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The threshold effect of electricity consumption and urbanization on carbon dioxide emissions in Ghana

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Abstract

Purpose – The quest for economic development has brought adverse effects on the environment through the release of greenhouse gases, such as carbon dioxide (CO_2). This will counter the efforts to achieve the Sustainable Development Goals (SDGs) by 2030. This study, therefore, investigates the effect of electricity consumption and urbanization on CO_2 emissions in Ghana. Electricity consumption and urbanization are among the factors that can be used to reduce CO_2 emissions.
Design/methodology/approach – Following the STIRPAT framework with the Hansen (2000) least squares threshold estimation strategy, the study employed annual time series data from 1971 to 2019.
Findings – The study revealed a single threshold effect of both electricity consumption and urbanization on CO_2 emissions. Electricity consumption intensity reduces CO_2 emission when electricity consumption is below the threshold (6287GWh) but increases when consumption passes the threshold. However, urbanization exerts a positive influence on CO_2 emissions regardless the level of urbanization (either before or after the threshold point). Again, the empirical results revealed that the urbanization threshold moderates the effect of electricity consumption on CO_2 emissions.
Research limitations/implications – Policymakers have to consider redesigning the current urbanization mode to include some new-type urbanization elements.
Originality/value – The threshold effect of electricity consumption and urbanization on CO_2 emissions in Ghana is examined using the Hansen (2000) least square method.

Keywords Threshold effect, Electricity consumption, Urbanization, Carbon dioxide emission, Ghana, Hanssen (2000)

Paper type Research paper

1. Introduction

The consequences and reality of pollution of our natural environment are becoming more and more severe in recent times. The total increase of the world population coupled with energy consumption, farming and other human activities has led to the accumulation of gases, such as carbon dioxide (CO_2), in the atmosphere. Between 1970 and 2011, global CO_2 emissions increased by about 90% of which fossil fuel and other industrial activities contributed the largest share of about 78% and then followed by agricultural and other forestry activities (World Resources Institute, Climate Analysis Indicator Tool (WRI CAIT, 2015).

Ghana's share in global CO_2 emissions, according to data from Our World in Data (OWID) database (2020), has increased by 97% (from 0.015 metric tons to 0.05 metric tons) between 1990 and 2018. The greenhouse gas (GHG) factsheet of Ghana published by the USAID (2016) indicated that as of 2011, 53% of the growth in CO_2 emissions are due to land and forest use followed by energy with a share of 25% on the GHG profile. From the total energy sector emissions, 39% is due to transportation, 29% is due to other fuel combustion and 19% is due

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to electricity and heat. This suggests that for Ghana to achieve a sustainable environment as indicated by the SDGs, goals 7, 11, 12, 13 and 15, energy, in general, and electricity consumption, to be specific, should be among the numerous factors to consider.

Even though electricity consumption has no direct effect on CO_2 and other GHG emissions, it affects CO_2 emissions through the activities associated with electricity consumption. Empirical studies, both local and international (Lee and Chang, 2005; Twerefou *et al.*, 2007), have come to conclusions in support of the assertion that electricity consumption promotes economic growth and further improves life through activities ranging from manufacturing to services. There is also another strand of literature (Charlita *et al.*, 2011; Adom *et al.*, 2012) that has established a positive link between economic growth and CO_2 emissions. This, therefore, suggests that economic activity is one of the key channels through which electricity consumption might result in CO_2 emissions. Concurrent with economic growth and industrialization induced by electricity consumption is rapid and widespread urbanization (Parikh and Shukla, 1995; Wu *et al.*, 2019). Urbanization is gaining global attention in the CO_2 emission debate due to its faster pace of growth and the conditions that facilitate the release or absorption of carbon (Chester *et al.*, 2014). For example, industrialization, transportation, urban infrastructure and agricultural mechanization that come with urbanization might result in increased electricity and other fuel consumption and hence increase CO_2 emissions (Jones, 1991). Contrary, urban vegetation, high-rise buildings and other urban infrastructure, on the other hand, can also absorb carbon and hence reduce CO_2 emissions (Pataki *et al.*, 2011). The magnitude of these impact channels can vary depending on diminishing returns or threshold effects (Ehrilich and Holdren, 1971).

From the discussions so far, it is clear that electricity consumption and urbanization are among the key variables to achieve sustainable growth and development. For this reason, it is necessary to inform policymakers in the country on energy and urbanization situations. However, it would be inconclusive to recommend any such national policy without empirical evidence to support it. This has aroused the interest of researchers to investigate the drivers of electricity consumption (Adom and Bekoe, 2012; Adom, 2013); the effect of electricity on economic growth (Kwakwa, 2012) and the effect of electricity crisis on businesses and households in Ghana (Abeberese *et al.*, 2021). To date, the effect of electricity consumption and urbanization on CO_2 emissions has not received the needed attention in the literature space of Ghana. However, the few that have set the pace to examine this phenomenon has been mixed. Whiles Asumadu-Sarkodie and Owusu (2017) found that electricity consumption increases CO_2 emissions, Kwakwa (2021) concluded that this effect is insignificant.

These inconsistent and contradictory findings from previous studies may indicate that there is some form of nonlinearity in the link between urbanization, electricity (energy) consumption and CO_2 emissions, which might prompt a threshold analysis. The current study aims to fill this gap by examining the threshold effect of electricity consumption and urbanization on CO_2 emissions in Ghana. This is because, from theory (urban environmental transition, ecological modernization, compact city and energy rebound theory), the impact of these variables on CO_2 emission may vary and hence difficult to determine *a priori*. Therefore, following the threshold approach will help to ascertain the actual relationship.

