Electricity Supply and System losses in Ghana. What is the red line? Have we crossed over?

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Abstract

Electricity supply and sustainable economic development are two complementary forces. However, in Ghana, the capacity limitations in the electricity sector has restraint production levels threatening the sustainable development of the country. The aim of this study is to investigate the key drivers of electricity supply in Ghana. Specifically, we determine the red line in system losses and whether we have crossed over the red line. Further, the effects of pricing, climate change, investment, and economic growth are examined. We identified the major constraints to electricity supply as inefficient pricing, rising fuel cost, higher system losses, and climate change. Adopting the marginal cost pricing rule and reducing distribution losses below 5% will help improve electricity supply security significantly in the country. Further, achieving a **sustained** economic growth will help boost supply security as well as investing in renewable energies.

Keywords: Electricity supply; system losses; climate change; electricity price; fuel cost; Ghana

JEL: Q4, Q41, Q48

1. Introduction

Electricity supply and economic growth are closely connected. Zeshan (2013) found the causality between them to be bidirectional. Thus, ensuring sustainable and uninterrupted electricity supply forms the basis for a nation's sustainable economic development. In Ghana, the supply constraints in the electricity sector have proven to be a major development challenge for the country. Amidst the supply constraints, electricity demand is also growing at a much faster pace of about 5-10% per annum. The major drivers include changing population dynamics, rural electrification programmes, urbanization, rising middle-income class, below marginal cost pricing, which facilitates bad energy use practices, and changing nature of what constitute residential consumers (see: Adom et al., 2012; Adom and Bekoe, 2012; Adom and Bekoe, 2013; Mensah et al., 2016; Ahali, 2016, *inter alia*). Consequently, there is a significant demand-supply gap causing power crisis in the country. The economic cost of these power crises have been documented to range between $320 and $920 million per annum according to the Institute of Statistical, Social and Economic Research (ISSER), Ghana. As indicated by the Wholesale Power Reliability Report in 2010, inadequate and unreliable electricity supply cost the nation between 2-6% of her gross domestic product. The World Bank (2013) also estimate the cost to gross domestic product at 1%. Particularly, the negative consequences on the industrial sector have been documented (see: Adom et al., 2015; Kwabla, 2015; Doe and Asamoah, 2014; Adom et al., 2012; GRIDCo, 2010). Also, the health implications on tertiary students have also been documented (Ibrahim et al., 2016). These crises have also had cross-border effects. Power supply was significantly reduced to Togo, Benin, and Burkina Faso. These results show, at least, improving upon the security of the electricity system in Ghana has both national and regional relevance. This makes the case of Ghana very interesting to study.

In order to solve the chronic problem in Ghana's electricity sector, both demand-side management and supply expansion options have to be pursued aggressively. In the case of the supply-side options, it is important to understand the causal factors of electricity generation in the country. Such studies provide policy makers with vital information on the weights that should be attached to key policy variables. Obviously, in the pool of drivers, each is expected to have different effects, and policy makers must be aware of these to inform them of the corresponding weight to put on each policy variable. Motivated by this, the current study studies the supply-side of the electricity sector in Ghana. Though there are studies addressing the demand side of Ghana's electricity sector (see: Adom et al., 2016; Adom et al., 2012; Adom and Bekoe, 2012; Adom and Bekoe, 2013; Adom, 2013; Mensah et al., 2016; Adom (unpublished)), on the supply side, most of the studies have been descriptive in nature (Eshun and Amoako-Tuffour, 2016; Gyamfi et al., 2015; Ackah et al., 2014; GRIDCo, 2010; International Financial Cooperation, 2012; Fritsch and Poudineh, 2015; Ahali, 2016). Few studies have attempted to quantitatively model electricity supply in the country. Peprah (2015) modelled electricity generation for sub-Saharan Africa, which included Ghana. Basically, the effects of privatization, institutional quality, renewable energy resource, and income were examined within a panel setting. Kwakwa (2015) modelled hydro power generation in Ghana. The study focused on the effects of environmental degradation measured by carbon dioxide emissions, trade openness, financial development, alternative fossil fuel, and foreign direct investment. Though these studies address different important aspects of electricity generation in the country, the very core issues remain unresolved, quantitatively.

Pricing and system losses (i.e. sum of transmission and distribution losses) remain the two main important challenges that confront the country's electricity sector. The below marginal price charged on end-users in the sector has ensured, the utility companies are not able to mobilize enough revenue in the sector. This has stifled investment in the sector particularly in transmission and distribution lines and generation capacities. Moreover, metering problems, electricity theft, and travel of distribution and transmission lines across long distances to rural areas are also prevalent. Altogether, these have created higher systemic losses in the electricity sector; a major contributor to the increasing demand-supply gap in the sector. While between 1971 and 1999, system losses were below 12% of total electricity generated, the rate has significantly increased beyond 20% after 2000. This, compared to the best practices in advanced countries of 4-12%, is very unacceptable for a country that strives to achieve a sustainable economic development. These losses represent significant economic losses to the country and requires a country-wide perspective on the subject. The current condition in the electricity sector suggests increasing electricity price and reducing system losses to ensure reliable electricity supply. Engineering wise, it may not be possible to totally get rid of system losses, but an acceptable level that does not deteriorate electricity generation is still attainable. Though one is tempted to use levels in developed countries as a benchmark, the differences in system operating conditions suggest, the acceptable levels for production may differ from country to country. It is a well-known fact that, higher prices incentivize production, and investment in infrastructure improve efficiency in production and distribution. But the critical questions which still remains unresolved are; does the current electricity price dis-incentivise electricity generation in the country? Do we really have to pay more for electricity to get more? To what extent should we cut down system losses? The current study provides quantitative responses to these critical questions in Ghana's electricity sector.

In terms of the general literature, while there is a plethora of studies focusing on the demand-side of the electricity sector (see: Do et al., 2016; Hamdi et al., 2014; Pourazarm and Cooray, 2013; Martin-Rodriguez and Caceres-Hernandez, 2005; Athukorala and Wilson, 2010; Dergiades and Tsoulfidis, 2008; Halicioglu, 2007; Zaman et al., 2012; Wiesmann et al., 2011; Bernstein and Madlener, 2015; Blazquez et al., 2013; Hung and Huang, 2015; Narayan and Smyth, 2005; Narayan et al., 2007; Fan and Hyndman, 2011; Krishnamurthy and Kristrom, 2015; Nakajima, 2010; Dilaver and Hunt, 2011; Arisoy and Ozturk, 2014; Adom et al., 2012; Adom and Bekoe, 2012; Adom and Bekoe, 2013; Adom, 2013; Adom (unpublished); Mensah et al., 2016, *inter alia*), very few studies have attempted to quantitatively model the drivers of electricity supply empirically (see: Liu et al., 2014; Ubi et al., 2012; Opeyemi et al., 2014; Peprah, 2015; Kwakwa, 2015 ; Zeshan, 2013; Ma et al., 2009; Wen et al., 2004; Tishler et al., 2008) possibly for the reason that, the supply-side is considered more an engineering problem. This study contributes to the scanty literature on the subject. In terms of novelty, however, the current study determines the threshold of system losses that is not harmful to electricity generation (referred to in this study as system loss red line). The role of structural breaks is also effectively modelled in this study.

