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Dynamic Modelling of Renewable Energy Consumption and Production on African Economic Growth and the Environment Using Vector Error Correction Models

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Abstract Prior research has explored the influence of renewable consumption on economic growth and carbon emissions (CO_2), but few studies have examined the impact of both renewable energy consumption (REC) and renewable energy production (REP) on economic growth and CO_2 emissions in Africa. The objective of this work is to dynamically estimate the effects of both REC and REP on economic growth and CO_2 emissions in Africa, based on empirical evidence and using a data set from the years 1965 to 2020. This research aims to determine how REC and REP affect the economies and ecosystems of Africa. The Error Correction Models (ECMs) were utilized in the analysis, focusing on how REP and REC influence economic growth and environmental carbon dioxide emissions (CO_2). Vector Error Correction Models (VECM) and Johansen cointegration methods were used on the data set. The results demonstrated that economic forces existed between the variables and that there was a long run equilibrium relationship between GDP and CO_2 emissions in Africa, from REC to REP. Additionally, the outcomes showed that both REC and REP slowed down environmental deterioration while promoting economic growth. Africa can lower the negative impacts of environmental pollution caused by the consumption of non-renewable energy sources by adopting and aggressively promoting renewable energy production and utilization.

Keywords Cointegration; renewable energy; economic growth; energy consumption; energy production; CO_2 emissions

Mathematics Subject Classification 62J02, 91B84

1 Introduction

Energy is essential for the continuing growth and advancement of nations. Specifically, both renewable energy and energy from fossil fuels such as coal have been demanded on a regional and global scale. However, the expansion of energy-consuming activities in Africa and the rest of the world has given rise to two major issues: the problem of global warming caused by the exponentially increasing emissions of greenhouse gases such as carbon dioxide (CO_2) and pollutants; and the depletion of the most readily available energy resources (primarily fossil fuel). Due to the global scale of energy issues, renewable energy sources must receive the optimum utilization they merit. Renewable energy is obtained from natural resources such as the sun, wind, geothermal heat, tides and waves, biomass, and wood. In contrast to conventional energy sources, renewable energy is not only ecologically good but also fully risk-free and virtually endless. According to forecasts, renewable energy will eventually surpass several traditional energy sources and take the lead in terms of global energy consumption share. In China, for example, the output of wind power has overtaken that of nuclear power and is expanding at a faster rate than that of coal [1].

Global communities, regions, governments, and transnational regulatory agencies are integrating renewable energy sources (RES) into the global energy infrastructure [2]. Because of the scarcity of fossil fuel energy sources, there is a growing demand for new technologies and RE sources [3]. Renewable energy sources, such as solar, hydro, and wind, are highly correlated with economic expansion [4]. Due to environmental concerns, businesses and governments must make substantial investments in renewable energy research [5, 6]. Renewable energy contributes to achieving the contemporary goals of lowering carbon dioxide emissions and mitigating the effects of climate change, as well as ensuring long-term energy security and stability without harming the environment [7]. The category of modern sources excludes resources derived from fossil fuels and other inorganic sources, including biomass (organic material) [8]. Biofuels were created because of a global effort to identify alternative energy sources. In terms of both supply and efficiency, they compete with fossil fuels. There are numerous compelling reasons to invest in renewable energy, including environmental benefits that are closely correlated with long-term growth [9]. The term ”sustainability” was coined because ecology has shown that ecosystems may return to normal operation in the face of societal and environmental shocks. The depreciation of natural resources is explicable by economic ideas [10]. Research into RES is required as a potential solution to the global problem of meeting energy demand without harming the environment.

Energy security and economic stability have been key issues for governments, technologists, and thinkers in numerous regions and nations [11]. Both the Kyoto Protocol and the Paris Climate Change Conference attempted to limit global warming to 2°C by reducing CO2 emissions and greenhouse gases (GHGs) [12]. To achieve this goal, a greater proportion of renewable energy sources must be utilized. Electricity was the industry that utilized renewable energy sources the most, with almost 26.4%. The 2019 publication of the ”UNESCO carbon emission gap report” recommended governments and regions set more ambitious renewable energy development goals. The Africa Renewable Energy Initiative also commits to providing policy direction in terms of achieving these goals for optimizing RE use [6]. If further RE map alternatives are to be introduced by 2030, all renewable energy technologies will need to expand substantially [14]. Wind turbines and solar PV, on the other hand, would grow at least five- and twelvefold, respectively, between now and 2030, adding between 70 and 60 GW of new capacity each year. It is becoming increasingly evident that wind and solar energy are the future of the world’s energy supply. This is excellent news for Africa, as a few are rising and expanding economies. Notably, China is increasing its real estate investments [13].

