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Nexus between Resource Utilization and Environmental Pollution: Evidence from 23 Countries in Africa

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Abstract:
As Africa becomes more open to trade and globalization, emissions in the region continue to increase steadily. In the context of the prevailing economic and political conditions in Africa, it is anticipated that climate change shocks will impede developmental progress and hinder economic growth within the region. This research endeavors to empirically investigate the interconnections among GDP per capita, renewable energy consumption, freshwater withdrawals, forest area, and greenhouse gas emissions across 23 African nations from 2001 to 2020. The analytical framework incorporates the Pedroni cointegration test and the Fully Modified Ordinary Least Squares (FMOLS) method to establish a durable relationship among the variables under scrutiny.
The outcomes of our investigation disclose that a 1% escalation in GDP per capita and freshwater withdrawals corresponds to an 87.75% and 16.93% increase in greenhouse gas emissions, respectively. Conversely, a 1% rise in renewable energy consumption and forest area manifests a decline in greenhouse gas emissions by 58.51% and 13.24%, respectively. The examination reveals a negative coefficient for GDP per capita squared, affirming the validity of the Environmental Kuznets Curve (EKC) hypothesis. Furthermore, the Pairwise causality test indicates bidirectional causation between renewable energy consumption and greenhouse gas emissions and between renewable energy consumption and GDP per capita. Additionally, unidirectional causality exists from GDP per capita to greenhouse gas emissions, freshwater withdrawals to GDP per capita, forest area to GDP per capita, and freshwater withdrawals to forest area. The study recommends the sustainable use of resources in order to achieve low emissions.

Keywords: *Greenhouse gas emission, ecological environment, renewable energy and climate change*

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) Working Group I report (2021), the global temperature is expected to reach 1.5^{o}c of warming in the next decades if the necessary steps to reduce emissions are not implemented. Almost 35.4 percent of the population in sub-Saharan Africa live on $2.15 per day (World Bank, 2019). Given the poverty and economic and political situation in Africa, environmental shocks such as natural disasters and extreme weather conditions will likely worsen the situation. Greenhouse gas emissions contribute significantly to global warming, and the failure to control emission levels might destroy the ecosystem (Lawrence et al., 2022). Africa boasts a diverse ecosystem and abundant natural resources. The agricultural sector plays a significant role in the GDP of most African countries. While agricultural activities contribute to economic growth, they also release greenhouse gases and contribute to environmental degradation (Selcuk et al., 2021). Among African countries, South Africa and Nigeria have the highest emissions due to their continued reliance on fossil fuels for industrial and household use. Figure 1 shows that the emission figures in Africa continue to increase steadily. The heightened vulnerability of Africa to climate change demands concern from pertinent stakeholders, warranting attention to address the consequential challenges.

Africa has many forest types, such as montane forests, dry forests, mangroves, and tropical rainforests. These woods provide numerous ecological services, including soil protection, water management, carbon sequestration, biodiversity preservation, and support for the livelihood of indigenous residents. The forest cover in Africa is essential to the overall environmental quality of the continent. Simultaneously, Africa faces pronounced ecological degradation with multifaceted causes and consequences impacting both local and global environments. A primary driver is deforestation, prominently contributing to forest degradation on the continent. The permanent conversion of forest land to non-forest uses, such as mining, logging, agriculture, and urbanization, is called deforestation. Numerous plant and animal species, many of which are endemic—found nowhere else on earth—can be found in forests. Forest degradation results in the release of stored carbon into the atmosphere as carbon dioxide, amplifying greenhouse gas emissions. The depletion of African forests exacerbates the repercussions of global warming and climate change. Freshwater withdrawals are essential to Africa's water management and sustainability. Poor water management causes significant risks to food production and economic development. Freshwater supply, access, and utilization are significant challenges for the region. Due to rapid urbanization, the increasing demand for water in cities has strained available water supplies. In addition, industrial processes like mining and manufacturing need large volumes of water, which results in large withdrawals from freshwater sources. The limited availability of environmentally friendly technologies further exacerbates environmental pollution in Africa. Industrialization and the rapid growth of affiliated companies in low-income nations increase pollution due to increased economic activity and the prioritization of economic development. Capital-intensive industries are deemed to be highly polluting, and capital-rich countries (developed countries) enjoy a comparative advantage in the manufacture of polluting commodities (Mirziyoyeva1 and Salahodjaev, 2023; Christoforidis & Katrakilidis, 2021). Switching from non-renewable to renewable energy is essential in reducing environmental pollution (Mahalik et al., 2020).