If the increasing trends of many countries' share of the global CO_2 are left unattended to, it could disrupt the global efforts to achieve low carbon economies. Consequently, agricultural yields could reduce and that could have long-lasting increasing effects on poverty, inequality and environmental-related diseases. For instance, over the past few years, Ghana has seen an average temperature rise of about 1^oC and is expected to increase (Ministry of Environment, Science, Technology, and Innovation (2016)). Such a situation could worsen the plight of the many people who depend on farming for survival and could also render most coastal dwellers homeless due to the loss of coastal land as a result of risen sea level. The insight from the above motivates this current study. This is because the findings from this study will serve as a guide to environmental policymakers and will also provide the needed information for policy analysis.

In addition to the provision of policy implications from the findings of the study, it differs and contributes to the literature in three main folds. First, the threshold regression analysis is used to examine the linkages between electricity consumption, urbanization and CO_2 emissions in Ghana. Second, the moderating role of urbanization in the relationship between electricity consumption and CO_2 emissions is analyzed. To that end, an interaction term, constructed as a product of urbanization and energy or renewable and nonrenewable energy, used by Adusah-Poku (2016) and Kwakwa and Alhassan (2018) is used to capture the impact of energy consumption on CO_2 emissions. This technique imposes *a priori* restriction that the effect of energy on CO_2 emissions monotonically increases (or decreases) with the level of urbanization. This strategy as used by Adusah-Poku (2016) and Kwakwa and Alhassan (2018) has the flexibility to accommodate the possibility that a certain level of urbanization has to be reached before electricity consumption can have any adverse or favorable impact on CO_2 emissions. Third, it uses a longer span of time series data (i.e. from 1971 to 2019), which is sufficiently large to enable robust conclusions to be drawn than those used in previous studies (see for example Kwakwa (2021), Asumadu-Sarkodie and Owusu (2017) and Kwakwa and Alhassan (2018).

The rest of the study is organized as follows. Section 2 covers a brief literature review on related studies; section 3 presents the empirical modeling, estimation technique and data. The empirical results are discussed in section 4, while section 5 concludes the study with some policy recommendations.

2. Review on linear and nonlinear studies

Most studies on environmental quality across the globe (Poumanyvong *et al.*, 2012; Sadorsky, 2014; Shahbaz *et al.*, 2014, etc.) centered their debate on environmental pollution around the environmental Kuznets curve (EKC) hypothesis, urban environmental transition, ecological modernization and the compact city theories. In many of these studies, CO_2 or other GHG emissions are used as a measure of environmental pollution to test these theories. The debate surrounding the effect of urbanization and energy or electricity (to be specific) is receiving much attention from the empirical literature in recent times with different econometric methods and data types across different countries and regions of the world. Under this current review, two strands of literature, comprising studies that relied on linear approaches, on the one hand, and nonlinear approaches, on the other hand, are considered.

Most studies that based their argument on the possible effect of urbanization on CO_2 emission on a linear approach have come out with contradictory findings. Studies from Kasman and Selman (2015), Kwakwa and Alhassan (2018), Nathaniel (2019) and Adusah-Poku (2016) concluded that urbanization is a key factor in environmental pollution. This is due to other activities that come along with urbanization, such as infrastructural development, industrialization, transportation and other energy-intensive activities that increase CO_2 emission. Contrary, there are others (Poumanyvong *et al.*, 2012; Wang and Zhao, 2018) with the view that urbanization reduces CO_2 emission as the built environment can serve as a carbon sink. However, another group of studies (Salim *et al.*, 2017; Zhang *et al.*, 2018) that postulates that urbanization has no significant effect on CO_2 emissions due to the counter effect of the factors of urbanization that facilitate the release or absorption of CO_2 emission. The linear approach studies of the effect of energy or electricity consumption on CO_2 emissions have also been mixed. Whiles some concluded that electricity consumption and energy, in general, is a crucial driver of CO_2 emissions (Danish *et al.*, 2020; Kwakwa and Alhassan, 2018; Mohiuddin *et al.*, 2016), some also reported the reverse case (Asumadu-Sarkodie and Owusu, 2017; Bello *et al.*, 2018), and even in some other cases, insignificant conclusions were drawn (Kwakwa, 2021; Pata, 2018; Rafiq *et al.*, 2016).

The strand of empirical literature studies considered here is those investigating the effect of urbanization in environmental quality debate using a nonlinear approach. Shahbaz *et al.* (2014) concluded with a U-shaped relationship. Thus, urbanization decreases environmental pollution in the initial stages to a certain level and later worsens it as urbanization increase. On the contrary, others (Bekhet and Othman, 2017; He *et al.*, 2017) concluded with an inverted U-shaped association between urbanization and CO_2 emission. Thus in the initial stages of urbanization, CO_2 emission increases to a certain maximum and then starts to reduce as urbanization increases. Another set of nonlinear studies are those that used the threshold model. In these studies, some concluded that regardless of the urbanization threshold, there is a positive effect of urbanization on CO_2 emissions even though the impact is more significant when urbanization crosses a threshold (Du and Xia, 2018; Zi *et al.*, 2015), whiles others concluded that the impact differs with the level of urbanization (He *et al.*, 2017; Wang *et al.*, 2019).

From the strands of literature (studies) reviewed above, it can be seen that very few of those studies, especially in Ghana (e.g. Asumadu-Sarkodie and Owusu, 2017; Asumadu-Sarkodie *et al.*, 2017; Kwakwa and Alhassan, 2018; Kwakwa, 2021), strictly followed the Stochastic Impact by Regression on Population, Affluence and Technology (STIRPAT) model. Also, these studies relied on autoregressive distributed lag (ARDL) and fully modified ordinary least squares (FMOLS) models, neglecting the possibility of a structural breakpoint in the data which could amount to nonlinearity between energy use and the environment. In addition, those studies neglected causal test and failed to account for the various levels of energy consumption and urbanization variables and their impact on carbon emissions in their models. By recognizing such limitations and weaknesses in those studies, this current study considers the test for structural breakpoints and examines how urbanization moderates the impact of electricity consumption on CO_2 emission at the various stages of urban development.

3. Data and methods

This section presents the study's framework and dataset. It begins explicitly with empirical modeling, data source, variables descriptions and finally, the estimation technique used.

