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# Dynamic Modeling of Causal Relationship Between $CO_2$ emissions, Economic Growth, Energy Consumption and Foreign Direct Investment in The Gambia

Baseedy Bojang
Faculty of Forestry and Environment, Universiti Putra Malaysia,
43400 Seri Kembangan, Selangor, Malaysia

**Abstract**
Environmental degradation is a problem in developing countries. The use of non-renewable energy consumption for economic growth causes environmental degradation, but the consequences of environmental degradation cannot be ignored. The aim of the study was to understand relationship between $CO_2$ (Carbon dioxide) emissions, economic growth, energy consumption and Foreign Direct Investment (FDI) in The Gambia for the period from 1980 to 2019. To investigate the relationship between the variables, cointegration and granger causality are used. The findings support the existence of long-run equilibrium between the variables. The empirical results reveal that energy consumption positively influences $CO_2$ emissions in short-run. Moreover, in the long-run, energy consumption and FDI influence $CO_2$ emissions. The results of the study also reveal that there are two-way causalities between $CO_2$ emissions and economic growth, and between energy consumption and economic growth in both short-run and long-run in The Gambia. Therefore, policies aimed at increasing energy efficiency, as well as the adoption and utilization of renewable energy sources to replace old traditional energy sources such as charcoal, firewood, gas, and oil, are critical in reducing $CO_2$ emissions in the country while also sustaining economic development.
**Keywords:** $CO_2$ (carbon dioxide) emissions, Economic growth, Energy consumption, Foreign direct investment, The Gambia
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## 1. Introduction

Climate change and greenhouse gases (GHG) emissions are the world's most challenging problems. Carbon dioxide ($CO_2$) is widely acknowledged as primary source of GHG emissions and has received considerable attention in recent years. The amount of $CO_2$ emissions from energy consumption in developing countries has increased significantly over the study period. These countries' $CO_2$ emission trends are expected to continue (Al-mulali and Binti, 2012; Marcotullio et al., 2005). The Gambia is no exception; the country's economy is rapidly expanding, and this trend is expected to continue in the future. The Gambia's economy is based on agriculture, and agriculture is the country's dominant sector. However, agricultural land is being depleted due to the slow growth of The Gambia's industrial sector. Aside from that, rapid population growth leads to deforestation (Heß et al., 2018); The Gambia is the top ranking West African country in terms of deforestation. Increased economic growth and industrial sectors use energy to grow, degrading the environment. The Gambia has a high energy demand, and traditional energy sources such as biomass, including fuelwood, accounts for about 80% of the country's energy supply, and for more than 90% of household energy consumption -reaching up to 97% in some rural areas.

In order to address the issue of $CO_2$ emissions, the concept of 'green economy' and 'low carbon city' are currently gaining traction in developing countries, particularly in The Gambia. Therefore, investigating factors influencing $CO_2$ emissions behavior appear to be top priority for dealing with greenhouse gas emissions and global warming in The Gambia. Surprisingly, empirical research on factors influencing $CO_2$ emissions in The Gambia is lacking. Understanding the factors that influence $CO_2$ emissions is critical for energy and environmental policy making. Economic growth, energy consumption, foreign direct investment (FDI) are the key determinants of $CO_2$ emissions, according to previous literature, but their impact on $CO_2$ emissions remains contentious. With output-$CO_2$ emissions relationship, previous research have not been able to come to a consensus on the effects of output on $CO_2$ emissions. Despite the fact that the environmental Kuznets curve (EKC) hypothesis posits an inverted U-shaped relationship between output on $CO_2$ emissions, there are some evidence that ECK hypothesis is valid in the U-shape connection (Tang and Tan, 2015), while some found the EKC hypothesis invalid. Apart from this, some research concluded that energy consumption has a positive beneficial impact on $CO_2$ emissions, whereas others stated that energy use has no impact on $CO_2$ emissions (Esso and Keho, 2016). With regards to the FDI-pollution nexus, Pollution Halo Hypothesis (PHH) postulates that FDI may lead to a reduction in $CO_2$ emissions by promoting the use of energy-efficient technologies and better environmental practices (Al-mulali and Tang 2013). In contrast, others believe that it has a positive impact on $CO_2$ emissions when pollution-intensive companies are more likely to relocate from developed to developing counties due to the weaker environmental standards and regulations, generally refer to as the Pollution Heaven Hypothesis (PHH).

In light of these considerations, we investigate the links between $CO_2$ emissions, economic growth, energy consumption and foreign direct investment in The Gambia. Intriguingly, this study not only provides some insights into the impact of economic growth, energy consumption and FDI on $CO_2$ emissions, but it also enable us ascertain the validity of the energy-led growth, FDI-led growth and Pollution Heaven hypothesis in The Gambia. Thus, the study's findings are expected to provide useful information to policy makers in developing effective environmental and economic growth policies.

The article is organized as follow: in Section 2, review of empirical studies, section 3 presents econometric methodology and data description used in this study, and section 4 reports findings and discussion. The final section presents conclusions and recommendations.