The remainder of the study is structured as follows. Section 2 briefly reviews the literature on the determinants of electricity supply. Section three presents the theoretical and empirical specifications and discusses the data. Section 4 presents and discusses the main findings of the study. Section 5 concludes the paper and make policy recommendations.

2. Literature review

In developing countries, particularly in Africa, electricity supply is seriously constrained and continuous to pose serious growth challenges in the continent. Interestingly enough, research in this area of the electricity sector is very limited compared to its counterpart, demand. This leaves a big lacuna in the literature, particularly from the perspective of Africa. This section reviews the few attempts in the literature that seek to address the supply-side.

In this area of research, one of the topical issues been discussed is the potential impact of climate change on electricity/energy supply. The main arguments in these studies are that, rising temperature and changes in climate dynamics will affect the speed of wind flow, water levels and flow and sunshine. This consequently will cause in many cases a reduction in energy supplied from wind, solar, and hydro sources.

Van Rheenen et al (2003) examined the impact of climate change on hydro power supply in the central valley and Lake Shasta. The result showed hydro power could decrease by 8-11% in Lake Shasta and by 10-12% in the central valley as a whole. Barnett et al (2004) report that, climate change will reduce hydro power based on the Colorado River by 49% by the middle of the century. Demers and Roy (2006) also found in the province of Quebec, while water inflows increased, the summer inflows decreased due to climate change. In the Nordic region, Beldring et al (2006) revealed based on a simulation model, there will be a general increase in river flow and increased hydro power supply, but the variable winter climate is expected to increase the frequency and fast inflows that may challenge the reservoir capacity of dams.

Durmayaz and Sogut (2006) examined the impact of climate change on thermal efficiency of nuclear plants. Their result confirms power output reduces by 0.45% for a one degree Celsius increase in temperature of the environment. World Nuclear Association (2008) also revealed, in France, Spain, and Germany, utility companies were forced to shut down some of their nuclear plants and reduced power at others in 2006 due to Europe's brutal heat wave. Linnerud et al (2009) used monthly data to investigate the impact of climate change on electricity generation via thermal cooling. Their result showed nuclear power output decreased by 0.8% while coal and gas power output decreased by 0.6% for a one degree Celsius rise in temperature. Greenlent et al (2009) assert that extreme weather conditions can temporarily restrain energy infrastructures and consequently energy supply. BNRCC (2011) also assert that climate change will most certainly impact negatively the already limited power supply via its impact on hydro and thermal generation. Enete and Alaba (2011) confirmed climate change undermines power and energy generation. Khan et al (2013) investigated the impact of climate change on power generation in Australia. Their result confirmed temperature rise and power generation efficiency are correlated. In a review study, Mideksa and Kallbekken (2010) came to the conclusion, the impact of climate change on energy supply is not very obvious. Nonetheless, the potential of climate change to reduce energy supply is very high.

Other studies have also considered the effects of other important variables. Kwakwa (2015) examined the drivers of hydro power generation in Ghana in the long-run. Their result showed a negative impact of environmental degradation and alternative sources of energy on hydro generation, but the effects of foreign direct investment and trade openness are positive. Opeyemi et al (2014) investigated the impact of climate change on energy supply in Nigeria. Their result shows no significant impact of climate change on energy supply. The result remained the same even after interacting the climate change variable with the institution variable. Further, the result showed a significant negative impact of power losses, technology and investment on energy supply in the country, but a significant positive effect of income on energy supply. Ubi et al (2012) also investigated the determinants of electricity supply in Nigeria. Their result confirmed power losses have a negative impact on electricity supply. However, the impact of technology is positive. Further, their result showed a positive impact of electricity price and government funding on electricity generation in the country. Iwayemi (2008) also attributes the poor supply of electricity in Nigeria to the high levels of power losses. Peprah (2015) based on a panel data of 14 sub-Saharan African countries investigated the drivers of electricity generation. Their result showed privatization, labour and income positively impact electricity generation. Zeshan (2013) examined the causal relationships between electricity production and economic growth in Pakistan. The result showed a bidirectional causality between these variables.

In Indonesia, Sihombing (2010) investigated the drivers of electricity supply in North Sumatra Indonesia. Their result showed a positive effect of electricity price but a negative effect of energy losses and price of fuel on electricity supply. Nababan (2016) also investigated the drivers of electricity supply in Indonesia. Their result also showed a negative effect of energy losses and price of fuel, but a positive effect of electricity price on electricity supply. In China, Liu et al (2014) examined the determinants of supply capacity in China's electricity industry. They found GDP growth has a direct impact on capacity growth. However, power prices affect capacity supply indirectly via its effects on electricity demand.

The above review shows limited attempts to understand the drivers of electricity supply in Africa, which motivates further research in the area. Though, studies have shown the negative impact of energy losses on electricity supply, for policy actions, it will be more interesting to establish what the red lines are, whether we have crossed over, and how much effort may be required to reduce energy losses. This study attempts to answer these pressing questions on the supply-side of the electricity sector.

3. Methodology and Data

3.1 Empirical Model

Theoretically, supply of any commodity is determined by the price of the commodity (P_E), the market size/number of buyers (M_S), cost of inputs (I_C), technological (T_{EC}), and weather (W). In the case of electricity supply, these factors are very crucial. Mathematically, the theoretical relations for electricity supply can be written as Equation 1.1.

$$ES = F(P_E, I_C, M_S, T_{EC}, W) \quad 1.1$$

The empirical framework in this study is strongly motivated by equation 1.1. In this study, we model electricity supply as a function of own price, input cost, technology, market size, and weather variability. This is depicted by equation 1.2.

$$ES_t = \alpha_0 + \beta P_{E,t} + \chi I_{C,t} + \delta M_{S,t} + \phi T_{EC,t} + \gamma W_t + \varepsilon_t \quad 1.2$$

Electricity supply is measured as total electricity generated from all sources in gigawatts per hour. In order to ensure conformity, we transformed electricity production data in gigawatts units into kilowatts unit per hour using the information, 1GWh= 1,000,000KWh. The use of aggregate electricity generation in this study makes the current study different from Kwakwa (2015), who used hydro power generation only. Though the concentration of hydro power is still significant in the country, the share of power generated from thermal sources has increased significantly beyond 40% of total electricity generated. Electricity price is the average end-user tariff in local currency per kilowatts hour. This imposes the unusual assumption that, supply decisions are made at averages and not at the margin. However, the lack of data on marginal electricity prices makes this assumption necessary for this study. Input cost is measured using the international price of crude oil Brent crude (P_O) measured in US$/barrel. Crude oil supports about 80% of electricity generation and accounts for more than 30% of electricity generated (Adom, 2013). We use the real gross domestic product per capita (Y) as a proxy for number of buyers/market size. This basically shows the country-wide purchasing ability. In order to capture technological investment in the sector, we use the total system losses (SL) as a proxy. This has strong correlation with technological investment. Total system losses, which is the sum of distribution and transmission losses, is measured as total electricity lost as a percent of total electricity generated. Also, we include gross fixed capital formation (IV) to denote country-wide investment. Finally, climate change has its greatest impact on hydro power generation. The uncertainty in power generation from hydro sources (H_V) is largely due to the effects of climate change. To capture the effect of weather/climate change, we used the uncertainty in hydro power generation, which is calculated as the standard deviation[1]. Thus, our baseline model, in its log form, takes the form in Equation 1.3

$$\ln ES_t = \alpha_0 + \beta \ln P_{E,t} + \chi \ln P_{O,t} + \delta \ln Y_t + \varphi \ln SL_t + \kappa \ln IV + \gamma \ln H_{V,t} + \varepsilon_t \qquad 1.3$$

We test the hypothesis of nonlinear effect of system losses on electricity generation by modifying the baseline model to include the square of system losses. This is shown in Equation 1.4.

$$\ln ES_t = \alpha_0 + \beta \ln P_{E,t} + \chi \ln P_{O,t} + \delta \ln Y_t + \varphi \ln SL_t + \varphi_1 \ln SL_t^2 + \kappa \ln IV + \gamma \ln H_{V,t} + \varepsilon_t \qquad 1.4$$

Next, we account for structural break in the parameters of crude oil price and electricity price. The Quandt-Andrews test shows the maximum breakpoint location occurs in 1986. As shown in Table 1, all tests confirm rejection of the null of no breakpoints within 15% trimmed data.