3.1 Empirical modeling

Theoretically, the study employs the STIRPAT model by Dietz *et al.* (1994), which was later adopted and modified by York *et al.* (2003). In the STIRPAT model, environmental impact (I) is expressed as a function of population (P), affluence (A) and technology (T). The economic form is therefore given as follows:

$$I = f(P,\ A,\ T) \tag{1}$$

In the stochastic form, the model is expressed econometrically as follows:

$$I_t = aP_t^b\ A_t^c\ T_t^d\ e \tag{2}$$

where a is a constant term whereas b, c and d are the parameters that tell the unique impact of each variable ($P,\ A,\ T$) on I, e is a random error term and t is a time variable, which indicates that I, P, A and T vary across time. Equation (2) is therefore expressed in the logarithm form to become additive as follows:

$$lnI_t = a + blnP_t + clnA_t + dlnT_t + e_t \tag{3}$$

For this study, equation (3) is adopted and modified. I is proxied by CO_2 emissions and denoted by CO_2. P is represented by total urban population proxied as urbanization and denoted by *URP and A* is represented by income proxied by per capita gross domestic product (GDP) (denoted by *PGDP)*. To investigate the effect of electricity consumption and urbanization on CO_2 emissions, the study included electricity consumption intensity, denoted by *IN* as a proxy for T. Additionally, secondary and tertiary industrial structures, as well as trade openness which studies (Aye and Edoja, 2017; Poumanyvong *et al.*, 2012; Zhang and Lin, 2012) have shown that they significantly affect CO_2 emissions, are controlled for and entered in equation (3) as a proxy for T. Equation (3) is then specified as a linear model in the form as given by equation (4) below:

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnURP_t + \alpha_2 lnPGDP_t + \alpha_3 lnELC_t + \alpha_4 SIS_t + \alpha_5 TIS_t + \alpha_6 TOP_t + \mu_t \quad (4)$$

where *lnELC* is the natural log of electricity consumption, *lnURP* and *lnPGDP* denote the natural log of total urban population and per capita GDP, respectively. *SIS, TIS* and *TOP* represent the secondary industrial structure, tertiary industrial structure and trade openness, respectively. Whereas α_0 is the constant term, $\alpha_1 - \alpha_6$ are the parameters to be estimated, and μ_t *and* t are the respective error term and time.

3.1.1 Threshold mode. Based on the study's objectives, the threshold mode by Hansen (2000) is adopted to account for the threshold effect of electricity consumption and urbanization on CO_2 emissions. This modeling strategy allows the role of the threshold variable to differ depending on whether the variable is below or above some unknown level of threshold. Again, it allows one to test for linearity or nonlinearity in the dataset before it can be used for analysis. The model specified in a single threshold or two-regime mode is given as follows:

$$y_t = \alpha + \theta_1 Z_t I\{q_t \leq \gamma\} + \theta_2 Z_t I\{q_t > \gamma\} + \boldsymbol{X}'\beta + \varepsilon_t \quad (5)$$

where y_t is the dependent variable; Z is the explanatory regressor or the threshold independent variable; X is a vector of regressors hypothesized to impact on y_t; q_t is the threshold variable that is used to divide the observation into two regimes, with coefficient θ_1 and θ_2 depending on whether q_t is either smaller or larger than γ (threshold value); I{.} is the indicator function, whereas α and ε_t are the respective constant and the random error. It is also significant to note that the threshold variable (q_t) can at the same time be expressed as the threshold regressor (Z). The equation (5) above assumes that there is only one threshold, i.e. the effect of each regressor on y is divided into two mechanisms due to the different threshold values. However, there may appear multiple thresholds. Assuming $\gamma_1 < q_t \leq \gamma_2$ and taking the double-threshold (three-regime) model as an example, the models are modified to

$$y_t = \alpha + \theta_1 Z_t I\{q_t \leq \gamma_1\} + \theta_2 Z_t I\{\gamma_1 < q_t \leq \gamma_2\} + \theta_3 Z_t I\{q_t > \gamma_2\} + \boldsymbol{X}'\beta + \varepsilon_t \quad (6)$$

However, the choice of a particular form of the threshold model will depend on the final test on the presence of the threshold effect (where $\theta_1 \neq \theta_2$).

In this form of modeling, the first step according to Hansen (1999) is to test the null hypothesis of linearity (i.e, H_0: $\theta_1 = \theta_2$) against the alternative threshold model (i.e, H_1: $\theta_1 \neq \theta_2$) in (5). Since the threshold parameter γ was not identified under the null, this became a nonstandard inference problem. The Wald or LM test statistics, therefore, did not carry their conventional chi-square limits. Instead, inferences were implemented by calculating a Wald or LM statistic for each possible value of γ and subsequently basing inferences on the supremum of the Wald or LM across all possible γ s. The limiting distribution of this supremum statistic is nonstandard and depends on numerous model-specific nuisance parameters. Since tabulations were not possible, inferences were conducted via a model based on bootstrap whose validity and properties were established by Hansen (1999). Once an estimate of γ was obtained (as the minimizer of the residual sum of squares computed across all possible values of γ), estimates of the slope parameters followed trivially as $\widehat{\theta}(\widehat{\gamma})$.

