynamics of the electricity generation sector in Ghana. An unrestricted Vector Autoregression Regression (VAR) model is employed to examine the empirical ramifications of the Ghanaian electricity energy sector and power consumption. The data period ranges from 2002 to 2021. Precisely, the results detected structural long-run and short-run headwinds for the unrestricted models. The findings depict that the reactions of the GDP growth rate and electricity from fossil fuels react directly to headwinds based on their correlation. Also, the Granger causality analysis shows a feedback relationship between the Gross Domestic Product (GDP) growth rate and electricity from fossil fuel sources since they are significant. The impulse function indicates that the GDP growth rate responds to outside forces, and the effects last for a long time. the variance decomposition results backed up this analysis, showing that renewable energy without hydropower explains less than 1% of the variance due to shocks and total global greenhouse emissions, further explaining about 85% of the variance due to headwinds in the time period. Electricity from fossil fuel sources explains more than 100% of the variance owing to headwinds hitting the system, implying the nation's overreliance on conventional energy sources. Installed renewable energy will grow to over 2500 MW by 2036, at 57.8%. As a recommendation, the Energy Commission of Ghana needs to exploit renewable energy sources.

Keywords: Ghana, Vector Autoregression Regression, Electricity, Energy, Conventional Energy, Renewable Energy Sources.

Introduction

Ghana's electricity generation dynamics disproportionately lean toward traditional sources of energy generation. Conventional sources comprise about 68.8% of the generation mix, followed by hydropower at 29.1% and the rest of the renewable energy sources (RES) at 2.1%, respectively (Energy Commission of Ghana, 2020). The country's overreliance on fossil fuels makes its energy insecure, threatening its already energy-insecure nature. Even though the country's import bill has been reduced, the government continues to import gas from the West African Gas Pipeline (WGP) to generate electricity (Morgan et al., 2021; Kingston et al., 2019). Ghana spends more than one-third of its GDP on importing energy to power its economy, which is not sustainable. Hydropower dominated Ghana's electricity generation until 2015, when thermal sources overtook the largest chunk of the generation mix. This comes next after the power sector deregulation, which saw the formation of independent power producers (IPPs) alongside government-owned power

plants in the country. Even though the government still controls utility fees, the country has put in place reforms in the power sector that encourage participation from the private sector. This is called "unbundling" the energy sector.

The country's energy consumption is dominated by the industrial and residential sectors, with a per-head consumption of 540 kWh. According to the Energy Commission of Ghana, the country's electrification rate was about 87% in 2020. In 2019, the total energy supply was 12.52 billion kilowatt-hours (bn kWh). Ghana targets achieving full electrification capacity by 2030 and completing a 10 percent deployment of RES. As of 2019, final electricity consumption was 15.5 TWh, and cumulative carbon dioxide emissions were 18.5 megatons (mt). Ghana's total reliable capacity is 4,738.6 MW, a 13% increase between 2017-2018 installations (ECG, 2020). On the other hand, the installed generation capacity connected to the grid was 4,990 megawatts (MW) in 2019; 4,580 MW is active and running. When embedded supply and solar are added, the total capacity goes up to 4,990 megawatts (MW) (ECG, 2020).

In 2020, electricity generation increased to 20,170 gigawatts (GW). 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) stands at about 61.6 billion dollars. The country's GDP can grow even faster if there is adequate energy to turbocharge the growth. An alternative source of reliable energy is Renewable Energy Sources (RES). RES continues to form an insignificant part of the generation energy mix. The country is equally a signatory to the Paris Agreement that seeks to ensure full access to cleaner energy sources by 2030. Consequently, the government aimed in tandem with the full electrification program and added to the Nationally Determined Contributions (NDCs) to improve and grow access to efficient cooking stoves by 2030 by supplying about two million of those stoves (Sun et al., 2020). In furtherance to bridging the access gap, the country seeks to decrease the electrification rates between urban and rural centers of 87% and 60% by taking steps to reduce costs of power connection to the national grid because of low-income levels of the populace and due to places, that are not economically viable to generate or extend power to (Sun et al., 2020). 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 (Sun et al., 2020 & ECG, 2020).

Per previous literature, there were deficits in the power supply in the late 2000s, so the government of Ghana 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. This surplus capacity made the government enter into a forty-three power agreement to avoid \$680 million in annual debt, which would happen. All these were compounded by high management inefficiencies and operational costs that exacerbated the dire financial situation of the power sector. The energy sector debt will be \$12.5 billion by 2030 (ECG, 2020). 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. The Public Utilities Regulatory Commission (PURC) revises tariffs, and the average user tariffs stand at 13–15 cents per kWh. Despite these adjustments, the tariff rates in Ghana are one of the highest in Africa (Foster, 2021). Yet, the sector can't raise enough funds to meet its operating expenses.

Concerning the empirical analysis, the study deploys an unrestrictive VAR model that innovates the study by modeling it and applying econometric analysis to examine its observed outcomes (Sack 2000 & Rezaei 2013). The VAR approaches the endogenous parameters to their unrestrictive functions in a granular way.

Within the past years, post-deregulation of the electricity sector in Ghana, the power sector has seen a significant transformation, with IPPs playing a prominent role in power generation. Ghana generates enough electricity to power its economy. Nonetheless, it comes mainly from fossil fuel sources. Even though Ghana now has adequate energy access and generates enough electricity, household electricity for cooking is very low, with about 20% access to modern cooking solutions (Ampah, 2022). Ghana spends about 27% of its GDP on imported fuels to power its development, irrespective of the abundance of local RES. A study by Aitor et al., 2022, finds that the social cost of owning an internal combustion engine vehicle is over 164% and that the generation of RES in the energy mix below 20% is harmful to the environment. This calls for scaling up the deployment of electronic vehicles (EVs) and the development of the necessary infrastructure to enable sector uptake. The study concurs that EVs will drastically cut emission levels in the country, up to 33%, with a single diesel engine replaced.