Table 1: Quandt-Andrews unknown breakpoint test
Null Hypothesis: No breakpoints within 15% trimmed data
Varying regressors: LNSL LNP_O LNP_E LNY LNIV H_V
Equation sample: 1971-2011
Test sample: 1978-2005
Number of breaks compared: 28

Statistic	Value	Prob.
Maximum LR F-statistic (1986)	7.791932	0.0000
Maximum Wald F-statistic (1986)	46.75159	0.0000
Exp LR F-statistic	2.633626	0.0000
Exp Wald F-statistic	20.49570	0.0000
Ave LR F-statistic	3.749081	0.0000

1 $H_v = \sqrt{\frac{1}{n}\sum\left(H_n - \overline{H}\right)^2}$

Ave Wald F-statistic	22.49449	0.0000
Note: probabilities calculated using Hansen's (1997) method		

Apart from this period coinciding with general economic-wide structural shift, the electricity sector, particularly the production structure, has changed significantly after 1980s. Before this period, electricity was solely generated from hydropower sources. Though electricity prices were regulated, the sole dominance of renewables in the production structure ensured low cost of production, which enabled the utility companies to continue production without serious supply restraint. Until the coming in of thermal sources in 1980s, supply challenges were mainly driven by weather variability. Since the shift to thermal generation sources after 1980s, cost of production has significantly increased. However, electricity prices have not adjusted accordingly posing significant supply-side problem to the utility companies. Though prices have adjusted upward compared to the period before, the constant interference in pricing from the government has ensured that, even at the so-called present high price level, production incentives within the utility companies continue to decline. These dynamics show crude oil price is likely to have its greatest impact on supply during this thermal age compared to the hydro age. Also, the prevalence of government interference, albeit this has change since 2016, in this thermal age implies the current price does not incentivize production in the electricity sector. In order to capture these dynamics in the electricity sector, we introduced the structural break dummy (SD), which takes ones after 1986 and zeros otherwise, and interact it with the electricity price and crude oil price variables. This is shown in Equation 1.5.

$$\ln ES_t = \alpha_0 + \beta \ln P_{E,t} + \beta_1 \ln P_{E,t} * SD_t + \chi \ln P_{O,t} + \chi_1 \ln P_{O,t} * SD_t + \delta \ln Y_t + \varphi \ln SL_t + \kappa \ln IV + \gamma \ln H_{V,t} + \varepsilon_t \qquad 1.5$$

Finally, we based on the information from equation 1.4, we augment equation 1.5 with below and above red line information. Thus, we estimate two other models; below the red line and above the red line regressions. These equations are depicted in Equations 1.6 and 1.7. We only expect the coefficient of system losses to switch signs in equations 1.6 and 1.7 while the remaining coefficients remain robust.

$$\ln ES_t = \alpha_0 + \beta \ln P_{E,t} + \beta_1 \ln P_{E,t} * SD_t + \chi \ln P_{O,t} + \chi_1 \ln P_{O,t} * SD_t + \delta \ln Y_t + \varphi \ln SL_t (SL < RL) + \kappa \ln IV + \gamma \ln H_{V,t} + \varepsilon_t \quad 1.6$$

$$\ln ES_t = \alpha_0 + \beta \ln P_{E,t} + \beta_1 \ln P_{E,t} * SD_t + \chi \ln P_{O,t} + \chi_1 \ln P_{O,t} * SD_t + \delta \ln Y_t + \varphi \ln SL_t (SL > RL) + \kappa \ln IV + \gamma \ln H_{V,t} + \varepsilon_t \quad 1.7$$

Equations 1.3 to 1.7 are estimated within the cointegrating autoregressive distributed lag framework. Thus, our empirical models allow dynamism, which is very important for the sector we deal with in this study. Except for equations 1.5 to 1.7, where we focus only on the long-run, we provide both short-run and long-run estimations for the rest of the equations. Our focus on the long-run for equations 1.5 to 1.7 is motivated by the fact that, parameter instability is more of a long-run phenomenon. As a robustness check for our long-run parameters, we employed the fully modified OLS (Phillip and Hansen, 1990) and Canonical cointegration regression (Park, 1992) techniques. This is important since the assumption of weak exogeneity imposed by the cointegrating autoregressive distributed lag method (Pesaran et al., 2001) can be problematic. The FM-OLS and CCR corrects for simultaneity bias and serial correlation and therefore presents as a more robust long-run estimates. In order not to flood the manuscript with many Equations, we have decided to leave the technical description of these econometric methods since we do not contribute to the technical modification of these methods. We encourage interested readers to consult Park (1992), Phillip and Hansen (1990), and Pesaran et al (2001) for the technical discussion of these techniques.

3.2 Data

This study used annual time series data covering 1971-2011. Data on electricity price was obtained from the Volta River Authority, Electricity Company of Ghana, and Energy Commission, Ghana. Crude oil price was sourced from the BP statistical review of world energy. Electricity production, gross domestic product per capita, hydro power production, gross fixed capital formation, and system losses in the electricity sector were sourced from the World Bank development indicator database. Table 2 shows the descriptive statistics of the series. Mean electricity price is GhȻ0.035 with a standard deviation of 0.059. Electricity price is positively skewed and non-normally distributed. Thus, the right tail of the distribution is longer than the left tail. Average investment is about 16% of gross domestic product with a deviation from the actual values by 7.72, which is on the higher side. The low mean investment shows economic-wide investment is very low in the country. Table 1 shows investment is negatively skewed and normally distributed. Thus, there are more decreases in economic-wide investments than increases.

Price of crude oil averages at US$51 per barrel with a deviation from the actual values by 28. The data is positively skewed and normally distributed, which denotes there are more increases in crude oil price than decreases. Income per capita averages at US$962 with a standard deviation of 169. The distribution is not normal, and the data is positively skewed. Thus, there are more increases in per capita income than decreases. Average system losses on the average stands at approximately 10% with a standard deviation of 8.98. The data is positively skewed and non-normal. Average electricity generation for the period is 5720GWh with a deviation from actual values by about 2000GWh. The distribution is normal and positively skewed. Average variability in hydro power generation is about 1.8 with a standard deviation of 1.04, which denotes high volatility clustering in hydro power generation. The data is positively skewed and non-normal.

