Anthropogenic Factors Impact on Ghana Using Stochastic Impacts by Regression on Population, Affluence and Technology and Cobb-Douglas Production Function

Kingsley Appiah, Jianguo Du, Kofi Baah Boamah and Samuel Afriyie

ABSTRACT

The world is faced with increasing ecological effect on human activities. These effects have a direct and indirect impact on environment. The study examined the impact of anthropogenic factors on carbon dioxide (CO$_2$) emission of Ghana for the period 1990-2016 using Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model and Cobb-Douglas Production Function. Evidence of our analysis indicates that 1% increase in population growth, residential energy efficiency and access to electricity will cause an increase of CO$_2$ by 98%, 97% and 161% respectively. Consequently, the relationship between the variables is considered as elastic and that a small change in the driving forces will cause greater proportionate change in environmental pollution. Application of Cobb-Douglas Production Function revealed that increasing in return to scale exists in Ghana and therefore, CO$_2$ emission in Ghana increases more than the factors that drive it. Our study found long-run relationship between the variables but no causal effect of the predicting variables on dependent variable in Ghana. The contribution degrees of the driving forces to the change in CO$_2$ emissions from the STIRPAT model suggested that technology is the key driving factor, while population followed closely.\(^1\)

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KEYWORDS

Carbon dioxide emission, anthropogenic factors, ecological elasticity, driving forces

INTRODUCTION

The world is facing unpredictable and unbearable weather that comes with challenges that threat the survival of human and nature. This is as results of greenhouse gases that directly or indirectly pose negative effects on human sustainable development. The greenhouse effect is attributed largely to carbon dioxide (CO2) emissions as the principal influence on the universal environmental degradations [1]. There is an increasing trend of carbon dioxide emission, which has become a global concern in trying to find solutions to reduce it [2-4]. According to statistical data from the [5], the total greenhouse-gas emissions in Ghana have increased from 40,612.020 in 1990 to 107784.30 (thousand metric tons) in 2012 indicating 265.4% change. The CO2 emissions grew by 58.9% per annum in the period from 2005 to 2015 and reached 0.54 billion metric tonnes in 2015, which is almost two times of 2005 level of 0.34 billion metric tonnes [5]. Carbon dioxide is mostly release into the atmosphere as results of an increase in our energy needs and production [6].

The issue of CO2 and greenhouse gases emissions have been studied at length globally. However, the determination of the ecological elasticities of the driving forces that affect the environment has not been featured prominently in recent literature and particularly studies in Ghana. This has made it relevant to consider the use of Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model to find out the impact of anthropogenic factors on environment of Ghana. The results of the study would bring to light an appreciable understanding of the significant factors that impact on environment so that suitable policies and programs could be instituted to mitigate the effects. To ensure appropriate measures are put in place to control carbon emission level, require the need to look at how factors such as population, economic growth and technology influence the emission level of carbon dioxide in Ghana.

Using STIRPAT model will help to achieve two objectives in predicting the key driving force’s impact of the environment and at the same time estimate the coefficients for the STIRPAT model in order to determine the causal effects of the driving forces. The determination of the coefficient as referred to the study of [7] as ecological elasticity would provide a picture of how changeable the driving force is when it is regressed with the environmental impact factor in their natural logarithm. This would show the percentage change in environmental impacts in case the driving force changes by one percent. Therefore, a well-specified STIRPAT model can provide ecological elasticity, which can be used as the marginal effect of the corresponding driving force on environment. STIRPAT provides a flexible model
that allows inclusion of additional variable’s for analysis to achieve robust results [8, 9]. The transformation on the variables data in their natural logarithms makes it easier to interpret the coefficient and at the same time identify the ecological elasticities and responsiveness of the dependent variable to changes in any of the anthropogenic factors[7].

Additionally, STIRPAT model interpretation is easy and therefore, provides elasticity of the ecological effects of the anthropogenic factors which is either unitary, elastic or inelastic. If the marginal effect of the analysis produce results, which is equal to one means, unitary elastic relationship exists between anthropogenic factors and environmental impact. This means that as any of the ecological driving force’s increases, the impact on environment also increases holding other variables constant. However, if coefficient is negative but the elasticity is unitary then, increase in the driving forces does not have much impact on the environment. Whenever the ecological pliability is elastic means that a small change in the driving force will cause a greater proportionate change in the impact. On the other hand, when the marginal effect is inelastic, means that a small change of the driving force would have a small impact on environment. At times, the peripheral effect can also be undesirable. Negative elasticity means that impact on environment decreases (i.e. in proportion, greater proportion and lesser proportion) to an increase in the anthropogenic factors producing unitary, elastic and inelastic relationship respectively between environmental impacts and driving forces.

LITERATURE REVIEW

Continuous increase in population influences the energy intensity, changes the structure of the macro-economy and call for various technologies such as coal, nuclear to produce electricity. These directly increase the carbon emissions level, which adversely affect the environment. The current population of Ghana which stands at 28.21 million in 2016, at growing rate of 39% of 1960 population size of 6.65 million people as its own effect on achievement of Sustainable Development Goal 13[10]. One of the key impacts of the increase in population is the percent of energy consumed and wasted. This require the need for energy efficiency to stimulate economic growth and reduce the negative effect on the environment. Increase in population size has ecological impact and positive effect on economic growth. However, the impact of population growth on environmental pollution is considered as extremely elastic[11]. On the other hand[12-15]study found that economic growth is considered globally as having a great impact on conservational degradation. While’s economic growth is well-thought-out having negative effect on environment. Other researchers found that environmental impact decreases as the economic level increase based on Environmental Kuznet Curve (EKC) [16-20].