Rewriting equation (3) in the single threshold mode as in equation (5) to account for electricity consumption and urbanization threshold effect models, respectively, as given in equations (7) and (8) below:

$$lnCO_{2t} = a + \varnothing_1 lnIN_t I\{lnEC_t \leq \gamma\} + \varnothing_2 lnIN_t I\{lnEC_t > \gamma\} + \beta X_t' + \mu_t \tag{7}$$

$$lnCO_{2t} = \delta_0 + \delta_1(lnURP_t,\ lnELC_t)I\{URP_t \leq \gamma'\} + \delta_2(lnURP_t,\ lnELC_t)I\{URP_t > \gamma'\} + \beta X_t' + \epsilon_t \tag{8}$$

Because electricity consumption has no direct effect on CO_2 emissions but through the activities electricity consumption brings, the study uses electricity consumption intensity (*IN*), which measures how much electricity is used per unit of output in the economy to measure the activities driven by electricity consumption. In equation (7), $lnIN_t$ and $lnEC_t$ are used as the threshold regressor (*Z*) and threshold variable (q_t), respectively. Also, in equation (8), $lnURP_t$ is used as both the threshold regressor (*Z*) and variable (q_t). Also, because urbanization influences electricity consumption (Kasman and Selman, 2015; Wu *et al.*, 2019), $lnEC_t$ is additionally used as a threshold regressor (*Z*) in equation (8). Thus, equation (8) estimates the threshold effect of urbanization on CO_2 emissions and how the urbanization threshold effect moderates the impact of electricity consumption on CO_2 emissions. Also, $lnCO_{2t}$ represents y_t, and X_t' does consist *lnPGDP, SIS, TIS* and *TOP* in both equations (7) and (8).

3.2 Data source and variable description

The study employed annual time series data covering the period 1971–2019 for Ghana. Data on all variables are purely secondary sourced from the World Bank's World Development Indicators (WDI), OWID and International Energy Agency (IEA). Details on data for each variable are presented in the appendix section (see Appendix 1).

3.3 Estimation technique

Time series studies required that the series used for analysis should not contain unit roots to avoid spurious regression. For this very purpose, a unit roots test is conducted to determine stationarity properties and the order of integration. However, the standard unit roots test, such as Augmented Dickey–Fuller (ADF), Phillips and Perron (PP), etc. cannot account for the issue of structural breaks, which is sometimes common in time series. These standard tests may lead to the nonrejection of a unit root when the sample under study is suspected to incorporate economic events capable of causing shifts in the regime. To account for this, the study employs the Zivot–Andrews unit root test, which could account for structural breaks that sometimes may affect the results of these standard unit root tests.

A cointegration analysis was carried using the ARDL bounds testing approach to cointegration after analyzing the unit root properties of the series. This econometric technique is statistically a more robust method since it can be used irrespective of whether the variables are purely 1(1) or purely 1(0), or both. Specification of the ARDL model is specified as follows:

$$\Delta lnCO_{2t} = \alpha_0 + \alpha_1 lnCO_{2t-1} + \alpha_2 lnELC + \alpha_3 lnPGDP_{t-1} + \alpha_4 lnIN_{t-1} + \alpha_5 SIS_{t-1} + \alpha_6 TIS_{t-1} + \alpha_7 TOP_{t-1} + \sum_{i=1}^{s} \pi_i \Delta lnCO_{2t-i} + \sum_{j=1}^{u} \rho_j \Delta lnELC_{t-j} + \sum_{v=1}^{k} \sigma_v \Delta \ln PGDP_{t-v} + \sum_{m=1}^{b} \infty_m \Delta lnIN_{t-m} + \sum_{q=1}^{l} \omega_q \Delta \alpha_5 SIS_{t-q} + \sum_{c=1}^{h} \tau_c \Delta TIS_{t-c} + \sum_{x=1}^{d} \partial_c \Delta TOP_{t-x} + \mu_t \quad (9)$$

$$\Delta lnCO_{2t} = \beta_0 + \beta_1 lnCO_{2t-1} + \beta lnELC_{t-1} + \beta_3 lnPGDP_{t-1} + \beta_4 lnURP_{t-1} + \beta_5 SIS_{t-1} + \beta_6 TIS_{t-1} + \beta_7 TOP_{t-1} + \sum_{i=1}^{s} \delta_i \Delta lnCO_{2t-i} + \sum_{j=1}^{u} \varphi_j \Delta lnELC_{t-j} + \sum_{v=1}^{k} \epsilon_v \Delta \ln PGDP_{t-v} + \sum_{m=1}^{b} \lambda_m \Delta lnURP_{t-m} + \sum_{q=1}^{l} \vartheta_q \Delta \alpha_5 SIS_{t-q} + \sum_{c=1}^{h} \varnothing_c \Delta TIS_{t-c} + \sum_{x=1}^{d} ב_\gimel \Delta TOP_{t-x} + \varepsilon_t \quad (10)$$

where $\alpha_1 - \alpha_7$ represent long-run coefficients, $\pi, \rho, \sigma, \infty, \omega, \tau,$ *and* ∂ represent short-run coefficients, α_0 *and* β_0 represent a constant and μ is a white noise error term in (9). In (10), $\beta_1 - \beta_7$ represent long-run coefficient, δ, φ, λ, ε, ϑ, $\varnothing$, *and* ב represent short-run coefficients, β_0 represent a constant and ε is a white noise error term. Δ is the first difference operator.

In this testing procedure, first, the null hypothesis of the absence of long-run correlation among the variables is tested against the alternative hypothesis of the existence of a long-run relationship among variables by using an *F*-statistic. Pesaran *et al.* (2001) specified bound critical figures tables that show both lower and upper bound critical values where there is an assumption that variables applied in the ARDL model are I (I). Hence, the null hypothesis is rejected when the *F*-statistics are greater than the upper bound critical value, indicating the existence of a long-run relationship among the variables. On the other hand, if the F-statistics are below the lower bound critical value, there is no cointegration. Also, the outcome is inconclusive when *F*-statistics lies within the lower and upper bound values.

The Hansen (2000) least square estimation strategy is employed after confirming cointegration to estimate the threshold effect of electricity consumption and urbanization on CO_2 emissions in Ghana.

4. Results and discussion of findings

This section presents the summary statistics, the results of unit roots and the threshold regression analysis.

4.1 Summary statistics and correlation matrix of variables

Table 1 reports the summary statistics of the variables employed in the study. From Table 1. it can be observed that by comparing the standard deviations to their respective means, except electricity consumption intensity (IN), secondary industrial structure (SIS) and tertiary industrial structure (TIS), all the other variables have a standard deviation of almost half of their means, suggesting a high variation in the series across the period under study.

