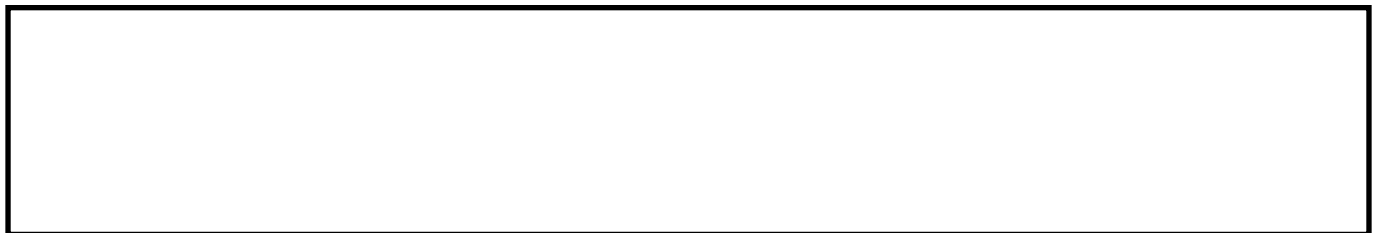


# The impact of energy consumption and economic growth on carbon dioxide emissions.

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Article

# The Impact of Energy Consumption and Economic Growth on Carbon Dioxide Emissions

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**Abstract:** This study explored the effect of energy consumption and economic growth on CO<sub>2</sub> emissions. The relationship between energy consumption, economic growth and CO<sub>2</sub> emissions was assessed using regression analysis (the pooled OLS regression and fixed effects methods), Granger causality and panel cointegration tests. Data from 70 countries between 1994–2013 were analysed. The result of the Granger causality tests revealed that the study variables (population, capital stock and economic growth) have a bi-directional causal relationship with CO<sub>2</sub> emissions, while energy consumption has a uni-directional relationship. Likewise, the outcome of the cointegration tests established that a long-run relationship exists among the study variables (energy consumption and economic growth) with CO<sub>2</sub> emissions. However, the pooled OLS and fixed methods both showed that energy consumption and economic growth have a significant positive impact on CO<sub>2</sub> emissions. Hence, this study supports the need for a global transition to a low carbon economy primarily through climate finance, which refers to local, national, or transnational financing, that may be drawn from public, private and alternative sources of financing. This will help foster large-scale investments in clean energy, that are required to significantly reduce CO<sub>2</sub> emissions.

**Keywords:** climate change; climate finance; economic growth; CO<sub>2</sub> emissions; energy consumption

## 1. Introduction

Environmental issues have taken leading discussions in our contemporary times in both developing and developed economies due to environmental deterioration. This further raises concerns about climate change and global warming, which arises mainly from the emission of greenhouse gases [1]. These changes are often linked to natural causes (i.e., continental drifts, volcanic activities, solar radiation and ocean currents) and direct and indirect human activities, which affect the global atmospheric composition and variability of the natural climate. However, scholars have argued that the increase in human activities due to the emergence of industrialization, the increase in the growth of the global population and the need to meet up with such transformations are the main causes of climate change [2,3]. Also, human activities such as deforestation for agricultural and commercial purposes, burning of fossil fuel and changes in the use of land due to population growth are contributing significantly to a surge in greenhouse gas emissions. Despite the contribution of industrialization in promoting economic growth by increasing the amount of goods and services produced, shaping lives and making the society a better place, it left us with an issue of increasing greenhouse emissions.

In today's world, the demand for energy due to the growing population and urbanization is on the increase [4]. This is essential to keep pace with the rapid disruptions and transformation in

global economies. Energy is pivotal to human lives and to the social, economic and environmental development of the global economy. It is likely impossible to produce, deliver, or use mainstream commodities without consuming energy. Hence, Yildirim [5] observed that insufficient energy would negatively impact the performance of different sectors of the economy such as transport and a country's social life. However, the increase in the consumption of energy is becoming a threat to the global ecosystem. This has given rise to more prolonged droughts, rising sea levels and the rising occurrence of heatwaves, which are of grave negative impacts on the environment. Although there is an awareness about the consequences of human activities, Urry [3] observed that there is a rise in the emission level of greenhouse gases such as Carbon dioxide (CO<sub>2</sub>) into the atmosphere.

Likewise, the need for economic growth has led to environmental degradation, which is often a resultant effect of development and industrialization in both developing and developed countries. The economic growth of any country is dependent on different factors, which may impose negative impacts on the environment such as unsustainable natural resource exploitation, environmental pollution and climate change [6]. Also, the rapid increase in urbanization in many countries has fast-tracked economic growth with the resultant effect of an increase in energy consumption. Hence, the key issue that many countries are facing is the level of carbon dioxide in the environment that is increasing significantly due to energy consumption and economic growth. According to Kasman and Dunman [7], a majority of the energy originates from fossil fuels such as coal and natural oil and gas, which also has resulted in the increase of CO<sub>2</sub> emissions level. This has further prompted scholars to argue that CO<sub>2</sub> emission is invisible, and its effect may take years to materialise [8].