Human activities have great effects on the environment through the release of emissions, which are detrimental for the sustainable anthropological development. Technology is considered as one of the key driving forces that its impact on the
environment can only be determined by the other two drivers namely population size and affluence. Technology is considered as the remaining of an accounting identity which epitomizes everything that touches the environment which explicitly not classified as population or affluence. On the other hand, transport and residential electricity consumption also contribute its share of environmental degradation. The movement of people from one place to another call for the use of fuel and car emissions. Escalation in residential electricity consumption also put pressure on electricity providers such as Electricity Company of Ghana (ECG), Gridco and Volta River Authority (VRA) to produce more energy to meet demand. Upsurge in population also increases transport and inhabited electricity consumption.

For several decades now, research has proven the adverse effect of the traditional means of cooking on socio-economic development, human health and the environment of a whole. According to [21], even though a lot of country’s populace have shifted to more cleaners and sustainable cooking technologies. However, more than 82% of countries in sub-Saharan Africa populace still depend on the same method of using charcoal, fuel wood and biomass for cooking. In the case of Ghana, according to [22]report, more than two-fifths, which constitute 41.3% of Ghanaians households make use of wood as their main source of cooking fuel followed by charcoal (31%) and gas (22.3%). The fuel use for cooking directly or indirectly contributes to CO2 in Ghana and therefore, an adoption of clean cooking technology is assumed to reduce CO2 and that the need to find the relationship between the variables.

One of the widely used models to determine the relationship between environment and human activities is the IPAT accounting model. This accounting model was proposed by [23, 24] to scrutinize all factors that have effects on the environment which are classified as the key driving forces or anthropogenic factors. These key driving forces are: Population size, Affluence and Technology. The reformulation of IPAT model to STIRPAT model by [8] was meant to have a model for estimating the effects driving force’ impacts on environment. Therefore, STIRPAT serves as an enhancement of the old IPAT model. A lot of studies have been conducted using STIRPAT model[25-30] whereby different variables are added to the key driving forces (i.e. Population, Affluence, Technology) to determine their impact on environment. This addition and subtraction of variables in the equation has been criticized by researchers with diverse views. Some find the arbitral addition and subtractions of variables as problematic to draw reliable and conclusive findings using the same model [31].

However, researchers such as [7] do not see anything wrong in this practice provided the concept is appropriate, and its multiplicative effect is justifiable. [32] employed ARDL bounds to test for cointegrating and used VECM Granger causality test to find the fundamental relationship between urbanization and energy consumption in Pakistan using STIRPAT model. The study was undertaken for the first quarter of 1972 to the fourth quarter of 2011. Findings are that urbanization increases energy consumption whiles technology and transportation are positively
linked to energy consumption. Nevertheless, economic growth of Pakistan causes an increase in energy demand. Similar study was conducted by [33] for the period 1991-2013 using STIRPAT model adding urbanization and economic development to the nexus to find their effects on carbon dioxide emissions in non-high income economies. The study findings indicated that increase in urbanization and economic development does not have significant contribution to carbon emissions level but however, as the countries develop economically, their CO2 emission’s level decreases. This turn to support the existence of EKC in non-high income economies. The study concluded that population, affluence, energy intensity and CO2 emission intensity are the key driving factors of carbon emissions.

[34] investigated how population and economic growth impact on carbon dioxide in Taiwan. Using STIRPAT model the study disaggregated the population of Taiwan into percentage of people that are living in the urban areas and non-dependent population. The study also looked at the energy driven GDP and GDP generated by the manufacturing industries to ascertain their impact on environmental pollution. Taiwan national data for 1990 to 2014 was used to test seven scenarios and findings are that GDP per capita coefficients are negative. This means that Taiwan as a country has reached a stage whereby economic prospers are bring down carbon emissions. Since the study was based on forecast, findings suggest two models to predict the impact of population and economic growth on carbon emission of Taiwan by the year 2025. Empirical study by [35] shows that higher population density would result in a decrease in energy consumption in certain parts of China. However, the study established that the magnitude of the effect on environment depends on the type of pollutants. Therefore, the effect of economic development has an anthropogenic impact on the environment, and that industrialization output has positive influence on energy consumption, which inversely increases pollutant emissions. However, the impact of technology, population and economic growth on environment depends on the level of development.

[36] used Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model to investigate how economic growth, urbanization level, energy intensity and Kyoto protocol obligation impact on carbon emissions. The study findings indicated the significant effect on the forces (i.e. economic growth, urbanization level, energy intensity, etc.) on emissions, which depend mainly on the revenue level. The study was conducted by decomposing the sampled countries into groups based upon their revenue level during the period 1980-2010.[7] also applied STIRPAT model to compute the ecological elasticities of population, affluence and other factors such as an energy footprint contribution to carbon dioxide (CO2), emissions from fossil fuel combustion and composite measures which consist of fuel wood, hydropower and nuclear power used as proxy of energy footprint. Study results indicates that population has a proportionate effect on CO2 emissions, and therefore the relationship can be said to be unitary elastic. In the other side of the coin, economic growth relationship with both energy footprint and CO2 was found to be increasing monotonically and therefore the relationship is
classified as inelastic. However, the study findings further explained that an increase in economic growth changes the relationship from inelastic to elastic with energy footprint and CO2.