Based on the EKC hypothesis, environmental deterioration worsens initially but improves over time as a country's income per capita rises, generating an inverted U-shaped curve. The EKC framework predicts that people will seek healthier and more sustainable conditions as income grows. Initially, pollution levels tend to rise when a country experiences industrialization and economic growth due to expanding industries and natural resources. However, countries can allocate more funds to environmental protection measures as economies improve and invest in environmental laws and regulations. This allows for the use of technology to reduce pollutants, which slows down ecological degradation. Diverse empirical studies have explored the Environmental Kuznets Curve (EKC) hypothesis across various countries and regions. The consistent findings reveal an inverted U-shaped relationship between pollution and income levels, substantiating the validity of the EKC hypothesis. For instance, Jalil and Mahmud (2009) observed a positive association with income and a negative correlation with the quadratic income term, affirming the EKC hypothesis in China. Similarly, Osabuohien et al. (2014) affirmed the EKC hypothesis in Africa. Notably, Kostakis et al. (2023) further confirmed the EKC hypothesis with an inverted U-shaped relationship. These collective outcomes underscore the widespread acknowledgment of the EKC hypothesis in diverse global contexts.

Few studies have been conducted regarding the nexus between resource utilization and the ecological environment in Africa. In addition, limited studies have included freshwater withdrawals and forest areas in their studies and the EKC hypothesis. Therefore, the present study seeks to fill this gap and contribute significantly to the existing literature. In light of the aforementioned information, we pose the following research inquiries:

- What impact does renewable energy consumption have on the ecological environment in Africa?
- How is the relationship between freshwater withdrawals and the ecological environment in Africa characterized?
- To what extent does an expansion of forest area mitigate ecological environment degradation?

To achieve this objective, we test for cointegration using the Pedroni (1999, 2004) cointegration test. Subsequently, we employ the Fully Modified Ordinary Least Squares (FMOLS) method to establish an enduring relationship among the study variables, followed by utilizing the Pairwise causality test to determine causality direction. This study will provide policymakers and the relevant stakeholders with empirical evidence and recommendations on the emission situation in Africa. The subsequent sections are structured as follows: Section 2 delves into the literature review, while Section 3 provides a detailed overview of the data and methodology employed in the study. In section 4, we present the empirical results. Finally, section 5 states the conclusion with policy recommendations.