Furthermore, RES, seen as the panacea to the current energy crisis, seeks to determine the degradation of solar Photovoltaic (PV) in varied climate conditions in Ghana (Aboagye et al., 2022). 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 seeks to back this assertion. It advocates the government of Ghana improve its newly crafted policy to attract private sector participation and implement it comprehensively (Awuku et al., 2022). They opine that solar energy can bring about off-grid access via PPPs models.

Consequently, as Ghana's emissions levels are on the increase, Acheampong, 2022, utilizes the Stochastic regression to determine the de facto political, economic, and social internalization of Ghana's pollutions levels and produces dichotomous results that explain that a negative and positive variation in political internationalization carbon dioxide emissions levels, in the long run, while a negative and position variation in political internationalization reduces carbon dioxide emissions levels. Mary, 2022, Estimated that about 85% of the aggregate landmass in Ghana is appropriate for solar energy deployment. This potential can meet the energy needs of the country sustainably and over. However, the country has not explored this solar potential to the fullest. In justifying the cost-competitive nature of solar energy for Ghana, Foster et al., 2021, 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.

Further, Morgan et al., 2022, find the Levelized Cost of Solar Energy (LCOE) of diesel thermal plants to be as high as Gh¢351.44 kWh and Solar thermal plants to be Gh¢4.08 kWh, regarding Ghana. Alemzero et al., 2021, additionally estimated wind energy costs to have fallen by 30% in Africa between 2010-2019. Gyimah et al., 2022, find renewable energy to promote economic growth in Ghana and attract foreign direct investment. Energy Efficiency is an important aspect of power generation in Ghana, as Never, B. *et al.*, 2022, believe it is very important for the environmental sustenance of Ghana. Adjei-Mantey & Adusah-Poku, 2021, stated that socioeconomic factors in the form of poverty and reduced education levels act as hindrances to the acceptance of light bulbs that are energy efficient in Ghana.

This paper takes a different approach to analysis by using an unrestrictive VAR model by evaluating the dynamic relationship among GDP growth rate, Electricity from renewable sources excluding hydropower, Ghana's total greenhouse gas emissions, the price at the pump per liter for gasoline, Electricity from fossil fuels sources' VAR makes room for the identification of shocks and to determine their impact on the electricity sector in the long and short periods. The paper makes an empirical contribution by using the VAR model to empirically understand shocks, especially energy crises, on the energy generation dynamics and trends. This offers pragmatic importance to policy formulation. The paper also provides an empirical analysis of the energy generation dynamics of the power sector in Ghana, bearing in mind the global dynamics and seeing how they impact on electricity generation of the economy given current shocks prevailing in the energy markets.

Method and Data

Model Estimation

It is cumbersome to determine which variables to use as the dependent variable when estimating the relationship among variables. So, we employ Vector Autoregression Regression (VAR), a multivariate stochastic process of vector generalization of scalar autoregression. It talks about cointegration that implies casualty among variables. Also, economic principles sometimes need help determining which variables to use as the explained parameter and the exploratory variables. Given this background, the VAR is the appropriate model since all the variables are considered endogenous. The VAR model was introduced by Sims (Cristiano, 2012; Das, 2019; Sun et al., 2020) for the first time and was made popular by (Robert & Byung, 1987).

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

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

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

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

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

The above equations are presented in a matrix as below.

$$\begin{bmatrix} 1 & -\beta_{11} \\ -\beta_{12} & 1 \\ 1 & -\beta_{23} \\ -\beta_{34} & 1 \\ 1 & -\beta_{45} \\ -\beta_{55} & 1 \end{bmatrix} + \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \\ Q_{23} & Q_{24} \\ Q_{34} & Q_{44} \\ Q_{55} & Q_{45} \end{bmatrix} + \begin{bmatrix} X_{t-1} \\ X_{t-3} \\ X_{t-4} \\ X_{t-5} \end{bmatrix} + \begin{bmatrix} \epsilon_{1t} \\ \epsilon_{2t} \\ \epsilon_{3t} \\ \epsilon_{4t} \\ \epsilon_{5t} \end{bmatrix} \quad (6)$$

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

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

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

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

(8)

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

(9)

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

(10)

Order Selection

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

$$AIC = \text{Log}|\widehat{\Sigma}_P| + 2M^2P/T \quad P = 1, ..2, P$$

(11)

$$SIC = \text{Log} \left| \widehat{\Sigma}_P + (\log)m^2P \right| T \quad P = 1, ... 2, P \quad (12)$$

Hence, $|\widehat{\Sigma_P}|$ 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 (Paulsen, 1984).

Data

The study relies on data from the World Bank development indicators (WDI) between 2002-2021 to estimate the electricity generation dynamics in the energy mix of Ghana. The study uses an unrestrictive VAR model to determine how these endogenous parameters work to impact the energy mix. The gross domestic product growth rate (GDPGRWT) is one of the endogenous parameters. This will enable the study to comprehend how GDP impacts the country's electricity generation levels. It is undeniable that no country progresses socioeconomically without access to adequate energy.

Similarly, another endogenous parameter is electricity generation from fossil fuel sources (EFOSSST). Ghana generates over 70% of electricity from conventional energy sources. Electricity from renewable energy sources without hydropower (ELRESXHDY) is equally evaluated to determine the contribution of RES sources to the country's electricity generation. We have, in addition, the total greenhouse gas emission (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 sector as well as for farming and the manufacturing sector. Hence the imperative to examine the importance of this variable. Before the analysis, the variables were assumed stationary as it is not a necessary pre-condition to the examination process.