The development of consumption and production of renewable energy is more vital and urgent than in any other emerging region. Africa is the region most severely affected by climate change. Initially, the African continent is well-positioned for the transition to RES, particularly in hydroelectricity. Africa possesses a total theoretical capacity of 470000 TWh for concentrated solar power, 660000 TWh for photovoltaics, and 460000 TWh for wind. Africa has more severe energy issues than other nations and areas due to a shortage of electricity. Around 600 million Africans still do not have access to electricity [14-17]. Africa is home to most of the world's population that does not have access to electricity. It is essential to invest in renewable energy to address the expanding demand for clean energy in Africa. Numerous experts believe that the solution to Africa's significant problem of excessive electricity consumption lies in the development of renewable energy sources. This research hopes to utilize renewable energy resources to facilitate economic growth and development in Africa. Nonetheless, there are still several practical obstacles to facilitating this. Renewable energy, socioeconomic development, and the innovative process can only be researched if an empirical foundation is established that includes essential scientific studies and reflects Africa's current state of knowledge.

Consequently, the objectives of this study work are as follows: To investigate the relationships between renewable energy production, consumption, carbon emissions, and economic growth in Africa, to determine whether there are any correlations between the variables, such as whether renewable energy consumption and production influence economic growth and ecology in Africa as a whole and vice versa and to find the best error correction model to determine the impact of REC and REP on the continent's economic growth and CO_2 emissions. Innovativeness consists of using empirical evidence to fill the existing gaps in the literature and studies on whether there is a relationship between REC, REP, carbon emissions, and economic growth in Africa and selecting the best statistical model to model and examine these variables.

2 Literature Review

In empirical work, it is important to bear in mind that stationary variables will generate restricted cointegrating vectors. Thus, it is a standard practice in econometrics to always include tests on the cointegrating vectors to determine if appropriate limitations are rejected or not. If such restrictions are not examined, a non-zero cointegrating rank may be erroneously interpreted as evidence for cointegration between variables [18, 19]. This is especially significant when there are strong prior judgments regarding which variables "must" be in the cointegrating relationship. Cointegration approaches are prevalent in the statistical econometric literature, in which variables are subjected to test for reliable inferences. The assumption is that every time-variant variable should be I(1) or has a pure unit-root process that is stationary I(0). It is necessary to distinguish between I(1) and I(0) variables a priori to analysis to avoid erroneous inference [19].

While few studies have explored the relationship between REC, REP, and CO_2 emissions or economic growth, a great deal of study has focused on the interrelationship between energy use, renewable energy consumption, CO_2 emissions, and economic growth. Different econometric approaches demonstrate significant associations between REC and GDP growth. The following hypotheses can be derived from the findings: The most widely held belief is that increased energy consumption stimulates economic growth [20]. According to the second conservation hypothesis, a rise in economic output induces an increase in energy demand. In the third feedback hypothesis, there are two-way causal linkages between increased energy use and economic growth. And last, there is no presumption of causal direction (the neutrality hypothesis) [21].

There is less consensus regarding the relationship between energy consumption and economic growth, even though REP and REC might significantly reduce carbon dioxide emissions. The Environmental Kuznets Curve (EKC) hypothesis is being explored across countries utilizing everimproving econometric methodologies, and the relationship between GDP growth and CO_2 emissions has been examined on numerous occasions. Solar, wind, hydro, geothermal, and biomass are some of the sustainable energy sources gaining international attention. Population and energy demand are rising as fossil fuel supplies decrease. Experts must gain a better understanding of renewable energy's impact on economic growth and CO_2 emissions.

Some studies show a favorable correlation between energy use and economic growth. Growth, conservation, and bidirectional (feedback) hypotheses have been suggested. There are techniques for non-regime switching in panels, such as [22, 23]. These studies assume the linearity of the relationship, which means variables act identically regardless of regional industrial structure. For the growth hypothesis, most of the theoretical literature, such as [20, 23-26], believed that REC and REP should generate economic growth and improve environmental sustainability. Although some literature contradicted these relationships, which observed a negative relationship between REC and economic growth [28, 29], others observed a neutral relationship [30-32]. Economic growth and environmental studies have revealed positive relationships, such as [33-36] for negative relationships, [37-40] for neutral relationships, and [41, 42] for neutral relationships.

