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Research Paper

The influences of economic growth, renewable energy and technological innovations on carbon dioxide emissions in Tanzania: A dynamic ordinary least square (DOLS) analysis

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Abstract

This study examines the intricate relationship between economic growth, renewable energy, technological innovations, foreign direct investments (FDI), and CO2 emissions in Tanzania. Using time series data from the World Bank spanning from 1990 to 2023, the study investigates how these factors influence environmental quality. The Augmented Dickey-Fuller (ADF) unit root test confirmed a mixed order of integration among the variables, both at level and first differences. Based on these findings, this paper applied the Dynamic Ordinary Least Squares (DOLS) technique to analyze the impact of economic growth, renewable energy, technological innovations, and FDI on carbon emissions. To ensure the robustness of the findings, further checks were conducted using Fully Modified OLS (FMOLS) and Canonical Cointegration Regression (CCR) methods, which affirmed the DOLS results. The empirical findings indicate that economic growth and renewable energy have a negative effect on carbon dioxide emissions, suggesting an environmental benefit. In contrast, technological innovations and FDI appear to have a detrimental effect on environmental quality in Tanzania. These results highlight the need for the Tanzanian government to strengthen the environmental policies, promote the adoption of green energy technologies, and improve institutional quality to mitigate the adverse effects of economic development on the environment.

Keywords: Economic growth, Renewable energy, Technological innovations, Dynamic ordinary least square, Fully modified ordinary least square.

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Introduction

The relationship between economic growth and carbon dioxide (CO_2) emissions is complex and multifaceted. Economic expansion is typically accompanied by increased industrial activities, consumption of energy, and urbanization, all of which confer higher CO_2 emissions and exert significant pressure on environmental sustainability (Mbwambo, 2024; Balcilar et al., 2023). The rapid pace of economic growth, driven by the need to meet rising human demands, often leads to environmental degradation, particularly through increased carbon emissions. In this context, Tanzania faces a critical challenge in balancing economic growth with environmental sustainability (Mbwambo, 2024; Khan et al., 2019).

A key strategy for achieving this balance lies in the adoption of energy that is in renewable energy form. Empirical evidence suggests that using renewable energy significantly lessen CO_2 emissions. The renewable energy includes wind energy, bioenergy, solar energy, oceanic power, hydroelectric power, and geothermal energy (Akadiri et al., 2019). However, the effective deployment of renewable energy requires technological innovation, which plays a significant role to give promotion of environmental sustainability. Environmentally friendly technologies not only enhance renewable energy utilization but also stimulate economic growth (Guo et al., 2022). Conversely, reliance on outdated technology exacerbates environmental degradation, as it is associated with higher CO_2 emissions during the production process. Thus, advancing technological innovation is imperative for mitigating the adverse environmental impacts of industrialization.

In addition to economic growth and technological advancements, FDI has emerged as a key driver of industrial expansion in Tanzania and the broader East African region (Chowdhury et al., 2024; Akadiri et al., 2019). Over the last ten years, Tanzania has experienced a significant influx of foreign investors, motivated by opportunities in domestic and international trade and in mineral explorations and extractions. Tanzania has minerals like gold, diamond, Tanzanite just to mention a few (Chowdhury et al., 2024; Akadiri et al., 2019). While FDI contributes to economic growth, it can also escalate environmental challenges if production processes are not aligned with sustainable practices. High levels of industrial output from foreign investors may intensify carbon emissions unless accompanied by sophisticated and environmentally friendly technologies (Hussain et al., 2022). Therefore, achieving sustainable industrial production necessitates the integration of advanced technological innovations within FDI-driven enterprises.

Given this circumstance, this paper investigates the interconnections of economic growth, consumption of renewable energy, FDI, and technological innovation on CO_2 emissions in Tanzania. This paper makes several key contributions to both academic literature and policy discourse. First, the issue of CO_2 emissions and its determinants has gained substantial global attention among researchers, policymakers, and scholars due to its critical implications for environmental sustainability. Tanzanian environmental policy issues focused on land degradation, deterioration of water sources, loss of wildlife habitats and biodiversity, deterioration of aquatic ecosystems, deforestation, environmental pollution, climate change and safe use of modern biotechnology as well as cross cutting issues like gender, good governance and resource mobilizations (URT, 2021). However, research on environmental degradation in

Tanzania remains relatively limited, underscoring the necessity for detail empirical investigation (URT, 2021; Mbwambo, 2024). A study by Mbwambo (2024) investigated only globalization, urbanization, energy consumption, economic expansion and industrialization using ARDL model that cannot deal with endogeneity problem as compared to DOLS technique. Also, the study ignored the impact of foreign direct investment and technological innovation on environment.