Although several factors such as population size, the carbon intensity of energy, economic growth, clean nuclear energy use, fossil energy consumption, renewable energy, urbanization and other air pollutants (PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO, B(a)P) [9,10] have been identified to be responsible for the growth in the global CO<sub>2</sub> emissions level, the aim of this study is to explain the impact of energy consumption and economic growth on CO<sub>2</sub> emissions. Given the rapid global economic growth resulting in increased energy consumption, understanding the relationship between these variables is essential to ensure a balance between energy consumption, economic growth and CO<sub>2</sub> emissions. Also, it will help direct focus on addressing the threats (i.e., preventing a 40°C world) posed by the changes in global climate.

## 2. Literature Review

### 2.1. Overview of Greenhouse Gas Emissions

Greenhouse gases have been categorised as atmospheric gaseous constituents, both anthropogenic and natural. These constituents are known to imbibe and emit radiation at certain wavelengths within the spectrum of infrared radiation emitted by the clouds, atmosphere and the surface of the Earth. Hossain [11] and Paiva et al. [12] asserted that greenhouse gases remain a significant cause of climate change and global warming. This is consistent with Resnik's [13] argument that the adverse effects of climate change due to greenhouse gases on human health, the environment and society are profuse. Hence, Meltzer [14] concluded that over 150,000 deaths per year are attributed to the resultant effects of environmental pollution. Although there are many greenhouse gases, CO<sub>2</sub> is attracting more recognition due to its persistence in the atmosphere and for its use as a baseline for estimating the global warming potential (GWP) of other greenhouse gases [15–17]. Rahman [18] added that between 1990 to 2013, the greenhouse gas concentration has increased by 34% with over 80% of this figure being a resultant effect of CO<sub>2</sub> emissions. This is in line with Amri's [19] assertion that CO<sub>2</sub> emissions have increased significantly from 67 million metric tons to 134 million metric tons. Considering that the rising CO<sub>2</sub> emission level remains a global concern [18,20], it is crucial to explore the drivers of CO<sub>2</sub> emissions [21,22]. Based on previous studies (Table 1), one could conclude that energy consumption and economic growth are the two most mentioned drivers of CO<sub>2</sub> emissions.

**Table 1.** Drivers of CO<sub>2</sub> emissions (summarised from the literature).

Authors	CO <sub>2</sub> Emissions Drivers
Stolyarova [23]	GDP and energy consumption.
Sharma [24]	Per capita GDP and urbanization.
Cetin and Ecevit [25]	Energy consumption and urbanization.
Keho [26]	The share of industrial sector in GDP, per capita income and trade openness.
Zakarya et al. (2015) [27]	GDP, energy consumption and Foreign direct investments.
Ab-Rahim and Xin-Di [28]	Energy consumption, trade openness and economic growth.
Jiang and Guan [29]	GDP per capita, population, carbon intensity of energy and GDP energy intensity.
Jiang et al. [30]	Social consumption and consumption behaviour.
Talbi [9]	Economic growth, population size, fossil energy consumption, clean nuclear energy use, renewable energy and waste energy conversion.
Wang and Lin [10]	Urbanization, energy structure, GDP and energy intensity

## 2.2. The Nexus of Energy Consumption, Economic Growth and CO<sub>2</sub>

In recent times, several studies have focused on understanding the link between energy consumption, economic growth and CO<sub>2</sub> emissions [5]. Nevertheless, the relationship that exists between these variables has been explained in different ways [18,20]. Table 2 present a synopsis of preceding empirical studies implemented to explain the link between energy consumption, economic growth and CO<sub>2</sub> emissions.

**Table 2.** Synopsis of preceding empirical studies on the relationship between energy consumption, economic growth and CO<sub>2</sub> emissions (authors generated).

Author	Time	Method	Country	Results
Abdallah and Abugamos [31]	1990–2014	Parametric and semi-parametric panel fixed effects models	MENA Countries	There exists an inverted u-shaped relationship between CO <sub>2</sub> emissions and urbanisation. However, there is a significant relationship between GDP and EC with respect to CO <sub>2</sub> emissions. The population shows a positive impact, but only significant at 5% using a semi-parametric model.
Mizra and Kanwal [32]	1971–2009	Error correction model and Johansen–Juselius Cointegration	Pakistan	A bidirectional causality relationship exists between EC and GDP, CO <sub>2</sub> and GDP, CO <sub>2</sub> and EC, in both the short and long run.
Nairn et al. [33]	1971–2011	ARDL bounds test	India	There exists a long-run relationship between energy consumption, GDP and CO <sub>2</sub> emissions. Besides at both aggregated and disaggregated levels, there is no feedback causality in the short and long run.
Rehman and Rashid [34]	1960–2015	Johansen Fisher and Pedroni cointegration, FMOLS and DLOS	SAARC Countries	There exists a relationship between GDP, energy consumption and CO <sub>2</sub> emissions. Also, there exists an inverted U-shaped relationship between GDP and CO <sub>2</sub> emissions.
Eso and Keho [17]	1971–2010	Bounds Testing	Sub-Saharan Countries	A long-run causality relationship exists between GDP and EC and CO <sub>2</sub> emissions. However, a short-run causality relationship exists between the variables for Ghana, the Democratic Republic of Congo, Benin, Nigeria and Senegal.
Dogan and Aslan [35]	1995–2011	Fixed effects OLS, DLOS, Emirmahmutoglu–Kose Granger causality test and FMOLS	25 EU countries	A long-run relationship exists among the variables used. Also, energy consumption increases CO <sub>2</sub> emissions while tourism and real income lessen it.
Kasman and Dunman [7]	1992–2010	FMOLS and Granger causality	EU member and candidate countries	There exists a long-run relationship between energy consumption, GDP, CO <sub>2</sub> emissions, urban population and trade openness. Likewise, there exists an inverted U-shaped relationship between CO <sub>2</sub> emissions and real income.
Saidi and Hammami [20]	1990–2012	Generalised method of moments	58 countries	CO <sub>2</sub> has a significant positive impact on energy consumption. Likewise, economic growth has a positive impact on energy consumption.
Dritsaki and Dritsaki [36]	1960–2009	ECM and FMOLS DOLS	Greece, Portugal and Spain.	There exists a long-run relationship between energy consumption, GDP and CO <sub>2</sub> emissions. Likewise, positive and significant relationships exist between EC and CO <sub>2</sub> emissions and between GDP and energy consumption for Greece and Spain at a 1% significance level and at a 10% significance level for Portugal.