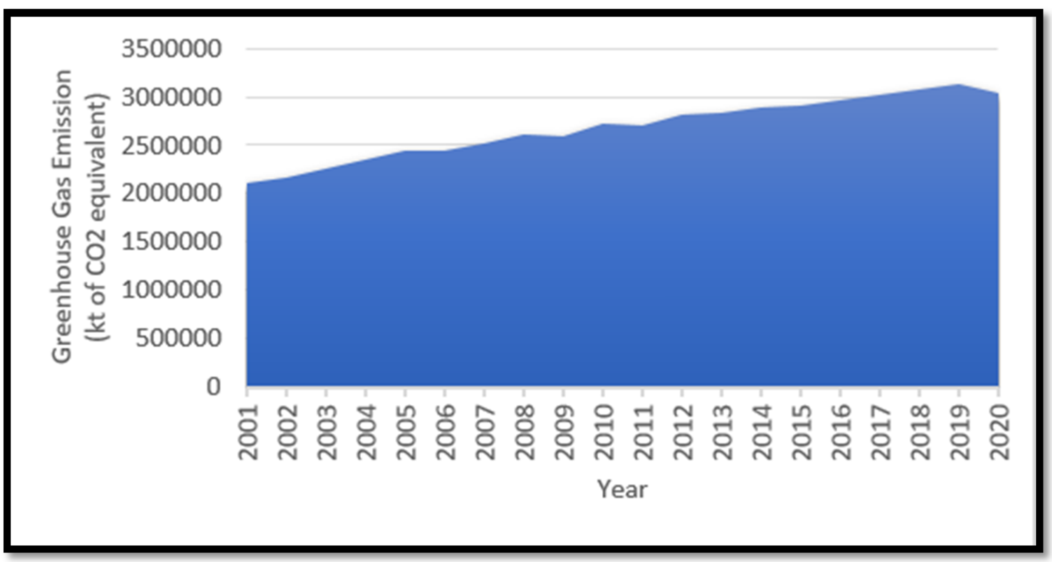

Figure 1: Greenhouse Gas Emissions in Africa from 2001 to 2020

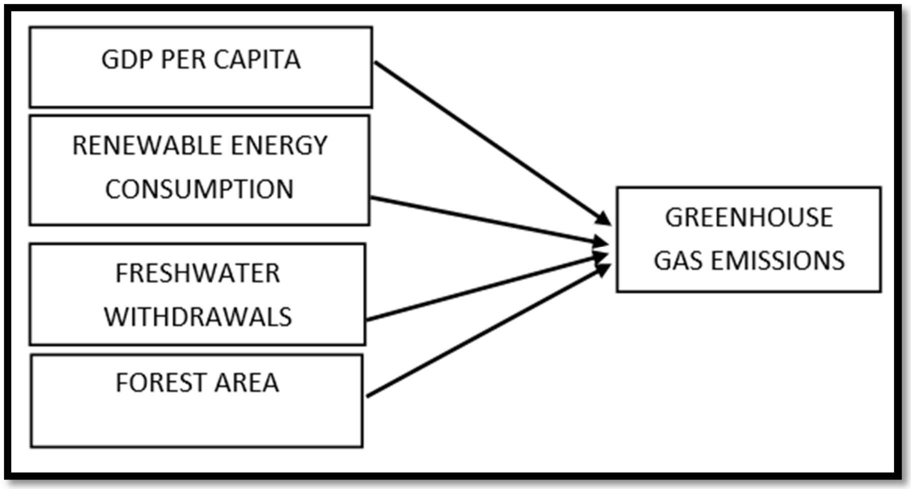

Figure 2: Conceptual Framework

2. Literature Review

The literature review encompasses numerous empirical research papers exploring the interconnections among GDP per capita, renewable energy consumption, freshwater withdrawals, forest areas, and greenhouse gas emissions. These empirical studies are categorized to facilitate a thorough comprehension of the relationships among the variables.

2.1. GDP Per Capita and Greenhouse Gas Emissions

Sarkodie and Adams (2018) supported the EKC hypothesis in South Africa. The study found that developing economies emit more to expand their economy and later adopt environmentally friendly approaches after achieving a certain level of economic growth. Murshed et al. (2021) affirmed the Environmental Kuznets Curve (EKC) hypothesis for Bangladesh in alignment with prior investigations in this domain. The investigation disclosed that Bangladesh's anticipated growth has not surpassed the real GDP per capita threshold, suggesting a trade-off between environmental degradation and economic advancement. Jaunky (2011) analyzed data from 36 high-income countries (1980-2005), discovering a unidirectional causal link from GDP per capita to CO_2 emissions. In a broader scope, Fávero et al. (2022) utilized panel data from 187 countries, employing a multilevel model to scrutinize the interplay between economic growth and CO_2 emissions. Collectively, these studies contribute valuable insights into the intricate dynamics of environmental consequences tied to economic progress. The study revealed a positive signal of the parameters that measure the impact of linear and cubic income on CO_2 emissions. Moreover, the findings indicated that a percentage rise in GDP correlates with a 2.24 percent increase in CO_2 emissions.

In their 2022 study, Onofrei et al. employed the dynamic ordinary least squares (DOLS) method to scrutinize the correlation between economic growth and CO_2 emissions in EU countries. The results affirmed a sustained relationship between economic growth and CO2 emissions over the long term. Furthermore, the study detected a statistically significant and positive association between economic growth and CO_2 emissions. Meanwhile, Patiño et al. (2020) investigated the interplay of energy, CO_2 emissions, and GDP per capita in Colombia, revealing a positive coefficient for GDP per capita. This implies that an upsurge in GDP per capita corresponds to an escalation in environmental pressure. Likewise, Yusuf et al. (2020) identified a positive link between economic growth and CO_2 emissions in their study.