The correlation matrix (see Appendix 3) of the variables employed in the two linear models indicates that the correlation coefficients range between −0.591 and 0.767 for Model (1) and 0.464 and 0.780 for Model (2). This range is acceptable to avoid the problem of multicollinearity in the models.

4.2 Stationarity results

The unit root tests of all the variables are conducted with a constant and trend term in all the tests procedures employed. The results are presented in Table 2. As shown, the upper part of the table reports the results of unit root tests without a structural break using the ADF and PP tests. All test results suggest that none of the series are stationary at any levels except for electricity intensity. At first difference, each variable is stationary at the 5 and 1% level of significance except for urbanization under the PP test. The plots of the key variables

Variable	Observation	Mean	Std. deviation	Minimum	Maximum
CO_2	49	6.474	4.546	2.292	18.298
ELC	49	5823.592	2777.8	1,151	13,943
URP	49	7879361.2	4451447.8	26,17,854	1,72,49,054
PGDP	49	1067.509	317.241	693.949	1884.285
IN	49	0.319	0.094	0.127	0.495
SIS	49	20.949	6.856	6.247	34.86
TIS	49	34.651	8.74	21.882	52.243
TOP	49	57.104	28.343	6.32	116.048

Table 1.
Summary statistics

	ADF test		PP test	
Variable	At level	At first difference	At level	At first difference
$lnCO_2$	−03.220	−9.706***	−0.015	−12.126***
lnELC	−2.595	−5.595***	−2.740	−5.480***
lnURP	−1.188	−3.696**	−1.654	−1.256
lnPGDP	−1.812	−5.609***	−1.835	−5.516***
lnIN	−4.053***	−5.969***	−2.574*	−3.600***
SIS	−2.192	−5.057***	−2.442	−4.953***
TIS	−2.266	−6.398***	−2.413	−6.389***
TOP	−1.789	−6.430***	1.822	−6.422***
	Zivot-Andrew (with structural breaks)			
	At level	Breakpoint	At first difference	Breakpoint
$lnCO_2$	−5.609	1985	−7.754***	2012
lnELC	−4.726	1983	−7.437***	1985
lnURP	−5.194**	2006	−6.492***	1984
lnPGDP	−3.452	1981	−6.887***	1984
lnIN	−4.881*	2003	−7.422***	1985
SIS	−3.822	1984	−5.602***	2011
TIS	−4.049	2009	−7.182***	2009
TOP	−3.392	1996	−7.656***	2001

Note(s): ***, ** and * denote 1, 5 and 10% significance levels, respectively

Table 2.
Unit root test results

(see Appendix 2) suggest that the data might have a structural break(s). Therefore, considering a structural break in the series led to employing a unit root test with structural breaks. As presented in the lower part of the table, the Zivot-Andrew test points out that all variables are $I(1)$ except for electricity intensity. Noteworthy is that, when considering the structural breaks, urbanization is an $I(1)$ variable, and the structure change takes place in 1984.

4.3 Cointegration test results

Table 3 presents the results of the ARDL bounds test for the two different threshold models. The F-statistic value of 5.58 of the electricity consumption threshold effect model is greater than the upper bound critical value of 4.93 at 1% significant level. Thus, based on the bound test results, it can be concluded that CO_2, electricity consumption, income, secondary and tertiary industrial structures, trade openness and electricity consumption intensity are cointegrated. Similarly, the F-statistic of 5.65 of the urbanization threshold models exceeds the upper bound critical values of 4.93% at 1% significance level and hence suggests that CO_2, urbanization, electricity consumption, income, secondary and tertiary industrial structures and trade openness are cointegrated. Hence, there is a long-run relationship between all the variables used in the electricity consumption threshold effect model as well as the urbanization threshold effect model.

4.4 Electricity consumption and urbanization threshold test

As shown by Table 4, electricity consumption has a single threshold effect on CO_2 emissions. The bootstrap p-value of 0.049 rejects the null hypothesis of no threshold effect at a 5% significance level while that of 0.409 fails to reject the null hypothesis of one (single) threshold effect at the 5% significance level. Also, there is a single threshold effect of urbanization on CO_2 emissions. This is evident by the bootstrap p-value of 0.010 (0.704) for the rejection (fail to reject) of the null hypothesis of no (one) threshold effect at the 5% significance level.

Therefore, the test procedure concludes that there is indeed a nonlinear relationship between these two variables and CO_2 emissions in Ghana. This suggests that the entire sample should be divided into two sub-samples (regimes) of low and high electricity

Model	K	F-statistic	Lower bound	Upper bound
Electricity threshold model	6	5.58***	3.6	4.3
Urbanization threshold model	6	5.65***	3.6	4.3

Note(s): K denotes the number of regressors in the model; *** denotes 1% critical value

Table 3. Cointegration test based on ARDL bounds test

Hypothesis	LM-test statistics	p-value
Electricity consumption threshold effect		
H_0: No threshold, $H_{1:}$ threshold	15.514	0.049
H_0: One threshold, $H_{1:}$ two thresholds	7.673	0.409
Urbanization threshold effect		
H_0: No threshold; $H_{1:}$ threshold	16.030	0.010
H_0: One threshold; $H_{1:}$ two thresholds	6.773	0.704

Note(s): The p-value and test statistics are based on the bootstrap method with 2,000 replications and 0.15 trimming percentage

Table 4. Threshold test results

consumption for the electricity consumption threshold effect model and or low urbanize stage and high urbanize stage for the urbanization threshold effect model.