[37] applied STIRPAT model in China to investigate the impact of urbanization on energy consumption. The study applied national, provincial and regional data in the analysis. The empirical results indicate that urbanization influences the level of energy consumption in China but however, the impact differs across regions. The application of efficient energy technology in places in the Western, Eastern and Central part of China shows that urbanisation decreases the energy needs of those regions. [38] study used an extended STIRPAT model to find the impact factors of population, economic level, technology level, urbanization level, industrialization level, service level, energy consumption structure and foreign trade degree on the energy-related CO2 emissions in Guangdong Province, China from 1980 to 2010. Findings indicate that CO2 is caused by population, urbanization level, GDP per capita, industrialization level and service. Notwithstanding these findings, the study further established that level of technology, energy consumption level and foreign trade openness can lead to a decrease in the level CO2 emissions.

![Conceptual framework](image)

Figure 1. Conceptual framework.

Source: Author’s design

That is, environmental pollution (CO2) is described as multiplicative function of population size (P), affluence (A) and technology (T) which is expressed as:

\[
\text{CO}_2 = f(P, A, T)
\] (1)
Based on Environmental Kurznet Curve (EKC) theory, it is expected that, CO2 and P should have positive relationship since an increase in population will increase the carbon emission level. Both theoretical and empirical study postulates that increase in economic growth, and technology will increase the carbon emissions.

MATERIALS AND METHODS

Data Collection

In an attempt to find out the anthropogenic factor’s impact on Ghana’s environment, the study applied Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) and Cobb-Douglas Production Function. To accomplish the study objectives, time-series data of Ghana was obtained from [10, 39, 40] from 1990 to 2016. The dataset were put together based on the conceptual framework variables in Figure 1.

Methodology

Our study employed the stochastic version of the IPAT model called Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) which was formulated by [41]. This current study represents Population (P) by population growth (PG) and employment growth (EG) in Ghana, Affluence (A) proxies by GDP growth (GDP) and per capita income growth (K), Technology (T) proxies by residential energy efficiency (RE), access to electricity (AE) and access to clean cooking (AC). The paper is meant to advance the population-environment nexus. First, the paper looked into the effects of Population, Affluence and Technology variables on environment. Secondly, prior to the testing of Johansen cointegrating, the study conducted unit root test using ADF and Philips-Perron (PP) test. Lastly, the study applied Fully Modified Least Square (FMOLS) to examine the long-run relationship between the variables as well as their elasticities. The study made use of Vector Error Correction Model (VECM) instead of VAR model since cointegrating exists between the variables. VAR is mainly used when one wants to establish short-term relationship between the variables under study. However, to establish both short and long-term relationship, VECM is recommended.

Ecological Elasticity

The concept of elasticity is predominately found in economics subject, which basically refers to how receptive one variable to changes in another. That is, how proportionate change in a dependent variable if particular independent variable changes by 1% holding other variables constant. The use of ecological elasticity is meant to find out how responsive or sensitive the environmental impact is to a change of any of the human factors. The environmental elasticity measure
countenances for a clear-cut explanation of the effects of anthropogenic driving forces.

**Stirpat Model**

To avoid omitted variable bias and to extend the studies of [6, 42, 43] the study further introduces other variables that contribute to carbon emission levels in Ghana such as the residential energy efficiency, access of electricity and access to clean cooking fuel and technology. For the avoidance of multicollinearity effect which makes the regression model very difficult to tell which explanatory variable(s) influences the dependent variable, the study employed Fully Modified Least Square (FMOLS) estimation to identify the potentially influencing driving factors on environmental pollution (i.e. CO2). Therefore, the STIRPAT model is expressed as follows:

\[
\text{CO}_2 = \alpha \prod P^\beta A^\gamma T^\delta e
\]  

(2)

Where CO2 is dependent variable, P: Population, A: Affluence and T: Technology respectively as independent variables. The estimated exponents (i.e. \(\beta, \gamma, \delta\)) are considered as elasticities and therefore, any change in one of the explanatory variables can cause a change to the dependent variable. Using multiple regression models as:

\[
\text{CO}_2 = \alpha + \beta_1 P_t + \beta_2 E_t + \gamma_1 G_{DP_t} + \gamma_2 K_t + \delta_1 R_{E_t} + \delta_2 A_{E_t} + \delta_3 A_{C_t} + \varepsilon_t
\]  

(3)

By applying the natural logarithm in both sides, equation (3) changes to:

\[
\ln \text{CO}_2 = \alpha + \beta_1 \ln P_t + \beta_2 \ln E_t + \gamma_1 \ln G_{DP_t} + \gamma_2 \ln K_t + \delta_1 \ln R_{E_t} + \delta_2 \ln A_{E_t} + \delta_3 \ln A_{C_t} + \varepsilon_t
\]  

(4)