Table 2. Cont.

Author	Time	Method	Country	Results
Hwang and Yoo [37]	1965–2006	Granger causality test	Indonesia	Unidirectional causality between EC and GDP, unidirectional causality between CO <sub>2</sub> emissions and GDP and bidirectional relationship between CO <sub>2</sub> emissions and EC.
Omri [38]	1990–2011	Generalised method of moments	MENA Countries	A bidirectional causality relationship exists between energy consumption and GDP. Also, a unidirectional causality relationship exists between CO <sub>2</sub> emissions and GDP.
Alam et al. [39]	1971–2006	Granger Causality, Generalised Impulse response function	India	There exists a short-run relationship between CO <sub>2</sub> emissions and income. Also, there exists a Granger causality relationship between CO <sub>2</sub> emissions and EC both in the short run and long run. Besides this, there exists no causal relationship between energy consumption and income. However, a short-run relationship exists using the GIRF method.
Hossain [40]	1960–2009	Bounds Test, VEC model and Johansen–Juselius	Japan	In the long-run, energy consumption contributes to CO <sub>2</sub> emissions. Trade openness has a negative impact, while urbanization and GDP have a positive impact. However, it is not statistically significant in the long run.
Wang et al. [16]	1995–2007	Granger causality	China	A long-run causality relationship exists between GDP and EC and CO <sub>2</sub> emissions. Likewise, a U-shaped relationship exists between CO <sub>2</sub> emissions and GDP.
Menyah and Wolde-Rufael [41]	1965–2006	Granger causality and ARDL	South Africa	Both short-run and long-run relationships exist between capital, energy consumption, labour and CO <sub>2</sub> emissions. Also, a positive and significant relationship exists between GDP and CO <sub>2</sub> emissions.

Note: GDP = Economic growth and EC = Energy consumption.

As evident from these studies, scholars have focused on different periods and countries, while using different energy usage proxy variables. This has given rise to some inconsistencies in the findings and results across these studies [35,42]. Hence, the different studies analysed suggest that there is a need to take policy-related actions to address these outcomes [11,17]. It is, therefore, not surprising that efforts are being made at the global scene to further prevent the effects of CO<sub>2</sub> emissions by fostering a low carbon economy [1,43].

### 2.3. The Role of Climate Finance in the Transition to a Low Carbon Economy

Organisations such as the United Nations (UN) and the Intergovernmental Panel on Climate Change (IPCC) have taken different actions and measures in addressing climate change issues [3]. Worth mentioning is the 13th Conference of Parties (COP) held in 2007 at Bali in which the stakeholders presented finance as a pivotal factor to address climate change issues [44]. Thus, the emergence of the concept of “climate finance”. Even though the concept lacks a generally accepted definition, it is perceived as the resources invested in climate change mitigation and adaptation measures [44,45]. The 2009 COP held in Copenhagen further affirmed the importance of climate finance in combating global climate change. This led to the generation of over \$30 billion in aid between the period of 2010 to 2012 from developed countries to developing economies [14]. Also, an additional mobilization for \$100 billion a year by 2020 was proposed by developed economies to developing economies. This is scheduled to extend until 2025. This is in line with the argument by Steckel et al. [46] that even though most of the CO<sub>2</sub> emissions come from developed countries due to industrialization, it is essential to involve both the developing and emerging economies in the fight against the reduction of global emissions.

## 3. Materials and Methods

The aim of this study was to explore the impact of energy consumption and economic growth on CO<sub>2</sub> emissions. As a result, quantitative data for this study was sourced from the World Bank (World development indicators), a reliable and credible database. It is the primary World Bank collection of development indicators, compiled from officially recognised international sources. In addition, it presents the most accurate and current global development data available and includes national, regional and global estimates. The data was analysed and examined quantitatively using Granger causality to fulfil the study aim and allowed for conclusive and reliable findings [36,47].

### Definition of Variables and Model

To achieve the study aim, the dependent variable is CO<sub>2</sub> emissions (assumed to be caused or influenced by other factors), while energy consumption, economic growth, population and capital stock are independent variables [48,49] as shown in Table 3.

