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Assessing the nexus of economic growth indicators and carbon-dioxide emission in West Africa: A dynamic panel data approach

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Abstract

This research aims to evaluate the correlation between economic development and carbon dioxide emissions in a specific subset of West African nations. The study used a quantitative research methodology to gather data on carbon dioxide emissions, GDP, urban population, rural population, access to gas, and access to electricity from the years 1990 to 2021. The data was analysed using the Panel ARDL approach, and all requisite tests were conducted to ascertain the characteristics of the data. The research reveals the existence of persisting correlations among the selected variables, indicating that changes in GDP, electricity availability, petrol availability, rural population, and urban population have long-lasting impacts on carbon dioxide emissions in West African countries. The findings indicate that in the process of striving for economic development, addressing economic inequalities, and enhancing productivity in various economic sectors in West African countries, there is a potential for increased carbon dioxide (CO2) emissions. The magnitude of emissions growth is contingent upon the response of these countries to the evolving economic landscape.

Keywords: Panel ARDL, GDP, CO2 emission, Co-integration, correlation, error correction term

1. Introduction

Climate change is a formidable problem in contemporary society, demanding a more comprehensive examination of the intricate dynamics between economic development and ecological preservation. Historically, the process of economic growth has been marked by a rise in carbon-dioxide (CO2) emissions, which is closely linked to rising industry, urbanisation, and energy consumption (Smith, 2015) [10]. The interdependent connection between economic development and greenhouse gas emissions has emerged as a topic of utmost significance in scholarly investigations and discussions around policy.

A variety of economic growth indicators have been examined in order to determine their influence on carbon dioxide (CO2) emissions, with particular attention given to gross domestic product (GDP) (Stern, 2007) [11]. Nevertheless, the correlation between the variables is not strictly linear, leading researchers to explore a wider range of factors that impact the amounts of emissions. The impact of income levels on consumption patterns and energy demand has been shown in previous research, which in turn has an indirect effect on carbon dioxide (CO2) emissions (Dinda, 2004) [12]. In contrast, the degree of trade openness may have an effect on emissions via its influence on the kind and quantity of traded commodities and their corresponding carbon footprints (Grossman & Krueger, 1991) [13].

The primary aim of this study is to provide a valuable contribution to the current scholarly discussion around the complex and multidimensional nature of this connection. In this study, our objective is to shed light on the complex interrelationships between economic development indicators and CO2 emissions by conducting a thorough examination and analysis of the available literature (Zhang & Cheng, 2009) [14]. In addition, we will conduct a thorough analysis of the methodological techniques used in different research in order to get a comprehensive understanding of the intricacies and difficulties associated with evaluating this correlation.

One of the main mechanisms through which economic expansion influences carbon dioxide (CO2) emissions is via the augmentation of energy consumption. The expansion of economies is accompanied by an increased requirement for energy to support various sectors such as industry, transportation, and domestic consumption (Zhang & Cheng, 2009) [14].

The increased use of energy, mostly sourced from fossil fuels, results in heightened emissions of carbon dioxide (CO2) into the Earth's atmosphere. In order to effectively address this correlation, policymakers should prioritise the promotion of energy efficiency measures, the transition towards cleaner energy sources, and the provision of incentives to encourage sustainable consumption habits (Smith, 2015) [10].

Increased industrialization and manufacturing activity are often accompanied with economic development. According to Stern (2007) [11], these industries play a crucial role in the emission of CO2 as a result of their heavy dependence on energy-intensive procedures. Policies designed to mitigate emissions originating from industrial activities may include the implementation of rigorous environmental rules, the promotion of cleaner technology, and the encouragement of enterprises to embrace sustainable production practises.

The correlation between increasing earnings and economic growth might result in changes to consuming behaviours. There is an often seen correlation between higher levels of wealth and several factors such as increasing ownership of vehicles, larger consumption of energy-intensive commodities, and a transition towards diets that need more resources (Dinda, 2004) [12]. Policymakers have the capacity to tackle this issue via the promotion of sustainable consumption patterns, allocation of resources towards public transport infrastructure, and implementation of strategies aimed at mitigating emissions originating from the agricultural and food industries.

Economic expansion has the capacity to stimulate technical innovation, therefore presenting an opportunity for the mitigation of emissions. According to Grossman and Krueger (1991) [13], the stimulation of economic growth may result in increased investments in research and development, which in turn can facilitate the advancement of cleaner energy technologies and more efficient industrial processes. Policy interventions should be designed to provide support and provide incentives for these technologies, so facilitating a shift towards an economy that has reduced carbon emissions.