## 2. Literature Review

In the literature, the relationship between $CO_2$ emissions, economic growth, energy consumption, and FDI is divided into four research clusters. The first research cluster focuses on the relationship between $CO_2$ emissions and economic growth in order to test the Environmental Kuznets Curve (EKC) hypothesis's validity. The second research cluster looks into the energy-growth nexus, the third looks into the relationship between $CO_2$ emissions and FDI to test the validity of the Heaven hypothesis, and the fourth looks into the dynamic relationship between $CO_2$ emissions, economic growth, energy consumption and FDI.

A number of studies have attempted to incorporate the environmental factors into the model due to global warming concerns. For example, the famous environmental Kuznets Curve (EKC) hypothesis which has been widely discussed in literature and proposes an inverse U-shaped relationship between economic activity and environmental pollution Kuznets, S. (2019). It explains that environmental degradation initially increases with income increases, reaches a threshold point then declines with income increases (Coondo and Dinda, 2008; Managi and Jena, 2008). Several studies have been conducted to test the EKC hypothesis. However, empirical findings are mixed/contrasting. For instance, Esso and Keho (2016) examined the long-run and causal relationships among energy consumption, $CO_2$ emissions and economic growth for a sample of 12 sub-Saharan African countries. The study applied bounds test to cointegration and Granger causality test covering the period of 1971 to 2010. The empirical results showed that energy consumption and economic development are associated with atmospheric pollution in long-run. Results from Granger causality tests showed evidence of economic growth causing $CO_2$ emissions in short-run in Benin, Democratic Republic of Congo, Ghana, Nigeria and Senegal. Tang and Tan (2015) studied the relationship between $CO_2$ emissions, energy consumption, FDI and economic growth in Vietnam from 1976 to 2009. The results showed that energy consumption and income positively influenced $CO_2$ emissions. This outcomes support EKC hypothesis in Vietnam. Saboori et al. (2014) used panel FMOLS method to examined the relationship between energy consumption, $CO_2$ emission, and economic growth in OECD countries from 1960 to 2008. Their results showed that, there are a long-run bidirectional positive relationship between economic growth and $CO_2$ emissions. The study also found a long-run bidirectional positive relationship between energy consumption and $CO_2$ emissions. Cowan et al. (2014) examined the causal links between electricity consumption, economic growth, and $CO_2$ emissions in The BRICS countries from 1990 to 2010. It is discovered that there are causality running from economic growth to $CO_2$ emissions in South Africa and from $CO_2$ emissions to economic growth in Brazil. In addition, Granger causality from electricity to $CO_2$ emissions has been discovered in India. Likewise, Khan et al. (2020) investigated the nexus between energy consumption, economic growth and $CO_2$ emissions in Pakistan using time series data from 1965 to 2015. The results of ARDL showed that energy consumption and economic growth increased the $CO_2$ emissions in Pakistan in both short-run and long-run.

With regards to the energy-growth nexus most studies have found bidirectional causality running from energy consumption to $CO_2$ emissions. For example, Hanif (2018) used the GMM model to examined the relationship between the study variables and the effects of economic growth, urbanization, and consumption of fossil fuels, solid fuels, and renewable energy on $CO_2$ emissions in sub-Saharan Africa from 1995 to 2015. His results showed that, the use of fossil fuels and solid fuels had a positive impact on $CO_2$ emissions, whereas renewable energy helped to reduce $CO_2$ emissions. Saboori et al. (2014) examined the bidirectional long-run relationship between energy consumption and in the road transport sector with $CO_2$ emissions and economic growth in OECD countries. Using time series data from 1960 to 2008 Employing the Fully Modified Ordinary Least Square cointegration approach. The results showed positive significant long-run bidirectional relationship between $CO_2$ emissions and economic growth, road sector energy consumption and economic and economic growth and $CO_2$ emissions and road sector energy consumption in all the OECD countries. Similarly, Saboori et al. (2017) investigated the relationship between oil consumption, economic growth and environmental degradations in three Asian counties from 1980 to 2013 using Johansen cointegration test to check the relationship between the study variables. The findings showed an unidirectional causality running from oil consumption to economic growth in China and japan, and from oil consumption to $CO_2$ emissions in South Korea. Bhat (2018) used the Panel ARDL model to investigate the relationship between the research variables and the influence of energy consumption and economic growth on

 

$CO_2$ emissions from 1992 to 2016. His findings showed that capita, labor, population, per capita income an nonrenewable energy usage positively impact $CO_2$ emissions.

The Pollution Heaven Hypothesis (PHH) suggests that FDI inflows contributes to rising $CO_2$ emissions in developing countries. Developing counties with cheap resources and labor tend to have less stringent environmental regulations. While countries' environmental regulations become more expensive for business due to the costs associated with meeting these standards. As a result, companies that choose to physically invest in foreign counties tend to do so in counties with the lowest environmental standards or weakest enforcement. The Pollution Halo Hypothesis, on the other hand, contends that FDI may reduce $CO_2$ emissions by encouraging the use of energy-efficient technologies and better environmental management practices.