4.5 Discussion of electricity threshold regression results

Models (1) and (2) from Table 5 are the threshold and the linear (OLS) models, respectively. The first row of the table presents the threshold value of electricity consumption at which the sample is divided into two groups of low and high electricity consumption levels. This, according to the data, is estimated to be 6,287 GWh of electricity consumption (after taking the anti-log of the natural logarithm value of 8.7462). That is to say, annual consumption of electricity below or equal to 6,287GWh, according to the sample split, is in the low consumption level (low regime) and any year where consumption is above 6,287GWh is in high consumption level (high regime). From Model (1), the effect of electricity consumption intensity on CO_2 emissions is found to be negative and statistically significant at 5% when electricity consumption is below 6,287GWh but positive and significant at 1% when consumption passes the threshold point of 6,287GWh. This means that holding all other things constant, at a low consumption level, a 1% increase in electricity consumption intensity leads to less than a disproportional unit reduction in CO_2 emissions by about 0.194% and after 6,287 GWh of electricity consumption whiles a 1% increase in electricity consumption intensity will cause less than a proportional unit rise in CO_2 emissions by about 0.538% in Ghana. This suggests that the results from the linear model (which is negative and statistically insignificant) are misleading, hence will lead to an underestimation of the impact of electricity consumption intensity on the environment (CO_2 emissions) in Ghana. Thus, in comparing the fitness of these two models using the Akaike information criterion (AIC) as presented in Table 5, the threshold model (Model (1)) is a better fit relative to the linear model (Model (2)). The better the fit, the smaller the AIC; hence, AIC of −229.756 from Model (1) is significantly smaller than the AIC of −81.042 from Model (2).

In the context of Ghana, CO_2 emission is reported to be 14,469,986 tons in 2016 of which building sector, noncombustion, other industrial combustion, power industry and transportation account for 8.1, 10.0, 13.2, 18.2 and 50.5%, respectively (IEA, 2019). Given these figures, the power sector is the second largest contributor to CO_2 emission in Ghana as overall electricity consumption rose by 140% within the period 2000 and 2020

Electricity consumption threshold value ($\hat{\gamma}$)		6,287GWh (8.7462)		
		Threshold model		Linear model
Variables	(1)	Low (ELC ≤ $\hat{\gamma}$)	High (ELC > $\hat{\gamma}$)	(2)
lnIN		−0.194** (0.077)	0.538*** (0.171)	−0.148 (0.091)
lnURP		0.881*** (0.055)	1.565*** (0.149)	0.925*** (0.068)
lnPGDP	0.456*** (0.111)			0.534*** (0.123)
SIS	0.009** (0.004)			0.013** (0.005)
TIS	−0.009*** (0.003)			−0.009** (0.004)
TOP	−0.002** (0.001)			−0.003*** (0.001)
Constant	−18.03*** (0.832)			−18.57*** (1.156)
Observations	49			49
AIC	−229.756			−81.247
Wald X^2	20.43***			–
R-squared	–			0.979

Note(s): 1) **, *** denote $p < 0.05$ and $p < 0.01$, respectively, 2) figures in parentheses are robust standard errors

Source(s): Author's computation based on data obtained from the WDI (2020), IEA (2019) and OWID (2020)

Table 5. Results of electricity consumption threshold effect on CO_2 emissions

([Energy Commission, 2021](#)). Thus, a threshold estimate of 6,287GWh per annum (translating into 8.1% after inverting the semi-log transform) indicates electricity consumption above the threshold raises CO_2 emissions but slows down CO_2 emissions below the threshold. This reveals that high electricity consumption is an essential driver of CO_2 while low consumption is not. In effect, positive shocks in electricity consumption matter while adverse shocks do not matter.

The negative impact of electricity consumption (intensity) on CO_2 emissions at the low consumption level is consistent with previous studies, such as Kwakwa and Alhassan (2018) and Bello *et al.* (2018). Intuitively, the result is in line with the electricity generation mix of Ghana between 1971 and 1995 (where most of the low consumption periods fall). Ghana during this period relied heavily on hydropower. Because the hydropower plant was probably able to meet the nation's demand, there was no need to support the national grid with thermal plants, which are high CO_2 emitters (Kwakwa and Alhassan, 2018). For instance, evidence from the data indicates that hydropower share in the total electricity mix during this period in Ghana ranged from 98.1 to 100% (WDI, 2020). On the other hand, the positive influence at the high consumption regime can partly be attributed to the inability of the three primary hydropower plants to generate enough electricity to meet demand. Therefore, there was the need to be supported with thermal plants. The burning of fossil fuel is the primary source of CO_2 emissions, and since thermal plants use fossil fuels, it is likely to increase CO_2 emissions.

4.6 Discussion of urbanization threshold regression results

The first row of Table 6 presents the threshold point of urbanization beyond, which the impact of urbanization on CO_2 emission changes. According to the data used, the estimated threshold value is 3,995,739 (after taking the anti-log of the natural logarithm value of 15.2007), corresponding to the total urban population of Ghana in 1984. As Model (3) indicates, the effect of urbanization on CO_2 emission is positive and statistically significant at 1% significant level at both low and high urbanize stages. However, their magnitude and responsiveness to CO_2 emissions differ, as observed by the different elasticity coefficients of 1.16 (low urbanized stage) and 1.00 (high urbanized stage). Though it indicates positive unit

Table 6. Results of urbanization threshold effect on CO2 emissions

Urbanization threshold value ($\hat{\gamma}$)		3,995,739 (15.2007)		
Variables		Threshold model		Linear model
	(3)	Low (URP $\leq \hat{\gamma}$)	High (URP $> \hat{\gamma}$)	(4)
lnURP		1.161*** (0.057)	1.000*** (0.072)	1.020*** (0.081)
lnELC		−0.220*** (0.070)	0.0565 (0.046)	−0.146 (0.091)
lnPGDP	0.441*** (0.168)			0.672*** (0.096)
SIS	0.015*** (0.004)			0.013** (0.006)
TIS	−0.008* (0.004)			−0.009** (0.004)
TOP	−0.002*** (0.001)			−0.003*** (0.001)
Constant	−17.55*** (0.855)			−17.56*** (0.970)
Observations	49			49
AIC	−236.460			−81.247
Wald X^2	56.13***			–
R-squared	–			0.979

Note: 1) * and *** denote $p < 0.1$ and $p < 0.01$, respectively, 2) figures in parentheses are robust standard errors.
Source(s): The author's computation based on data obtained from the World Bank's WDI (2020), IEA (2019) and OWID (2020)

elastic impact from the linear model (Model (4)), it is insignificant. This can result in misleading policies when based on the linear model for any policy formulation.