In order to harmonise economic progress with the preservation of the environment, the adoption of carbon taxes or cap-and-trade mechanisms may serve as effective measures to provide economic motivations for enterprises and people to curtail their emissions. According to Stern (2007) [11], the income derived from these measures might be used towards the funding of renewable energy programmes and sustainability projects. It is essential for governments to implement and enforce environmental rules that establish emission reduction objectives for industry and promote the use of cleaner technology. Regulatory frameworks play a crucial role in ensuring that economic development is conducted in a way that upholds environmental responsibility. According to Smith (2015) [10], the provision of subsidies and incentives for renewable energy sources, energy-efficient technology, and sustainable transportation alternatives has the potential to expedite the shift towards a low-carbon economy. The dissemination of information and education on the environmental consequences of consumption decisions has the potential to facilitate voluntary transitions towards more sustainable ways of living (Dinda, 2004) [12].

According to the study conducted by Ang and Su (2010) [1], This literature review aims to investigate the interrelationship among carbon dioxide (CO2) emissions, gross domestic product (GDP), rural population, and urban population. The present research used the Logarithmic Mean Divisia Index (LMDI) decomposition approach to examine the determinants of variations in carbon dioxide (CO2) emissions. Specifically, it investigated the influence of economic development, as measured by gross domestic product (GDP), and the distribution of people between rural and urban regions on these emissions. The research revealed that alterations in carbon dioxide (CO2) emissions may be deconstructed into four primary determinants: gross domestic product (GDP) per capita, energy intensity of GDP, carbon intensity of energy, and population size. The findings of the research indicate that there is a positive correlation between GDP growth and CO2 emissions, but this relationship is somewhat mitigated by advancements in energy efficiency. Furthermore, the process of urbanisation has been shown to be correlated with a rise in carbon dioxide (CO2) emissions, mostly attributable to the elevated levels of energy consumption seen in metropolitan regions.

The study conducted by Sahoo and Dash (2016) focuses on analysing the Environmental Kuznets Curve for Carbon Emissions in India. The research employs a methodology that combines cointegration analysis with a dynamic error correction model to provide empirical evidence. The present study used time-series data and conducted cointegration analysis in conjunction with a Dynamic Error Correction Model (DECM) to investigate the presence of an Environmental Kuznets Curve (EKC) in relation to carbon emissions in India. The investigation also examined the influence of GDP, rural population, and urban population on carbon emissions. The research discovered empirical support for the existence of an Environmental Kuznets Curve (EKC) phenomenon in India. This implies that while the country's Gross Domestic Product (GDP) experiences early growth, there is a corresponding increase in carbon emissions. However, after a certain income level is reached, further economic development results in a decline in emissions. Furthermore, the study revealed that both the rural and urban population factors had noteworthy beneficial impacts on carbon emissions, underscoring the significance of population dynamics in the development of environmental policies.

The study conducted by Zaman et al. (2017) focused on investigating the relationship between economic growth, urbanisation, and carbon emissions in Pakistan, using empirical evidence. The present research used a vector error correction model (VECM) to examine the interconnections among economic development (Gross Domestic Product or GDP), urbanisation, and carbon emissions within the context of Pakistan. The findings of the research demonstrated a reciprocal causal connection between gross domestic product (GDP) and carbon emissions, suggesting a mutual impact between economic growth and emissions. Moreover, the study revealed a unidirectional causal relationship whereby urbanisation positively influenced carbon emissions, indicating that as urbanisation levels rose, so did the levels of carbon emissions. The aforementioned results highlight the intricate interplay of urbanisation, economic expansion, and environmental sustainability.

The study conducted by Lin et al. (2018) The present research used panel data analysis to examine the correlation between rural-urban migration, CO2 emissions, and economic development in China. The investigation included variables like GDP per capita and the proportion of rural and urban population. The findings of the study demonstrated a strong correlation between rural-urban migration in China and CO2 emissions, suggesting that the phenomenon of urbanisation had a significant role in the increase of emissions. Nevertheless, the study also identified a positive correlation between GDP per capita and CO2 emissions, indicating that economic expansion has a substantial influence. The aforementioned results shed light on the difficulties associated with achieving a harmonious equilibrium between economic progress and environmental considerations in increasingly urbanising nations such as China.

In their research, Apergis et al. (2019) used panel data analysis to examine the correlation between urbanisation, carbon dioxide (CO2) emissions, gross domestic product (GDP), and several control factors within a sample of developing nations. The study revealed that the process of urbanisation exerted a noteworthy and favourable influence on carbon dioxide (CO2) emissions, indicating that when nations underwent urbanisation, there was a corresponding rise in their carbon emissions. Furthermore, the research emphasised the significance of income levels, namely Gross Domestic Product (GDP), in mitigating the correlation between urbanisation and CO2 emissions. Countries with higher economic levels shown more capacity to adopt and execute cleaner technology, so effectively reducing the rise of emissions associated with urbanisation.

According to the study conducted by Shrestha et al. (2020), The present research used panel data analysis to investigate the complex relationship between economic development, urbanisation, and carbon dioxide (CO2) emissions in many Southeast Asian nations. The findings of the investigation revealed a favourable correlation between both economic development and urbanisation, and CO2 emissions within the Southeast Asian region. Nevertheless, the research also revealed disparities among nations, underscoring the significance of regional characteristics and policy choices in shaping emissions trends. This highlights the significance of using customised approaches in order to achieve sustainable development.