In this paragraph, we focus on studies that confirmed the validity of PHH. For example, Assamoi et al. (2020) applied ARDL approach to investigate the validity of PHH in Cote d'Ivoire. For this purpose, FDI, real domestic product (GDP) per capita, energy consumption and agriculture value added are included the $CO_2$ emission's function, using time series data from 1980 to 2014. The results validated the PHH in Cote d'Ivoire as they found a positive relationship between FDI and $CO_2$ emissions. Likewise, the results also showed that GDP per capita, energy consumption, and agriculture value added have a positive impact on $CO_2$ emissions. Omri et al. (2014) investigate the causality between $CO_2$ emissions, FDI, and Economic growth using dynamic simultaneous-equation panel data models for a global panel of 54 countries for the period 1990 to 2011. The results discovered evidence of bidirectional causality between FDI inflows and economic growth for all the panels and between FDI and $CO_2$ emissions for all the panels, except Europe and North Asia. They also indicated the existence of unidirectional causality running from $CO_2$ emissions to economic growth, with the exception of Middle East, North America and sub-Saharan panel. Kivyiro and Arminen (2014) investigated the causal link between $CO_2$ emissions, energy consumption, economic development and FDI in six sub-Saharan African counties. Their results supported EKC hypothesis in the cases of Democratic Republic of Congo, Kenya and Zimbabwe. Moreover, FDI increase $CO_2$ emissions in some countries, while the opposite impact can be observed in others. The most common unidirectional Granger causality relationships run from the other variables to $CO_2$ emissions, with different variables causing $CO_2$ emissions in different counties, and from GDP to FDI. Granger causality running to $CO_2$ emissions appears more likely in countries where the evidence support the EKC hypothesis. Solarin et. al (2017) discovered a positive relationship between FDI and $CO_2$ emissions in Ghana, implying that increase in FDI causes increased $CO_2$ emissions. The study used ARDL approach with structural breaks on data from 1989 to 2012. They revealed that due to less stringent environmental regulation, Ghana has been attracting high-polluting industries through FDI.

## 3. Research Methodology

### 3.1. *Model specification*

The Cointegration and Causality model was used in this study to analyze the relationship between $CO_2$ emissions, economic growth, energy use and foreign direct investment because the model has been widely accepted by scholars for several decades. The model was based on C.J Ganger (1986), which was adopted and used in numerous studies such as Chonatanawat, J. (2020); Cetin and Ecevit (2015) and Gorus and Aydin. (2019). The following function is used to identify and analyze the factors affecting groundnuts exports in The Gambia:

$$CO = f(Y, EN, FDI) \quad (1)$$

Where CO is $CO_2$ emissions, Y is the Gross Domestic Product (GDP) per capita , EN is the energy use per capita, and FDI is foreign direct investment, net inflows.

The cointegration method is used in this study to analyze the relationship between $CO_2$ emissions, economic growth, energy use and foreign direct investment in The Gambia. This approach, on the other hand, is based on the stationarity of the time series variables used. Again, this techniques necessitates the integration (stationary) of the variables in the same order, as well as the existence of a stationary linear combination Granger, 1986; Malik, 2010).

These requirements need to be met, since most economic time series included are not stationary at levels and any regression of such series could produce spurious, meaningless and irrelevant results (Granger, 1986), as result, the unit root test on the variables of interest is the first step in time series econometric analysis. The test determines whether or not the data series is stationary. The conventional Augmented Dickey-Fuller (ADF) test is used to test for detecting unit roots. The equation for ADF test is based on the following form.

$$\Delta Z_t = \alpha_1 + \alpha_2 t + \alpha_3 Z_{t-1} \sum_{i=1}^{p} \beta_{1i} \Delta Z_t + \quad _t \quad (2)$$

Where ADF regression tests for the presence of unit root of $Z_t$, the logarithm values of all models variables at time t. The null (and alternative) hypothesis that tests the presence of unit root in the variable is $H_O$: $\alpha_3$:= 0 (non-stationary) against $H_1$: $\alpha_3 \neq 0$ (deterministic trend).

Based on the Vector Autoregression (VAR) and Vector Error Correlation Model (VECM) representations, the nature of stationarity indicates the presence of cointegration and causality. The cointegration test is used to determine whether or not there is a long-run relationship between variables. In contrast, lack of cointegration implies that such variables have no long-run link; and in principles they can wonder arbitrarily from each other (Dickey, et al. 1991).The study employs the Johansen (1988) maximum likelihood ratio to test and take into account two test statistics, namely the trace statistics and the maximum eigenvalue statistics (Johansen & Juselius,1990). They are expressed as follows:

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \log(1-\hat{\lambda}_i) \quad (3)$$

$$\lambda_{max} = -T \log(1-\hat{\lambda}_{r+1}) \quad (4)$$

Where $\hat{\lambda}_{r+1}\ldots\ldots\hat{\lambda}_n$ are the ( n-r) smallest estimated eigenvalues, The null hypothesis of r cointegrating vectors is tested here against the alternative hypothesis of r+1 cointegrating vectors in this paper. The cointegration would determine which model, VAR or VECM, the study would use to analyze the relationship between CO2 emissions, economic growth, energy use and foreign direct investment in The Gambia. First, if the variables employed in this study are stationary and not cointegrated, the following VAR model described below must be used:

$$CO_t = \beta_0 + \sum_{i=1}^{p} \beta_{1i}\, CO_{t-1} = \sum_{j=1}^{p} \beta_{2j} Y_{t-j} + \sum_{k=1}^{p} \beta_{3k} EN_{t-k} + \sum_{r=1}^{p} \beta_{4r} FDI_{t-r} + U_{1t} \quad (5)$$