Renewable energy supposedly boosts the economy, and Africa has an abundance of renewable energy potential theoretically. Studies show energy use drives economic growth. Well-being and living standards affect economic output since some studies' analyses reported energy shocks could hurt the economy. This ignores renewables' flexibility to existing in this technological era. Excessive usage of traditional biomass fuels harms the economy and environment milder than expansion. Theoretically, growth drives energy demand, thereby increasing production and consumption, which enhances economic activity and production [43]. Consequently, Africa's oil-producing nations must invest in carbon-reduction technology [44]. Some empirical studies supporting these arguments are summarized in Table 1 for the African case.

According to Maji *et al.* [43], renewable energy affects economic progress in some African countries and can hamper economic growth. West African wood biomass is dominant, particularly in rural areas. Solar, wind, and hydropower are little used in West Africa. Cleaner technologies are recommended to maximize the RE benefits and minimize its problems [43] because RE is Eco-friendly [45]. Pedroni panel cointegration test shows long-term links in six Sub-Saharan African states from 1990 to 2015. The result reveals similar estimates of renewable and nonrenewable elasticity [45]. Nonrenewable energy lowers GDP and pollution [44]. Every country can use renewable energy to cut carbon emissions [22]. Shahbaz *et al.* [22] reexamined the influence of renewable energy on 38 countries' economies from 1990 to 2018. Renewable energy boosts the economy, capital, and labor since 58% of countries use renewable energy. Global cooperation agencies, energy organizers, governments, and linked organizations must expand renewable energy investment for low-carbon growth [22]. West Africa's renewable energy use and economic development from 1990 to 2018 were anticipated using panel estimates. RECs didn't affect economic growth (GDP) [46].

This study evaluates long-term linkages and causality, notably in REP and REC, so that RE is reexamined in Africa due to economic and population upheavals and environmental degradation. This study intends to investigate possible long-term linkages and causalities not addressed in previous studies, notably regarding renewable energy generation. Most literature studies opined that renewable resource usage drives economic growth and silence on renewable energy production, see Table 1. This study explores the nexus between renewable energy, REP, and REC. This is a unique study because it emphasizes the model selection, as well as the relationship between the variables, and many African studies disregard the energy production aspect of RE. The study makes significant contributions to having longer data than others and recently collected data to examine if REP and REC help economic growth and environmental sanitation in Africa. Africans have never adopted long-term strategies with clear data justifications.

Table 1: Summary of Some Reviewed Related Literature

Reference	Region	Period	Method	Findings
Shahbaz *et al.* [22]	38 countries	1990 – 2018	DOLS, FMOLS	RE has a beneficial effect on EG.
Nioh [23]	Africa	1990 – 2014	GLM	Hydroelectricity reduces environmental degradation, this increases REC
Maji *et al.* [43]	West Africa	1995 – 2014	DOLS	RE and Economic Growth have a negative association.
Awodumi and Adewuyi [44]	West Africa	1980 – 2012	Systematic Eqn. Models	There is a significant link between renewable energy and economic growth.
Vural [45]	6 African Countries	1990 – 2015	FMOLS	There is a positive link between renewable energy and economic growth.
Nathaniel *et al.* [46]	West Africa	1990 – 2018	Robust Panel Estimation	renewable energy consumption (REC) had no significant impact on economic growth (GDP)
Namahoro *et al.* [47]	50 African Countries	1980 – 2018	Panel estimation and causality tests	renewable energy consumption (REC) had no significant impact on economic growth (GDP)
Amri [48]	72 countries	1990 – 2012	DSE	Feedback link between renewable energy and economic growth.
Acaravci [51]	Turkey	1968-2005	VECM	Electricity generation is neutral to economic growth
Hondroyiannis *et al.* [52]	Greece	1960-1996	ECM	There is link between energy consumption and economic growth
Altinay and Karagol [53]	Turkey	1950-2000	ECM	Economic growth is neutral to energy consumption
Ang [54]	Malaysia	1974-1999	VECM	Economic expansion leads to increases energy consumption
Paul and Bhattacharya [55]	India	1950-1996	ECM	Economic growth causes energy consumption
Ang [56]	France	1960-2000	VECM	Economic growth Increases energy consumption
Lee and Chang [57]	Taiwan	1955-2003	VECM	Energy consumption causes economic growth
Akinlo [58]	Nigeria	1980-2006	VECM	Electricity consumption drives economic growth
Dagher and Yacoubian [59]	Lebanon	1980-2009	VECM	Economic growth Increases energy consumption and vice versa
Iyke [60]	Nigeria	1971-2011	VECM	Electricity consumption led economic growth
Odhiambo [61]	Tanzania	1971-2006	VECM	Electricity consumption increases economic growth
Wang [62]	China	1995-2007	VECM	Economic expansion and vice versa, increases energy consumption
Waheed [63]	Multi-countries	1980-2019	VECM	Energy consumption leads to economic growth increase
Kahauli [64]	South Mediterranean Countries	1995-2015	ARDL and VECM	The findings support cointegration of the variables which indicates the existence of the long-term partnership.
Hasan [65]	Bangladesh	1990-2016	VECM	Long-run causality observed from energy consumption to energy consumption and to GDP