To expound in this research gap, the present paper employs the Dynamic Ordinary Least Squares (DOLS) estimator to analyze the long run impact of economic growth, renewable energy, technological innovation, and FDI on CO_2 emissions in Tanzania over the period 1990–2023. The choice of the DOLS methodology is justified by its robustness in handling serial correlation and problem of endogeneity (Zwane et al., 2023). Furthermore, the study enhances the reliability of its findings by conducting robust investigation by utilizing Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR). The empirical findings of this paper will give valuable intuitions for policymakers wishes to formulate strategies that integrate growth of economy, renewable energy, technological advancements, and FDI while minimizing CO_2 emissions. These insights will be instrumental in shaping future policies to foster a sustainable balance between economic expansion and environmental preservation in Tanzania.

The present study provided the comprehensive recommendations for policy makers to resolve the challenges and economic opportunities in line with the renewable energy consumption, economic growth, technological innovations and FDI on CO2 emissions in Tanzania. The study recommended that CO2 emissions and all other forms of emissions should be reduced to attain the environmental quality in Tanzania. To attain environmental sustainability, it is imperative to address all sources of emissions and implement solutions, especially in those areas prone to high levels of carbon emissions. To achieve environmental sustainability, the government should strengthen the policies, legislative framework, and environmental awareness initiatives to reduce carbon dioxide emissions. Thus, policymakers can use these findings to formulate and implement interventions aimed at reducing carbon emissions. The Tanzanian government ought to prioritize the promotion of innovative technologies particularly green technology to mitigate CO2 emissions and strengthen quality of environmental. Technological innovations offer a meaningful role in turning down CO2 emissions, and policymakers must invest in renewable energy sources to support this transition.

Section 2 the current study reviews the previous research activities on the relationship between renewable energy, economic growth, technological innovations and FDI on CO2 emissions. The current study reviewed both theoretical issues and empirical literature regarding the study. Section 3 gives the research methods and data utilized in the present study. The study utilized the Dynamic Ordinary Least Squares (DOLS) technique to investigate the influence of growth of economy, technological innovation, renewable energy and FDI on CO_2 emissions in Tanzania. Data used in the study are gathered from database owned by World Bank running from 1990 to 2023. To ascertain the DOLS results, the robustness checks were performed using FMOLS and CCR. Section 4 presents the empirical findings and shed the lights of the impact of the variables under study like renewable energy, growth of economy, technological innovations and FDI on CO2 emissions in Tanzania. The final section in this study provides the conclusion based on empirical findings and pointing out the practical

implications for Asian businesses.

Literature Review

Theoretical Literature Review

The present paper draws upon two key economic theories to establish the relationship between growth of economy, renewable energy, technological innovations, FDI, and CO_2 emissions: Endogenous Growth theory and Keynesian Theory.

Keynesian Theory posits that government expenditure plays a significant role in instigating growth of economy. In the circumstance of consuming renewable energy, increased public investment in sustainable energy sources now has become a prime concern for many emerging economies countries. The renewable energy is contemplated as a vital driver of sustainable economic growth. However, while economic expansion contributes to national development, it is also associated with increased CO_2 emissions. Achieving sustainable development necessitates mitigating environmental degradation (Hardi et al., 2023).

Similarly, Endogenous Growth Theory emphasizes the significance of factors within the country like technological innovations and FDI—in fostering economic growth. Technological advancements and FDI contribute significantly to economic expansion, yet they also have environmental implications. Rapid economic growth is often correlated with escalation of CO_2 emissions. Thus, study intends to confirm the interplay among growth of economy, consumption of renewable energy, technological innovations, and FDI is pivotal in understanding environmental sustainability.