Results and Discussion

Table 1. is the descriptive statistics of the unrestricted VAR model that analyses the electricity generation dynamics of the Ghana power sector. As conspicuous from the table, Electricity from fossil fuels sources derives the highest mean value. This is so as Ghana generates nearly 70% of its Electricity from thermal sources. The gross domestic growth rate is the next variable with the highest mean value. Ghana experienced a significant GDP rate in the mid - the 2000s. It was seen as the fastest-growing economy in the African continent. More so, Electricity from renewable resources, excluding hydropower, has the least mean value since Ghana does not generate much from RES. Ghana's total greenhouse gas has been on a growing trajectory since 2010 when the country started exploring and developing hydrocarbons.

1 **Table 1. Descriptive Statistics**

	EFOSSST_	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.	2143.408	0.001855	200.2550	338164.2	3.403775
Dev.					
Observations	20	20	20	20	20

2
3 Furthermore, from table 2, the correlation matrix explains the relationship
4 with the variables. The correlation between Electricity from RES, excluding
5 hydropower, derives the significant relationship to Electricity from fossil
6 sources. This direct correlation implies that there is a need to generate
7 Electricity from other renewable sources to replace the fossil fuel sources that
8 are very expensive and pollute the environment. Another interesting correlation
9 that exists is between Electricity from renewable sources, excluding
10 hydropower, and that total greenhouse gas emissions. The correlation is
11 adverse. This connotes that as RES consumption increases, emissions levels
12 decrease. Hence RES abates greenhouse gas pollution.

13 **Table 2. Correlation Matrix**

	EFOSSST_	ELRESXHDY	GDPGRWT	TGHE_	PPGPLIT
EFOSSST_	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

15 Source. Author's estimation.

16
17 Similarly, table 3 shows the results of the VAR model. In the model where
18 total greenhouse gas (TGHE) is the explained parameter, its second lag is
19 significant with a direct correlation. The significance implies the expansion in
20 emissions levels in the country as the economy grows²³. The greenhouse gas
21 emissions levels increased from the 2010s when the nation discovered oil.
22 Similarly, the Electricity from fossil fuels sources (EFOSSST) as the dependent
23 variable is significant to the pricegasoline price per liter. The magnitude of the

1 correlation is direct as well. This explains the growing demand for gasoline in
 2 the downstream transport in the country and for farming and other industrial
 3 purposes. Equally, in this model, the total greenhouse gas emissions lag is
 4 significant to the Electricity from fossil fuel sources. Also, Electricity from
 5 renewable sources, excluding hydropower, is significant as an independent
 6 variable to Electricity from fossil energy sources. The direction is negative.
 7 The magnitude depicts the inverse relationship among the variables. As one
 8 increases, the other reduces. This calls for transitioning to RES electricity
 9 generation, which is cheaper and sustainable (Monyei, 2022). In addition,
 10 Electricity from fossil fuels sources as the independent variable is meaningful
 11 to the gross domestic growth rate. This connotes that electricity consumption
 12 impacts economic growth (Yao et al., 2020).

13 Nonetheless, the negative coefficient suggests the decoupling of energy
 14 consumption from GDP growth. This is mind-boggling because Ghana has not
 15 decoupled its GDP growth rate from its economic development. Perhaps it
 16 depicts the future trajectory the economy should take. Furthermore, in the
 17 model that has Electricity from renewable sources as the explained parameter,
 18 the price per liter at the gasoline pump is meaningful at the lag first and second
 19 lags. This confirms that Electricity from RES impacts the price Ghanaians pay
 20 at the pump for gasoline. However, the relationship is negative, implying that
 21 as one source increases, the other source reduces. This is rightly so because
 22 RES acts as substitutes, not complements, in the energy transition drive.
 23 Hence, if Ghana is to achieve its 10% RES capacity by 2030 and its NDCs,
 24 RES will have to be scaled up within the shortest possible time. This fact is
 25 backed by Pena et al. 2022 & Huang et al., 2022, regarding China's evolving
 26 energy landscape. The country is behind schedule in achieving 10% of RES on
 27 its energy mix by 2030. More so, the price per liter at the pump is significant.
 28 Besides, the total greenhouse gas emissions levels are significant in the first
 29 and second lags of the model, where RES, excluding power, is the dependent
 30 variable. This corroborates the scientific facts that RES abates pollution (Pena
 31 et al., 2022). This further was buttressed by the correlation where they are
 32 harmful. As one variable increases, the variable reduces.

33 Broadly speaking, if Ghana is to reduce its emissions levels, Ghana has to
 34 increase renewable electricity generation. Ghana equally bears the brunt of
 35 climate change and its worse consequences in Accra in the form of flash
 36 floods, changing weather farming seasons in the northern part of Ghana, and
 37 many others. As a result, the country has to hasten the deployment of RES in
 38 no time. Ultimately, the second lag of renewable energy sources, excluding
 39 hydropower, is significant but has an inverse relationship. It explains the
 40 relevance of RES in encouraging economic growth in Ghana (Baarsch et al.,
 41 2020; Chen et al., 2022; Petrovic et al., 2020 & Mohsin et al., 2021)

Table 3. VAR Results

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

Source. Author's Calculations

Figure 1 below depicts the residual graphs, using the lag ‘14’ for endogenous parameters. This depicts that the stochastic term linked to the variance increases reaches a maximum and then plunges to the end year for GDP growth rate. The residuals for the Electricity from fossil fuels sources are pretty steady around the mean diverges away from the stochastic term. All the variables vacillate around the mean, thus depicting the steadiness of the stochastic term in the analysis. Generally, the matching model is a better time series model.



Source. Author's calculations. Figure 1. Residual Graphs of the model of the variables.

Figure 2 is the endogenous graphs for the analysis. The endogenous parameters show that the GDP growth rate started on an increasing path, peaked in the 2010s, and then went into a trough and continued on a steady pathway. Indeed, 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. Also, electric generation peaked in 2006 and decreased in 2009 and 2014. Similarly, Ghana. As the graphs depict, total greenhouse emissions peaked in 2010 and have been on a trajectory owing to the uptake of the upstream petroleum sector in the country. This is backed¹³ whereby globalization has increased Ghana's emissions levels. Aside from this, the price per liter at the pump is growing in a zig-zag manner depicting the increase and decrease pathway. Additionally, RES generation without hydropower peaked midway and has remained flat.