Specifically, holding all other things constant, a 1% increase in urbanization raises CO_2 emissions by more than proportional by about 1.16% at the low urbanized stage and a proportional unit increase at the high urbanized stage. This indicates that in Ghana, CO_2 emissions were very sensitive to changes in urbanization at the low urbanized stage than the high urbanized stage. This finding of the positive relationship between urbanization and CO_2 emissions confirms previous studies (Abbasi *et al.*, 2020; Kwakwa and Adusah-Poku, 2020; Kwakwa and Alhassan, 2018). In theory, the result at the various levels of urbanization supports the argument that, in developing countries like Ghana, people migrate to benefit from urban amenities (Abbasi *et al.*, 2020). The continuous influx of people into the urban mining centers particularly in the mid-1980s to seek employment during the boom in the sector made this sector the highest foreign exchange earner and contributed to over 30% of domestic tax revenue (Government of Ghana, 2010). Given the significant expansion in the mining sector, which attracted huge influx of people to the urban centers, there is a high probability that it contributed substantially to the emission of CO_2 at the early stages of urbanization in Ghana.

The moderating role of urbanization on the effect of electricity consumption on CO_2 emission as presented in Table 6 indicates that the effect of electricity consumption on CO_2 emission is negative inelastic at the low urbanized stage but insignificant at the high urbanized stage. However, in the linear model, it is negative insignificant throughout the period. This suggests that based on the linear model (Model (4)), any policy analysis will be misleading, especially when urbanization is at the low regime. At that regime, the benefit of electricity consumption on environmental quality will be underestimated. Meanwhile, at the low urbanized stage, all else same, a unit increase in electricity consumption reduces CO_2 emissions by about 0.22. The findings revealed in the low urbanized stage are consistent with the findings of Bello *et al.* (2018), Kwakwa and Alhassan (2018) and Kwakwa (2021). Intuitively, because the primary source of electricity during this period in Ghana was eco-friendly hydropower, it produced no CO_2 emissions. At the low urbanized stage (from 1971 to 1984), though industrialization might have risen with urbanization, the amount of electricity consumed during this period was within the capacity of the nation's hydropower plants. Hence, there was no need to support the system with thermal plants that are higher emitters of CO_2. Even though urbanization at the low regime will promote certain lifestyles and economic activities that are electricity-intensive, as far as the demand could be met by the country's hydropower plant which is a clean energy source, it will lead to a reduction in CO_2 emissions.

Stability and diagnostic tests are performed to examine whether the models are free from any econometric challenges and are stable. The results are presented in the appendix (see Appendix 4). The Breusch–Godfrey test of serial correlation and Autoregressive Conditional Heteroskedasticity (ARCH) test of heteroscedasticity indicated the nonexistence of serial correlation and heteroskedasticity in the model. Furthermore, the Jarque–Bera test of normality and the Ramsey RESET test of stability also indicated the absence of those challenges in the model.

5. Conclusion and policy implication

The study examined the threshold effect of Ghana's electricity consumption and urbanization from 1971 to 2019. This has become necessary because the quest for economic development has brought adverse effects on the environment, contrary to the Sustainable Development Goals (SDGs). Specifically, the threshold effect of electricity consumption and urbanization on CO_2 emissions is evaluated within the STIRPAT model framework, accounting for trade openness, secondary and tertiary industrial structures of the Ghanaian economy.

The bootstrapping approach recommended by Hansen (2000, 1996, 1999) is used to verify the nonlinearity of the dataset before being used in the analysis.

A single threshold effect of electricity consumption and urbanization on CO_2 emissions is revealed in Ghana for the period under study. The study further revealed that electricity consumption intensity reduces CO_2 emissions when electricity consumption is below the threshold and promotes CO_2 emissions when electricity consumption passes the threshold. The effect of urbanization on CO_2 emissions is revealed to be positive regardless of the level of urbanization. However, the magnitude of impact is more severe when urbanization is below the threshold point than above. The study further revealed that urbanization moderates the impact of electricity consumption on CO_2 emissions in Ghana. Thus, electricity consumption reduces CO_2 emissions below the urbanization threshold, but it has an insignificant impact on CO_2 emissions when urbanization crosses the threshold. Again, other factors, such as income and secondary industrial structure, are among the key contributors of CO_2 emissions. In contrast, trade openness and tertiary industrial structure significantly contribute to the reduction of CO_2 emissions in Ghana. The findings further conclude that Ghana is currently in its high electricity consumption regime and at a high urbanization level. Thus, the country is currently at a stage where electricity consumption and urbanization threaten environment. However, on average, the elasticity coefficients indicate that CO_2 emissions are not very sensitive to the impact.

The findings from this study serve as a guiding principle for policymakers in Ghana and also contribute to the debate on environmental pollution in the literature. For instance, a clear evidence that a certain level of electricity consumption (or urbanization) has to be attained before electricity intensity (urbanization) can associate or disassociate with CO_2 emission provides a guide for policymakers to put in efforts to provide measures that will streamline electricity consumption (urbanization) to maintain favorable levels. By so doing, it will help to implement actions or adjust existing national policies and strategies regarding electricity consumption, urban development and climate change mitigations.