3 Methodology

The aim of this study is to analyses the impact of REP, REC, CO2 on the growth of Africa economy and environment using unit root test, co-integration estimation technique and error correction models (ECM) using data set from 1965-2020.

3.1 Data Scope and Sources

Annual statistics for Africa were compiled from a variety of sources between 1965 and 2020, including the World Bank, the International Energy Agency, and other energy-related websites. This study examines the RE impact (wind, solar, geothermal, and biomass) on GDP and CO_2 emission. The study's hypotheses and assumptions were strengthened due to a large number of independent variables. The term is based on a well-known literary reference. The lists of the model's variables for the inferences and other statistics include REP: Renewable Energy Production (TWh), REC: Renewable Energy Consumption (TWh), CO_2: Carbon dioxide (Tones), and GDP: Chained Total GDP ($). The empirical model established in the study is VECM due to the nature of the variables involved and to test hypothesis on the long run association between these variables and short run. And this follows the unit root test hypothesis and Johansen Test: series are cointegrated at rank= 0,1,2,3 vs their respective alternatives.

3.2 VECMs and Model Specification

The nexus of the energy-growth-environment examined is represented by REC-REP-GDP-CO_2 (where REC, REP, GDP, and CO_2 denote renewable energy consumption, renewable energy production, gross domestic product, and carbon dioxide emission, respectively). These four variables will enter the system equation to be estimated simultaneously using the VECM model. In particular, the variables examined can be written as a vector y,

$$y_t = [REC_t, REP_t, GDP_t, CO_{2t}]' \,. \tag{1}$$

Multivariate time series models, including VECM (Vector Error Correction Modeling), are the most basic modeling strategy when dealing with non-stationary data. In cointegration research, the potential of VECMs is like the normal cointegration regression of known terms for independent and bound variables' (p), where p is the lag of endogenous variables with cointegration rank $r \leq k$ as in Equation (3) which derived from vector autoregression of order p written in Equation (2).

$$\Delta y_t = c + \phi_1 y_{t-1} + \ldots. + \phi_p y_{p-1} + u_t. \tag{2}$$

Equation (2) can be rewritten as Equation (3)

$$\Delta y_t = c + \mathit{\Pi} y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta \, y_{i-1} + u_t, \tag{3}$$

where

$$\begin{aligned} \Delta &: \text{differencing operator, implies } \Delta y_t = y_t - y_{t-1}, \\ y_{t-1} &: \text{vector variable endogenous with } 1^{st} \text{ lag}, \\ u_t &: \text{vector residuals}, \\ c &: \text{vector intercept}, \end{aligned} \tag{4}$$

$\mathit{\Pi}$: matrix coefficient of cointegration (rank matrix)

$$\mathit{\Pi} = -\sum_{i=1}^{p} \phi_i - I, \tag{5}$$

Γ_i : kxk matrix coefficient of the i^{th} endogenous variable

$$\Gamma_i = -\sum_{j=i+1}^{p} \phi_j. \tag{6}$$

When the cointegration relationship exists, Equation (3) can be rewritten as:

$$\Delta y_t = c + \alpha\beta' y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta \, y_{i-1} + u_t, \tag{7}$$

where $\beta' \, y_{i-1} = EC_{t-1}$ is the error correction term or the speed of adjustment, which captures the long-run equilibrium relationships of Equation (3). If the model is stable, the error correction term should be in negative value, i.e., 0<EC_{t-1}<-1, as a sign to show convergence to the equilibrium level. Then Equation (3) can be written as:

$$\Delta y_t = c + \alpha EC_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \, \Delta \, y_{i-1} + u_t. \tag{8}$$

Equation (8) is the vector error correction model (VECM). An error-correction representation of economic growth (GDP), the environment (CO2), or REP or REC function allows for adjustment towards long-run equilibrium caused by short-run disturbance. The error-correction term's statistical significance indicates that the long-run equilibrium relationship between the variables, which underlies the economic forces at play, is valid.