Figure 2. Endogenous Graphs of the variables

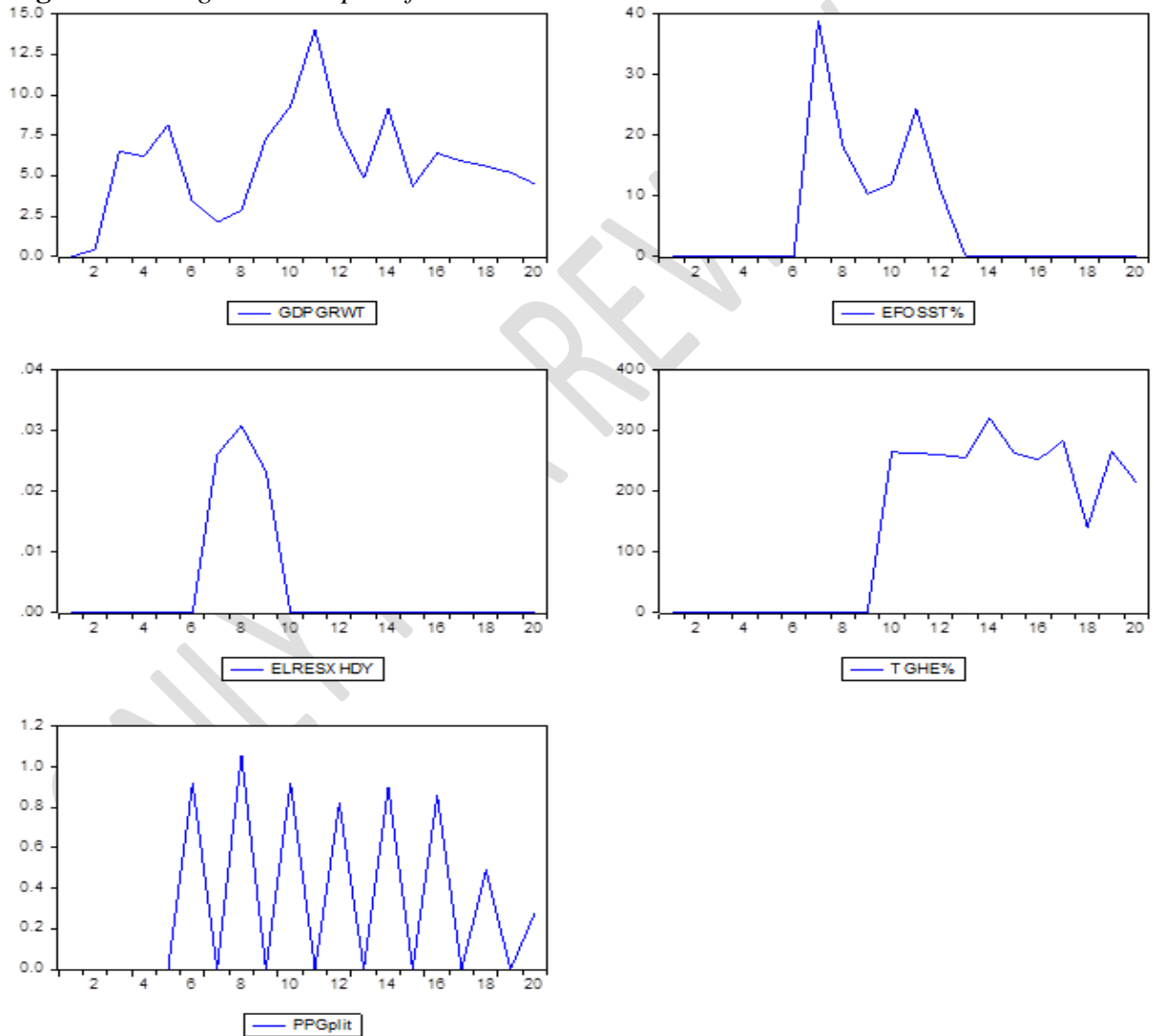


Table 4 presents eight complex roots of $0.846586 - 0.215968i$; $0.846586 + 0.215968i$ with an equal modulus of 0.873699 . Also, $488625 - 0.671621i$; $0.488625 + 0.671621i$ have an equal modulus of 0.830560 and $0.033735 - 0.721956i$; $0.033735 + 0.721956i$ attain an equal modulus of 0.722744 . Finally, $-0.385059 - 0.096138i$, 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 4. 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

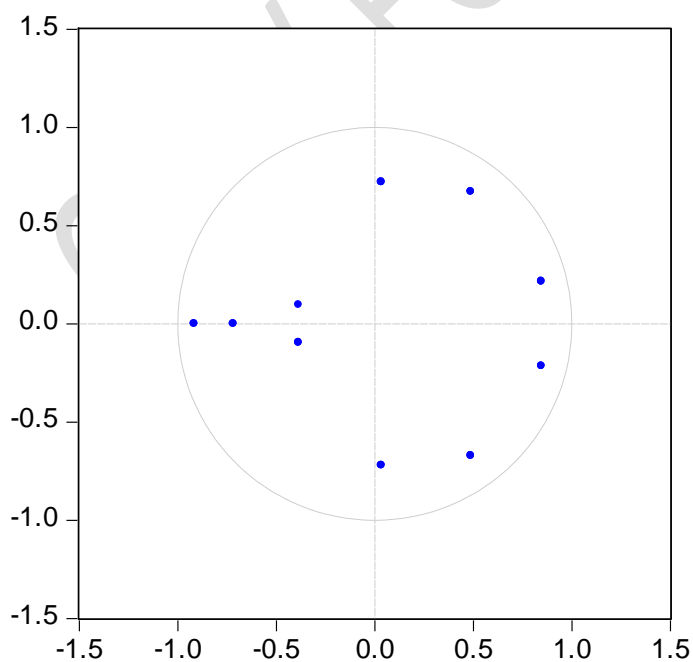
No root lies outside the unit circle.