Table 2: Descriptive Statistics

	P_E	IV	P_O	Y	SL	ES	H_V
Mean	0.035219	15.90973	50.64649	962.1304	9.782147	5.72E+09	1.749142
Median	0.007904	14.44400	42.28842	921.7460	4.687500	5.72E+09	1.373490
Maximum	0.245000	29.00214	115.2213	1471.971	28.83373	1.12E+10	5.649587
Minimum	0.000430	3.377636	12.86817	701.5265	1.989004	1.83E+09	0.158879
Std. Dev.	0.058554	7.722307	27.53587	169.1620	8.981724	1.99E+09	1.038812
Skewness	2.169803	-0.008574	0.731191	0.899121	0.904856	0.544709	1.834253
Kurtosis	7.119411	1.677401	2.531707	3.667006	2.081482	3.354399	6.453228
Jarque-Bera	61.16129	2.988833	4.028005	6.284226	7.036171	2.242067	44.41977
Probability	0.000000	0.224379	0.133453	0.043191	0.029656	0.325943	0.000000
Sum	1.443988	652.2990	2076.506	39447.35	401.0680	2.34E+11	73.46396
Sum Sq. Dev.	0.137145	2385.361	30328.97	1144631.	3226.855	1.59E+20	44.24435
Observations	41	41	41	41	41	41	41

4. Results and Discussion

This section presents and discusses the main findings of the study. It begins with a preliminary test of data and then proceeds to the baseline supply model both short- and long-run. Next, we present the result on the nonlinear effects of system losses. The effects of structural break are then discussed followed by a discussion of the below and above red line regressions.

4.1 Preliminary Data Test

4.1.1. Unit Root Test

Without Structural Breaks

Table 3 shows the test of unit root based on the Phillip-Perron Unit root test. The result shows electricity supply, system losses, price of crude oil, investment, and income per capita are stationary after first difference for all three cases on the deterministic terms. For electricity price, the result shows stationarity in levels both when there are no deterministic terms and we include both constant and trend terms. However, the result show stationarity after first difference when we control only for constant. The result for volatility in hydro power generation shows the opposite. The series is stationary in levels when we control only for intercept and both intercept and trend, but become stationary at first difference when we exclude all deterministic terms. Perron (1989) argues, failure to account for unit root introduces a bias, which reduces the ability to reject a false null hypothesis. In what follows, we present the Zivot-Andrews unit root test with structural break.

Table 3: Phillip-Perron Unit root test

Variables	No constant & trend		Constant and no Trend		Constant & Trend	
	Level	First Difference	Level	First Difference	Level	First Difference
LNES	3.745	-5.011***	-1.301	-7.983***	-2.511	-8.787***
LNSL	-0.070	-7.580***	-1.322	-7.530***	-2.479	-7.545***
LNP_O	0.816	-6.051***	-2.109	-6.158***	-2.077	-6.078***
LNP_E	3.226**	---------	0.185	-11.676***	-3.912**	---------
LNIV	0.201	-7.403***	-1.167	-7.427***	-2.865	-7.287***
LNY	0.699	-3.816***	0.230	-3.877***	-0.471	-5.771***
H_V	-0.990	-8.769***	-3.724***	---------	-4.060**	--------

,* denote 5% and 1% significance levels, respectively.

With Structural Breaks

Table 4 shows the results of unit root with structural break for three different cases. The null hypothesis is, the series has a unit root with a structural break in intercept, trend or both trend and intercept. For the crash model, the results unanimously reject the null for all the variables. Except for electricity price, the test also unanimously reject the null hypothesis for all variables for the changing growth model. For the combined model, the test reject the null for system losses, price of electricity, investment, and volatility in hydro generation, but fails to reject for electricity supply, price of oil and income per capita. In all, unit root with a structural break seems not to be a problem for most for the variables.

Table 4: Zivot-Andrews unit root test with structural breaks

	Zivot-Andrews Test Statistics			
Variables	Crash model[a]	Changing growth model[b]	Combined model[c]	Chosen lag length
LNES	-5.485**	-4.630	-5.373	1
	(1983)	(1985)	(1983)	
LNSL	-7.276***	-3.249*	-6.344***	0
	(2000)	(1994)	(2000)	
LNP_O	-3.710***	-3.481***	-3.276	0
	(1986)	(1999)	(2001)	
LNP_E	-7.084***	-4.043*	-8.301***	0
	(1984)	(1988)	(1984)	
LNIV	-3.462**	-3.045**	-4.514***	0
	(1987)	(2001)	(1984)	
LNY	-2.503***	-3.174***	-3.531	1
	(1979)	(1984)	(1982)	
H_V	-4.466**	-4.431***	-4.752**	3
	(2005)	(2001)	(1999)	

[a.] Null Hypothesis: the series has a unit root with a structural break in intercept.
[b.] Null Hypothesis: the series has a unit root with a structural break in trend
[c.] Null Hypothesis: the series has a unit root with a structural break in both intercept and trend
Note: the figures in the parenthesis denote the chosen breakpoint location

4.1.3. Cointegration Test

Finally, we test for long-run relationship for all five models based on the ARDL bounds test technique. The result is shown in Table 5. For the baseline supply model, the result shows the computed F-statistic fall within the two critical bound at 5% and 10% significance levels. According to Kremers et al (1994), in such a case, we base the cointegration decision on the significance of the error correction term. Table 6 shows the error correction term is statistically significant at 1%, and the adjustment to equilibrium factor is very high of about 88%. This suggests there is a high degree of equilibration after a shock, and for the first year, about 88% of the initial error will be corrected. By implication, there exist a long-run supply model. The test for the remaining models show the calculated F-statistics exceed the upper critical values at 5% significance level. Thus, we reject the null hypothesis of no long-run relationship for all these models.

Table 5: ARDL Bounds Test
Null Hypothesis: No long run relationship exist

	10% Critical Values		5% Critical Values		1% Critical Values	
Model F-statistics	Lower bound I (0)	Upper bound I (1)	Lower bound I (0)	Upper bound I (1)	Lower bound I (0)	Upper bound I (1)
F_{BLR}=2.815	1.99	2.94	2.27	3.28	2.88	3.99
F_{NLR}=3.363	1.92	2.89	2.17	3.21	2.73	3.9
F_{SD}=4.144	1.85	2.85	2.11	3.15	2.62	3.77
$F_{SL<RL}$=3.072	1.85	2.85	2.11	3.15	2.62	3.77
$F_{SL>RL}$=3.072	1.85	2.85	2.11	3.15	2.62	3.77

4.2 Baseline Supply Model

4.2.1. Short-run

Table 6 shows the baseline short-run supply model. There is persistence in electricity supply as indicated by the positive significance of the coefficient of the one year lag of electricity supply. System losses significantly causes a reduction in electricity supply. The elasticity suggests a 10% increase in system losses causes a reduction in electricity supply by 0.92%. Similarly, volatility in hydro generation significantly drains electricity supply in the short-run. For every 10% increase in the volatility in hydro generation, electricity supply will decrease by 0.49%. This suggests variability in weather due to climate is an important supply restraint in the short-run. Price of electricity significantly increases electricity supply in the short-run. The elasticity shows a 10% increase in electricity price causes electricity supply to increase by 2%. Thus, the power generators in the country are incentivize by higher prices. However, crude oil price seems not to be an important supply restraint factor in the short-run. The result shows a significant positive effect on electricity supply. The effects of income and investment seem not to play a significant role in the short-run. The short-run result shows raising electricity prices can help compensate for any supply loss due to system losses.