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} Y_{t-i} + \sum_{j=1}^{n} \alpha_{2j}\, CO_{t-j} = \sum_{k=1}^{p} \alpha_{3k} EN_{t-k} + \sum_{r=1}^{p} \alpha_{4r} FDI_{t-r} + U_{2t} \quad (6)$$

$$EN_t = \Upsilon_0 + \sum_{k=1}^{p} \Upsilon_{1i} EN_{t-k} + \sum_{i=1}^{n} \Upsilon_{2j}\, COe_{t-1} = \sum_{j=1}^{p} \Upsilon_{3k} Y_{t-j} + \sum_{r=1}^{p} \Upsilon_{4r} FDI_{t-r} + U_{1t} \quad (7)$$

$$FDI_t = \delta_0 + \sum_{r=1}^{p} \delta_{1i} FDI_{t-r} + \sum_{j=1}^{p} \delta_{2j} Y_{t-j} + \sum_{k=1}^{p} \delta_{3k} EN_{t-k} + \sum_{i=1}^{n} \delta_{4r}\, CO_{t-r} + U_{1t} \quad (8)$$

where β ,α, and ϒ, δ are parameters.

Second, if the variables in this study are cointegrated, the following VECM would be used:

$$\Delta CO_t = \beta_1 + \sum_{i=1}^{p} \alpha_{11,l}\, \Delta CO_{t-l} = \sum_{j=1}^{p} \Upsilon_{12,l} \Delta Y_{t-l} + \sum_{k=1}^{p} \delta_{13,l}\, \Delta EN_{t-l} + \sum_{r=1}^{p} \lambda_{14,l}\, \Delta FDI_{t-l} + p_1 ECT_{t-1} + \pi_t \quad (9)$$

$$\Delta Y_t = \beta_2 + \sum_{i=1}^{p} \alpha_{21,l}\, \Delta Y_{t-l} + \sum_{j=1}^{n} \Upsilon_{22,l}\, \Delta CO_{t-l} = \sum_{k=1}^{p} \delta_{23,l} \Delta EN_{t-l} + \sum_{r=1}^{p} \lambda_{24,l} \Delta FDI_{t-1} + + p_2 ECT_{t-1} + \pi_t \quad (10)$$

$$\Delta EN_t = \beta_3 + \sum_{k=1}^{p} \alpha_{31,i} \Delta EN_{t-l} + \sum_{i=1}^{n} \Upsilon_{32,l}\, \Delta CO_{t-l} = \sum_{j=1}^{p} \delta_{33,l} \Delta Y_{t-l} + \sum_{r=1}^{p} \lambda_{34,l}\, \Delta FDI_{t-l} + p_3 ECT_{t-1} + \pi_t \quad (11)$$

$$\Delta FDI_t = \beta_4 + \sum_{r=1}^{p} \alpha_{41,l}\, \Delta FDI_{t-l} + \sum_{j=1}^{p} \Upsilon_{42,l}\, \Delta Y_{t-l} + \sum_{k=1}^{p} \delta_{43,l} \Delta EN_{t-l} + \sum_{i=1}^{n} \lambda_{44,l}\, \Delta CO_{t-l} + + p_4 ECT_{t-1} + \pi_t \quad (12)$$

where, ECT is the error correction term; the cointegration regression residual estimates. A negative and significant coefficient indicates that past equilibrium errors influence current outcomes. The individuals coefficients of the difference terms capture the short-run dynamics.

One of the challenges that researchers may face when estimating a VAR model is determining the appropriate lag order. In this study, we consider the Schwarz (Schwarz,1978) and Hannan-Quinn (Hannan-Quinn,1979) lag order selection criteria. The Granger Causality test (Granger, 1988) is also used in this study to examine the relationship between variables. We also run some diagnostic tests on model's residuals. For the possibility of autocorrelation, we used Lagrange-multiplier test (LM), Jarque-Bera test (JB) and Eigenvalue stability condition (ES).

### 3.2. *Data Description and Source*

In this study, we examine the causal relationship between $CO_2$ emissions, economic growth, energy use and foreign direct investment in The Gambia. For this aim, the study uses the annual data of $CO_2$ emissions per capita (metric tons), GDP per capita (constant 2010 US dollars), energy use per capita (kg of oil equivalent), and FDI (constant 2010 US dollars). All the data are obtained from Our World in Data and World Bank Indicators, and cover the years 1980 to 2019. To account for proliferative effect of time series, all data were represented logarithmically in the study.