VAR satisfies the stability condition.

Subsequently, figure 3 presents the actual valued eight roots of the VAR model, which corroborate that the model is stable and graphs the roots using a complex coordinate system. As shown on the graph, all the coordinates lie inside the circle signifying the stability condition. Thus, it is appropriate to analyze the dynamic electricity situation in Ghana.

Figure 3. AR ROOT GRAPH

Inverse Roots of AR Characteristic Polynomial



Source. Author's construct

From Table 5, the granger causality test is done to ascertain the relationship among the variables. To determine which variable granger causes the other. The connection is based on the null hypothesis that an endogenous variable that doesn't granger cause the other variables. Given this, the model of GDP growth rate (GDPGRWT) has a chi-sq of 25.00574 and a P-value of 0.000; therefore, the null hypothesis is rejected, and GDPGRWT does granger cause EFOSST, which has a chi-square of 132.3742 and a p-value of 0.000. Furthermore, the model of ELRESXHDY, EFOSST, significantly granger causes total greenhouse gas emissions (THE) and price per liter at the pump (PPGPLIT). It is therefore concluded that there is a feedback relationship among GDP growth rate, EFOSST, and ELRESXHDY. This is apt since GDP growth requires energy to bring about growth. No meaningful development can take place without adequate and sustainable energy.

Table 5. VAR Granger Test/ Wald Test

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
EFOSSST_	0.400585	2	0.8185
ELRESXHDY	0.697107	2	0.7057
TGHE_	0.124586	2	0.9396
All	2.688177	8	0.9524

Source. Author's calculations

Additionally, from table 6. 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 lags interval '16'.

Table 6. *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*

* indicates lag order selected by the criterion

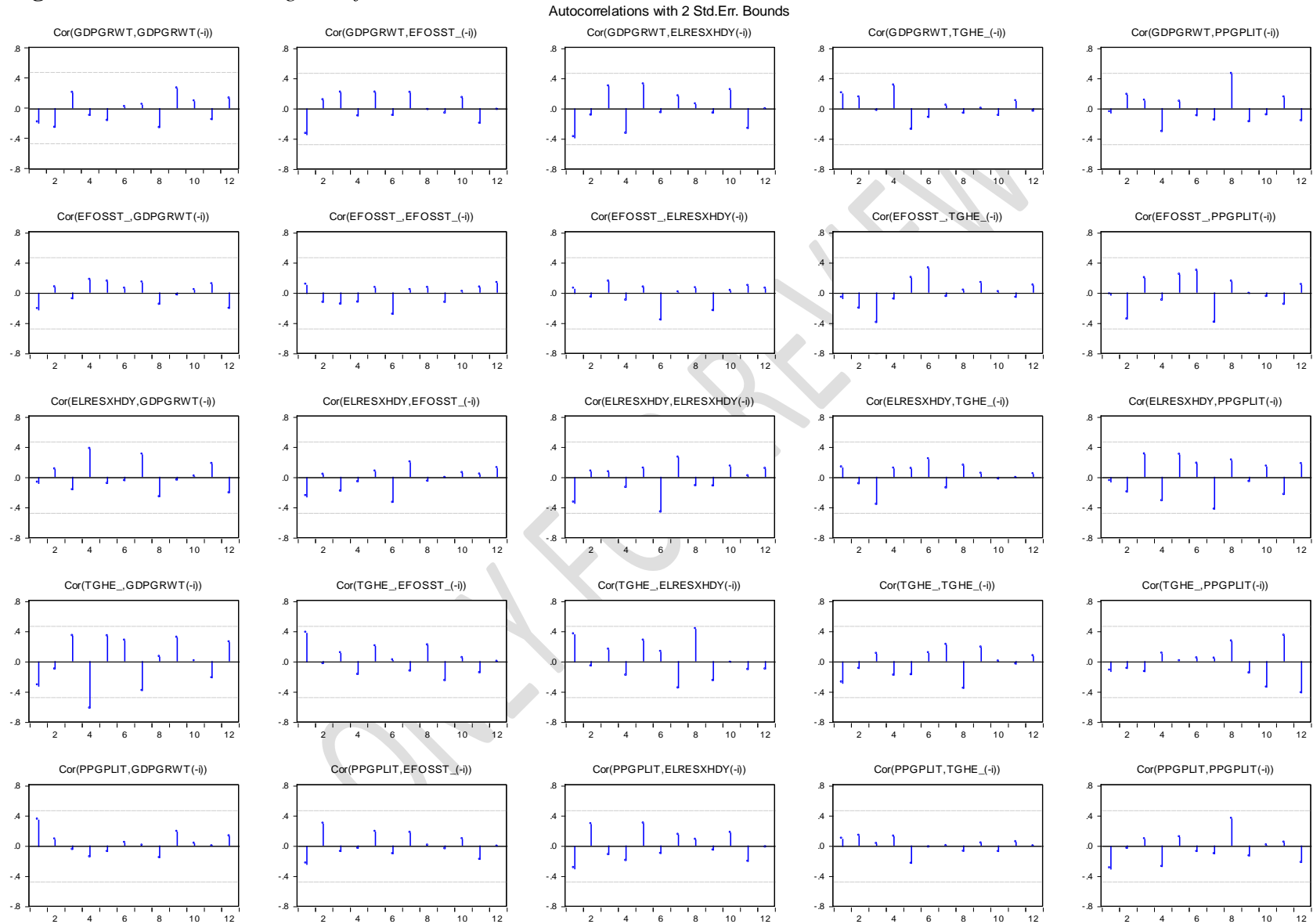
LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

Figure 4 presents the correlogram of the VAR model alongside the endogenous variables with a lag interval of '16'. It presents five graphs of the endogenous parameter, which depict that one or two of the matching study unit autocorrelation are meaningful. Their significance confirms the importance of these variables in explaining the dynamics in the electricity generation mix of Ghana. Some of the graphs show that some of the autocorrelations are outside the interval with two standard error bounds. The other graphs depict that some of the autocorrelations are outside the interval.