Table 6: Baseline short run electricity supply

Variable	DLNES_1	DLNSL	$DLNP_O$	$DLNP_E$	DLNY	DLNIV	DLNIV_1	H_v	ECT_1
Coef	0.525***	-0.092*	0.114**	0.201**	0.308	-0.138	-0.138	-0.049**	-0.883***
	(0.1476)	(0.0489)	(0.0547)	(0.0764)	(0.4934)	(0.0996)	(0.1011)	(0.0230)	(0.1491)

*,**,*** denote 10%, 5%, and 1% significance level

4.2.2 Long-run

The long run model is shown in Table 7. System losses significantly restrain electricity supply in the long-run. A 10% increase in system losses cause electricity supply to decrease by 0.84%. This result is confirmed by the estimates of FM-OLS and CCR. They both show system losses significantly reduce electricity supply by between 1.05 and 1.07% for every 10% increase in system losses. In the long-run, electricity price significantly boost electricity supply. Supply of electricity is expected to increase by 0.83% for a 10% increase in electricity supply. Similar results are provided by the FM-OLS and CCR. Electricity price will increase electricity supply by between 1.24 and 1.25% for every 10% increase in electricity prices. Based on this study's estimate, the problem of rising system losses can be compensated by increasing the price of electricity in the long-run.

Investment significantly boost electricity supply in the long-run according to the ARDL and FM-OLS estimates. The elasticity shows an increase in supply of between 1.65 and 3.81% for every 10% increase in investment. Though the effect is positive in the case of the CCR, it is not significant. Income significantly boost electricity supply according to the result of the FM-OLS and CCR. The elasticities suggest an increase in electricity supply of between 4.62 and 5.08% for every 10% increase in income per capita. However, the ARDL shows this effect is not significant, albeit positive. This implies further economic growth that translates into higher income will exonerate the electricity sector from supply constraints. The ARDL shows again in the long-run crude oil price increase does not restraint electricity supply. However, this effect is found to be insignificant from the results of the FM-OLS and CCR. Unanimously, all three methods show an insignificant negative effect of hydro generation uncertainty on electricity supply.

Table 7: Baseline Long run electricity supply

Variables	ARDL (2, 0, 0, 0, 0, 2,0)[1]	Fully Modified OLS[2]	Canonical Cointegration Regression[2]
LNSL	-0.084*	-0.105**	-0.107**
	(0.0472)	(0.0456)	(0.0485)
LNP_E	0.083**	0.124***	0.125***
	(0.0332)	(0.0271)	(0.0290)
LNP_O	0.226**	0.064	0.054
	(0.0970)	(0.0686)	(0.0758)
LNY	0.211	0.508**	0.462*
	(0.3005)	(0.2478)	(0.2644)
LNIV	0.381***	0.165*	0.161
	(0.1354)	(0.0854)	(0.0993)
H_v	-0.055	-0.020	-0.004
	(0.0356)	(0.0352)	(0.0468)
Constant	19.760***	19.041***	19.391***
	(1.6934)	(1.5631)	(1.6730)
R^2	0.885	0.730	0.725
Adj. R^2	0.844	0.680	0.675
S.E.R	0.142	0.205	0.207
L.R variance	---------	0.030	0.030
f-statistics	21.590***	-----------	-----------

[1.] ARDL model selected based on the Akaike Information criterion. [2.] Long-run covariance estimate (Prewhitening with lag=0 from SIC maxlags=3, Bartlett kernel Newey-West fixed bandwidth=4.0000)

The ARDL model was subjected to some diagnostic statistics. The model passed the serial correlation and heteroscedasticity tests, but failed the normality test at 10% significance level. The cumulative plots also show stable parameters (see Appendices A and B for the results). The FM-OLS and CCR were also investigated for multicollinearity problem. The coefficient variance decomposition was estimated for both models. Based on the recommendations of Belsely et al (2004), we conclude no multicollinearity among the regressors (see Appendices C1 & C2 for the results).

4.2.3. Comparison of baseline results with the literature

The negative effect of climate change on electricity generation is also confirmed by Van Rheenan et al (2003), Linnerud et al (2009), Enete and Alaba (2011), and Kwakwa (2015). Similarly, the negative effect of system losses confirms the results of Opeyemi et al (2014), Ubi et al (2012), Sihombing (2010) and Nababan (2016). The positive effect of electricity price is in conformity with the conclusions of Ubi et al (2012), Sihombing (2010) and Nababan (2016). The positive effect of income is also confirmed by Peprah (2015), Liu et al (2014), and Opeyemi et al (2014). However, the positive effect of fuel price is in sharp contrast to the results of Nababan (2016) and Sihombing (2010). This could be attributed to different fuel pricing regimes and production structure in these economies. As indicated above, production structure has shifted since the mid-1980s towards thermal generation source. Therefore, the negative consequences of fuel price is likely to be visible only during this thermal age.

4.3 Nonlinear effect of system losses

Here we modify the baseline regression to include the square of system losses. First, is to test the hypothesis of nonlinear effect of system losses, and second is to see if the model characteristics will improve. Compared to the baseline regression, the model characteristics have improved. For the ARDL model, the r-square has increased while the sum error of the regression has decreased (see the bottom part of Table 9). Also, the model now passes all the error diagnostic tests (see Appendix D for the result) as well as model stability test (see Appendix E for the result). Also, for the FM-OLS and CCR, the long run variance has reduced. This means the adjustment has improved our model features.

4.3.1 Short-run

Table 8 shows the short-run results. Electricity price significantly boost electricity supply in the short-run. Elasticity suggests an increase in supply of 1.97% for every 10% increase in electricity prices. Investment becomes significant in the short-run, but the effect of income is still not significant. According to the estimate, increasing investment in the short-run by 10% will cause electricity supply to increase by 1.8%. Again, crude oil price does not restraint electricity supply in the short-run. The elasticity is positive and significant. Uncertainty in hydro generation significantly restraint electricity generation. Compared to the baseline model, the coefficient has increased after the modification. A 10% increase in hydro generation uncertainty in the short-run will reduce electricity supply by 0.63%. The nonlinear effect of system losses is not confirmed in the short-run. As indicated by Table 8, the relationship is U-shaped and statistically insignificant in the short-run. The error correction term is significantly negative with an above 50% adjustment factor, which suggests higher tendency to reach equilibrium after a short-term perturbation.

Table 8: short run

Variable	$DLNP_E$	$DLNP_O$	DLNY	DLNIV	H_V	DLNSL	$LNSL^2$	ECT
Coef	0.197***	0.217***	0.283	0.180**	-0.063***	-0.114	0.044	-0.664***
	(0.0460)	(0.6830)	(0.4394)	(0.0875)	(0.0209)	(0.2362)	(0.0675)	(0.0913)

, * denote 5% and 1% significance levels

4.3.2 Long-run

Table 9 shows the long-run results. Electricity price significantly boost electricity production in the long-run. This is confirmed by all three methods. The elasticities suggest an increase of between 1.02 and 1.54% in electricity supply for every 10% increase in electricity price. Also, income and investment significantly boost electricity supply in the long-run. For income, the elasticities suggest an increase of between 5.48 and 6.52% in electricity supply for every 10% increase in income. In the case of investment, the long-run elasticities suggest an increase of between 1.97 and 5.82% in electricity supply for every 10% increase in electricity price. The ARDL suggests a significant negative effect of uncertainty in hydro generation on long-run electricity supply. The elasticity suggests a decrease of 1.18% in electricity supply for every 10% increase in hydro generation uncertainty. However, the FM-OLS and CCR dispute this result, albeit the effect in all cases is negative. Crude oil price seems not restraint long-run electricity supply according to the ARDL, but the CCR and FM-OLS show otherwise. Both the ARDL and FM-OLS confirm the nonlinear effect of system losses. The result suggests a red line of between 5 and 7%. Though the CCR also portrays the same relationship, statistically it is not significant. This implies the issue of nonlinear effect of system losses is more of a long-run phenomenon.