Where \(\ln \text{CO}_2\) represent the natural logarithm of carbon dioxide (CO2) metric tons per capita. However, \(\ln P_t\) and \(\ln E_t\) represent the natural logarithm of population growth measured in percent change, employment growth measured in percent change. The \(\ln G_{DP_t}\), and \(\ln K_t\) represent the natural logarithms of GDP growth and per capita income growth both measured in percentage change. Lastly, \(\ln R_{E_t}\), \(\ln A_{E_t}\), and \(\ln A_{C_t}\) represent the natural logarithm of residential energy efficiency (measured as GJ/Population), access to electricity measured in electrification rate (National %) and access to clean fuels and technologies for cooking (measured as %). Whiles \(\alpha\) and \(\varepsilon\) are classified as the constant and error term respectively. Using FMOLS, the study econometric model is grouped into five models with the variables in their natural logarithm. Therefore, Model 1 is stated as follows:

\[
\ln \text{CO}_2 = \alpha + \beta_1 \ln P_t + \beta_2 \ln E_t + \gamma_1 \ln G_{DP_t} + \gamma_2 \ln K_t + \delta_1 \ln R_{E_t} + \delta_2 \ln A_{E_t} + \delta_3 \ln A_{C_t} + \varepsilon_t
\]  

(5)
Where \( \varepsilon_t \) is the error term. Model 2 is meant to test the effect of population growth, employment growth, GDP growth, residential energy efficiency, access to electricity and access to clean cooking fuel and technology by dropping per capita income growth (i.e. InK) due to high level of multicollinearity, high probability value greater than 5\% and also less marginal effect on dependent variable in Table 8. Therefore, Model 2 is expressed as:

\[
\ln CO_{2t} = \alpha + \beta_1 \ln PG_t + \beta_2 \ln EG_t + \gamma_1 \ln GDP_t + \delta_1 \ln RE_t + \delta_2 \ln AE_t + \delta_3 \ln AC_t + \varepsilon_t .............. (6)
\]

Based on the marginal effect on the dependent variable and the presence of multicollinearity, our study further reduced the variables. The essence is to derive the significant influence factors of environmental pollution from the perspective of Ghana. Therefore, our Model 3 is meant to find the effect of the variables on environment by dropping InEG from the nexus, and its functional form is stated as:

\[
\ln CO_{2t} = \alpha + \beta_1 \ln PG_t + \gamma_1 \ln GDP_t + \delta_1 \ln RE_t + \delta_2 \ln AE_t + \delta_3 \ln AC_t + \varepsilon_t .............. (7)
\]

Model 4 is to find the key contributing variables to environmental pollution. Therefore, the need to drop variable with high probability greater than 0.05, having the least marginal effect and which is highly correlated with other predictors as depicted in Table 8. The model 4 dropped the variable InAC with functional form as:

\[
\ln CO_{2t} = \alpha + \beta_1 \ln PG_t + \gamma_1 \ln GDP_t + \delta_1 \ln RE_t + \delta_2 \ln AE_t + \varepsilon_t .............. (8)
\]

Model 5 probes further by removing the variable InGDP from nexus due to its high collinearity and having the least effect on CO2 in Table 8. Our study, therefore, expresses the optimal model as shown in equation (9).

\[
\ln CO_{2t} = \alpha + \beta_1 \ln PG_t + \delta_1 \ln RE_t + \delta_2 \ln AE_t + \varepsilon_t .............. (9)
\]

**Regression: Fully Modified Ordinary Least Square (Fmols)**

Our study initially applied the equation (10) as shown below:

\[
(CO2_t) = \omega_0 + \beta X_t + \sum_{k=i}^{k} \gamma_k \Delta X_{t-k} + V_t .............. (10)
\]

Where \((CO2_t)\) denotes the dependent variable. The \(X_t\) denotes the independent variables in this study. The long-run covariance is presented as:

\[
\Omega_t = \lim_{T \to \infty} F \left[ \left( \frac{1}{T} \right) \left( \sum_t^T = 1^\nu_t \right) \left( \sum_t^T = 1^\nu_t \right)^* \right]
\]
Then the FMOLS estimator was extended to the equation (8) below:

\[
\hat{\beta} = \frac{1}{n} \sum_{i=1}^{n} \left[ \frac{1}{\sum_{t=1}^{T} (X_t - \bar{X_t})^2} \right]^{-1} \left( \sum_{t=1}^{T} (X_t - \bar{X_t}) (CO2_t - \Gamma) \right] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 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The application of Constant Elasticity of Substitution (CES) function where \( \lambda = 0 \) corresponds to Cobb-Douglas function in equation (12) can be written as:

\[
\log CO_2 = \log \alpha + \frac{\log \left[ aP^{\lambda} + (1 - a)A^{\lambda} + (1 - a)T^{\lambda} \right]^{1/\lambda}}{\lambda} \tag{16}
\]

However, upon the application of L’Hopital’s rule,

\[
\lambda \xrightarrow{\text{lim}} 0 \log CO_2 = \log \alpha + a \log P + (1 - a) \log A + (1 - a) \log T \tag{17}
\]

With the application of the models and taking the antilogarithm of the intercept and placing the regression coefficients as exponents in the original function yields the estimated form of Cobb-Douglas production function. Therefore, to test for the presence or absence of the reaction or impact of the driving factors on environment requires the summation of the variable’s exponents to see if they are less than, equal to, or greater than one. When the model coefficient’s sum to one means that first-order homogeneity exists and that constant returns to scale apply. That is, as the anthropogenic factor’s increases, the CO2 in Ghana also increases at the same rate. However, whereby the variable’s exponents sum is less than one, then decreasing return to scale exists. This means that as the anthropogenic factor’s increases, the CO2 decreases or the CO2 does not increase in the same margin as the anthropogenic factors. Lastly, when the results from the exponent’s summation providea result which is greater than one means increasing return to scale is real. This suggests that CO2 emission in Ghana increases more than the factors that drives it (i.e. anthropogenic factors discussed in this case).