According to the study conducted by Ogunmuyiwa and Owolabi (2021) [6], The present research used a fixed-effects panel regression model to examine the impact of rural and urban population sizes on carbon dioxide (CO2) emissions in nations located in Sub-Saharan Africa. The study revealed that there was a strong and positive correlation between the sizes of both rural and urban populations and CO2 emissions. Nevertheless, it is worth noting that the impact of the urban population exhibited more significance, so suggesting that the phenomenon of urbanisation had a more significant position in the escalation of emissions within the given area. Saharan Africa. The results of this study highlight the need of implementing specific strategies and measures to tackle emissions within the Sub-Saharan African region.

The motivation behind this paper is to critically assess the long run relationship between some selected West African Countries CO2 emission and its economic growth indicators using dynamic panel data regression methodology.

2. Materials and Methods

The quantitative research methodology was applied in achieving the aim of this paper. This paper adopted the panel ARDL method in estimating the influence of economic growth indicators on carbon-dioxide emission in some selected West African countries between1990-2021. In achieving this, Johansen Fisher panel cointegration technique was used to confirm if their exist long run relationship among the variables of study. The Fisher equation as adopted is written in equation (1) as:

$$CO2_{it} = a_i + \beta_i \pi_{it} + \varepsilon_{it} \qquad (1)$$

Where $CO2_{it}$ is the rate of Carbon dioxide released by manufacturing companies at time t for country i, π_{it} is economic growth (GDP) rate and its associated indicators consisting physical access to electricity (AE), access to gas (AG), urban population (UP) and rural population (RP), Given that $CO2_{it}$ and π_{it} are both stationary and their linear combination is stationary, then they are said to be in a cointegration relationship (Engle and Granger, 1987).

Given that co-integration relation exist between $CO2_{it}$ and π_{it}, rejection of co-integrating vector (1,1) i.e. $\beta = 1$ can be rejected in equation (2)

$$\ln CO2_{it} = a_i + \beta_i \pi_{it} + \sum_{j=-k}^{k} \delta_i \Delta \pi_{it-j} + \mu_{it}$$

After achieving equation (1) and (2), the panel co-integration models were estimated using the Panel ARDL (PMG). Stock and Watson (1993), Pedroni (2001) and Pesaran, Shin and Smith (1999) developed the Panel ARDL (Pooled Mean Group model). The PMG ARDL assumes dynamic heterogeneity in the panels. The long run model is specified explicitly by transforming the variables in natural log as given in equation (3.4):

$$\ln CO2_{i,t} = \varphi(\ln GDP)_{i,t} + \alpha(\ln AE)_{i,t} + \theta(\ln AG)_{i,t} + \Theta(\ln UP)_{i,t} + \vartheta(\ln RP)_{i,t} + \mu_{i,t}$$
(3)

The short run dynamic of the panel ARDL model is written as.

$$\ln(CO2)_{i,t} = \gamma_0 + \sum_{j=1}^{k} \gamma_{1j} \Delta \ln(CO2)_{i,t-j} + \sum_{j=1}^{k} \varphi_{1j} \ln(AE)_{i,t-j} + \sum_{j=m}^{k} \alpha_{1j} \Delta \ln(AG)_{i,t-j} + \sum_{j=m}^{k} \theta_{1j} \Delta \ln(UP)_{i,t-j} + \sum_{j=m}^{k} \Theta_{1j} \Delta \ln(RP)_{i,t-j} \qquad (4)$$

According to Banerjee, Dolado and Mestre (1998), the error correction term indicates the speed adjustment to restore equilibrium in the dynamic model. The error correction coefficient shows how quickly variables converge/diverge to equilibrium and it should have a statically significant coefficient with a negative/positive sign. The highly significant Error Correction Term further confirms the existence of a stable long-run relationship. The ECT is estimated as

$$ECM_{i,t} = \ln(CO2)_{i,t} - \gamma_1 - \sum_{j=1}^{k} \gamma_{1j} \ln(GDP)_{i,t-j} - \sum_{j=m}^{k} \alpha_{1j} \Delta \ln(AE)_{i,t-j} - \sum_{j=m}^{k} \theta_{1j} \Delta \ln(AG)_{i,t-j} - \sum_{j=m}^{k} \Theta_{1j} \Delta \ln(UP)_{i,t-j} - \sum_{j=m}^{k} \theta_{1j} \Delta \ln(RP)_{i,t-j} \qquad (5)$$

Augmented Dickey Fuller -Fisher Chi-square and Philips Peron-Fisher Chi-square was used to test the variables for unit roots in order to confirm the suitability of the dynamic models under study.