**Table 3.** Dependent and independent variable synopsis.

Name	Description	Eviews Code
CO <sub>2</sub> emissions	CO <sub>2</sub> emissions in kilo tonne (kt)	CO <sub>2</sub>
Energy consumption	Energy use (kg of oil equivalent per capita)	ENRGY_CONSC
Economic growth	GDP growth (annual %)	GDP
Population	Population total	POP
Capital stock	Gross fixed capital formation (constant 2010 US\$)	CAP_FORM

The independent variables are briefly defined below:

*GDP growth (% annual)*: It measures a country's economic performance, which is determined by its annual percentage growth from one year to the next. There has been an increase in CO<sub>2</sub> emissions due to the persistent rise in land clearance and energy use resulting from growth through urbanization and industrialization. Hence, we expect a positive relationship between the variables. This variable has also been used in previous literature [5,50].

*Energy consumption*: It measures the energy use that is obtained through fossil fuel from oil and coal. The unit of measurement for energy use was taken to be kg of oil equivalent per capita, which measures energy consumption per head of the population of a country. Due to the increase in energy consumption, the CO<sub>2</sub> emission level is expected to increase also. Thus, we expect a positive relationship. This variable has been included in studies conducted by Esso [17] and Saidi and Hammami [20].

*Capital Stock*: To measure capital stock, this study employed the Gross fixed capital formation (constant 2010 US dollar), which is essential to any country's economic growth. This study expects a positive relationship because an increase in capital stock will result in an increase in CO<sub>2</sub> emissions [38,47].

*Population*: This variable accounts for the total number of people living in a country at a point in time. A rise in a country's population will give rise to an increase in deforestation, land clearances for commercial and/or agriculture purposes and energy use (fossil fuel). These actions significantly add to global CO<sub>2</sub> emissions. Hence, we do expect a positive relationship between the variables [34,51].

To test the effects of the independent variables on the dependent variable, longitudinal data [52] that covered a 20 year period, between 1994 and 2013 for 70 countries (Table 4) was collected from the World Bank database. This avails the authors of the opportunity to establish changes that may have occurred over the time horizon covered.

**Table 4.** List of countries considered for the study.

Argentina, Arab Republic, Austria, Armenia, Azerbaijan, Australia, Bangladesh, Belgium, Brazil, Bulgaria, Bhutan, Canada, Chile, China, Congo, Cote d'Ivoire, Colombia, Costa Rica, Czech Republic, Democratic People's Republic, Egypt, Ethiopia, France, Finland, Germany, Georgia, Greece, Ghana, Guatemala, India, Indonesia, Iran, Iraq, Islamic Republic, Israel, Italy, Japan, Korea, Kenya, Morocco, Mongolia, Mexico, Mozambique, Malaysia, Mauritius, Nigeria, Norway, Netherlands, New Zealand, Pakistan, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Republic, Russian Federation, Switzerland, Spain, Sweden, South Africa, Syrian Arab Republic, Sri Lanka, Tanzania, Thailand, Turkey, Tunisia, United Kingdom, United States, Vietnam and Zambia.
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Using a four-step process, the gathered data was analysed using Granger causality, cointegration tests and a linear regression model. The first step ascertained the stationarity and order of integration

among the study variables using the unit root test. In the second step, the long-run relationship between the study variables was examined using the cointegration tests. The third analysed the causal relationship between the study variables using the Granger causality test. The fourth involved investigating the effect of the independent study variables on CO<sub>2</sub> emissions using the regression analysis method. The regression model is therefore as stated below:

$$y_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} \dots \dots \dots \beta_n x_{nit} + dt + a_i + u_{it} \quad (1)$$

where:

y = Dependent variable

x = Independent variable

$\beta_0$  = Constant

$\beta_1, \beta_2, \beta_n$  = Coefficient of  $x_1, x_2$  and  $x_n$  respectively.

dt = dummy variable

uit = error term

$a_i$  = unobserved heterogeneity

t = Time

i = Country.

It is worth stating that this study did not include dummy variables. This is because behaviour is assumed not to vary over time. Also, the study employed the fixed effects model alongside the pooled OLS to address unobserved heterogeneity concerns.

Hence, the regression model is rewritten as:

$$(\text{CO}_2)_{it} = \beta_0 + \beta_1 \text{GDP}_{it} + \beta_2 \text{ENRGY\_CONSC}_{it} + \beta_1 \text{CAP\_FORM}_{it} + \beta_1 \text{POP}_{it} + u_{it} \quad (2)$$

Nevertheless, the study variables were altered to take into consideration the natural logarithm for estimation. Hence, obtaining elasticity interpretation besides the growth rate in GDP. The analysis was carried out using Eviews 9.5 software.

## 4. Results

### 4.1. Descriptive Statistics

The obtained values for CO<sub>2</sub> emissions range between 212.69 to 10249463 with a positive skewness that is greater than 0 (normal distribution for skewness stands at 0). This suggests that the distribution has a long right tail. Likewise, the CO<sub>2</sub> Kurtosis value is 41.3 and is greater than 3 (normal distribution for kurtosis stands at 3). This suggests that the distribution is peaked. However, Table 5 revealed that the data is not distributed normally as the CO<sub>2</sub> P-value, which stands at 0 is less than the significant levels of 1%, 5% and 10% proposed for the study. Hence, we reject the null hypothesis (H<sub>0</sub>).