Table 9: long run

Variables	ARDL (1, 1, 0, 0, 1, 1,1,1)[1]	Fully Modified OLS[2]	Canonical Cointegration Regression[2]
LNP_E	0.102**	0.154***	0.151***
	(0.0485)	(0.0273)	(0.03240)
LNP_O	0.337**	0.097	0.084
	(0.1212)	(0.0603)	(0.0738)

LNY	0.652*	0.595**	0.548**
	(0.3871)	(0.2253)	(0.2411)
LNIV	0.582***	0.203**	0.197**
	(0.1825)	(0.0762)	(0.0965)
H_V	-0.118**	-0.012	-0.002
	(0.0572)	(0.0309)	(0.0454)
LNSL	1.716**	0.563*	0.499
	(0.6858)	(0.2912)	(0.4185)
$LNSL^2$	-0.446**	-0.174**	-0.157
	(0.1717)	(0.0758)	(0.1068)
Constant	14.507***	17.858***	18.277***
	(2.6673)	(1.5015)	(1.6824)
R^2	0.900	0.757	0.753
Adj. R^2	0.856	0.704	0.699
S.E.R	0.138	0.198	0.199
L.R variance	---------	0.023	0.023
f-statistics	20.321***	-----------	-----------

,,*** denote 10%, 5%, and 1% significance levels, respectively.*

4.4 Test for Structural Break: Long-run supply

In section 3.1, we observed, the changes in production structure combined with the continuous interference by the government after the 1980s may have changed the dynamics of how prices affect electricity generation in the country. Table 10 shows the long-run shifts in the price elasticities of electricity and crude oil. All three methods show electricity prices did not adversely affect production incentives in the electricity sector prior to 1986. As shown in the table, the coefficient is consistently positive but significant only in the FM-OLS and CCR models. However, electricity prices seem to have adversely affected production incentives post-1986. The elasticities for all three models are significantly negative. On the whole, electricity prices do not encourage production incentives in the country. According to the estimates, the overall price elasticities range from -0.073 to -0.478. Further, the result shows crude oil price did not dis-incentivise production incentives prior to 1986, but this has changed after 1986. The result shows consistent negative effect of crude oil price on electricity generation. This shows the shift to thermal sources has subjected the power sector to oil price shocks, and this has generally increased production cost in the sector and hence restraint electricity supply.

The effect of system losses is negative but significant in the FM-OLS and CCR models. The elasticities suggest a decrease in electricity supply of between 0.49 and 0.59% for every 10% increase in system losses. Income significantly boost production incentives in the long-run. The elasticities suggest an increase in long-run electricity supply of between 19.25 and 47.69% for every 10% increase in income. Uncertainty in hydro generation has a consistent negative effect on production in the long-run but statistically insignificant. Similarly, investment seems not to be a significant supply booster in the long-run. Compared to the baseline regression, the consideration of structural breaks has improved the model features. For the ARDL model, the r-square has increase while the sum of error of the regression has declined. The model passes all the tests on the error term (see Appendix F for the results), and the parameters are stable according to the cumulative plots (see Appendix G for the results).

Table 10: Shift in long run oil and electricity price elasticities

Variables	ARDL (1,1,2,2,2,1,2,0)	Fully Modified OLS	Canonical Cointegration Regression
LNSL	-0.022	-0.049**	-0.059*
	(0.0736)	(0.0238)	(0.0284)
LNP_E	0.091	0.147***	0.149***
	(0.0849)	(0.0230)	(0.0263)
LNP_E*SD	-0.569**	-0.224***	-0.222***
	(0.2216)	(0.0381)	(0.0485)
LNP_E	0.726**	0.239***	0.234***
	(0.2625)	(0.0400)	(0.0451)
LNP_O*SD	-0.586*	-0.218***	-0.210**
	(0.2930)	(0.0475)	(0.0784)
LNY	4.769***	1.925***	1.931***
	(1.6153)	(0.2018)	(0.2499)
LNIV	0.174	0.015	-0.003
	(0.1939)	(0.0482)	(0.0594)
H_V	-0.104	-0.012	-0.010
	(0.0693)	(0.0172)	(0.0246)
Constant	-12.708	9.075***	9.104***
	(11.6964)	(1.3687)	(1.6928)
R^2	0.950	0.845	0.842
Adj. R^2	0.889	0.804	0.802
S.E.R	0.120	0.61	0.162
L.R variance	-------	0.0065	0.0065
f-statistics	15.498***	--------	--------

*,**,*** denote 10%, 5%, and 1% significance levels, respectively

4.5 Electricity supply and Red lines in system losses

Finally, we re-estimate the model in Table 10 by accounting for the below and above system loss red line. We choose the system loss red line suggested by the FM-OLS (i.e. 5%). The below red line regression shows system losses below 5% do not deteriorate production in the electricity sector. Estimates by the FM-OLS and CCR show a significant positive effect of system losses on electricity generation. On the contrary, system losses beyond 5% deteriorates production in the electricity sector. Estimates based on the FM-OLS and CCR confirm a negative effect of system losses on electricity generation. This result confirm our earlier result which showed system losses below 5% will not harm production incentives in the electricity sector but beyond this level, electricity generation will suffer a downward trend.

The question is have we already crossed over this red line? The answer is a big YES. The descriptive statistics showed an average system loss of about 10% within the sample we consider. Thus, even using the average levels, it shows the country has already exceeded this threshold by almost 100%. The current actual losses are within the figures of twenties. In 2013, total system losses in the electricity sector stood at 21.54%. Much of these losses were found in the distribution companies: Electricity Company of Ghana (ECG) and National Electricity Department Company (NEDCo). In 2006, about 24.3% of power distributed by ECG got lost. This increased to 27.2% in 2011 and reduced to 22.7% in 2015. Similar picture is observed for NEDCo. Distribution losses was about 29.7% in 2006. This decreased to 19.3% in 2011 and increased to 27.5% in 2015. In absolute terms, the losses in ECG are much higher than in NEDCo since it serves the largest clients in the country. On the other hand, transmission losses are on the lower side of below about 5%. Transmission losses in 2006 was 3.5%. This increased to 4.8% in 2013 but increased to 3.8% in 2015. These facts suggest, technically, to achieve total system losses below or at 5%, ECG and NEDCo have to cut their losses by more than 20%.