3. Results and Discussion

Descriptive statistics measure the distribution of observations in the data set. The measures of the central tendency and dispersion for the data are displayed below:

Table 1: Data Description

Statistic	CO2 (M'tonnes)	GDP (N'Billion)	AG	AE (Megawatts)	RP	UP
Mean	23.66145	5.070708	46.47850	10357.67	5949047.	16384619
Median	5.986349	4.703091	41.31365	37.56944	3363456.	9547434.
Maximum	120.4000	30.14513	103.7840	749004.0	21904983	1.01E+08
Minimum	0.400000	0.040925	1.027836	1.100000	28352.00	193416.0
Std. Dev.	34.13900	3.578246	35.32480	87112.29	6910705.	25101610
Skewness	1.420275	1.883203	0.279457	8.308010	0.941295	2.399529
Kurtosis	3.301002	11.54027	1.553510	70.02610	2.582164	7.259861
Jarque-Bera	97.91195	1045.465	28.85661	57223.09	44.62476	494.1283
Probability	0.000000	0.000000	0.000001	0.000000	0.000000	0.000000
Observations	288	288	288	288	288	288

Source: Extracted from E-views Output, Version 10.0

Table 1 presents the descriptive statistics for the variables that are used for prediction and clarification. The study utilised a dataset spanning 31 years obtained from the World Bank repository, specifically focusing on nine (9) selected West African countries. This dataset provided a total of 288 observations for the purposes of this study. According to the data presented in the table, the average CO2 emission is 23.66145, with the lowest recorded value being 0.4 and the highest recorded value being 120.40. The West African countries exhibit a significant prevalence of CO2, as evidenced by the relatively high mean value of 23.66145 and a standard deviation of 34.139. The economic growth (GDP) has a mean value of 5.071, with a minimum value of 0.0409 and a maximum value of 30.14513. These figures indicate that the selected West African countries experienced diverse levels of economic growth throughout the studied period. The mean values for Access to Gas (AG), Access to Electricity (AE), Rural Population (RP), and Urban Population (UP) are 46.47850, 10357.67, 5949047, and 16384619, respectively. These values have been recorded over time, along with their corresponding minimums, maximums, and standard deviations. The inference drawn from this result indicates that a lower percentage of the west African countries included in the study invest in physical infrastructure, specifically in areas such as electricity and gas access. This lack of investment may contribute to a reduction in CO2 emissions, ultimately leading to a decrease in the gross domestic product of these countries. Insufficient industrial presence in these countries can be attributed to this phenomenon.

Table 2: Correlation Matrix of the Study Variables

Correlation							
Probability	**CO2**	**GDP**	**AG**	**AE**	**RP**	**UP**	
CO2	1						
GDP	0.009869	1					
	[0.8676]						
AG	0.780579	-0.036894	1				
	[0.0000***]	[0.5329]					
AE	-0.020565	-0.097524	0.167416	1			
	[0.7282]	[0.0986*]	[0.0044**]				
RP	0.527729	-0.040651	0.598638	0.054786	1		
	[0.0000***]	[0.4920]	[0.0000***]	[0.3542]	-----		
UP	0.740987	-0.015335	0.525970	-0.066083	0.724702	1	
	[0.0000***]	[0.7955]	[0.0000***]	[0.2636]	[0.0000***]		

**,*** and * represents significant @1% and 5% and and 10% levels
Figures in [ ] represents p-values
Source: Extracted from E-views Output, version 10

Table 2 presents the correlations observed between the predicted variable and the explanatory variables. The findings presented in the table indicate that the explanatory variables, namely GDP, AG, AE, RP, and UP, exhibit a moderate level of correlation ranging from -0.097524 to -0.015335. These results suggest that there is no significant or high connection observed among the variables. The statistical analysis reveals that there is a significant connection between AG and GDP at a significance level of 0.05 (two-tailed). However, it is important to note that the interrelationships between FI and MF do not exhibit statistical significance, as their associated p-values exceed the 0.05 level of significance. The table presents evidence of a modest nevertheless inverse relationship between GDP, AE, RP, and UP, as evidenced by the coefficients AG (-0.03689), AE (-0.09752), RP (-0.040651), and UP (0.015335). The observed differences in the coefficients indicate a discrepancy in the level of correlation between each individual independent variable and the dependent variable. The correlation coefficient between CO2 and GDP (0.00987) indicates a weak positive association. In contrast, CO2 has strong positive relationships with other variables, such as RP (0.537729) and UP (0.740987). On the other hand, the correlation between CO2 and AE is weakly negative (-0.020565) and statistically insignificant.

Nevertheless, the findings validate the presence of a linear correlation between independent variables representing economic growth indicators and the dependent variable of CO2 emissions. This prerequisite is essential for the execution of a regression analysis. Furthermore, it is worth noting that none of the correlation coefficients surpassed the value of 0.74099. This observation provides evidence to support the notion that the predictor variables, which are independent of each other, do not exhibit a strong relationship.

3.1 Regression Assumptions Tests

Given the observed outcomes of the correlation matrix, which indicate the presence of a linear association between the predicted variable and predictor variables, the study proceeded to conduct additional tests to assess the fulfilment of regression assumptions, as the linearity assumption has been met. These tests are conducted in order to verify that none of the aforementioned assumptions were violated and that the data met the requirements for regression analysis.