2.2. Renewable Energy Consumption and Greenhouse Gas Emissions

In their 2022 research, Chen et al. investigated the correlation between renewable energy and CO_2 emissions using a panel threshold model. Findings indicated a negative impact of renewable energy on CO_2 emissions when countries surpass a specific threshold of renewable energy consumption. Similarly, Rahman et al. (2022) employed the non-linear autoregressive distributed lag (NARDL) method and a pooled mean group (PMG) estimation approach to examine the asymmetric connections among renewable energy, technological innovation, and export quality in relation to CO_2 emissions. The study found a bidirectional causal relationship between renewable energy and CO_2 emission. Shobande et al. (2023) investigated the impact of the emission trading system and energy transition on carbon intensity and reported that investments in renewable energy can significantly reduce CO_2 emissions. Likewise, Chen et al. (2018) advocated the essential role of renewable energy in mitigating CO_2 emissions in China.

2.3. Freshwater Withdrawals and Greenhouse Gas Emissions

In their 2021 research, Tian et al. employed a multiregional input-output (MRIO) approach to scrutinize the interconnection among water consumption, energy utilization, and carbon emissions in China. The authors highlighted the intertwined relationship between water usage and energy. Furthermore, they noted that unsustainable water consumption and high carbon emissions are predominantly observed in developing nations, exerting adverse environmental impacts. Similarly, Zhang et al. (2020) investigated the correlation between embodied water usage and greenhouse gas emissions in China, establishing a robust association between water consumption and greenhouse gas emissions. Poor management of water sources due to human activities significantly degrades the ecological environment

(Albert et al., 2020). Nair et al. (2014) determined that heightened demand for quality water results in increased withdrawals and disposal, consequently escalating greenhouse gas emissions.

2.4. Forest Area and Greenhouse Gas Emissions

Employing the Autoregressive Distributed Lag (ARDL) bounds test, and the Dynamic Ordinary Least Squares (DOLS) method, Raihan and Tuspekova (2022) demonstrated that a 1% expansion in forest area could lead to a 4.29% reduction in emissions. The author recommended that sustainable forest management policies reduce emissions. Toledo et al. (2022) highlighted that nations must reduce total dependence on forests since all activities reduce the forest cover, which degrades the ecological environment. In a separate investigation, Raihan et al. (2023) scrutinized the dynamic connections between environmental factors and CO2 emissions in Thailand through the dynamic ordinary least squares (DOLS) method. Results indicated that a 1% rise in forest area could potentially decrease CO2 emissions by 0.69%. The study further reveals that CO2 emissions can be reduced through forest development. Springgay et al. (2019) suggested that a reduction in the forest cover could increase erosion and ecological degradation, which harms water quantity and quality.

3. Data and Methodology

We employed different approaches to analyze the nexus between resource utilization and greenhouse gas emissions in 23 selected countries in Africa which includes Angola, Botswana, Cameroon, Democratic Republic of Congo, Egypt, Ethiopia, Gabon, Ghana, Ivory Coast, Kenya, Libya, Morocco, Mozambique, Niger, Nigeria, Republic of Congo, Senegal, South Africa, Sudan, Tanzania, Tunisia, Uganda and Zambia. These countries show high emission values with a sufficient amount of data for the period used in the study. Five variables, including greenhouse gas emissions (dependent variable), GDP per capita, renewable energy consumption, freshwater withdrawals, and forest area (independent variables), were selected for our analysis. Previous studies, in addition to the environmental situation in Africa, influenced our choice of variables. Our dataset from 2001 to 2020 was retrieved from the World Bank (2023) website. Table 1 shows a brief description of our dataset.

Abbreviations	Variable Name	Unit	Source
GHG	Greenhouse Gas Emissions	kt of CO2 equivalent	World Bank (2023)
GDPPC	GDP Per Capita	constant US $	World Bank (2023)
REN	Renewable Energy Consumption	% of total final energy consumption	World Bank (2023)
WTR	Annual Freshwater withdrawals	billion cubic meters	World Bank (2023)
FTR	Forest Area	square kilometers	World Bank (2023)

Table 1: Indicators and Units of Measurement

3.1. Model Specification

Utilizing the Fully Modified Ordinary Least Squares (FMOLS) method, the investigation explored the enduring association among GDP per capita, renewable energy consumption, freshwater withdrawals, forest area, and greenhouse gas emissions across 23 African nations.