The GDP values as revealed in Table 5 range between −33.10% and 54.16% with a 0.86 skewness value. This indicates that GDP is slightly right-tailed. Also, it has a kurtosis value of 22.80. This further suggests that it is peaked. Besides this, with a probability of 0, the Jarque–Bera value remains high. Hence, the null hypothesis (H<sub>0</sub>) is rejected using a significance level of 1%, 5% and 10%.

Table 5 reveals that the value of energy consumption ranges between 125.79 and 8441.2 with a 1.15 skewness value. This indicates that energy consumption is right-tailed. Also, it has a kurtosis value of 3.6. This further suggests that it is peaked. Besides this, with a probability of 0, the Jarque–Bera value remains high. Hence, the null hypothesis (H<sub>0</sub>) is rejected using a significance level of 1%, 5% and 10%.

**Table 5.** Synopsis of descriptive statistics.

Variables	Mean	Median	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	Jarque–Bera	Probability	Sum	Sum Sq. Dev	Observations
ENRGY_C	2178.255	1474.045	8441.185	125.7875	1931.095	1.148612	3.589788	324.3803	0.000000	2,887,780	$4.77 \times 10^9$	1384
GDP	4.011148	4.000000	54.15777	−33.10084	4.600474	0.861933	22.79908	22,595.89	0.000000	4683.724	21,033.41	1373
CO <sub>2</sub>	351,706.8	70,743.76	10,249,463	212.6860	991,655.0	5.770660	41.29187	93,035.79	0.000000	$4.85 \times 10^8$	$1.35 \times 10^{15}$	1396
CAP_FORM	$1.92 \times 10^{11}$	$4.77 \times 10^{10}$	$3.56 \times 10^{12}$	$3.42 \times 10^8$	$4.49 \times 10^{11}$	4.649739	27.03661	34,125.27	0.000000	$2.36 \times 10^{14}$	$2.47 \times 10^{26}$	1233
POP	79,996,313	27,192,132	$1.36 \times 10^9$	514,877.0	$2.01 \times 10^8$	5.123719	29.44615	46,923.84	0.000000	$1.08 \times 10^{11}$	$5.57 \times 10^{19}$	1400



Also, Table 5 reveals that the values for capital formation range between  $3.42e + 08$  and  $3.56e + 12$  with a 4.95 skewness value. This means that capital formation is right-tailed. Also, it has a kurtosis value of 30.4 and a mean value that is greater than the median. This further suggests that it is peaked. Besides this, with a probability of 0, the Jarque–Bera value remains high. Hence, the null hypothesis (H0) is rejected using a significance level of 1%, 5% and 10%.

Furthermore, Table 5 reveals that the population values range between 514877 and  $1.36e + 09$  with a 5.12 skewness value. This means that the population is right-tailed. Also, it has a kurtosis value of 29.4 and a mean value that is greater than the median. This further suggests that it is peaked. Besides this, with a probability of 0, the Jarque–Bera value remains high. Hence, the null hypothesis (H0) is rejected using a significance level of 1%, 5% and 10%.

#### 4.2. Result of Correlation Analysis

Table 6 reveals that there exists a positive relationship between the study variables and CO<sub>2</sub>. The highest value emerges from the capital formation (i.e., 0.89) having a positive and strong correlation, while GDP has the lowest value (i.e., 0.07) having a positive but weak correlation. Also, revealed in the table are different relationship types that exist between the study variables.

**Table 6.** Result of correlation matrix.

Variables	ENRGY_C	GDP	CO <sub>2</sub>	CAP_FORM	POP
ENRGY_C	1.000000	−0.258039	0.266449	0.395075	−0.121009
GDP	−0.258030	1.000000	0.067149	−0.040234	0.194128
CO <sub>2</sub>	0.266449	0.067149	1.000000	0.889258	0.675107
CAP_FORM	0.395075	−0.040234	0.889258	1.000000	0.454021
POP	−0.121009	0.194128	0.675107	0.454021	1.000000

#### 4.3. Multicollinearity Test

Table 7 shows that all the study variables have a correlation coefficient that is less than 1. This means that there exists no high correlation between the study variables. Hence, the absence of multicollinearity.

**Table 7.** Independent variables correlation coefficient.

Variables	ENRGY_C	GDP	CAP_FORM	POP
ENRGY_C	1.000000	−0.258030	0.395057	−0.121009
GDP	−0.258030	1.000000	−0.040234	0.194128
CAP_FORM	0.395075	−0.040234	1.000000	0.454021
POP	−0.121009	0.194128	0.454021	1.000000

#### 4.4. Unit Root Test

Table 8 presents the study variables unit root test outcomes at the level and first difference. H0 is identified as the unit root and it is perceived as non-stationary, while H1 is termed stationarity. The table reveals that capital formation, energy consumption, population and CO<sub>2</sub> emissions are stationary at I (1). However, GDP is stationary at I (0).

Using a 5% significance level at both level and first difference, the result reveals that the null hypothesis is accepted at level (for IPS), while it is rejected at the first difference for both (LLC and IPS). This is because the significance level at 5% (0.05) at first difference is greater than the *P*-value of 0.00; hence, at I (1), LCO<sub>2</sub> is classified as a stationary variable. Also, using a significance level of 5% (0.05),

the null hypothesis is rejected because the significance level is greater than the  $P$ -value of 0.00. At I (0), LGDP is termed a stationary variable.