The Jarque-Bera test provides evidence regarding the normalcy of the data, hence bolstering the reliability of the descriptive statistics. Figure 4.1 displays the Jarque-Bera test of normality conducted on the dataset. The obtained results demonstrate that the JB statistic, with a value of 1.122037, and the corresponding p-value of 0.0000, was found to be statistically significant at a significance level of 5%. This suggests that the data exhibit normalcy, lack outliers, and are thus appropriate for generalisation. The histogram provides more evidence supporting the assumption of a normal distribution.

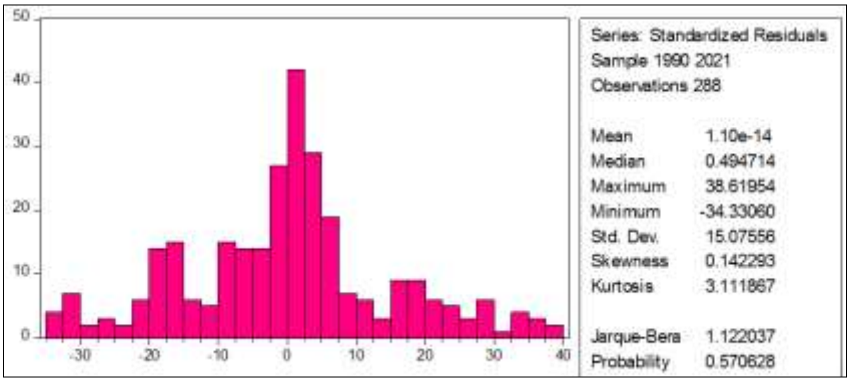

Fig 1: Normality test of residuals (Jarque-Bera test)

3.2 Panel Unit Root Test for the Study Variables

Conducting a unit root test prior to model estimation was an essential procedure in order to select the most suitable estimation technique. Previous research has indicated that panel data often exhibit mean variance, thus necessitating the examination of the stationarity criterion for these variables. Furthermore, the issue of spurious regression has led to the need for testing the presence of a unit root in panel series data. Prior to studying the relationship between variables, it is considered essential to investigate the stationary property of panel data series. This is because non-stationary series provide obstacles in regression analysis. The significance of this matter lies in the use of the proposed panel regression methodology, which is applicable solely for estimating models that involve variables exhibiting an integration order of zero [I(0)], under the assumption of an individual unit root process.

Table 3: Panel Unit Root Test

Variable	ADF-FC(Augmented Dickey Fuller -Fisher Chi-square)		PP-FC(Philips Peron-Fisher Chi-square)		Order of Integration	Remarks
	Test @ level	Test @1st difference.	Test @level	Test @1st difference		
AE	12.1322 [0.8403]	150.682# [0.0000]	27.5729 [0.0689]	227.407 [0.0000]	I(1)	Stationary at 1st difference
AG	28.0359 [0.0615]	-	36.9325 [0.0053]	-	I(0)	Stationary at level
CO2	41.4410 [0.0013]	-	68.3362 [0.000]	-	I(0)	Stationary at Level difference
GDP	50.3343 [0.0001]	-	114.658 [0.0000]	-	I(0)	Stationary at Level
RP	33.2149 [0.0157]	-	51.4364 [0.0000]	-	I(0)	Stationary at level
UP	40.3908 [0.0018]	-	35.3346 [0.0086]	-	I(0)	Stationary at level

Values in parenthesis [ ] represents p-values

Source: Extracted from E-views Output, version 10

The findings of the panel unit-root-test statistics for the research variables are presented in Table 3. The presence of a unit root in AE is supported by both adopted techniques of stationary tests (ADF-FC and PP-FC). This is evident from the results of either test type at levels, where the p-values above the 1% level of significance. As a means of eliminating the unit presence, the series was differenced at the first order. This decision was based on the findings of both test statistics, which indicated that the most suitable order of series integration was I(1). It is worth noting that additional variables, namely AG, CO2, GDP, UP, and RP, exhibited stationarity at levels. This led to a combination of integration orders, indicating that the analysis of the relationship between GDP, macroeconomic variables, and CO2 emissions in certain West African countries is conducted using panel autoregressive distributed lag modelling (Panel ARDL), also known as the pooled mean group (PMG) approach.

The subsequent sub-sections analyse the determination of the long-term link between the studied variable of CO2 emissions and indices of economic growth.

3.3 Lag order selection

The process of selecting the optimal lag to be included in the model was conducted in order to mitigate the occurrence of spurious coefficients and over-parameterization, hence achieving a more parsimonious fit.