Further, the results show pricing of electricity post-1986 has decreased production incentives causing significant reduction in electricity supply. The elasticities suggested by the FM-OLS and CCR exceeds the pre-1986 elasticities. Similarly, pricing of crude oil has decreased production incentives in the electricity sector post-1986 causing decline in electricity generation. The FM-OLS and CCR estimate the elasticities for this period to be significantly negative. On the other hand, higher income is a supply booster. The elasticities suggest an increase in electricity supply of between 19.73 and 22.12% for every 10% increase in income. Similarly, higher income has been found to boost electricity demand. Mensah et al (2016) suggest an increase in electricity demand of 27.10% for every 10% increase in income. Adom (2013) suggests an increase in electricity demand of 21.15% for every 10% increase in income. Adom and Bekoe (2012) suggest an increase in electricity demand of between 16.97 and 26.9% while Adom et al (2012) suggest an increase in demand of 15.91% for every 10% increase in income. Adom (unpublished) suggests an increase in electricity demand of between 11.16 and 37.54%. This means economic growth that translates into higher income will increase both supply efforts and demand in the electricity sector. In the more optimistic case, demand is likely to be more responsive to higher income than supply; again emphasizing the importance of demand-side management options. Both investment and uncertainty in hydro generation seem not to significantly affect electricity supply in the long-run.

Table 11: Long run supply model

	Below Red line regression			Above red line regression		
	SL<5%	**SL<5%**	**SL<5%**	**SL>5%**	**SL>5%**	**SL>5%**
Variable	*ARDL*	*FM-0LS*	*CCR*	*ARDL*	*FM-OLS*	*CCR*
LNP_E	0.052	0.146***	0.147***	0.052	0.146***	0.147***
	(0.0799)	(0.0226)	(0.0260)	(0.0799)	(0.0226)	(0.0260)
LNP_E*SD	-0.192	-0.236***	-0.232***	-0.192	-0.236***	-0.232***
	(0.1118)	(0.0350)	(0.0434)	(0.1118)	(0.0350)	(0.0434)
LNP_O	0.307**	0.232***	0.218***	0.307**	0.232***	0.218***
	(0.1176)	(0.0391)	(0.0466)	(0.1176)	(0.039)	(0.0466)
LNP_O*SD	-0.111	-0.228***	-0.214***	-0.111	-0.228***	-0.214***
	(0.1934)	(0.0579)	(0.0735)	(0.1934)	(0.0579)	(0.0735)
LNY	2.212***	1.973***	2.004***	2.212***	1.973***	2.004***
	(0.6759)	(0.1947)	(0.2396)	(0.6759)	(0.1947)	(0.2396)
LNIV	0.049	-0.001	-0.036	0.049	-0.001	-0.036
	(0.1678)	(0.0484)	(0.0655)	(0.1678)	(0.0484)	(0.0655)
H_V	-0.084	-0.012	-0.010	-0.084	-0.012	-0.010
	(0.0617)	(0.0168)	(0.0239)	(0.0617)	(0.0168)	(0.0239)
LNSL	0.095	0.071**	0.091**	-0.095	-0.071**	-0.091**
	(0.1085)	(0.0322)	(0.0403)	(0.1085)	(0.0322)	(0.0403)
Constant	6.102	8.678***	8.574***	6.197	8.750***	8.665***
	(4.5250)	(1.3157)	(1.6099)	(4.5188)	(1.3173)	(1.6083)
R^2	0.910	0.844	0.840	0.910	0.844	0.840
Adj. R^2	0.840	0.804	0.799	0.840	0.804	0.799
S.E.R	0.145	0.161	0.163	0.145	0.161	0.163
L.R. variance	-------	0.0062	0.0062	------	0.0062	0.0062
F-statistics	13.0254***	-------	--------	13.025***	-------	--------

*,**,*** denote 10%, 5%, and 1% significance levels, respectively

5. Conclusion and Policy Recommendation

This study investigated the supply-side of the electricity sector in Ghana. Specifically, we determined what the red line is in system losses and whether as a country we have already crossed over. Further, the effects of pricing, fuel cost, weather variability, income and investment were examined. The ARDL technique was employed, and, as a robustness check in the long-run, we employed the FM-OLS and CCR. We used annual time series data covering 1971 to 2011. Preliminary data test showed unit root but less evidence of unit root with structural break. The ARDL Bounds test confirms the existence of long-run relationship. The following results emerged from the study.

System losses significantly reduce electricity generation in the country. A threshold level above 5% is identified in the study to deteriorate production levels in the electricity sector. Currently, total system losses are above 20%. Much of this come from the distribution sector. The result suggests we cut down on system losses in the distribution companies by more than 20% in order to cross below the red line. This requires massive investment in distribution lines, meters, and accounting frameworks, which will require the assistance of the private sector given the tight budget the country is currently running. Peprah (2015) found privatization promotes electricity generation in sub-Saharan Africa. In North America, there have been success stories about privatization improving the operational performance of electricity companies causing significant drops in distribution losses. Enersis, a private company, took over large utility companies in Argentina (Edesur), Peru (Edelner), Brazil (Ampla and Coelce), Columbia (Codersa), and Chile (Chilectra) in the 1990s and 1980s. Soon after the take-over, operational performance of these utility companies improved significantly causing reductions in distribution losses. In Columbia, distribution losses reduced from 22% in 1997 to 9% in 2007. Argentina also experienced a decline in distribution losses from 24% in 1992 to 11% in 2007. In Peru, distribution losses fell from 18% in 1994 to 8% in 2007. In Chile, distribution losses reduced from 21% in 1985 to 6% in 2007. The government has to take a clue from these country experiences. ECG in September 29, 2016 signed a memorandum of understanding with the Korean Electricity Company. The partnership is expected to help ECG tap into the experiences of the Korean company to help it reduce distribution losses to about 3%. When this materializes, it will be a major boost to electricity supply security in the country. However, we hope this will not be another of the many white papers with no works. We recommend NEDCo, the other distribution company, to follow suit.

There is a significant shift in the own-price elasticity. Pricing post-1986 has reduced production incentives in the electricity sector causing electricity supply to decrease in the long-run. In order to boost supply, an above marginal cost pricing should be adopted in the sector. This among other things will boost the financial position of utility companies. By implication, the market should be allowed to operate freely in the sector. However, from welfare perspective, some form of cushioning may be required for the vulnerable in the sector. Adom (2016) observed that, while the industrial sector can be subjected to the full rudiments of the market, doing so in the residential sector may subject the sector to a perpetual disequilibrium. Thus, following from Adom (2016), we recommend a quasi-free market for the residential sector and a completely free market for the industrial sector. Though marginal cost pricing in the sector will help boost production incentives and hence supply, the inelastic nature of price suggests, pricing policies can only partially solve the problem in the electricity sector.

Similarly, the result showed a significant shift in the effect of crude oil price. Fuel prices have adversely affected production incentives in the sector causing decline in electricity supply. This has been fuelled by the shift in production structure towards thermal generation. The current structure means production in the sector will continue to be subjected to the developments in oil market. Given the volatile nature of oil market, the security of electricity supply is likely to be very uncertain. This will not be good for the sustainable development of the country. Renewable energies have to be pursued aggressively, albeit they come with its own uncertainty. Nonetheless, they can be combined with the traditional sources in a manner that ensures sustainable supply of electricity.

Climate change seems to drain electricity supply in the short-run, but not in the long-run, albeit the effect looks negative in the long-run. This suggests we integrate climate policies into the broad economic policy as well as the national energy policy. The results on economic-wide investment is not very convincing. While in some cases, it shows significant positive effects, in other cases, the effect was not significant. Generally, economic-wide investments during the period under study focused on road infrastructure and housing infrastructure. This crowded-out investment in the energy sector. In recent times, the trend is changing. There have been massive investments in hydro and gas processing plants to help the electricity sector. However, it will take some time before we start reaping the full benefits of these investments due to the long-term payback period of such investments.