## 4. Empirical Results and Interpretation

### 4.1 *Descriptive statistics*

The descriptive analysis of the variables is presented in Table 1. The Gambia's average carbon dioxide emissions per capita are 0.2203 metric tons, which is higher than in some West African countries such as Niger, Sierra Leone, Mali, and Guinea-Bissau, despite the fact that The Gambia is Africa's mainland smallest country. Similarly, energy consumption is higher in comparison to countries such as Guinea-Bissau, Togo, and Niger (World Bank 2021). The GDP per capita is USD577, which is higher than the GDP per capita in Guinea-Bissau, Liberia, Niger, Sierra Leone, and Togo. In addition, The Gambia has 82,208,102 in FDI inflows, which is high when compared to countries such as Cote D'Ivoire, Benin, Burkina Faso, and Guinea (see World Bank 2021).

Table 1. Descriptive Statistics

| | CO | Y | EN | FDI |
|---|---|---|---|---|
| Mean | 0.220384232 | 577.3214023 | 80.75938644 | 2,4030,203.63 |
| Maximum | 0.257078 | 924.511516 | 98.33748925 | 82,208,102.59 |
| Minimum | 0.186324161 | 234.654507 | 64.66638005 | -1,990,000 |
| Std. dev. | 0.020813663 | 199.7641114 | 11.14271172 | 24,497,463.06 |
| Skewness | 0.143297841 | -0.436750861 | 0.128482107 | 0.841449798 |
| Kurtosis | -1.146578435 | -1.205629594 | -1.365250552 | -0.285528401 |

### 4.2 *Stationarity*

The unit roots in each variable are tested as the first step in cointegration analysis. We use the Augmented Dickey-Fuller (ADF) and Philips-Perron stationary tests on the logarithmic forms of CO, Y, EN, and FDI to accomplish this. Tables 2 and 3 present the results of the ADF and Philips-Perron tests for the level and first difference of the variables, respectively. The results show that unit root tests applied to variables at levels fail to reject the null hypothesis of non-stationarity for all variables. It implies that all variables are non-stationary at levels. The null hypothesis is accepted when the series are first-differenced i.e. all the variables are first- differenced stationary. This implies that all the variables are integrated of order one, I(1).

Table 2. ADF tests results

| **Variable** | **Intercept** | | | | **Trend and intercept** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Level** | | **First difference** | | **Level** | | **First difference** | |
| | **t-stat** | **p-value** | **t-stat** | **p-value** | **t-stat** | **p-value** | **t-stat** | **p-value** |
| CO | -1.016 | 0.1583 | -5.561 *** | 0.0000 | -2.062 | 0.5674 | -6.539*** | 0.0000 |
| Y | -1.538 | 0.0665 | -4.143*** | 0.0001 | -2.142 | 0.5227 | -4.092*** | 0.0065 |
| EN | -1.174 | 0.1242 | -5.062*** | 0.0000 | -3.121 | 0.1014 | -5.078*** | 0.0001 |
| FDI | -2.655 | 0.0059 | -4.137*** | 0.0001 | -3.095 | 0.1075 | -4.091*** | 0.0065 |

Note: Y: GDP per capita; EN: energy consumption; CO: $CO_2$ emission; FDI: foreign direct investment; log: natural logarithm; and $^{***}$ indicates statistically significant at 1%, $^{**}$ statistically significant at 5% and $^{*}$ statistically significant at 10%.

Table 3. Philips-Perron tests results

| **Variable** | **Intercept** | | | | **Trend and intercept** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Level** | | **First difference** | | **Level** | | **First difference** | |
| | **t-stat** | **p-value** | **t-stat** | **p-value** | **t-stat** | **p-value** | **t-stat** | **p-value** |
| CO | -1.468 | 0.5490 | -8.230*** | 0.0000 | -2.277 | 0.4469 | -9.804*** | 0.0000 |
| Y | -1.528 | 0.5195 | -5.972*** | 0.0000 | -2.439 | 0.3591 | -5.892*** | 0.0000 |
| EN | -0.987 | 0.7579 | -5.755*** | 0.0000 | -2.876 | 0.1706 | -5.751*** | 0.0000 |
| FDI | -2.295 | 0.1736 | -6.612*** | 0.0000 | -3.743 | 0.0197 | -6.537*** | 0.0000 |

Note: Y: GDP per capita; EN: energy consumption; CO: $CO_2$ emission; FDI: foreign direct investment; log: natural logarithm; and $^{***}$ indicates statistically significant at 1%, $^{**}$ statistically significant at 5% and $^{*}$ statistically significant at 10%.

It is well known that the lag order of the VAR model can have a significant impact on the VAR analysis. When the differences in lag order are large enough, they can affect the interpretation of VAR estimates. The optimal lag selection considered in this study by using the Hannan-Quinn(HQ) and Schwarz (SC).Table 4 shows the Stata output for lag order selection based on each criterion.

Table 4. VAR lag order selection

| Lag order | LR | FPE | AIC | HQ | SC |
|---|---|---|---|---|---|
| 0 | - | 7.0e-07 | -2.81748 | -2.76539 | -2.62114 |
| 1 | 72.116* | 1.4e-07* | -4.48897* | -4.22852* | -3.50726* |
| 2 | 19.05 | 2.6e-07 | -3.94937 | -3.48056 | -2.18229 |
| 3 | 37.078 | 3.1e-07 | -4.16097 | -3.4838 | -1.60852 |
| 4 | 93.827 | 5.7e-08 | -6.73709 | -5.85156 | -3.39927 |

Note: LR: sequential modified test statistics; FPE: final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion; and $^{*}$ indicate optimal lag criteria.