3.3 Unit-root and Cointegration Tests

In order to examine the existence of the cointegration relationship in the model, unit-root and cointegration tests are performed before the estimation of the model. The Augmented Dicky-Fuller (ADF) unit-root test is performed to examine the stationarity of variables based on the AR(1) process:

$$\Delta y_t = y_t - y_{t-1} = c + (\phi_i - 1) y_{t-1} + u_t, \tag{9}$$

which is equivalent to (10):

$$\Delta y_t = y_t - y_{t-1} = c + \propto_0 y_{t-1} + u_t, \tag{10}$$

where $\propto_0 = \phi_i - 1$. And the general AR(p) process can be reparametrized as Equation (11):

$$\Delta y_t = c + \propto_0 y_{t-1} + \propto_1 y_{t-1} + \cdots + \propto_{p-1} y_{t-(p-1)} + u_t, \tag{11}$$

where $y_{t-1}, \; y_{t-1} \ldots\ldots\ldots\ldots\ldots\ldots y_{t-1}$ are the series past values or lags, u_t: white noise and c: process mean. Equation (11) can be compressed as Equation (12) below:

$$\Delta y_t = c + \propto_0 y_{t-1} + \sum_{j=1}^{p-1} \propto_j y_{t-j} + u_t. \tag{12}$$

The unit-root test hypothesis $H_0 : \propto_0 = \phi_i - 1 = 0$: system has unit-root versus $H_0 : \propto_0 < 0$, H_0 can be tested with t-test based on critical value of t. [20, 21, 49,50, 66]. The rejection of the ADF test indicates that the series tested is stationary or integrated of order zero, I(0). If all variables are getting stationary after the first differenced, I(1), one might proceed to test for the cointegration test.

Johansen proposed two tests namely the trace test and maximum eigenvalue test showing in equation (13) and (14).

$$J_{trace} = -T \sum_{j=r+1}^{p} \ln(1 - \widehat{\lambda}_i), \tag{13}$$

$$J_{max} = -T \ln(1 - \widehat{\lambda}_{r+i}) , \tag{14}$$

where T is the series length and $\widehat{\lambda}_i$ the ith largest canonical correlation. Equation (13) can be tests the null hypothesis of r cointegrated series (vectors) against its alternative that their n cointegrated series. Equation (14) can be used for the maximum eigenvalue test, which, on the other hand, teststhe null hypothesis of r cointegrating series against the alternative hypothesis of $r < k$ cointegrating Series

4 Results and Discussion

Before conducting the estimation, unit-root and Johansen cointegration tests are performed. Unit-root tests show that all variables are stationary after the first difference. Next, the Johansen test is performed to detect the existence of the cointegrating relationship. The results are summarized in Table 2.

Table 2: Johansen Cointegration Test at 5% Level of Significance

Rank	Eigenvalue	Trace Test	Lmax Test	Corrected Trace Test
0	0.65440	83.329 [0.0000]	57.373 [0.0000]	83.329 [0.0000]
1	0.27791	25.956 [0.1337]	17.583 [0.1509]	25.956 [0.1610]
2	0.13052	8.3737 [0.4336]	7.5527 [0.4348]	8.3737 [0.4530]
3	0.01509	0.82100 [0.3649]	0.82100 [0.3649]	.82100 [0.3780]

Log-likelihood = −2734.79 (including constant term: −2888.04) and values in brace are P-values

The null hypothesis is tested on the number of ranks. At most rank=3, i.e., three possible relationships can be tested in the combination of variables. The results show that rank=0 is rejected, and the first null hypothesis that cannot be rejected is rank=1. Hence, there exists at most one long-run relationship in the system equation. Since the long-run relationship is detected, it is eligible to apply the VECM model. The estimates of the model are in Table 3.