Figure 4. *Residual Correlogram of the VAR model*

Source. Author's construct.

From Table 7, VAR normality test is done 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 residual from the components and their P-Values, it is concluded that they are normality distributed since they are generally not significant or more than 0.5%.

Table 7. VAR Residual Normality test

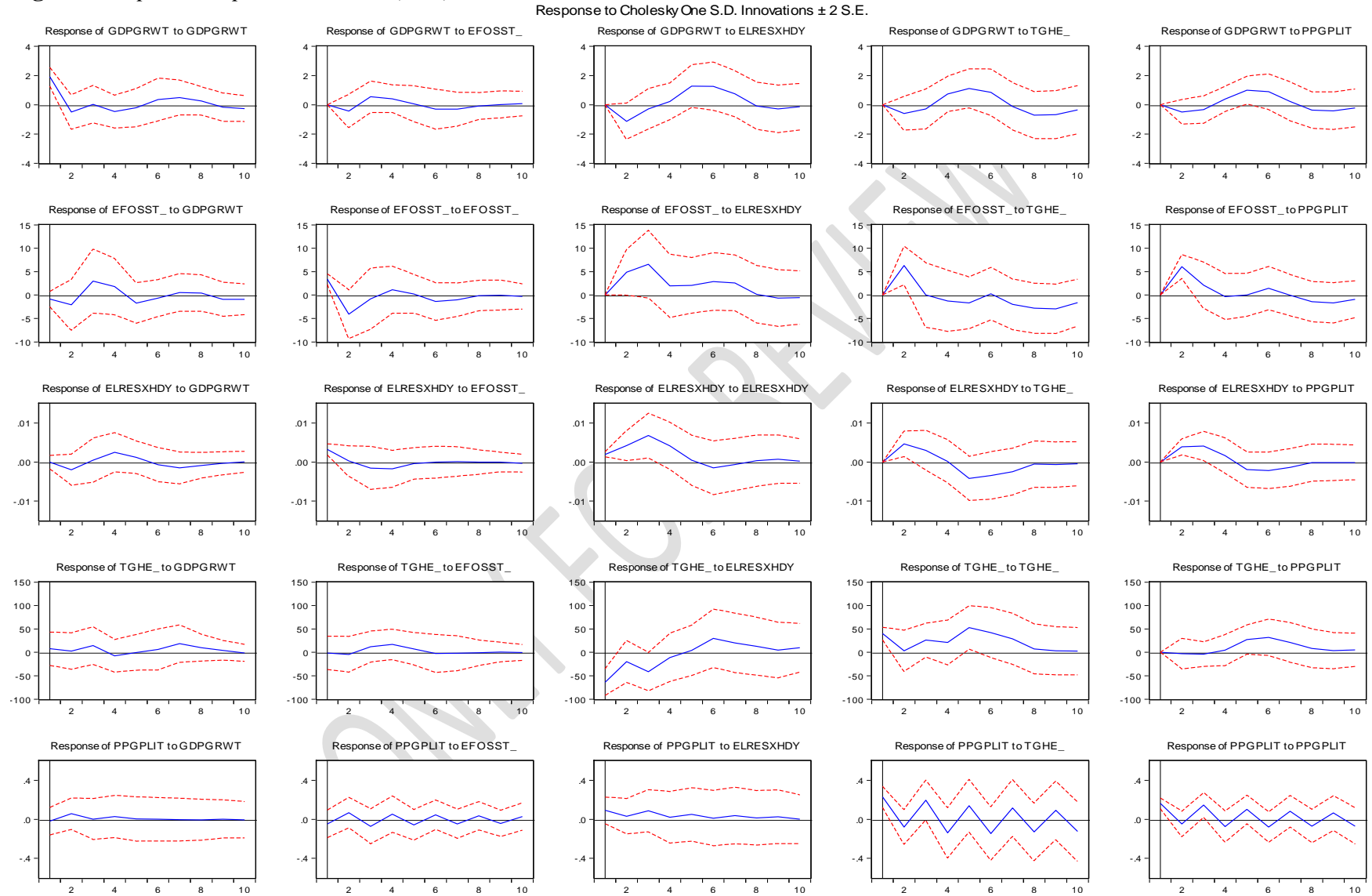
Component	Skewness	Chi-sq	df	Prob.
1	1.053272	3.328143	1	0.0681
2	0.259359	0.201801	1	0.6533
3	0.417071	0.521844	1	0.4701
4	-0.073606	0.016254	1	0.8986
5	-0.501819	0.755466	1	0.3848
Joint		4.823508	5	0.4378
Component	Kurtosis	Chi-sq.	df	Prob.
1	3.791337	0.469661	1	0.4931
2	2.319899	0.346903	1	0.5559
3	2.072214	0.645590	1	0.4217
4	2.982980	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	

Source. Author's calculations.

Figure 5 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 Electricity from RES, excluding hydropower, started from a negative point initially, dipped in the 3rd quarter, and went on an increasing trajectory throughout the rest of time. It is projected that RES capacity will increase when all projects come online. 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 in a steady pathway. The response of the GDP growth rate to total greenhouse gas emissions started on a positive pathway, peaked around quarter four, and continued on an upward trajectory. As the economy grows and relies heavily on fossil fuel sources, emissions levels will rise. A similar situation is noted regarding the price at the pump for gasoline per liter. It reacted to shocks by taking off in a higher trajectory, nosediving, and continuing steadily.