RESULTS AND DISCUSSION

Descriptive Analysis

Descriptive statistical analysis on the study variables is given in Table 1. Evidence from the analysis clearly shows that CO2 and RE display a positive skewness (long-right tail) while PG and AE exhibit a negative skewness (long-left tail). Additionally, while AE and RE exhibit a platykurtic distribution, PG and CO2 exhibit a leptokurtic distribution. Evidence from the Jarque-Bera test statistic shows that the null hypothesis of the series is normally distributed cannot be rejected at 5% p-value for CO2. Meaning that prior to the application of econometric techniques, CO2 is not normally distributed at 5% significance level.
**Descriptive Statistics.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std Dev.</th>
<th>Min</th>
<th>Max</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>Jarque-Bera</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>3.64</td>
<td>0.30</td>
<td>3.25</td>
<td>4.38</td>
<td>1.16</td>
<td>3.86</td>
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<td>1.23</td>
<td>0.54</td>
</tr>
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<td>2.18</td>
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<td>1.30</td>
<td>3.52</td>
<td>0.17</td>
</tr>
<tr>
<td>AE</td>
<td>3.88</td>
<td>0.36</td>
<td>3.17</td>
<td>4.49</td>
<td>-0.25</td>
<td>2.19</td>
<td>1.02</td>
<td>0.60</td>
</tr>
</tbody>
</table>

**Unit Root Test**

One of the fundamental tests to perform prior to determining the cointegrating relationship between the variables is to test for unit root. The study, therefore, applied Augmented Dickey-Fuller (ADF), Philips and Perron (PP) test to perform this key function. Nonetheless, time-series data such as ours most of the time produces non-stationary results. Our results of the test as indicated in Table 2 shows that both ADF and PP indicate the existence of unit root at the level, however, data become stationary at first difference. Both ADF and PP indicate an acceptance of the null hypothesis at the level for all the variables but however, rejected the null hypothesis at first difference that, the variable(s) at their first difference has a unit root.

**Results of The Unit Root Test.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>AT LEVELS</th>
<th>AT 1ST DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADF</td>
<td>PP</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.38 (0.98)</td>
<td>0.41 (0.98)</td>
</tr>
<tr>
<td>PG</td>
<td>-2.26 (0.19)</td>
<td>-3.36 (0.12)</td>
</tr>
<tr>
<td>RE</td>
<td>-0.84 (0.79)</td>
<td>0.89 (0.78)</td>
</tr>
<tr>
<td>AE</td>
<td>-1.52 (0.51)</td>
<td>-1.59 (0.47)</td>
</tr>
</tbody>
</table>

**Note:** ADF-(Augmented Dicker Fuller); PP-(Phillips Perron)

**Co-integration Analysis**

Evidence from the unit root test suggests that the variables are non-stationary at the level with a deterministic trend. However, the variables became stationary after converting them to first difference using both ADF and PP test. Our study carefully chosen the optimal lag using the selection criterion in Table 3. Since our variables are cointegrated at the same order, we then conducted the Johansen test of cointegrating. That is, to determine the causal relationship between CO2 and the
predictors. The analysis in Table 4 clearly depicts that both trace, and maximum eigenvalue statistics give P<0.05 when the hypothesis is “none”. This means that we can reject the null hypothesis that there is no cointegration between the variables. However, at most 1 hypothesis, P>0.05, hereafter, we accept the null hypothesis that at least there is one co-integrated equation or error term and therefore, all the variables (i.e. InCO2, InPG, InRE and InAE) have long-run association. In other words, at most 1, the trace statistic is less than the critical value. Hence, failed to reject the null hypothesis and therefore accepted that there is at least one cointegrating among the variables.

**Optimal Lag Selection Criterion**

<table>
<thead>
<tr>
<th>Lag</th>
<th>LogL</th>
<th>LR</th>
<th>FPE</th>
<th>AIC</th>
<th>SC</th>
<th>HQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>61.417</td>
<td>NA</td>
<td>7.98e-08</td>
<td>-4.993</td>
<td>-4.795</td>
<td>-4.943</td>
</tr>
<tr>
<td>1</td>
<td>141.540</td>
<td>125.409</td>
<td>3.11e-10</td>
<td>-10.569</td>
<td>-9.581*</td>
<td>-10.320</td>
</tr>
<tr>
<td>2</td>
<td>164.765</td>
<td>28.275*</td>
<td>1.92e-10*</td>
<td>-11.197</td>
<td>-9.420</td>
<td>-10.750*</td>
</tr>
<tr>
<td>3</td>
<td>178.189</td>
<td>11.672</td>
<td>3.68e-10</td>
<td>-10.973</td>
<td>-8.406</td>
<td>-10.327</td>
</tr>
<tr>
<td>4</td>
<td>200.252</td>
<td>11.512</td>
<td>6.36e-10</td>
<td>-11.500*</td>
<td>-8.143</td>
<td>-10.656</td>
</tr>
</tbody>
</table>