Table 3 summarizes the short-run estimates while the long-run estimates are evident in one relationship, as observed in the significant coefficient of EC_{t-1} in the REC equation, which will be explained next. Now, for the short-run estimates, each variable is mainly determined by its own lag or historical movement. Also, energy production imposes negative impacts on energy consumption and CO_2 emissions in the short run. The result also shows that the error correction term is significant and in negative value, indicating the adjustment rate of 26% of REC in converging to the equilibrium level in the long-run.

Table 3: SLR Estimate of VECM (1)

VECM (1)	ΔREC_t	ΔCO_{2t}	ΔGDP_t	ΔREP_t
c	117.12 (15.3564) [7.62702] ***	2.25×10^7 (8.67×10^6) [2,59732] ***	1.05×10^{10} (5.5×10^9) [1.92400] **	22.9259 (16.7740) [1.36675]
ΔREC_{t-1}	−0.1092 (0.1242) [0.87952]	64188.05 (70128.5) [0.91529]	−9106324 (4.4×107) [−0.20639]	0.130722 (0.13568) [0.96345]
ΔCO_{2t-1}	−0.0000 (0.0000) [−0.45644]	−0.300318 (0.18431) [−2.02455] **	−11.72486 (93.3292) [−0.12563]	−0.0000 (0.0000) [−0.93669]
ΔGDP_{t-1}	0.0000 (0.0000) [0.82034]	0.000294 (0.0002) [1.44214]	0.770102 (0.12820) [6.00691] ***	0.0000 (0.0000) [0.42570]
ΔREP_{t-1}	−0.580757 (0.16874) [−3.44178] ***	−188469.8 (95264.6) [−1.97838] **	−5.95×107 (0.0000) [−0.99333]	0.244776 (0.1468) [1.32804]
EC_{t-1}	−0.2546 (0.0510) [−5.00262]***	1260.658 (28732.2) [0.04388]	−15544714 (1.8×107) [−0.85990]	−0.0498 (0.0556) [−0,89635]

Note: The asterisk *, ** and *** represents statistically significant at 0.10, 0.05 and 0.01 significant level respectively. Values in brackets are standard errors and values in square brackets are *t*-values.

From Table 3, the only long-run relationship exits is on the REC equation, as the EC_{t-1} coefficient is statistically significant. The result of long-run estimate is summarized in Table 4.

Table 4: Long-run Estimate of VECM (1)

Cointegration Eqn.	EC_{t-1}
REC_{t-1}	1.00000
CO_{2t-1}	-0.0000 (0.0000) [-9.16439] ***
GDP_{t-1}	[0.0000] (0.0000) [2.50408] ***
REP_{t-1}	-1.464343 (0.42017) [−3.48511] ***
c	406.0731

Note: The asterisk *** represents statistically significant at 0.01 significant level. Values in brackets are standard errors and values in square brackets are *t*-values.

The EC_{t-1} can be expressed as Equation (15):

$$EC_{t-1} = REC_{t-1} - [\beta_0 + \beta_1 REP_{t-1} + \beta_2 GDP_{t-1} + \beta_3 CO_{2\ t-1}], \tag{15}$$

where REC, REP, CO_2, and GDP are the predefined economic variable in the methodology part of this work.

Equation (15) is the fitted EC_{t-1} represents the cointegration equation and the long run model. The VECM long run result estimates of the significant column can be expressed as

$$\widehat{REC}_{t-1} = [\beta_0 + \beta_1 REP_{t-1} + \beta_2 GDP_{t-1} + \beta_3 CO_{2\ t-1}]. \tag{16}$$

The estimates of the long-run coefficient's variables and constants $\beta_0 = C$ can be observed directly from Table 4. Equation (16) can be fitted to Equation (17).

$$\widehat{REC}_{t-1} = 406.07 - 1.46 REP_{t-1} + 0.000 GDP_{t-1} - 0.000 CO_{2\ t-1}. \tag{17}$$

The result implies that the long-run relationship exists in the REC equation (Equation 17). Among the regressors, REP has a negative long-run impact on REC. One unit increase in REP leads to a decline of 1.46 units in REC as energy intensity in Africa is low. Higher energy production will be exported to generate income.