The current study applies the model of Raihan et al. (2023) and Bekun et al. (2018) to accomplish the objectives. Additionally, our model uniquely incorporated freshwater withdrawals (WTR). Thus, the model is expressed as:

$GHG_{it} = f\,(GDPPC_{it}, GDPPC^2_{it}, REN_{it}, WTR_{it}, FRT_{it})$ (1)

In equation 1, GHG = Greenhouse Gas Emissions, GDPPC = GDP Per Capita, REN = Renewable Energy Consumption, WTR = Freshwater Withdrawals, and FRT = Forest Area. The following equation represents the empirical model:

$\mathrm{GHG_{it}} = \beta_0 + \beta_1 \mathrm{GDPPC_{it}} + \beta_2 \mathrm{GDPPC^2{}_{it}} + \beta_3 \mathrm{REN_{it}} + \beta_4 \mathrm{WTR_{it}} + \beta_5 \mathrm{FRT_{it}} + \mu_{it}$ (2)

We transformed the selected variables into natural logarithms to achieve a constant variance. The transformed equation is expressed as follows:

$\mathrm{lnGHG_{it}} = \beta_0 + \beta_1 \mathrm{lnGDPPC_{it}} + \beta_2 \mathrm{lnGDPPC^2{}_{it}} + \beta_3 \mathrm{lnREN_{it}} + \beta_4 \mathrm{lnWTR_{it}} + \beta_5 \mathrm{lnFRT_{it}} + \mu_{it}$ (3)

where: i = 1, …, N representing each country in the panel, t = 1, …, T indicates the time, and μ_{it} represents the error term. β_0 is the constant term, β_1, β_2, β_3, β_4 and β_5 represent the estimated coefficients such as lnGDPPC, $lnGDPPC^2$, lnREN, lnWTR and lnFRT, respectively. The expected sign for GDPPC and WTR is positive. Anticipated signs for $GDPPC^2$, REN, and FRT are negative, with expected outcomes for β1 and β2 validating the Environmental Kuznets Curve (EKC) hypothesis. A positive β1 and negative β2 signify an inverted U-shaped curve in environmental degradation.

The panel FMOLS estimator for the coefficient β is

$\hat{\beta} = N^{-1}\sum_{i=1}^{N}\left(\sum_{t=1}^{T}(y_{it} - \bar{y})^2\right)^{-1}\left(\sum_{t=1}^{T}(y_{it} - \bar{y})^2\right) z_{it}^{*} - T\hat{\eta}_i$ (4)

Where $z_{it}^{*} = (z_{it} - \bar{z}) - \frac{\hat{L}_{21i}}{\hat{L}_{22i}} \triangle\, y_{it}$, $\hat{\eta}_i = \hat{\Gamma}_{21i} + \hat{\Omega}_{21i}^{0} - \frac{\hat{L}_{21i}}{\hat{L}_{22i}}\left(\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^{0}\right)$ *and* $\hat{L}_i$ is a lower triangular decomposition of $\hat{\Omega}_i$. The associated t-statistic is stated as follows:

$t_{\beta^*} = N^{-1/2}\sum_{i=1}^{N} t_{\beta^*,i}$ where $t_{\beta^*,i} = \left(\hat{\beta}_i^{*} - \beta_0\right)[\hat{\Omega}_{11i}{}^{-1}\sum_{t=1}^{T}(y_{it} - \bar{y})^2]^{\frac{1}{2}}$ (5)

3.2. Methodology

The study proposes the following econometric techniques to analyze our data. The initial phase involves assessing stationarity and determining integration orders through the Im, Pesaran, and Shin (IPS) (2003) test and the Augmented

Dickey and Fuller (ADF) (1979) test for each variable. Subsequent steps entail cointegration testing utilizing the Pedroni (1999, 2004) method, revealing long-run equilibrium relationships among study variables. Additionally, the study employs the Fully Modified Ordinary Least Squares (FMOLS) method to discern the impact of independent variables on the dependent variable. Furthermore, the investigation employs the Pairwise test to evaluate the direction of causality between variables, ensuring a comprehensive analysis of the relationships under consideration.

4. Empirical Results

4.1. Summary Statistics and Correlation Analysis

Table 2 displays the descriptive statistics and correlation matrix for the study variables. The average greenhouse gas emissions is 10.870, with a minimum value of 9.075 and a maximum of 13.228. The mean value of GDP Per Capita is 7.338, with a maximum and minimum value of 9.527 and 4.705, respectively. Renewable energy consumption (3.781) accounts for the lowest mean value, and freshwater withdrawals (21.448) record the highest mean value. Forest area accounts for the highest standard deviation at 1.850, while greenhouse gas emissions record the lowest standard deviation at 0.975. The results further indicated that GDP per capita, renewable energy consumption, freshwater withdrawals, and forest area show a negative skewness, while greenhouse gas emission demonstrates a positive skewness.