**Table 8.** At level unit root test—CO<sub>2</sub>

Method	Stage	LENERGY_CONSCLGDP	LCO <sub>2</sub>	LCAP_FORM	LPOP
IPS	Level	0.8871	0.0000	0.9999	0.9737
LLC	Level	0.0284	0.0000	0.0033	0.0000
IPS	1st Difference	0.0000	0.0000	0.0000	0.0001
LLC	1st Difference	0.0000	0.0000	0.0000	0.0219

IPS = Im, Pesaran and Shin W-stat, and LLC = Levin, Lin and Chu.

Table 8 presents the unit root tests at the level and first difference. Using a 5% (0.05) significance level at both level and first difference, the result reveals that the null hypothesis is accepted at level (for IPS), while it is rejected at the first difference for both (LLC and IPS). This is because the significance level is greater than the  $P$ -value of 0.00; hence, at I (1), LENERGY\_CONSC is classified as a stationary variable.

Likewise, using a significance level of 5% (0.05), Table 8 reveals that at I (0), LCAP\_FORM is not stationary for IPS. However, at I (1), it is stationary for both unit root tests. This is because the significance level is greater than the  $P$ -value of 0.

At I (0), LPOP is not stationary for IPS using a 5% significance level as shown in Table 8. However, at I (1), it is stationary for both unit root tests. This is because the significance level is greater than the  $P$ -value of 0. Hence, the null hypothesis is rejected.

#### 4.5. Cointegration Test

Cointegration establishes the long-run relationship between two or more study variables. Hence, some pairs of variables that are not identical could move together. The alternative hypothesis is cointegration, while the null hypothesis is no cointegration based on the results from the Pedroni and Kao cointegration test as shown in Table 9. Most of the variables indicate that the null hypothesis should be rejected, thus, there exists a long-run relationship among the study variables. Hence, they are cointegrated. This is supported by the findings of Ezzo and Keho (Ezzo 2016).

#### 4.6. Granger Causality Tests

Given that a long-run relationship exists between the study variables based on the cointegration test results, a further test was carried out using the Granger causality test. The Granger causality test focuses on examining and assessing if any causal relationship exists among the study variables as shown in Table 10. The study outcome is in line with Yang and Zhao (2017) findings.

#### 4.7. Regression Analysis

All the study variables are positively significant at significance levels of 1%, 5% and 10% significance. This is because all the study variables'  $P$ -values are lesser than 0.01, 0.05 and 0.10, respectively. Hence, on average, holding the other variables constant, an increase in GDP will result in an increase in CO<sub>2</sub> emissions by 1.02%. Also, an increase in energy consumption by 1% will result in a 0.88% increase in CO<sub>2</sub> emissions. Likewise, a rise in capital stock by 1% will give rise to a 0.29% increase in CO<sub>2</sub> emissions, while a 1% increase in population will give rise to a 0.78% increase in CO<sub>2</sub> emissions as shown in Table 11.

**Table 9.** Synopsis of Cointegration Tests.

Type of Test	Specification Trend	Method	Probability	Decision		
Within Dimension						
Pedroni	Intercept	Panel rho-Statistic	1.0000	Accept		
		Panel v-Statistic	0.9999	Accept		
		Panel ADF-Statistic	0.0000	Reject		
		Panel PP-Statistic	0.0029	Reject		
Between Dimension						
	Intercept and Trend	Group rho-Statistic	1.0000	Accept		
		Group ADF-Statistic	0.0000	Reject		
		Group PP-Statistic	0.0000	Reject		
		Panel rho-Statistic	1.0000	Accept		
		Panel v-Statistic	0.9945	Accept		
		Panel ADF-Statistic	0.0000	Reject		
	No Intercept or Trend	Panel PP-Statistic	0.0188	Reject		
		Between Dimension				
		Group rho-Statistic	1.0000	Accept		
		Group ADF-Statistic	0.0000	Reject		
		Group PP-Statistic	0.0000	Reject		
		Panel rho-Statistic	0.9998	Accept		
Kao		Panel v-Statistic	1.0000	Accept		
		Panel ADF-Statistic	0.0072	Reject		
		Panel PP-Statistic	0.0652	Reject		
		Between Dimension				
		Group rho-Statistic	1.0000	Accept		
		Group ADF-Statistic	0.0000	Reject		
		Group PP-Statistic	0.0024	Reject		
		ADF	0.0000	Reject		

Furthermore, Table 11 revealed a 91% R-squared with little or slight difference to the adjusted R-squared of 91%. This shows how the variance in the dependent variables can be explained using the independent variables. Hence, most of the CO<sub>2</sub> emission (i.e., 91%) is explained by the study independent variables. Further assessment of the independent variables' total performance (i.e., a test of overall significance) was carried out using the F-statistic to test if all the study independent variables coefficient is equal to zero.

$$H_0 = \beta_1 = 0, \beta_2 = 0, \beta_3 = 0, \beta_4 = 0 \quad (3)$$

H1 = At least one of  $\beta_4 \neq 0$ .