Because Ghana is currently at a high electricity consumption regime where electricity intensity and CO_2 emissions are positively related, it is vital to reduce intensity. This can be done by promoting electricity consumption efficiency. Electricity consumption efficiency can be improved through subsidizing the prices of energy-efficient appliances (refrigerators, air conditioners, television sets, etc.) or financing research and development (R&D) into the manufacturing of these products. Policymakers can consider revising the composition of the economy in such a way that it supports clean production, where concentration is shifted from the electricity-intensive (secondary) industries to labor -, capital-, and technology-intensive (tertiary) industries. Again, there is the need to redesign the traditional mode of urban development to incorporate some elements of new-type urbanization systems that are environmentally friendly. Because urbanization is a key element of Ghana's development and modernization drive, it cannot be left out at any instance despite its role in promoting CO_2 emission. Policymakers need to redesign the current system of urbanization to account for at least three aspects: ecology (vegetation), production and lifestyle. In terms of ecology, the government must support and promote a green urban environment, such as tree planting through the regulatory or constitutional instrument. Also, the urban residents should be encouraged to adopt green consumption and a low-carbon lifestyle. Lastly, traditional enterprises should be supported through policy and finance to be transformed and upgraded from big and heavy industries to small and light industries that are energy efficient.

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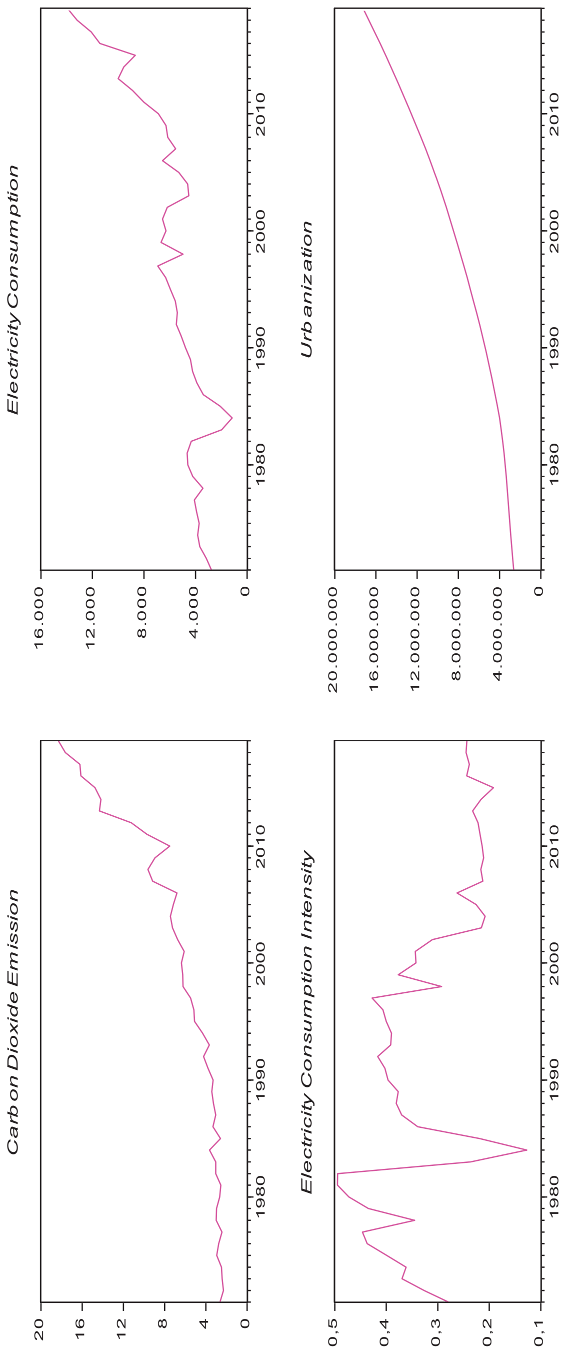
Appendix 1

Variable (Symbol)	Definition	Expected sign	Unit of measurement	Source
Carbon dioxide emission (CO_2)	Emission from the burning of fossil fuel and cement production		Metric ton (Mt)	OWID
Urbanization (URP)	Total urban population	±	Number	WDI
Per capita GDP (PGDP)	GDP divided by the total population	±	US$	WDI
Electricity consumption (ELC)	Final electric power consumed	+	GWh	WDI (1970–2014), IEA (2015–2019)
Intensity (IN)	Final electric power consumed divided gross domestic product	+	GWh/US$	Calculated
Trade openness (TOP)	The ratio of the sum of imports and export expressed as a percentage of GDP	±	Percent (%)	WDI
Secondary industrial structure (SIS)	Manufacturing share of GDP expressed as a percentage of GDP	+	Percent (%)	WDI
Tertiary industrial structure (TIS)	Service sector share of GDP expressed as a percentage of GDP	±	Percent (%)	WDI

Table A1.
Summary variable description

Appendix 2



Source(s): Authors' construction

Figure A1.
Graph of key variables

Appendix 3

Table A2.
Correlation matrix

Variables	lnURP	lnPGDP	lnIN	SIS	TIS	TOP
Model (1)						
lnURP	1.000					
lnPGDP	0.746	1.000				
lnIN	−0.581	−0.527	1.000			
SIS	0.760	0.735	−0.346	1.000		
TIS	0.701	0.753	−0.591	0.685	1.000	
TOP	0.767	0.487	−0.371	0.754	0.464	1.000
Model (2)						
lnURP	1.000					
lnPGDP	0.746	1.000				
lnELC	0.710	0.780	1.000			
SIS	0.760	0.735	0.765	1.000		
TIS	0.701	0.753	0.656	0.685	1.000	
TOP	0.767	0.487	0.615	0.754	0.464	1.000

Appendix 4

Table A4.
Diagnostic test of ARDL estimate

Diagnostic	Test	Electricity threshold model	Urbanization threshold model
Serial correlation	Breusch–Godfrey (*F*-stat)	0.890774 (0.4190)	0.984590 (0.3832)
Heteroscedasticity	ARCH (Chi-square test)	1.307586 (0.2528)	1.186287 (0.2761)
Normality	Jarque–Bera	4.288520 (0.117155)	4.302603 (0.116333)
Stability	Ramsey-RESET (*F*-stat)	2.014702 (0.1292)	2.069055 (0.1215)

Note(s): Figure in parentheses is the probability value

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