Generally, endogenous variables respond directly to shocks, which attain a permanent effect that advance to a new steady state in the long run. The dynamic reactions of most of the endogenous parameters are varied. Nonetheless, they are reassuring since it leads to an increase in the electricity generation mix of Ghana and advocates the reversal of trends of adverse reactions that don't impact economic development. Endogenous parameters such as total greenhouse emissions and high rising fossil fuels consumptions must be curbed since they are not sustainable generation sources. It is worth mentioning that some of these shocks are permanent, not transitional. The reaction of the GDP growth rate to shocks from global oil markets and the current energy crisis (the Russia -Ukraine conflict) bears permanently on the economy's economic growth from the short term to the long term.

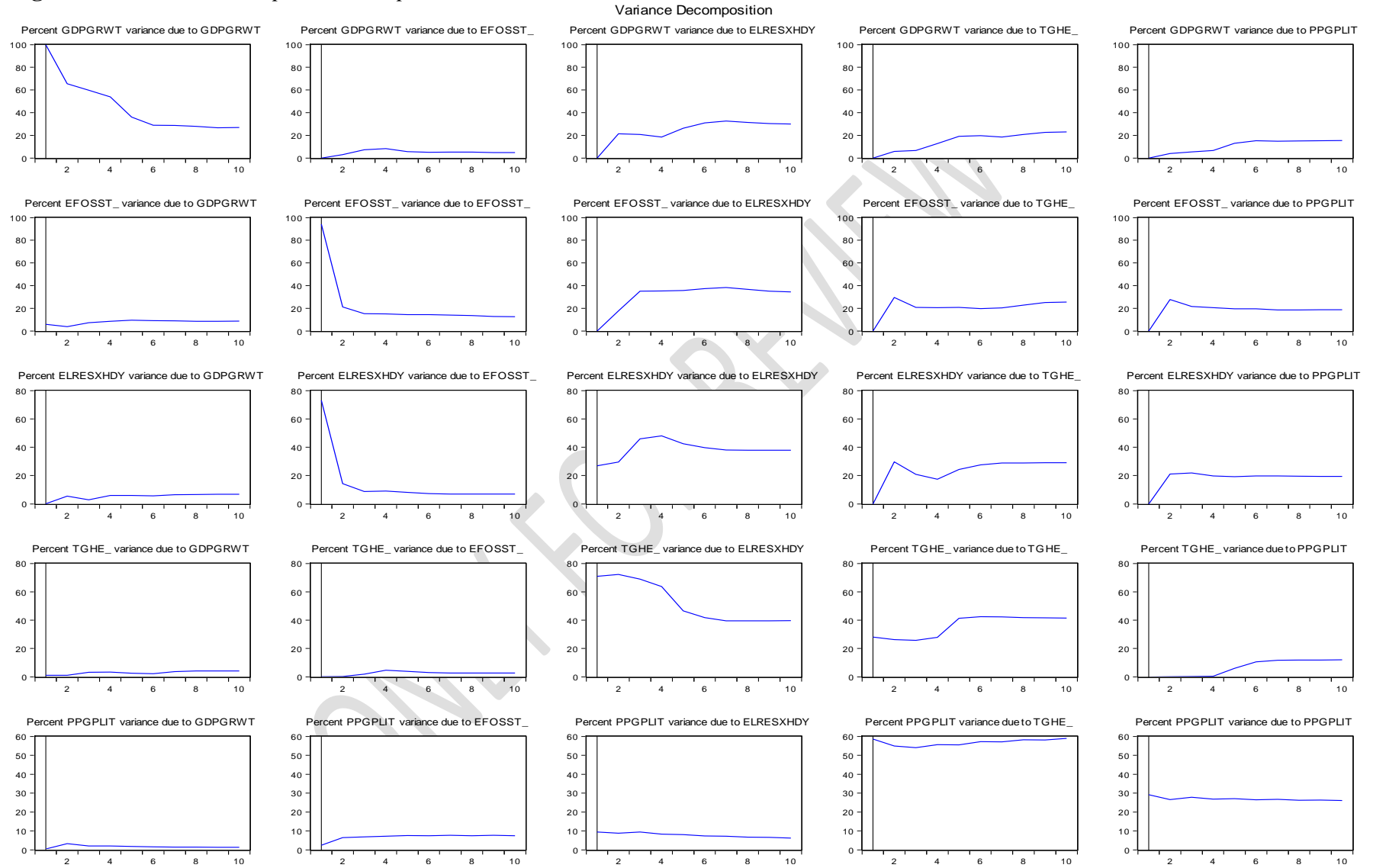
Figure 5. *Impulse Response Function (IRF)*

Source. Author's estimation

Figure 6 is 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%. Thus, the growth rate is very sensitive 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 over 20% and some instances, more than 70%. EFOSST explains a more significant proportion of the variance owing to electric generation dynamics shocks. Aside, the variance explained by total greenhouse gas emissions (TGHE) to itself and from different variables varied around less than 1% to nearly 70% in some cases. This equally depicts the greenhouse gas emissions levels of the country. Ghana's THE peaked around 2010 when the country began exploring oil and gas.

The variance connotes the importance of the supply aspect headwinds that account for the greater part of the variance in the electricity generation 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.