### 4.3. *Cointegration*

The Johansen technique was used to investigate the cointegration relationship between the variables lnCO, lnY, lnEN, and lnFDI. Table 5 shows the results of our cointegration test using Johansen's maximum likelihood method. Both the trace statistic ($\lambda_{trace}$) and the maximal eigenvalue ($\lambda_{max}$) statistics show that there is at least one cointegrating vector among lnCO, lnY, lnEN, and lnFDI. Under both test statistics at the 5% level of significance, we reject the null hypothesis of no integrating vector in favor of one cointegrating vector.

For both the trace and max-eigen test statistics, we could not reject the null hypothesis of at most one cointegrating vector against the alternative hypothesis of two cointegrating vectors. As a result, we conclude that lnCO, lnY, lnEN, and lnFDI have only one cointegrating relationship. This implies that The Gambia's GDP per capita, energy consumption, CO2 emissions, and foreign direct investment have a long-term relationship.

Table 5. Johansen's Cointegration Test

| Null hypothesis | Trace statistic | 5% Critical value | Max Eigenvalue | 5% Critical value |
|---|---|---|---|---|
| $H_0$: r = 0 | 72.1075 | 47.21 | 34.8491 | 27.07 |
| $H_0$: r ≤ 1 | 37.2584 | 29.68 | 22.9663 | 20.97 |
| $H_0$: r ≤ 2 | 14.2922** | 15.41 | 13.8530** | 14.07 |
| $H_0$: r ≤ 3 | 0.4392 | 3.76 | 0.4392 | 3.76 |

Note: r denotes the number of cointegrating vectors; ** denote rejection of null hypothesis at 5% significance.

Table 6. Short-run diagnostic test

| Test | LM | JB |
|---|---|---|
| Value | 0.652** | 0.736** |
| Interpretation | No autocorrelation at lag order | VAR satisfies stability condition |

Note: LM: Lagrange- multiplier test; JB:Jarque-Bera test; ** indicates the test statistics is significant.

Table 7. Estimation of the VECM

| Dependent variables | lnCO | lnY | lnEN | lnFDI |
|---|---|---|---|---|
| lnCO | -0.3214407<br>(0.112) | 1.664516**<br>(0.036) | 0.0289657<br>(0.914) | 15.6709<br>(0.138)* |
| lnY | -0.0552634<br>(0.190) | -0.0123633<br>(0.940) | -0.0212941<br>(0.703) | -1.008884<br>(0.647) |
| lnEN | 0.2093702*<br>(0.154) | -1.092061**<br>(0.058) | 0.140775<br>(0.470) | -4.966151<br>(0.518) |
| lnFDI | -0.0009172<br>(0.734) | 0.0074805<br>(0.479) | -0.0071644**<br>(0.045) | -0.213908<br>(0.129) |
| ECT | -0.0041835<br>(-0.973) | -1.18542**<br>(0.014) | 0.1227921<br>(0.450) | -28.33102***<br>(0.00) |
| Long –run Equilibrium | | | | |
| lnCO | lnY | lnEN | lnFDI | |
| | -0.0500992<br>(0.263) | 0.6750251***<br>(0.000) | -0.0264502***<br>(0.000) | |

Note: Numbers in the brackets (…) are z statistics, *** indicates statistically significant at 1%, ** statistically significant at 5% and * statistically significant at 10%.

Given that all variables have common integration properties, a long-run cointegrating relationship between them can be used to test for the linear deterministic trend (with no trend in the intercept). Table 5 displays the results of Johansson cointegration. At 5% level of significance, the results of both trace tests and maximum eigenvalue tests agree on existence of one cointegrated relationship. In addition, to supplement the study, we present the Lagrange-multiplier test (LM test) and the Jarque-Bera test (JB test). These diagnostic tests look for a lack of serial correlation in the residuals, robustness of estimated coefficients, and coefficient stability across the model. Table 6 displays the figures.

The existence of cointegration leads us to the use of the VECM as express by equation (9) – (12). The VECM is applied to analyses the causal relationship between carbon dioxide ($CO_2$) emissions, economic growth, energy consumption, foreign direct investment (FDI) in The Gambia and to determine the causality between factors. This model allows the long-run behavior of the endogenous variables to converge to their long-run equilibrium relationship while allowing for a wide range of short-run dynamics and long-run estimates.

The short-run results show that carbon dioxide ($CO_2$) emissions with respect to energy consumption is 0.21 and statistically significant at the 10% level. The coefficient of error-correction term (ECT) of carbon dioxide emissions (CO2) has the correct sign and is statistically significant at 10%, with a speed of convergence to equilibrium of 0.42 percent. As a result, short-run carbon dioxide emissions ($CO_2$) are adjusted by 0.42% of the previous year's deviation from equilibrium. It confirms the system's stability. However, because the value of ECT is so low (0.42), the path back to equilibrium will take much longer.