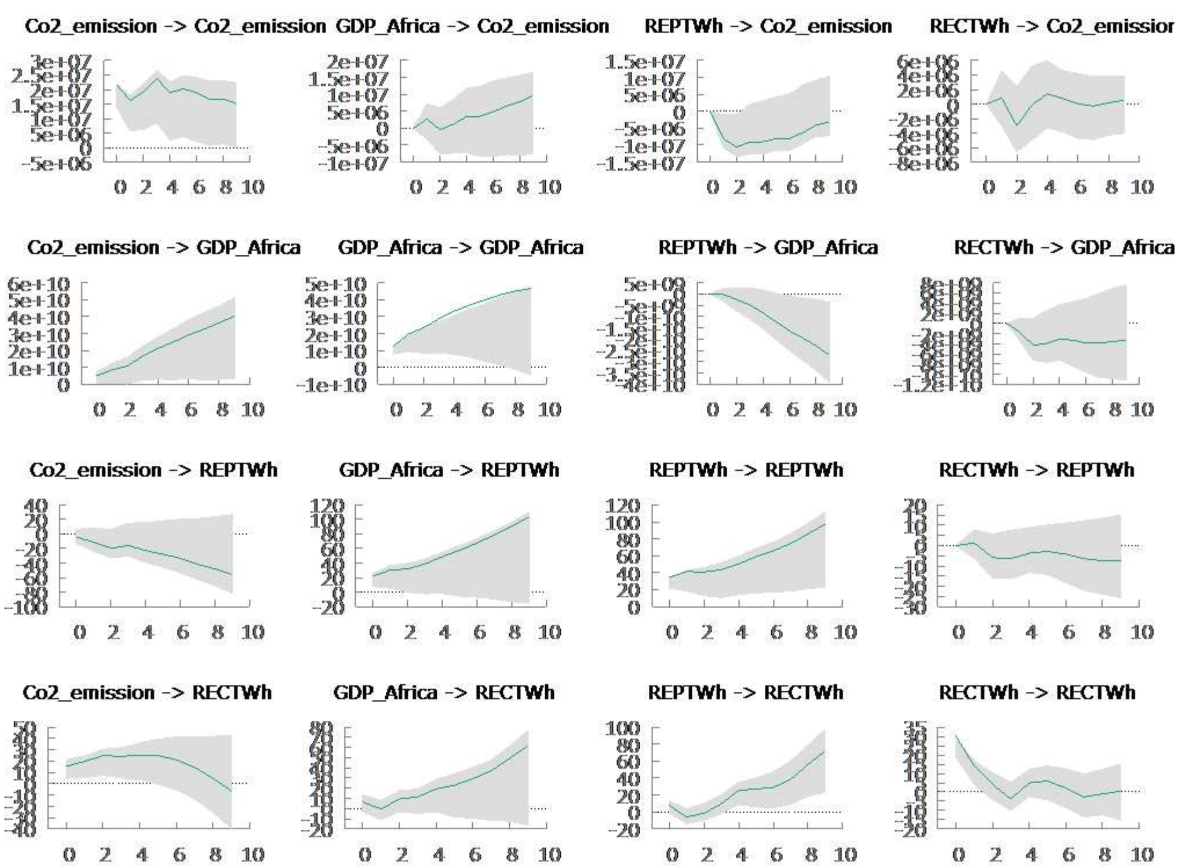

Figure 1: Impulse Response Function (IRF)

Figure 1 represents the impulse response function (IRF). Column one is the impulse of accumulated CO_2 shocks, and one may observe how each variable reacts to CO_2 shocks. As observed, CO_2 shocks lead to GDP increases but declines in REP and REC over time. In column 2, which depicts the shock's impulse, the response of each variable to the CO_2 shock results in increases in GDP, while increases in REP and REC can be observed. The slow shock in REP and CO_2 declined GDP while REP increased REC. In the fourth column, a shock in REC and CO_2 resulted in a decline in response to REP and GDP.