Table 4: VAR Lag Order Selection

Criteria						
Endogenous variables: CO2 GDP AG AE RP UP						
Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
0	-13996.23	NA	3.80e+44	119.6772	119.7658	119.7129
1	-11083.04	5652.081	7.95e+33	95.08582	95.70600	95.33588
2	-10870.89	400.7211	1.77e+33	93.58029	94.73207*	94.04469*
3	-10817.47	98.17076	1.52e+33	93.43138	95.11474	94.11011
4	-10755.27	111.1170	1.22e+33	93.20741	95.42236	94.10047
5	-10715.51	68.98525	1.19e+33	93.17527	95.92181	94.28267
6	-10676.09	66.36100*	1.16e+33*	93.14611*	96.42423	94.46784

* 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

Based on the information provided in Table 4, it is evident that the variables in the Vector Auto Regression (VAR) model exhibit a maximum lag structure of order six (6). The utilisation of AIC was chosen due to its comparatively lower statistical value in comparison to other criteria. Therefore, the development of the Panel ARDL model building is limited to a maximum lag structure of 2.

Table 5: Johansen Fisher Panel Co-integration Test

Unrestricted Cointegration Rank Test (Trace and Maximum Eigenvalue)				
Hypothesized No. of CE(s)	**Fisher Stat.* (from trace test)**	**Prob.**	**Fisher Stat.* (from max-eigen test)**	**Prob.**
None	202.2	0.0000	110.7	0.0000
At most 1	106.3	0.0000	62.80	0.0000
At most 2	57.46	0.0000	30.64	0.0150
At most 3	36.81	0.0022	24.09	0.0875
At most 4	24.93	0.0711	21.65	0.1549
At most 5	18.12	0.3167	18.12	0.3167

Source: Extracted from E-views Output, version 10

The results of the Johansen and Fisher co-integration tests, as shown in Table 5, indicate that there are significant co-integration relationships between CO2 levels in certain West African countries and the determinants of economic growth. The trace statistic ranges from 18.12 to 202.2, with a corresponding p-value of less than 0.05, indicating that there are up to three co-integrating equations. Similarly, the maximum eigenvalue statistic ranges from 18.12 to 110.7, with a corresponding p-value of less than 0.05, further supporting the presence of co-integration relationships. This suggests that the presence of a long-term panel co-integration relationship between CO2 emissions and economic growth, along with the relevant variables and determinants of economic growth gaps, is supported by the results of the Johansen Fisher trace and maximum eigenvalue co-integration tests. These tests reject the null hypothesis that there is no co-integration between the variables AE, AG, CO2, GDP, RP, and UP. The aforementioned findings indicate a potential relationship between long-term economic growth variables and the release of CO2. The analysis of individual cross-sectional data, as presented in the appendix, reveals the existence of five (5) cointegration linkages in the majority of West African countries, regardless of whether the constant is confined or unconstrained.

The data was analysed using the Panel Autoregressive Distributed Lag Model (Panel ARDL, PMG) to confirm the significance of the parameter estimates of the co-integrated vectors in the long run. This analysis was based on the observation that there is a long-term co-integration relationship between the predicted and explanatory variables. The presence of heterogeneous order of integration of the regressors, endogeneity, and small sample bias has been identified as the underlying factors contributing to this phenomenon (Arize, Mahindretos, & Gosh, 2015; Masih & Masih, 1996; Arize, Osang, & Slottje, 2000). The approach employed in this study aligns with the level of cross-sectional heterogeneity allowed in panel unit root and co-integration analyses, as the asymptotic properties were assessed inside the panel's within dimension.

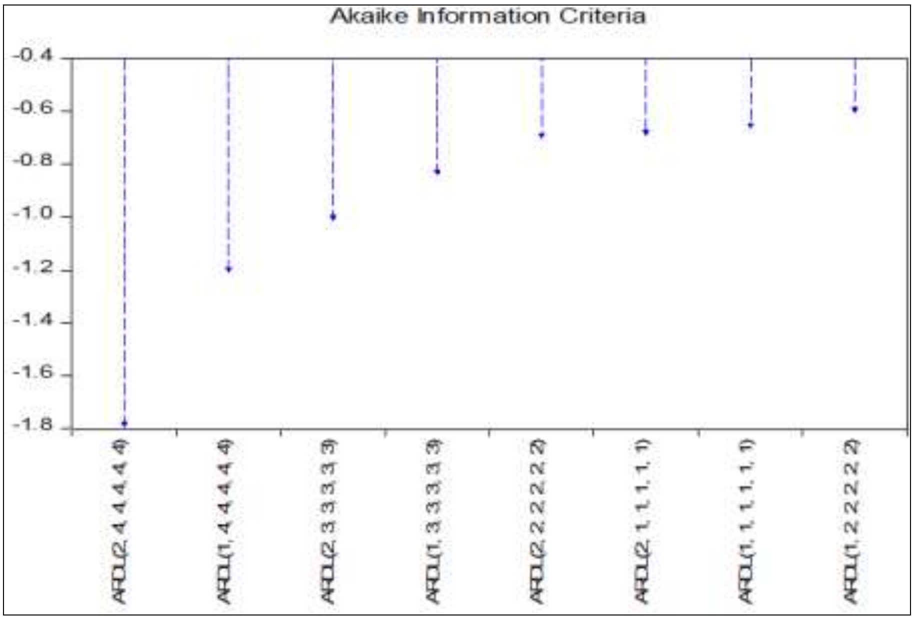

Fig 2: AIC of Iterated PMG models

From fig. 1, it can be seen that the selected PMG model was found to be ARDL (2, 4, 4, 4, 4) due to its lowest AIC of -1.8 among its model specifications.