Economic growth is found to be 1.66 and -1.09 in relation to $CO_2$ emissions and energy consumption, respectively, at the 10% significance level. The coefficient of error-correction term of economic growth has a negative sign and is statistically significant at 10%. It depicts the system's stability and convergence to the equilibrium path in the event of a disturbance in the system. Because the ECT is quite high, the rate of adjustment of economic growth toward equilibrium is very quick (118).

Energy consumption is found to be -1.007 with respect to foreign direct investment (FDI) and statistically significance at the 10% level. The coefficient of error-correction term of economic growth has a positive sign. It implies that due to any disturbance in the system, divergence from equilibrium will take place and the system will be unstable.

Similarly, foreign direct investment (FDI) is found to be 15.6 with respect to carbon dioxide emissions (CO2) and statistically significant at the 10% level. The speed of adjustment of 28 indicates that the variables can adjust to their long-run levels, with approximately 2800 percent of the adjustment occurring within the first year.

Due to the fact that long-run relationship exists among the series, the long-run coefficients are estimated. of $CO_2$ emission with respect to economic development, and foreign direct investment (FDI). The reports in Table 7 shows that energy consumption contribute significantly to atmospheric pollution and is positive as expected (0.67), like in the short-run. In the long-run, 1% increase in energy consumption will result in a 0.67 percent increase in $CO_2$ emission at 1% statistically significant level. This findings is consistent with Esso and Keho (2016), who reported that an energy consumption contributes significantly to atmospheric pollution in Benin, Congo, Ghana, Nigeria, Senegal, South Africa and Togo. Our results are also similar to the recent findings of Kivyiro and Armineh (2004), who reported a long-run relationship between energy consumption and carbon dioxide emissions in South Africa and Zimbabwe.

Similarly, the foreign direct investment (FDI) was found to have the expected positive sign (-0.26) and is statistically significant at the 1% level (keep in mind that sign of FDI can be either positive or negative). This means that a 1% increase in farm foreign direct investment (FDI) will decrease export earnings by 0.26% in the long-run. This finding is consistent with Kivyiro and Armineh (2004), who reported that an increase in foreign direct investment is associated with a decrease in carbon dioxide emissions in Democratic Republic of Congo and Zimbabwe.

Table 8. VEC Granger Causality Test

| **Short-run causality** | | | |
|---|---|---|---|
| Dependent Variable = ΔlnCO | | | |
| Excluded | Chi-sq | df | Prob |
| ΔlnY | 5.5071* | 2 | 0.064 |
| ΔlnEN | 3.1824 | 2 | 0.204 |
| ΔlnFDI | 0.08345 | 2 | 0.959 |
| Dependent Variable = ΔlnY | | | |
| ΔlnCO | 11.423*** | 2 | 0.003 |
| ΔlnEN | 8.4108** | 2 | 0.015 |
| ΔlnFDI | 1.6937 | 2 | 0.429 |
| Dependent Variable = ΔlnEN | | | |
| ΔlnCO | 1.8354 | 2 | 0.399 |
| ΔlnY | 5.4235* | 2 | 0.066 |
| ΔlnFDI | 3.3007 | 2 | 0.192 |
| Dependent Variable = ΔlnFDI | | | |
| ΔlnCO | 14.53*** | 2 | 0.001 |
| ΔlnY | 1.1804 | 2 | 0.554 |
| ΔlnEN | 11.668*** | 2 | 0.003 |

| **Long-run causality** | | |
|---|---|---|
| Dependent Variable = ΔlnCO | | |
| Excluded | | Prob |
| ΔlnY | -0.0677752** | 0.036 |
| ΔlnEN | 0.569585*** | 0.000 |
| ΔlnFDI | -0.0020005 | 0.623 |
| Dependent Variable = ΔlnY | | |
| ΔlnCO | -1.72624** | 0.036 |
| ΔlnEN | 1.669125*** | 0.005 |
| ΔlnFDI | -4.520043*** | 0.005 |
| Dependent Variable = ΔlnEN | | |
| ΔlnCO | 1.037389*** | 0.000 |
| ΔlnY | 0.1193553*** | 0.005 |
| ΔlnFDI | 0.0032348 | 0.555 |

| Dependent Variable = ΔlnFDI | | |
|---|---|---|
| ΔlnCO | -3.396645 | 0.623 |
| ΔlnY | 3.643853*** | 0.005 |
| ΔlnEN | 3.015578 | 0.555 |

Note: *** indicates statistically significant at 1%, ** statistically significant at 5% and * statistically significant at 10%.

The findings of the variables' stationary, cointegration between variables employed and the significant of ECT implies that there is causality relationship between variables. Although cointegration suggest the presence of causality, it does not provide information on the direction of causal relationships between variables. Hence, to shed light on the direction of causality, the causality tests were performed. Table 8 shows the statistical results of causal relationship among $CO_2$ emissions, economic growth, energy consumption and foreign direct investment in The Gambia.