Both Keynesian and Endogenous Growth Theories have limitations. Keynesian Theory has been criticized for its lack of consideration of external economic factors, while Endogenous Growth Theory overlooks the role of external influences on economic performance. To address these gaps, this study integrates both theories, offering a comprehensive framework for examining the role of growth of economy, technological innovations, consumption of renewable energy and FDI on CO_2 emissions in Tanzania. Keynesian Theory points out the importance of government spending on renewable energy, while Endogenous Growth Theory underscores the significance of technological innovation and FDI. The synthesis of these theories provides a strong foundation for understanding the enthralling of economic growth and environmental sustainability in Tanzania.

Empirical Literature Review

The association ship between growth of economy, consumption of renewable energy, technological innovations, and FDI in relation to CO_2 emissions has been widely debated in academic discourse, yielding mixed results on the other side of the different economies.

Several studies call attention to a positive relationship between economic growth and CO_2 emissions. Teniro et al. (2024), Matenda et al. (2024), and Zeeshan Zafar (2023) found that economic growth adversely affected environmental quality in Indonesia,

South Africa, and BRICS countries, respectively. Similarly, Raihan and Tuspekova (2022) confirmed that economic growth deteriorates environmental quality in India. However, contradicting evidence from Camila et al. (2024) suggests that economic growth reduces CO_2 emissions in OPEC countries. These conflicting empirical findings underscore the necessity of further investigation in the Tanzanian, where rapid economic growth, coupled with substantial government investment in renewable energy, technological innovations, and FDI, plays a critical role in exerting influence on environmental outcomes.

The influence of consumption of renewable energy on emissions of CO_2 also varies across studies. Sources of renewable energies like hydroelectric, solar, and geothermal power have been found to reduce CO_2 emissions. Research by Matenda et al. (2024), Pattak et al. (2023), and Leitão and Lorente (2020) demonstrated that the use of renewable energy remarkably reduces CO_2 emissions in South Africa and European Union countries. Conversely, energy derived from fossil fuels, oil, and coal has been associated with increased CO_2 emissions in several African countries and Italy (Matenda et al., 2024; Pattak et al., 2023; Ehigiamusoe, 2020). Furthermore, Dong et al. (2017) found that consumption of natural gas reduces CO_2 emissions in China, reinforcing the argument that non-fossil energy sources contribute to environmental sustainability.

The relationship between technological innovations and CO_2 emissions remains inconclusive. In some cases, technological advancements have led to lower CO_2 emissions, while in others, they have exacerbated environmental degradation. For instance, Fatima et al. (2024) and Raihan (2024) confirmed that technological innovation reduces CO_2 emissions in G7 countries and Malaysia, respectively. These findings support the Endogenous Growth Theory, as advanced technology in these countries tends to be environmentally friendly. However, Matenda et al. (2024) reported that technological innovations in South Africa have led to increased CO_2 emissions, suggesting that the environmental effect of technology depends on the nature of its application. The adoption of greener technologies is essential for improving environmental sustainability.

Foreign Direct Investment (FDI) also yields mixed results concerning CO_2 emissions. According to the Endogenous Growth Theory, FDI serves as an internal growth driver, as foreign investors contribute in the production of economic goods as well as services within the host economy. Khan and Ahmad (2021) confirmed that FDI elevated the CO_2 emissions in both developed and emerging economies countries, implying that foreign investments often rely on pollution-intensive industries. To ensure sustainable development, FDI inflows should prioritize environmentally friendly technologies. Conversely, Camila et al. (2024) found that FDI lessen CO_2 emissions in OPEC countries, indicating that foreign investment can also play a role in environmental conservation.

Given these conflicting findings across the regions regarding economic growth, renewable energy, technological innovations, and FDI, it is essential to conduct a study or empirical investigation in Tanzania. Empirical results described above provides the bases for study in Tanzania since environmental policy issues earmarked on sustainable environment and knowing the impact of these variables under study are imperative. This study aims to explore the interconnections among these factors and their impact

on CO_2 emissions, providing valuable insights for policymakers to make informed decisions on environmental management and sustainability.

Methodology

This paper employs a time-series data and analysis using the Dynamic Ordinary Least Squares (DOLS) approach to examine the relationship between CO_2 emissions, consumption of renewable energy, technological innovations, and economic growth — proxied by GDP. Additionally, FDI is incorporated as a control variable. The DOLS methodology is particularly suitable for this study as it accommodates variables with different orders of integration, whether integrated at I(0) or I(1). The dataset ranges from 1990 to 2023 and is sourced from World Bank's database, ensuring data completeness and reliability.