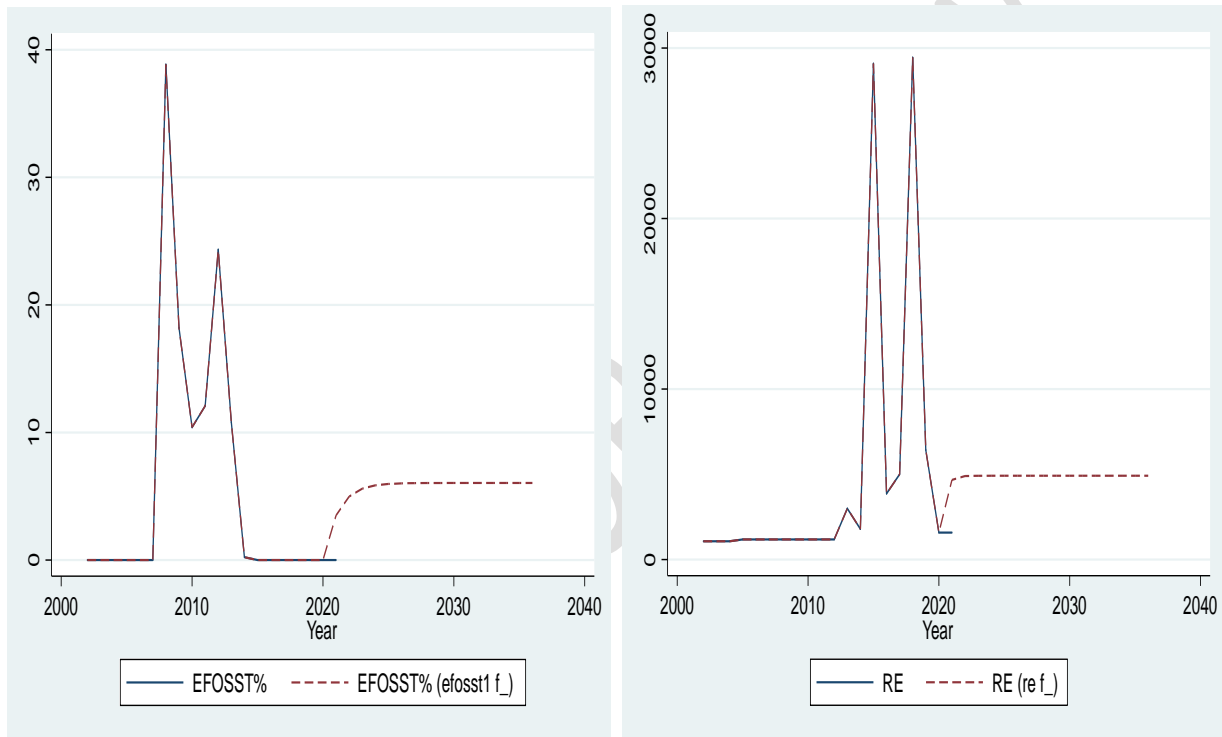
Figure 6. Variance Decomposition Graphs

Source. Author's Construct.

Figure 7 below defines the cumulative Electricity from oil and gas, and coal sources, which is forecasted 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.

On the other hand, the right-handed-sided figure shows Ghana's RE installed generation capacity will continue to grow despite reaching 6000 MW or more. Hydropower forms 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 total renewable energy installed capacity will have increased by about 57.8% by 2036.

Figure 7. *Forecast of EFOSSST and RE Installed Generation capacity*



Source. Author's construct

Figure 8 below depicts the electricity generation sources of 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 from 2000-2019.

Figure 8. *Electricity Generation sources of Ghana*

Conclusion

The study utilizes data from the WDI from 2002 - 2021 to study the electricity dynamics of Ghana. An unrestrictive VAR model was deployed in the analysis. After the analysis, it is evident that Ghana's electricity sector is

characterised by fossil fuels consumptions that exposed the country to external shocks impacting the macroeconomic stability of the country in the short term to the long term, eroding the gains made in building the economy. Current shocks that brought untold economic hardships were the Covid pandemic and the ongoing Russia-Ukraine aggression that has caused acute energy shortages in Ghana, reverberating throughout the entire economy. This shock will in no way impact the GDP growth rate of the country. The variance in GDP growth rate explained over 100% in reactions to shocks, as the analysis revealed.

Additionally, Electricity from fossil fuel sources equally explained a significant amount of variance in the variance decomposition and was significant in the VAR model. This depicts the importance of fossil fuels to the electricity generation dynamics of the country. This is a supply shock that directly impacts the generation of electricity. More explained about 96% of the variance in reaction to shocks. This is rightly so, as the current energy crisis has brought about queues at filling stations in Ghana.

Furthermore, the analysis reveals that renewable energy sources without hydropower are minimally deployed in Ghana. It explains low variance in reactions to shocks depicting the low levels of RES generation in the country, emerging energy sources per se, without traditional hydropower. Also, the granger causality analysis shows a feedback relationship between fossil fuel electricity generation and the country's GDP growth rate. Thus, both granger causes one another and are significant. The impulse response (IRFS) analysis depicts that the parameters reacted to shocks positively within the short to long term, keeping a steady trajectory going forward, with only one of them nosedived to a negative trajectory. Overall, the variables are increasing, reassuring their importance to the electricity generation dynamics of the country. The results likewise determine that Ghana is energy secure but that its energy consumption is from fossil fuel sources which are not sustainable. It exports 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.

Ultimately, the findings come with policy implications and consequences. They highlight the relevance of broad ranging policy toolbox to scale up RES deployment by diversifying the country's energy mix in the long run. The energy sector's indebted over \$12B owed to IPPs can be avoided if the government deploys RES. RES is cheaper and more sustainable means of consumption. Similarly, a negative bidding process for conventional power generation will reduce the energy sector. In this process, the bidders pay the state for electricity generation. This will avoid the situation of excess capacity. This will result in a deep and sustained reduction in our total greenhouse emissions levels and put the country on a pathway to achieving its NDCs. More so, there is the need to reform institutions and break down the institutional complex in the public sector, causing red tape and stifling private sector initiatives, especially in deploying RES. Besides, a robust regulatory environment is essential to transforming the electricity generation dynamics of

Ghana. It is high time the county forms pressure groups such as “The Ghana RES Association” to pressure the government to scale up the deployment of RES. That will protect the country from exogenous shocks and promotes sustainable economic development.

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