At a significance level of 5%, the null hypothesis is rejected because at least one of the coefficients  $\beta_n$ , is not equal to zero.

**Table 10.** Synopsis of Granger causality test.

Hypothesis	Observation	Probability	F-Statistic
LC02 does not Granger Cause LGDP and vice versa	955	$7 \times 10^{-5}$ $2 \times 10^{-5}$	9.67521 10.8376
LC02 does not Granger Cause LCAP_FORM and vice versa	1102	$2 \times 10^{-5}$ 0.0267	10.9395 3.63390
LC02 does not Granger Cause LENERGY_CONSC and vice versa	1240	0.1353 $7 \times 10^{-11}$	2.00341 23.7898
LC02 does not Granger Cause LPOP and vice versa	1256	0.0008 $5 \times 10^{-9}$	7.21191 19.3766
LGDP does not Granger Cause LCAP_FORM and vice versa	851	$4 \times 10^{-6}$ $4 \times 10^{-7}$	12.4948 15.0342
LGDP does not Granger Cause LENERGY_CONSC and vice versa	939	0.1947 $6 \times 10^{-12}$	1.63895 26.6460
LENERGY_CONSC does not Granger Cause LCAP_FORM and vice versa	1092	0.1403 0.0329	1.96732 3.42512
LGDP does not Granger Cause LPOP and vice versa	955	0.0672 0.0106	2.70768 4.56586
LCAP_FORM does not Granger Cause LPOP and vice versa	1102	0.1852 $2 \times 10^{-5}$	1.68911 11.1630
LENERGY_CONSC does not Granger Cause LPOP and vice versa	1244	0.0135 0.6512	4.31957 0.42915

**Table 11.** Result of pooled OLS.

Variables	Std. Error	Coefficient	Probability	T-Statistic
LENERGY_CONSC	0.035143	1.888638	0.0000	25.28638
GDP	0.004007	0.010245	0.0107	2.557112
CO <sub>2</sub>	0.257124	-15.75982	0.0000	-61.29278
LPOP	0.023221	1.778584	0.0000	33.52908
LCAP_FORM	0.022093	0.292241	0.0000	13.22807
R-squared 0.910162				
Adjusted R-squared 0.909866				
F-Statistic 3082.384				

#### 4.8. Fixed Effects

The unobserved heterogeneity is accounted for by using this method to estimate the mean deviations to eliminate heterogeneity. Based on the results as shown in Table 12 we have rewritten the econometric model as:

$$ICO_2 = -16.33 + 0.002gdp + 1.09lenergy\_consc + 0.05lcap\_form + 1.08lpop + vit \quad (4)$$

Table 12 shows further that at 1%, 5% and 10% significance levels, all the study variables are still positively significant except for GDP, which is only significant at 10%. However, on average, holding the other variables constant, an increase in the GDP growth rate will result in an increase in CO<sub>2</sub> emissions by 0.15%. Also, an increase in energy consumption by 1% will result in a 1.09% increase in CO<sub>2</sub> emissions. Likewise, an increase in both the population and capital stock by 1% will give rise to a 1.08% and 0.05% increase in CO<sub>2</sub> emissions, respectively. Based on the fixed effects method, a 100% R-squared was obtained. This suggests a rise in the independent variables explanatory power. Also,

F-statistic reveals that the rejection of the null hypothesis as at a  $P$ -value of 0.00 is lower than the 5% significance level. This further suggests that at least one of the coefficients  $\beta_n$  is different from zero.

**Table 12.** Result of fixed effect estimation.

Variables	Std. Error	Coefficient	Probability	T-Statistic
LENRGY_CONSC	0.030737	1.088263	0.0000	35.40530
GDP	0.000816	0.001593	0.0511	1.952462
CO <sub>2</sub>	0.689571	−16.32856	0.0000	−23.67930
LPOP	0.048312	1.076580	0.0000	22.28392
LCAP_FORM	0.011687	0.047629	0.0000	4.075240
R-squared 0.997254				
Adjusted R-squared 0.997087				
F-Statistic 5971.530				

#### 4.9. Interaction of Variables

This approach explains a situation where two independent variables have a joint effect. Hence, these two variables are said to have an influence on one another. The impact level of a variable relies on the level of the other variable. Energy consumption and population are identified to interact in this study. This means that energy consumption, as a variable, depends on the population. Likewise, the effect of the population depends on those that consume energy. Based on the results as shown in Table 13, we have rewritten the econometric model as:

$$\begin{aligned} \text{ICO}_2 = & -11.87 + 0.01\text{gdp} + 0.34\text{lenrgy\_consc} + 0.30\text{lcap\_form} + 0.55\text{lpop} \\ & + 0.03\text{lenrgy\_consc} * \text{lpop} + \text{vit} \end{aligned} \quad (5)$$

**Table 13.** Result of pooled OLS with interaction.

Variables	Std. Error	Coefficient	Probability	T-Statistic
LENRGY_CONSC	0.215666	0.344621	0.1103	1.597936
GDP	0.003998	0.010177	0.0110	2.545725
CO <sub>2</sub>	1.544142	−11.86706	0.0000	−7.685213
LPOP	0.092002	0.550960	0.0000	5.988572
LCAP_FORM	0.022104	0.296451	0.0000	13.41173
LENRGY_CONSC*LPOP	0.012145	0.031048	0.0107	2.556511
R-squared 0.910642				
Adjusted R-squared 0.910274				
F-Statistic 2478.431				