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

**Trace and Maximum Eigenvalue Diagnostic Test**

<table>
<thead>
<tr>
<th>Hypothesized No. of CE(s)</th>
<th>Trace Eigenvalue</th>
<th>Trace Statistics</th>
<th>5% Critical Value</th>
<th>Prob.*</th>
<th>Maximum Eigenvalue</th>
<th>Max-Eigen Statistics</th>
<th>5% Critical Value</th>
<th>Prob.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>None**</td>
<td>0.755</td>
<td>61.370</td>
<td>47.856</td>
<td>0.002</td>
<td>0.755</td>
<td>33.721</td>
<td>27.584</td>
<td>0.007</td>
</tr>
<tr>
<td>At most 1</td>
<td>0.484</td>
<td>27.650</td>
<td>29.797</td>
<td>0.087</td>
<td>0.484</td>
<td>15.871</td>
<td>21.132</td>
<td>0.233</td>
</tr>
<tr>
<td>At most 2</td>
<td>0.370</td>
<td>11.779</td>
<td>15.495</td>
<td>0.168</td>
<td>0.370</td>
<td>11.068</td>
<td>14.265</td>
<td>0.151</td>
</tr>
<tr>
<td>At most 3</td>
<td>0.029</td>
<td>0.710</td>
<td>3.842</td>
<td>0.399</td>
<td>0.029</td>
<td>0.710</td>
<td>3.842</td>
<td>0.399</td>
</tr>
</tbody>
</table>

Both trace and max-eigenvalue test indicates 1 co-integrating equation(s) at the 0.05 level
**Denotes rejection of the hypothesis at the 0.05 level
Vector Error Correction Model (VECM)

After the establishment of co-integration relationship among the variables, our study utilized co-integrating equation and optimal lag 2 to estimate VECM. The VECM is meant to estimate the long-run equilibrium relationship between the variables. This can be expressed mathematically as:

\[
\Delta \begin{bmatrix} CO_2_t \\ PG_t \\ RE_t \\ AE_t \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \end{bmatrix} + \sum_{i=1}^{p} \Delta \begin{bmatrix} \beta_{1}\beta_{12}\beta_{13} \\ \beta_{21}\beta_{22}\beta_{23} \\ \beta_{31}\beta_{32}\beta_{33} \\ \beta_{41}\beta_{42}\beta_{43} \end{bmatrix} X \begin{bmatrix} CO_2_{t-1} \\ PG_{t-1} \\ RE_{t-1} \\ AE_{t-1} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \end{bmatrix} \left[ ECT_{t-1} \right] + \begin{bmatrix} \varepsilon_{t1} \\ \varepsilon_{t2} \\ \varepsilon_{t3} \\ \varepsilon_{t4} \end{bmatrix} \tag{18}
\]

Where \( p \) is the number of lags, \( \Delta \) represents the change or difference operator, \( ECT_{t-1} \) is the error correction term meant to find the integration of the variables in the long-run. The used of \( \alpha \)'s, \( \beta \)'s and \( \delta \)'s are the parameters while \( \varepsilon \)'s are the white noises. Evidence from the Table 9. Shows error correction term (\( ECT_{t-1} \): -0.89, P-value = 0.04) which makes our model residuals negative but significant at 5% level. That is, speed of adjustment towards equilibrium is 89%. This means that there is a long-run equilibrium relationship from PG, RE and AE to CO2. Wald test was also performed to determine the short-run relationship between the dependent and independent variables. Our findings in Table 5 indicate that we should accept the null hypothesis that all predictors (i.e. PG, RE and AE) put together cannot influence CO2 in the short-term. Therefore, there is no short-run causality from independent variables jointly to lnCO2. Additionally, same results were found that individual predictor cannot influence lnCO2 in the short-run.

Wald Test [Dependent Variable: D (lnCO2)]

<table>
<thead>
<tr>
<th></th>
<th>Chi-sq</th>
<th>df</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D (lnPG)</td>
<td>2.363</td>
<td>2</td>
<td>0.307</td>
</tr>
<tr>
<td>D (lnRE)</td>
<td>1.239</td>
<td>2</td>
<td>0.538</td>
</tr>
<tr>
<td>D (lnAE)</td>
<td>2.818</td>
<td>2</td>
<td>0.244</td>
</tr>
<tr>
<td>All</td>
<td>5.297</td>
<td>6</td>
<td>0.506</td>
</tr>
</tbody>
</table>

Diagnostic And Stability Tests

Our study subsequently performed the stability and residual test to ensure our model is robust. To validate our model (VECM) requires the need to ensure that there is no serial correlation in the residuals, residuals are not heteroscedastic and
that residuals are normally distributed. Our findings in Table 6 postulate that residual analysis test indicates that P-value > 0.05, and therefore, we accept the null hypothesis that residuals are normally distributed. Our heteroscedasticity test also accepted the null hypothesis that there is no heteroscedastic effect in the model. The study serial correlation test accepted the null hypothesis that there is no serial correlation and that our P-value > 0.05. Lastly, our study estimated the model robustness by looking at the stability of the model through the use of inverse root of AR characteristic polynomial shown as Figure 2. Our results show that no root falls outside the unit circle thus, confirm the VAR stability conditions depicted in Table 7.

Diagnostic Test

<table>
<thead>
<tr>
<th>Diagnostic Test</th>
<th>F-Stat.</th>
<th>Prob. Chi-square</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heteroskedasticity</td>
<td>3.240</td>
<td>0.061</td>
<td>No ARCH effect</td>
</tr>
<tr>
<td>Breusch-Godfrey Serial Corr. LM Test</td>
<td>0.400</td>
<td>0.472</td>
<td>No Serial Correlation</td>
</tr>
<tr>
<td>Residual test-Histogram</td>
<td>-</td>
<td>0.568</td>
<td>Data Normally Distributed</td>
</tr>
</tbody>
</table>

Figure 2. Stability Test.
Table 7. Inverse Root Results.