The correlation matrix results revealed a robust positive correlation (0.803) between freshwater withdrawals and greenhouse gas emissions. GDP per capita exhibited a weak positive association (0.179), while renewable energy consumption displayed a moderate negative correlation (0.411) with greenhouse emissions. Additionally, forest area indicated a weak negative correlation (0.170) with greenhouse gas emissions.

Variables	LNGHG	LNGDPPC	LNREN	LNWTR	LNFRT
Mean	10.870	7.338	3.781	21.448	11.372
Median	10.744	7.338	4.280	21.176	12.062
Maximum	13.228	9.527	4.588	25.074	14.175
Minimum	9.075	4.705	0.837	17.635	6.109
Std. Dev.	0.975	1.046	0.998	1.668	1.850
Skewness	0.592	-0.062	-1.434	-0.167	-1.081
Kurtosis	2.682	2.357	3.862	2.911	3.729
Probability	0.000	0.016	0.000	0.318	0.000
Observations	460	460	460	460	460
Correlation Matrix					
LNGHG	1.000				
LNGDPPC	0.179	1.000			
LNREN	-0.411	-0.673	1.000		
LNWTR	0.803	0.037	-0.449	1.000	
LNFRT	-0.170	-0.317	0.677	-0.391	1.000

Table 2: Summary Statistics and Correlation Matrix
Source: Authors' Estimation Using EVIEWS 10

4.2. Unit Root Test

In this study, two types of unit root tests, the Im, Pesaran, and Shin (IPS) (2003) test and the Fisher-Augmented Dickey and Fuller (ADF) (1979) test, are employed. These tests assume variable autocorrelation coefficients vary across cross-sections based on individual unit root processes. Table 3 illustrates the results of the IPS and ADF unit root tests, indicating that greenhouse gas emissions, GDP per capita, renewable energy consumption, freshwater withdrawals, and forest area are all stationary at the first difference, with a significance level of 1%.

	ADF		IPS	
Variables	Level	1st difference	Level	1st difference
LNGHG	45.12	170.50***	0.96	-9.04***
LNGDPPC	101.57**	114.82***	-4.81**	-5.48***
LNREN	36.10	126.49***	0.54	-6.37***
LNWTR	162.40*	80.25***	-6.36**	-3.74***
LNFRT	1353.22**	1084.70***	-270.57*	-268.82***

Table 3: Panel Unit Test Results
*Note: *** Indicates Significance at a 1% level.*
Source: Authors' Estimation Using EVIEWS 10

4.3. Cointegration Test

The findings from table 4, displaying results from the Pedroni (1999, 2004) panel cointegration test, assess the cointegration of specified panel data. Utilizing four within-dimension and three between-dimension test statistics, it is found that six out of eleven exhibit significance at the 1% level. These results affirm the presence of a long-run relationship among study variables, rejecting the null hypothesis of no cointegration.

Alternative Hypothesis: Common AR Coefficients. (Within-Dimension)				
	Statistic	Prob.	Weighted Statistic	Prob.
Panel v-Statistic	-5.9522	1.0000	-4.1397	1.0000
Panel rho-Statistic	1.3046	0.9040	2.0706	0.9808
Panel PP-Statistic	-7.2200	0.0000***	-8.1023	0.0000***
Panel ADF-Statistic	-7.4319	0.0000***	-8.0752	0.0000***
Alternative Hypothesis: Individual AR Coefficients. (Between-Dimension)				
	Statistic		Prob.	
Group rho-Statistic	3.4516		0.9997	
Group PP-Statistic	-11.0049		0.0000***	
Group ADF-Statistic	-8.4194		0.0000***	

Table 4: Pedroni Cointegration Test Results
*Note: *** Represents the Rejection of the Null Hypothesis at 1% Significance Level*
Source: Authors' Estimation Using Eviews 10