Last, higher income has a long-run boosting effect on electricity supply in the country. Thus, ideally, we expect a *sustained* positive growth rates that translates into higher income to boost electricity supply security in the long-run. Among other things, sustained positive growth rates shape the prospects of the country in the international community. This has the effect of attracting foreign investment in the country, which the electricity sector is likely not to be exonerated from.

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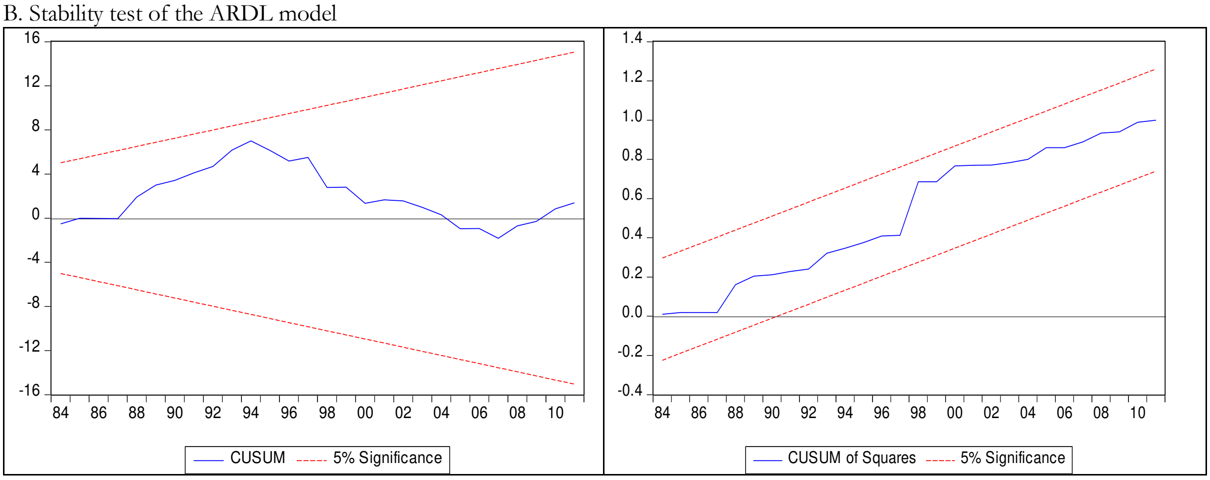
Appendices

A. Diagnostic test for ARDL model

Test	Statistics
Breusch-Godfrey serial correlation LM test	0.380
Heteroscedasticity test: ARCH	0.337
Normality test (Jarque-Bera)	4.838*

B. Stability test of the ARDL model



C1: Coefficient Variance Decomposition for FM-OLS

Eigenvalues	2.499438	0.015124	0.002770	0.001977	0.001221	0.000173	7.59E-06
Condition	3.04E-06	0.000502	0.002741	0.003840	0.006218	0.043904	1.000000
Variance Decomposition Proportions							
				Associated Eigenvalue			
Variable	1	2	3	4	5	6	7
LNSL	0.074586	0.005528	0.407095	0.501572	0.000307	0.010784	0.000129
LNP_E	0.015926	0.482650	0.263400	0.015336	0.074384	0.145845	0.002460
LNP_O	3.24E-06	0.655129	0.283257	0.059057	0.001507	0.000812	0.000236
LNY	0.910249	0.086359	0.000539	0.001509	0.001185	0.000100	5.85E-05
LNIV	0.026506	0.851444	0.042844	0.051468	0.026173	0.001494	7.08E-05
H_V	0.054657	0.023742	0.040294	0.141000	0.721883	0.018243	0.000180
Constant	0.999942	5.58E-05	6.59E-07	8.77E-07	6.94E-07	2.77E-08	3.13E-08

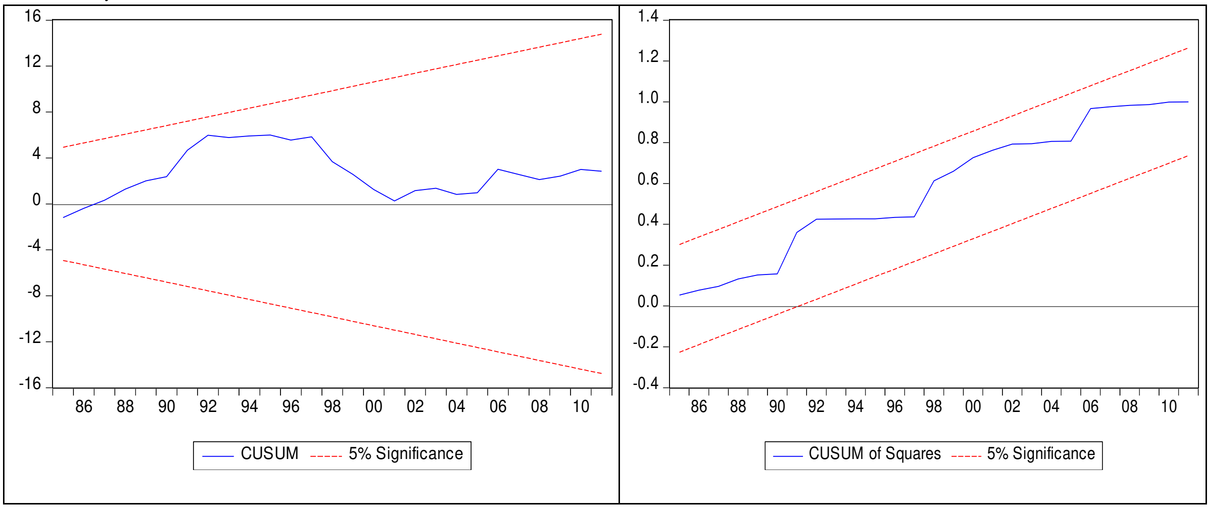
C2: Coefficient Variance Decomposition; CCR

Eigenvalues	2.862785	0.021292	0.002702	0.002211	0.001660	0.000192	7.55E-06
Condition	2.64E-06	0.000355	0.002795	0.003415	0.004549	0.039341	1.000000
Variance Decomposition Proportions							
				Associated Eigenvalue			
Variable	1	2	3	4	5	6	7
LNSL	0.151217	3.16E-06	0.349430	0.413254	0.076519	0.009470	0.000106
LNP_E	5.97E-08	0.639990	0.011224	0.137439	0.065162	0.143908	0.002277
LNP_O	0.034401	0.729308	0.043340	0.155331	0.036065	0.001369	0.000186
LNY	0.889564	0.107459	1.11E-05	0.000480	0.002315	0.000120	5.06E-05
LNIV	0.015336	0.898963	0.010796	0.015076	0.058586	0.001193	5.12E-05
H_V	0.060797	0.000970	0.691053	0.021453	0.216390	0.009247	9.07E-05
Constant	0.999937	6.11E-05	1.90E-10	9.17E-07	1.29E-06	4.29E-08	2.70E-08

D. Diagnostic statistics ARDL

Test	Statistics
Breusch-Godfrey serial correlation LM test	1.010
Heteroscedasticity test: ARCH	0.434
Normality test (Jarque-Bera)	0.195

E. Stability test



F. Diagnostic test for the ARDL model

Test	Statistics
Breusch-Godfrey serial correlation LM test	1.306
Heteroscedasticity test: ARCH	0.537
Normality test (Jarque-Bera)	0.416

G. Stability test