Table 6: PMG Long Run Equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ln(GDP)	0.056242	0.010171	5.529678	0.0000***
ln(AG)	0.711351	0.038162	18.64041	0.0000***
ln(AE)	0.087238	0.046460	1.877693	0.0648*
ln(RP)	0.632757	0.085428	7.406890	0.0000***
ln(UP)	-0.526892	0.245160	-2.149175	0.0352**

** ,*** and * represents significant @1% and 5% and and 10% levels

***Source**: Extracted from E-views Output, version 10*

The results of the PMG model indicate that the variables of economic growth and its indicators, namely Gross Domestic Product (GDP), Access to Gas (AG), Access to Electricity (AE), Rural Population (RP), and Urban Population (UP), have coefficients of 5.5297 (t-value 0.05624, p-value 0.000), 0.71135 (t-value 18.6404, p-value 0.000), 0.08724 (t-value 1.877693, p-value 0.0648), 0.632757 (t-value 7.406890, p-value 0.0000), and -0.526892 (t-value -2.149175, p-value 0.0352) respectively. However, the UP exhibits a detrimental impact that is statistically significant. Furthermore, the findings revealed that a 1% rise in GDP, AG, AE, and RP leads to a concomitant increase in CO2 emissions of 5.6%, 71.1%, 8.72%, and 63.27% among the selected West African countries during the long-term timeframe. This suggests that none of the factors examined have a CO2-reducing effect in the countries of Sub-Saharan Africa, accurately reflecting the situation in African nations. The long-term impact estimates align with the anticipated outcomes, with the exception of urban population, which decreases CO2 emissions by 52.7%.

Table 7: Short Run Equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ECT	-0.368873	0.801064	-0.460479	0.6467
Δln (CO2(-1))	28.10688	27.85302	1.009114	0.3166
Δln (GDP)	0.082363	0.084888	0.970256	0.3354
Δln (GDP(-1))	0.079666	0.035040	2.273542	0.0262**
Δln (GDP(-2))	0.010513	0.065919	0.159489	0.8738
Δln (GDP(-3))	-0.003830	0.048425	-0.079087	0.9372
Δln (AG)	0.712778	0.972044	0.733277	0.4659
Δln (AG(-1))	-27.77603	27.98619	-0.992491	0.3245
Δln AG(-2))	-0.472999	0.681164	-0.694397	0.4898
Δln (AG(-3))	0.077571	0.713570	0.108709	0.9138
Δln (AE)	-1.790268	1.906974	-0.938800	0.3512
Δln (AE(-1))	0.302217	1.259271	0.239994	0.8111
Δln (AE(-2))	1.653417	2.329878	0.709658	0.4804
Δln (AE(-3))	-0.892555	0.487499	-1.830887	0.0716*
Δln (RP)	-24.93187	23.82781	-1.046335	0.2992
Δln (RP(-1))	5.424730	33.22029	0.163296	0.8708
Δln (RP(-2))	-17.29961	13.62650	-1.269556	0.2086
Δln (RP(-3))	-15.68450	15.28379	-1.026218	0.3085

Δln (UP)	12.13038	99.17258	0.122316	0.9030
Δln (UP(-1))	73.84058	105.8513	0.697588	0.4878
Δln (UP(-2))	-52.59714	74.31891	-0.707722	0.4816
Δln (UP(-3))	2.408875	117.4084	0.020517	0.9837
C	-2.615912	2.140783	-1.221942	0.2260
@TREND	0.022498	0.033063	0.680467	0.4986

** ,*** and * represents significant @1% and 5% and and 10% levels

Source: Extracted from E-views Output, version 10

This component of the study examines the short-term findings after establishing the long-term correlation between CO2 emissions and economic growth in the chosen West African countries. Table 7 presents the short-term outcomes of the Error Correction Model, as predicted by the PMG estimator. After the selection of the PMG estimator as shown in the preceding table, the subsequent discussion focuses on the short-run outcomes obtained from the PMG model. The findings obtained from the Panel Vector Autoregression (PVAR) model indicate a statistically significant and negative value for the error correction term (ECT), specifically -0.368873. This suggests that there is a potential for 36.9% of the economic imbalance in West African countries to be rectified in the future, contingent upon a good response in the productivity of various economic sectors, resulting in an increase in CO2 emissions. According to Bannerjee et al. (1998), the duration for economic growth to return to equilibrium is 2.71 years, which can be calculated as 1 divided by 0.368873. The presence of a significantly high Error Correction Term (ECT) indicates the existence of a steady and robust association between carbon dioxide (CO2) levels and important economic indicators across all West African nations. Nevertheless, there is empirical evidence to support the notion that the coefficients of the parameters suggest a positive relationship between a 1% increase in CO2 in the subsequent year and a corresponding increase of 28.10688 units (p-value 0.0009< 0.05) in CO2 levels in the current year. This suggests that the present release of CO2 would continue to impact the rate of CO2 emission within the following year in the immediate term. Furthermore, it can be observed that there exists a negative correlation between the lagged values of GDP at lag 1 and AE at lag 3 with CO2 emissions, both in the short-term and long-term. This suggests that the economic growth indicators of GDP and AE have an impact on CO2 emissions in both the short-run and long-run, provided they are effectively controlled. Specifically, the lag 3 of AE exhibits negative associations, indicating that increased access to electricity is associated with a decrease in carbon dioxide emissions in the short run.