The results reveal that there exists a positively significant relationship between the study variables and CO<sub>2</sub> emissions except for energy consumption. This is because it has a  $P$ -value of 0.11, which is insignificant even though it is positive. This is greater than the significance levels of 1%, 5% or 10%. However, on average, holding the other variables constant, a 1% increase in population will give rise to a 0.55% increase in CO<sub>2</sub> emissions. Likewise, an increase in capital stock by 1% will give rise to a 0.30% increase in CO<sub>2</sub> emissions, while an increase in GDP will result in an increase in CO<sub>2</sub> emissions by 1.02%. Considering the level of significance between energy consumption and the population, an increase, in interactive terms, of energy consumption and population by 1% will result

in a 0.03% increase in CO<sub>2</sub> emissions. This suggests that the CO<sub>2</sub> emissions level, as it relates to energy consumption, changes depending on the value of the population.

Furthermore, Table 13 revealed a relatively high R-squared of 91%. This suggests that CO<sub>2</sub> emission levels are explained by the independent variables and the F-statistic. Hence, the null hypothesis is rejected. This indicates that at least one of the coefficients of  $\beta_n$ , is different from zero. As a result, CO<sub>2</sub> emissions are jointly influenced by the independent variables.

## 5. Conclusions and Discussion

This study explored the effect of energy consumption and economic growth on CO<sub>2</sub> emission levels by evaluating data from 70 countries between the period of 1994 and 2013. Hence, it draws attention to the fact that human activities over the years due to urbanization, industrialization and growth in population have been a major contributor to the global increase in CO<sub>2</sub> emission levels. This poses a major risk to human well-being and the environment at large.

Findings obtained from using the Pesaran, Levin, Lin and Chu (LLC) and the Im and Shin W-stat (IPS) unit root tests revealed that all the study variables were stationary at I (1) except for GDP. Also, it was revealed that a long-run relationship exists among the study variables using Pedroni and Kao cointegration tests. This aligns with the study outcomes of Nain et al. [33], which found that there exists a long-run relationship between the three variables. However, their study observed that there is no feedback causation in the short and long run at both aggregated and disaggregated levels. This is contrary to the current study's findings that found that a bi-directional causal relationship exists between the study variables and CO<sub>2</sub> emissions using the Granger causality tests, except for energy consumption, which has a unidirectional causal relationship.

Likewise, the results from using the pooled OLS revealed that all the study variables are positively significant. This indicates that all the study variables contribute to CO<sub>2</sub> emission levels. In addition, using the fixed-effect method revealed that all the study variables are positively significant except for economic growth which is only significant at a 10% significance level. This aligns with Dritsaki and Dritsaki [36] study results, which found that there exist a significant and positive relationships between the variables under consideration. The results of the R-squared for both the fixed effects and pooled OLS models, which are 100% and 91%, respectively, suggest that the study independent variables (i.e., energy consumption, GDP, population and capital stock) explain the variance in the CO<sub>2</sub> emission levels, which is the dependent variable. This means that the models are a good fit. Another key finding of the study is the introduction of an interaction term between the study variables (i.e., energy consumption and population) to the pooled OLS. The results revealed that there exists a positively significant interaction at 5% and 10% significance levels. This means that there exists a joint effect among the variables and that both variables should be kept in the model.

## 6. Policy Implications and Future Research

The study concludes that there exists a relationship between the three variables, as energy consumption and economic growth impact CO<sub>2</sub> emissions. As a result, policymakers should pay attention to making energy and economic related policies that focus on improving energy efficiency and promoting economic growth with no contributing impact on CO<sub>2</sub> emission. Also, the implementation of such policies should be done without affecting the energy consumption and economic growth of the society. For instance, climate finance has been taken on board at the global level as one of the actions needed to address the environmental impacts of CO<sub>2</sub> emissions. This involves investing in clean and climate-friendly options that will foster economic growth. The renewable energy sector fits into such an initiative. Future studies should therefore focus on creating awareness and promoting investment in different renewable energy sources. This will avail both developed and emerging economies of clean energy sources for both commercial and personal consumption. Hence, reducing any damage to the environment or limiting economic growth of nations.

Moreover, measures to curb deforestation by the citizens of the countries should be strengthened, since these activities release CO<sub>2</sub> emissions into the atmosphere. Emission standards should be set for industries and emission monitoring strategies should be put in place to ensure compliance. The development of the financial markets in these countries can also assist in enhancing investment in research and development in modern energy-efficient technologies, thus ensuring lower emissions. Further, since CO<sub>2</sub> is not a local pollutant but a global one, perhaps international cooperation would also help to reduce its emissions. Creating a union between these countries to establish unified environmental acts will increase the effectiveness of such regulations on the pollution levels. This does not however rule out individual national environmental laws and regulations. A lack of application of relevant laws and regulations will result in adverse effects on economic growth.

It is however important to state that the major limitation of this study was the unavailability of data for the variables considered for some of the countries used for the study. This also placed a limit in the choice of time horizon for the study (i.e., 1994–2013) as the authors would have preferred to extend the study time horizon to a much more up to date year (i.e., 2018).

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