4.4. Fully Modified Ordinary Least Squares (FMOLS) Regression

Table 5 displays long-run estimates investigating the relationship between GDP per capita (GDPPC), renewable energy consumption (REN), freshwater withdrawals (WTR), forest area (FRT), and greenhouse gas (GHG) emissions. FMOLS results reveal that a 1% GDPPC increase corresponds to an 87.75% emission rise, and a 1% renewable energy consumption increase leads to a 58.51% emission reduction, corroborated by Szetela et al. (2022). The findings indicate a significant long-term emission increase with GDPPC growth. Additionally, the positive sign for GDP per capita and negative for GDP per capita squared align with the Environmental Kuznets Curve (EKC) hypothesis, supporting the notion that environmental degradation initially rises but eventually declines with economic development. This discovery is consistent with the findings of Ekueme and Zoaka (2020), Bekun et al. (2021), and Jalil and Mahmud (2009). Based on data, renewable energy consumption in Africa has increased significantly, but there are still areas in the region without access to electricity. In this regard, more investments are needed in renewable energy technologies to ensure the sustainable usage of renewable energy. The significant positive result for freshwater withdrawals at the 1% significance level suggests that a 1% increase in withdrawals elevates emissions by 16.93%, aligning with findings in Zhang's (2020) study. Water is essential in energy generation, especially hydroelectricity, which is common in Africa. The relationship between water withdrawals and emissions is positively linked. This means that as more water is withdrawn, emission levels increase due to hydropower generation, which requires a considerable volume of water. The relationship between forest area and GHG emissions is negative and significant; a 1% increase in the forest area brings about a 13.24% reduction in emissions, which is validated by Raihan and Tuspekova (2022). In recent years, Africa has faced a significant reduction in its forest cover due to deforestation and natural disasters. Hence, the conservation and protection of the forest will help reduce emissions and climate shocks in the region. The forest area can be expanded through the planting of trees because as the forest expands, more trees are available to absorb carbon dioxide, hence lowering emissions in the atmosphere.

Variable	Coefficient	Standard Error	t-Statistic	Probability
LNGDPPC	0.8775	0.0623	14.0767	0.0000***
LNGDPPCSQ	-0.0509	0.0046	-11.0817	0.0000***
LNREN	-0.5851	0.0330	-17.7126	0.0000***
LNWTR	0.1693	0.0187	9.0478	0.0000***
LNFRT	-0.1324	0.0464	-2.8521	0.0046***
R-squared	0.9891			
Adjusted R-squared	0.9884			

Table 5: Results of the Fully Modified Ordinary Least Squares (FMOLS) Method
*Note: *** Denotes Statistical Significance at the 1% Level*
Source: Authors' Estimation Using EVIEWS 10

4.5. Causality Test

Table 6 displays the outcomes of the panel Pairwise causality test. This investigation reveals unidirectional causal links: from GDP per capita to greenhouse gas emissions (LNGDPPC→LNGHG), freshwater withdrawals to GDP per capita (LNWTR→LNGDPPC), forest area to GDP per capita (LNFRT→LNGDPPC), and freshwater withdrawals to forest area (LNWTR→LNFRT). A bidirectional causality exists between renewable energy consumption and greenhouse gas emissions (LNREN↔LNGHG) and renewable energy consumption and GDP per capita (LNREN↔LNGDPPC). This bidirectional causality underscores the role of renewable energy in emissions mitigation and the reciprocal impact of emissions on renewable energy sources. Furthermore, the findings affirm that GDP per capita escalation leads to increased emissions.