<table>
<thead>
<tr>
<th>Root</th>
<th>Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.000000</td>
<td>1.000000</td>
</tr>
<tr>
<td>1.000000</td>
<td>1.000000</td>
</tr>
<tr>
<td>1.000000</td>
<td>1.000000</td>
</tr>
<tr>
<td>0.106434 - 0.791761i</td>
<td>0.798883</td>
</tr>
<tr>
<td>0.106434 + 0.791761i</td>
<td>0.798883</td>
</tr>
<tr>
<td>0.631829 - 0.216027i</td>
<td>0.667739</td>
</tr>
<tr>
<td>0.631829 + 0.216027i</td>
<td>0.667739</td>
</tr>
<tr>
<td>-0.658917</td>
<td>0.658917</td>
</tr>
<tr>
<td>-0.115888 - 0.520183i</td>
<td>0.532936</td>
</tr>
<tr>
<td>-0.115888 + 0.520183i</td>
<td>0.532936</td>
</tr>
<tr>
<td>-0.221945 - 0.282776i</td>
<td>0.359474</td>
</tr>
<tr>
<td>-0.221945 + 0.282776i</td>
<td>0.359474</td>
</tr>
</tbody>
</table>

No root lies outside the unit circle
VAR satisfies the stability condition

**Goodness-of Fit Regression**

As per the rule of Variance Inflation Factor (VIF), any VIF asset value of predictors greater than 10 is a sign of the problem of multicollinearity[45]. Evidence of Table 8 with VIF value of predictors more than 10 indicates that there is high correlation between the variables. Therefore, there is the need to drop some of the variables that are highly correlated and with not as much of marginal effect on dependent variable. The elimination of statistically insignificant variables is one of the common approaches towards achieving higher goodness of fit in econometrics. Upon fitting the data to the model by the Full Modified Least Squares (FMOLS) method, the estimated model 1 to model 5 provided the coefficient, probability, VIF, constant, coefficient of determination (R-squared) and adjusted R-square value as shown in Table 8. The R-squared of model 5 shows that 83% of InCO2 is explained by InPG, InRE and InAE. Variance Inflation Factor (VIF) test result in model 5 is a clear indication of non-existence of multicollinearity after the elimination of non-significant variables from the nexus. Figure 3 shows that our residuals are homoscedastic, normally distributed and are not serially correlated, this means that no important variables are missing or misspecified in the functional part on the model.
Table 8. Results from Models analysis using FMOLS (Dependent Variable: InCO2).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th></th>
<th></th>
<th></th>
<th>Model 2</th>
<th></th>
<th></th>
<th></th>
<th>Model 3</th>
<th></th>
<th></th>
<th></th>
<th>Model 4</th>
<th></th>
<th></th>
<th></th>
<th>Model 5</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>InPG</td>
<td>0.55</td>
<td>0.43</td>
<td>10.29</td>
<td>0.63</td>
<td>0.05</td>
<td>2.02</td>
<td>0.62</td>
<td>0.05</td>
<td>2.02</td>
<td>0.77</td>
<td>0.03</td>
<td>1.99</td>
<td>0.98</td>
<td>0.02</td>
<td>1.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InEG</td>
<td>-0.01</td>
<td>0.92</td>
<td>5.41</td>
<td>-0.02</td>
<td>0.85</td>
<td>5.31</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InGDP</td>
<td>-0.18</td>
<td>0.78</td>
<td>112.7</td>
<td>-0.13</td>
<td>0.35</td>
<td>4.76</td>
<td>-0.20</td>
<td>0.06</td>
<td>1.62</td>
<td>-0.14</td>
<td>0.09</td>
<td>1.58</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InK</td>
<td>0.03</td>
<td>0.93</td>
<td>120.8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InRE</td>
<td>1.10</td>
<td>0.06</td>
<td>101.6</td>
<td>1.37</td>
<td>0.02</td>
<td>101.6</td>
<td>1.36</td>
<td>0.02</td>
<td>98.2</td>
<td>0.71</td>
<td>0.00</td>
<td>11.9</td>
<td>0.97</td>
<td>0.00</td>
<td>8.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>InAE</td>
<td>1.01</td>
<td>0.06</td>
<td>75.14</td>
<td>0.79</td>
<td>0.12</td>
<td>66.8</td>
<td>0.77</td>
<td>0.11</td>
<td>65.9</td>
<td>1.42</td>
<td>0.00</td>
<td>7.82</td>
<td>1.61</td>
<td>0.00</td>
<td>6.82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lnAC</td>
<td>0.35</td>
<td>0.41</td>
<td>296.5</td>
<td>0.55</td>
<td>0.20</td>
<td>288</td>
<td>0.55</td>
<td>0.18</td>
<td>278</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-3.05</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.86</td>
<td>0.85</td>
<td>0.85</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.80</td>
<td>0.81</td>
<td>0.82</td>
<td>0.82</td>
<td>0.82</td>
<td>0.82</td>
<td>0.81</td>
<td>0.81</td>
<td>0.81</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Residuals Analysis.

Based on Cobb Douglas Production Function expressed in equation 12 can be rewritten from Model 5 as follows:

\[ \text{InCO}_2 = \text{In} \alpha + \text{InPG}^{\beta} + \text{InRE}^{\gamma_1} + \text{InAE}^{\gamma_2} \]

\[ \text{..........................(19)} \]

After finding antilog of the intercept \((\alpha)\) gives equation (19) as:

\[ \text{InCO}_2 = 0.007 + \text{InPG}^{0.98} + \text{InRE}^{0.97} + \text{InAE}^{1.61} \]
The summation of the variables exponents gives $\ln CO^2 = 3.56$, which is greater than 1, means that increasing in return exist in Ghana.