The results of causality presented above show unidirectional causality running from economic growth to $CO_2$ emissions, and vice versa. The findings suggest that an increase in economic output could lead to an increase of $CO_2$, and vice versa. This finding is consistent with findings of Esso and Keho (2016), who discovered short-run causality running from economic growth to $CO_2$ emissions in Benin, Democratic Republic of Congo, Ghana, Nigeria and Senegal. Likewise findings of Munir et al.(2020) who found causality running from economic growth to $CO_2$ emissions in Philippines. In short, the findings show unidirectional causality from energy consumption to economic growth, as well as a link between economic growth and $CO_2$ emissions. Hence, any policies aimed at reducing energy consumption may have a negative impact on economic growth. Thus, policies aimed at increasing energy efficiency or utilizing potential renewable energy sources would be more appropriate.

In addition, this study finds bidirectional causal relationship between energy consumption and economic growth, implying that the level of economic activity and energy consumption mutually influence each other. This findings implies that an increase in energy consumption will lead to an increase in economic growth, and vice versa. This finding is consistent with findings of Wolde- Rufael (2005), who found bidirectional causality running from economic growth and energy consumption in Gabon and Zambia. Yang (2000) reach the same conclusion in the case of Taiwan, as well as Paul and Bhattacharya (2004) in India. Therefore, it is once again recommended that policy makers in The Gambia adopt and promote renewable energy sources that will help meet the demand for energy by replacing old traditional energy sources such as fuelwood and charcoal. Renewable sources are reusable and reduce $CO_2$ emission while ensuring The Gambia's long-term economic development.

A bidirectional positive causal relationship also exist between $CO_2$ emissions and foreign direct investment, and between energy consumption and foreign direct investment. This results implies that higher polluting emissions send positive signals to prospective foreign investors. It also demonstrates that The Gambia's government policy of attracting foreign investors to invest in renewable energy as a mitigation measure is effective. The result is in line with findings of Abdouli and Hammami (2017), who found bidirectional relationship between $CO_2$ emission and foreign direct investment in MENA countries and by one given by Omiri et al. (2014) for three regional sub-panels: Europe and central Asia, Latin America and Caribbean, and the Middle East, North Africa, and sub- Saharan Africa and Bozkurt and Akan (2014) for Turkey.

With respect to long-run causality, the results reinforce the finding of long-run relationships among variables. There is a bidirectional causal relationship between $CO_2$ emissions and economic growth. The study also discovered bidirectional causality from energy consumption to economic growth, energy consumption to $CO_2$ emissions, and from foreign direct investment to economic growth for The Gambia.

## 5. Concluding Remarks and Policy Implication

### 5.1 *Summary of Findings*

The study investigate a dynamic relationship between $CO_2$ emissions, economic growth, energy consumption and FDI in The Gambia, using the VECM with time series data for the 1980-2019 period. It has also analyzed the causality between these determinants using Granger causality test. The short-run empirical evidence from the study suggests that energy consumption has a positive impact on the $CO_2$ emissions; $CO_2$ emissions and energy consumption have positive effect on economic growth; FDI has positive impact on energy consumption; and $CO_2$ emissions have positive impact of FDI. The long-run results pointed out that economic growth, energy consumption and FDI have an effect on the $CO_2$ emissions in The Gambia. Furthermore, the VECM Granger causality models were used to investigate the causal relationship between variables. The findings show that economic growth granger causes $CO_2$ emissions in both short-run and long-run. In addition, the findings show that there is positive bidirectional relationship between energy consumption and economic growth in both short-run and long -run. Bidirectional causality between energy consumption and $CO_2$ emissions, and between FDI and economic growth in the long-run. The error correction term in the model is (-0.004) and is found to be statistically significant at 10%, suggesting that previous year's error (or deviation from long-run equilibrium) are corrected for within the current year at a convergence speed of 0.4 percent per annum as such confirming the validity of the long-term relationship among the variables.

5.2 *Conclusions and Recommendations*

With the continuous increase in greenhouse gas emissions from developing countries, this study is deemed critical in the effective design and implementation of policies aimed at reducing greenhouse gas emissions while sustaining economic growth in The Gambia.

Based on the results of this study, energy consumption has a positive impact on the $CO_2$ emissions and there is bidirectional causality between energy consumption and $CO_2$ emissions. It means that energy consumption has a positive impact on the $CO_2$ emissions and vice versa, thereby validating EKC hypothesis. Similarly, the results also show that energy consumption impacts $CO_2$ emissions and there is bidirectional causality between economic growth and energy consumption, meaning that energy consumption causes economic growth and vice versa. Therefore, it is recommended that policy makers in The Gambia promote alternative and cleaner energy sources for the country's economic activities in order to reduce the country's reliance on fossil fuel combustion. This can be accomplished by making full use of the country's natural energy potential such as solar, wind power, and hydraulic energy among others. In addition, The government should also adopt energy-saving policies and strive to improve overall energy efficiency through technological, behavioral, and other changes.

Furthermore, the findings also indicate that FDI has negative impact on $CO_2$ emissions in long-run and there is bidirectional causality running from FDI to economic growth and vice versa. It means that FDI causes economic growth and vice versa. Therefore, we recommend that The Gambian government should provide an inductive business environment in order to attract clean industries and technology transfer via FDI in order to improve environmental quality. Foreign investment in low-carbon or clean industries, in particular, may be eligible for tax breaks or exemptions. Foreign industries in the country should comply with local environmental standards by employing energy-efficient technology.

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