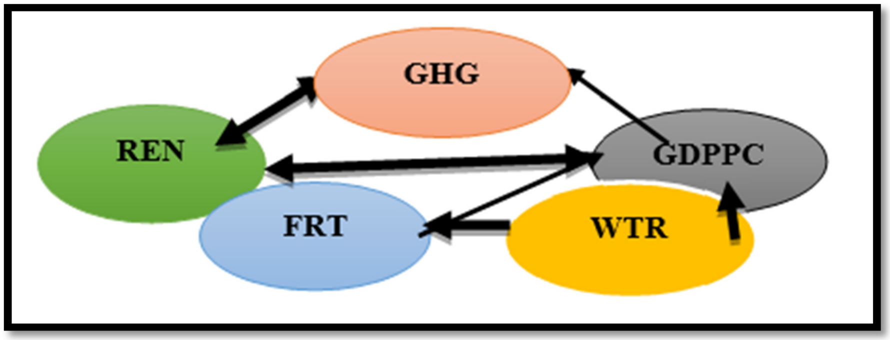

Figure 3: Direction of Causality

Null Hypothesis	F-Statistic	Prob.	Direction of Causality
LNGDPPC does not Granger Cause LNGHG	2.9078***	0.0059	LNGDPPC→LNGHG
LNGHG does not Granger Cause LNGDPPC	0.8482	0.5482	
LNREN does not Granger Cause LNGHG	3.1239***	0.0034	LNREN↔LNGHG
LNGHG does not Granger Cause LNREN	1.8077*	0.0856	
LNWTR does not Granger Cause LNGHG	0.7497	0.6300	LNWTR≠LNGHG
LNGHG does not Granger Cause LNWTR	0.1574	0.9929	
LNFRT does not Granger Cause LNGHG	0.0431	0.9999	LNFRT≠LNGHG
LNGHG does not Granger Cause LNFRT	0.0527	0.9998	
LNREN does not Granger Cause LNGDPPC	2.4444**	0.0190	LNREN↔LNGDPPC
LNGDPPC does not Granger Cause LNREN	3.4668***	0.0014	
LNWTR does not Granger Cause LNGDPPC	6.2522***	0.0000	LNWTR→LNGDPPC
LNGDPPC does not Granger Cause LNWTR	0.9411	0.4750	
LNFRT does not Granger Cause LNGDPPC	14.6244***	0.0000	LNFRT→LNGDPPC
LNGDPPC does not Granger Cause LNFRT	0.9826	0.4440	
LNWTR does not Granger Cause LNREN	0.6470	0.7168	LNWTR≠LNREN
LNREN does not Granger Cause LNWTR	0.3847	0.9110	
LNFRT does not Granger Cause LNREN	0.3683	0.9203	LNFRT≠LNREN
LNREN does not Granger Cause LNFRT	0.8376	0.5569	
LNFRT does not Granger Cause LNWTR	0.1021	0.9982	LNWTR→LNFRT
LNWTR does not Granger Cause LNFRT	3.8988***	0.0004	

Table 6. Pairwise Granger Causality Test Results
*Note: ***, **, and * Denote 1%, 5%, and 10% Significance Level, Respectively. → Represents Unidirectional Causality, ↔ Indicates Bidirectional Causality and ≠ Denotes No Causality*

5. Conclusion and Recommendations

This study investigates the interplay between resource utilization and the ecological environment in 23 African countries from 2001 to 2020. Utilizing the FMOLS approach, we analyze the enduring relationship between dependent and independent variables. Findings indicate positive impacts of GDP per capita and freshwater withdrawals on greenhouse gas emissions, while increased renewable energy consumption and forest area correlate with reduced emissions. All independent variables exhibit significance at the 1% level, emphasizing their substantial influence on greenhouse gas emissions in the examined African countries.

The research identifies unidirectional causality from GDP per capita to greenhouse gas emissions, freshwater withdrawals to GDP per capita, forest area to GDP per capita, and freshwater withdrawals to forest area. A bidirectional causal relationship exists between renewable energy consumption, greenhouse gas emissions, and GDP per capita. The positive signs for freshwater withdrawals and GDP per capita suggest that economic growth, coupled with heightened water withdrawals for industrial and household needs, contributes to elevated emission levels in the 23 selected African countries. Therefore, the sustainable management and utilization of water resources should be advocated by the relevant stakeholders. Conversely, the negative sign of renewable energy consumption and forest area indicates that these factors contribute to the reduction of emissions in Africa. Given the findings from our empirical study, we formulated the following recommendations:

- Renewable energy usage is essential in reducing emissions. Hence, investment in renewable energy facilities such as wind and solar power will increase access to clean energy in Africa. Public-private partnerships can facilitate the transmission and utilization of renewable energy technologies with adequate funding and technical assistance. Additionally, the relevant stakeholders should formulate transparent and concise policies that will attract investors to the renewable energy sector, thus accelerating growth in the sector.
- The sustainable preservation of the remaining forest area in Africa is crucial in addressing climate change. To achieve this goal, stakeholders should develop and implement feasible environmentally friendly initiatives such as

reforestation, afforestation, and responsible logging. The government should provide funding and technical support to the responsible authorities to facilitate forest conservation programs. Additionally, stakeholders are tasked to enforce existing legal frameworks and formulate new ones to conserve and expand the forest area sustainably.

- Stakeholders should invest in water-saving technologies and infrastructure, such as water treatment and storage plants, which are crucial in sustainable water management. Similarly, researchers can develop sustainable water management technologies through research and innovation.

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