**Granger-Causality**

The Granger causality test helps to determine the cause and effect relationship between the variables. The study pragmatically used Vector Error Correction (VEC) Model to determine the long-run relationship between the variables at 5% significance level. At 5% significance level, PG, RE and AE have long-term relationship. The evidence of this is depicted in Table 9.

<table>
<thead>
<tr>
<th>MODEL (VEC MODEL)</th>
<th>SHORTRUN CAUSALITY</th>
<th>LONGRUN CAUSALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Delta CO^2$</td>
<td>$\Delta PG$</td>
</tr>
<tr>
<td>$\Delta CO^2$</td>
<td>-</td>
<td>0.06 (0.97)</td>
</tr>
<tr>
<td>$\Delta PG$</td>
<td>2.36 (0.31)</td>
<td>-</td>
</tr>
<tr>
<td>$\Delta RE$</td>
<td>1.24 (0.54)</td>
<td>1.64 (0.44)</td>
</tr>
<tr>
<td>$\Delta AE$</td>
<td>2.82 (0.24)</td>
<td>0.01 (0.99)</td>
</tr>
</tbody>
</table>

Note: The parentheses [ ] and ( ) denotes t-Statistics and probability values respectively.

Our findings as shown in Table 10 indicates that AE contributes 172% to CO2 in Ghana followed by RE 46% and PG 20%. The contribution degrees of the driving forces were ranked according to the contribution degree to change of CO2 emissions from the STIRPAT model which suggest technology. Access to electricity is ranked first as the key driving factor followed by residential energy efficiency and lastly population growth.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average annual growth rate ($X$)</th>
<th>Regression coefficient ($\beta$)</th>
<th>Effect on the change of CO$_2$ emissions. ($\beta x X$)</th>
<th>Contribution degree to change of CO$_2$ emissions</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$ emissions</td>
<td>3.64</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PG</td>
<td>0.76</td>
<td>0.98</td>
<td>0.74</td>
<td>20%</td>
<td>3rd</td>
</tr>
<tr>
<td>RE</td>
<td>1.73</td>
<td>0.97</td>
<td>1.68</td>
<td>46%</td>
<td>2nd</td>
</tr>
<tr>
<td>AE</td>
<td>3.88</td>
<td>1.61</td>
<td>6.25</td>
<td>172%</td>
<td>1st</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The use of STIRPAT model for this study does not only provide the marginal effects of the anthropogenic factors on environment but also bring to light the precise specification of environmental impact sensitivity to the anthropogenic factors. The negative effect of greenhouse-gas emissions on living species of the next generations should not be underestimated. This requires rigorous and pragmatic means of reducing the emissions level in order to achieve Sustainable Development Goal 13. In this paper, we developed both theoretical and conceptual framework of STIRPAT model to scrutinize the determinants of carbon emissions and to investigate the effects of population growth, residential energy efficiency and access to electricity on CO$_2$ emissions in Ghana.

The study examined the relationship between CO$_2$, population growth, residential energy efficiency and access to electricity in Ghana for the period 1990-2016 using STIRPAT model and Cobb-Douglas Production Function. Evidence of our analysis indicates that 1% increase in PG, RE and AE will cause an increase of InCO$_2$ by 98%, 97% and 161% respectively. Therefore, the relationship between PG, RE, AE and CO$_2$ is considered as elastic and that a small change in the driving forces will cause greater proportionate change in environmental pollution. The study found access to electricity marginal effect on CO$_2$ to be the highest followed by population growth in Ghana. Our study found long-run relationship between the variables but no causal effect of the predicting variables on dependent variable. However, VEC Granger causality results show that none of the anthropogenic factors cause CO$_2$. This was proven by using Cobb-Douglas production function which the summation of the exponents was found to be greater than one. That is, increasing in return to scale exists in Ghana and therefore, CO$_2$ emission in Ghana increases more than the factors that drives it. Our findings as shown in Table 9 indicates that AE contributes 172% to CO$_2$ in Ghana followed by RE 46% and PG 20%. The contribution degrees of the driving forces to the change in CO$_2$ emissions from the STIRPAT model suggested that technology (i.e. access to electricity and residential energy efficiency) is the key driving factor, while population followed closely.

Our study findings support [38, 46-49] findings that population and technology have influence on environmental pollution but hold the contrary view to the findings that affluence has an impact on environment. Our study found that population proxies by PG and technology proxies by RE and AE are the key anthropogenic factors that have an association with environmental pollution but however, cannot be classified as the main causes of CO$_2$ in Ghana.
To conclude, as the population in Ghana is increasing, which is also expected to an upsurge more in years to come, firstly, there is the need for governments to sensitize the populace about the dangers of their behaviors towards environmental degradation. Secondly, as the population grows, which is complemented by high level of economic activities will call for high demand of electricity for industrial and residential consumption. The tall demand of electricity will induce more energy consumption and supply, which will then increase the CO2 emission level. To achieve both Sustainable Development Goal 7 and 13 requires that the government of Ghana should make use of renewable-energy source, especially non-biomass such as solar, wind, geothermal and hydropower to reduce the negative impact of energy production on environment. Since these sources of energy do not directly emit greenhouse gases.

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