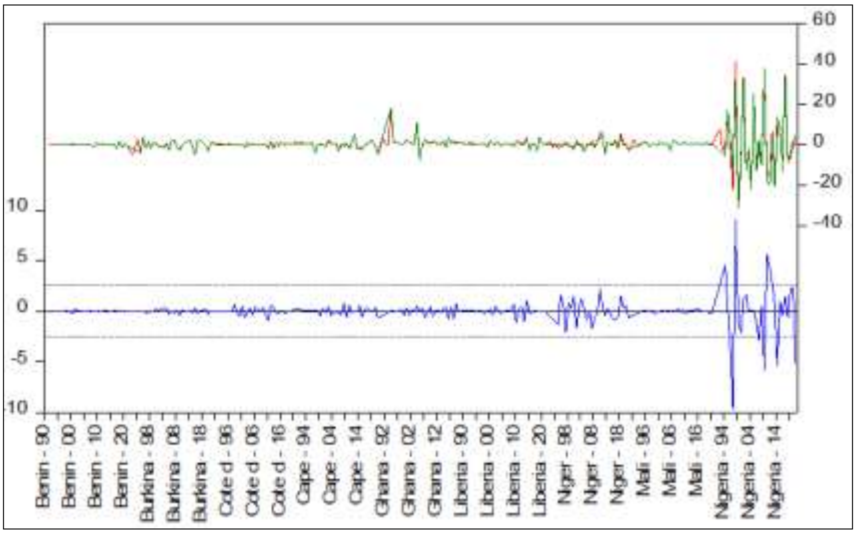

Fig 3: Residual, actual and Fitted CO2 from the macroeconomic indicators. Evidence from fig. 2 showed that the identified PMG (2, 4, 4, 4, 4) model fitted the data well as there exist almost nill variations between the actual and fitted values.

3.4 Major Findings

The utilisation of Panel Auto Regressive Distributed Lag (ARDL) modelling has been employed to examine the associations between carbon dioxide (CO2) emissions and a specific set of influential variables, including Gross Domestic Product (GDP), access to electricity, access to gas, urban population, and rural population, within chosen West African nations. This analysis has provided significant findings regarding the environmental and economic dynamics of the region. The present study utilised the Johansen Fisher Panel cointegration technique to examine the long-term and short-term associations among the aforementioned variables.

The results of this research provide empirical evidence supporting the presence of persistent associations among the chosen variables, suggesting that alterations in GDP, availability of power, availability of gas, rural population, and urban population have lasting effects on carbon dioxide emissions in West African nations. The findings of this study are consistent with the concept that greenhouse gas emissions are influenced by economic activities and the availability of energy resources. It is worth noting that, with the exception of urban population, all independent factors were observed to have a significant impact on long-term CO2 emissions. This observation implies that the process of urbanisation in the region may exhibit distinct dynamics in its relationship with CO2 emissions, thereby necessitating additional research.

The analysis of short-term dynamics has uncovered a significant element in the interplay between these variables, namely the existence of an error correction term at a rate of 36.9%. This observation suggests the presence of an adjustment mechanism within the West African countries under investigation. When instances of divergence from the long-term equilibrium arise, such as disparities in economic indicators and carbon dioxide emissions, a pronounced inclination exists for the system to rectify itself. In this particular scenario, the adjustment rate of 36.9% indicates that there is a high probability of economic imbalances being corrected over a period of time.

This discovery suggests that during the pursuit of economic growth, the rectification of economic disparities, and the improvement of productivity across diverse economic domains in West African nations may encounter a possibility of elevated carbon dioxide (CO2) emissions. The extent to which emissions will increase depends on how these nations respond to the changing economic situation. This highlights the significance of crafting sustainable development policies that concurrently address both economic growth and environmental preservation.

4. Conclusion and recommendations

This research offers significant contributions to understanding the intricate relationship between economic advancement and environmental considerations in nations within West Africa. The recognition of enduring associations between CO2 emissions and the independent variables underscores the need of considering these aspects jointly in the development of policies. The inclusion of the error correction factor in the short-run dynamics underscores the importance of implementing proactive actions to address economic imbalances and foster sustainable development within the region. It is imperative for future research and policymaking endeavours to include these findings in order to develop strategies that not only foster economic growth but also prioritise the responsible management of CO2 emissions. This will contribute to the establishment of a more sustainable and environmentally conscious West Africa.

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