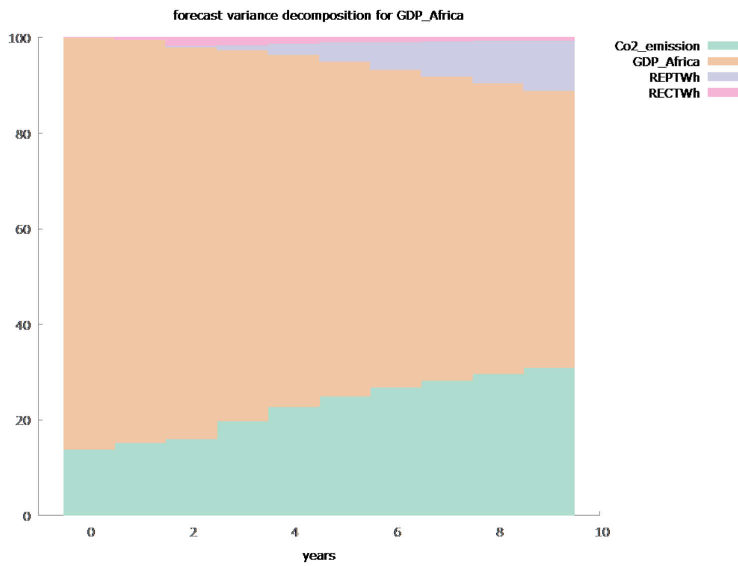

Figure 2: GDP Forecast Variance Decomposition

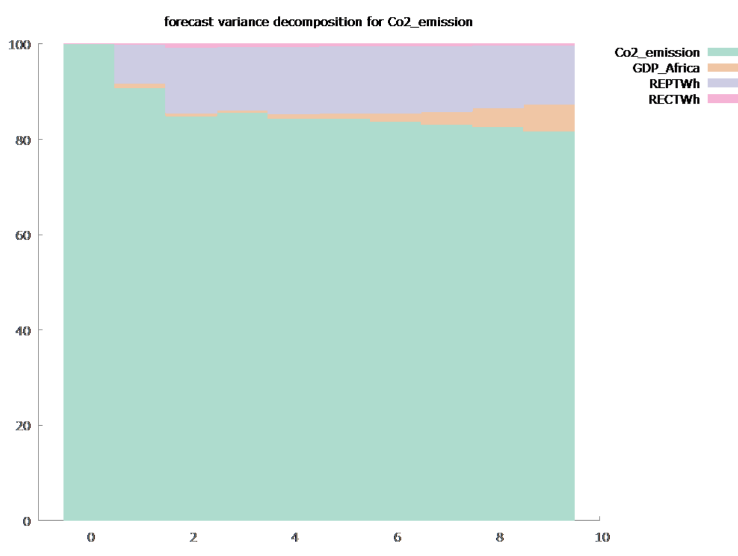

Figure 3: CO_2 Forecast Error Decomposition

Figure 2 and Figure 3 reveal forecast error variance decomposition (FEDV) for GDP and CO_2 emission, respectively, from 1965 to 2020 using data from Africa. The FEVD shows the explanatory power of different shocks (in percent) across the time horizons up to 10 years. The first figure is the FEVD that explains GDP. The plot shows that GDP is dominated by its own shock (GDP or real shock), which can predict nearly 90% of its movement at the current and one year ahead. The effect of GDP shock slowly declines over time. The second major determinant is CO_2 shock which could explain over 10% of GDP, and the effect is increasing over time. Other shocks have a very limited impact on the GDP forecast. The second figure shows that CO_2 emissions are mainly determined by their own shock (CO_2 shock), which explains nearly 100% of its forecast movement in the current and one year ahead. Besides, REP could explain about 15% of CO_2 emissions in the two years and above the forecast horizon. In sum, both FEDV and IFR supported the estimates of the model since IRF is significantly different from 0 and FEDV is non-uniform over the period.

5 Conclusion

This study seeks to examine the consequences of REC and REP on the economies and ecosystems of African nations. Using Error Correction Models (ECM), we analyze the effects of REP and REC on GDP growth and environmental carbon emissions (CO_2). According to the Johansen cointegration test, REC, REP, CO_2, and GDP are cointegrated. By utilizing linear associations, lags, and differentials, the error-corrected models were classified as VECM (p). The best model was selected based on the information criterion. According to the findings, VECM, with one lag, is the most accurate model for predicting GDP and CO_2 emissions in Africa. The study observed a negative correlation between REP and REP in Africa over the long term. Similarly, there is a negative correlation between REP, REC, and CO_2 emissions over the same period, and REP has a positive correlation with GDP in Africa over the short term. Also, evidence suggests that both REC and REP improve environmental quality, and REP drives economic growth and REC. African countries can mitigate the damage caused by non-renewable energy by adopting and actively promoting both renewable energy production and renewable energy consumption. To further improve this estimate, genetic algorithms can be applied to new models after incorporating more exogenous variables.

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