To enhance the robustness of the findings, this study also employs Fully Modified Ordinary Least Squares (FMOLS) and Canonical Cointegrating Regression (CCR) as supplementary estimation techniques, as recommended by Xiu et al. (2022). These checks corroborate the consistency and stability of the empirical results across different estimation frameworks. The theoretical footing of this study is anchored in Keynesian theory and endogenous growth theory, both of which emphasize the critical role of growth of economy, renewable energy adoption, and technological advancements in shaping environmental outcomes. These theories assert that economic expansion when driven by sustainable energy practices and technological progress, can significantly influence CO_2 emissions. By amalgamating these theoretical perspectives, this paper provides a robust analytical framework for understanding the dynamics between growth of economy, energy consumption, innovation, and environmental sustainability.

The regressand variable in this study is CO_2 emissions, while the regressors variables include renewable energy's consumption, technological innovations, and growth of economy, with FDI serving as a control variable. Table 1 provides a comprehensive summary of the study variables and their measurements, and data sources, ensuring transparency and replicability of the study.

Table 1: Variable descriptions

Variables	Symbols in the Model	Measurements	Sources
Carbon dioxide Emissions (CO_2)	$LNCO_2$	"CO_2 emissions Kilotons (kt) equal to 1000 tons. Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring".	WDI (2024)
Renewable Energy Consumption	LNRE	"Renewable energy consumption (% of total final energy consumption)" "Renewable energy consumption is the share of renewable energy in total final energy consumption".	WDI (2024)

Variables	Symbols in the Model	Measurements	Sources
Gross Domestic Product	LNGDP	Current US$	WDI (2024)
Foreign Direct Investment	LNFDI	"Foreign direct investment, net inflows (BoP, current US$)"	WDI (2024)

Note: Source from researcher's compilation in year 2025; Data were collected from "World Development Indicators" (WDI)

Model Specification

This study is grounded in an analytical framework that integrates two theoretical perspectives: endogenous growth theory and Keynesian theory. The Keynesian theory posits that government expenditure serves as a catalyst for economic growth by stimulating aggregate demand and investment levels, successively, may upraise carbon dioxide (CO_2) emissions. In this context, government spending on renewable energy has emerged as a critical policy agenda for achieving sustainable economic development. A lack of investment in renewable energy could exacerbate CO_2 emissions, underscoring the necessity of prioritizing green energy initiatives.

Conversely, the endogenous growth theory emphasizes the function of factors from within the country like human capital development as well as technological innovation in fostering long-term economic growth. However, these advancements are not immune to environmental consequences. Inadequate technological innovations may come up with increased CO_2 emissions, highlighting the need for sustainable technological progress.

Methodologically, this study adopts an approach similar to that of Raihan and Tuspekova (2022) and Xiu et al. (2022) to examine the effect of growth of economy, renewable energy's consumption, and technological innovation on CO_2 emissions in Tanzania. To ensure the robustness of the analysis, a unit root test is conducted using the ADF test. This test is crucial in determining the stationarity features of the variables, distinguishing between stationary and non-stationary time series. The ADF test is implemented using Equation (1) to obtain reliable unit root results.

$$\Delta y_t = \pi_0 + \alpha y_{t-1} + \delta_1 \Delta y_{t-2} + \cdots + \delta_p \Delta y_{t-p} + \varepsilon_t \quad (1)$$

Comprising Equation (1) we obtain the estimation model as shown in Equation (2)

$$\Delta y_t = \pi_0 + \alpha y_{t-1} + \sum_{j=l}^{p} (\delta_j \Delta y_{t-j}) + \varepsilon_t \quad (2)$$

y_t present data employed in the study, t is the time index, π stands for constant, α stands for coefficients indicating a unit root process, lag order is presented by p and ε_t is the error term.

To analyse the relationship between growth of economy, renewable energy, technological innovations and FDI in carbon dioxide emissions. The study formulated

a mathematical equation as shown in equation 3.

CO_2 Emissions = f (RE, TI, EG) 3

Where f stands for function of, RE is renewable energy consumption, TI is technological innovations, EG is economic growth proxied by gross domestic product (GDP). Understanding the influence of FDI in the economy, the study included it as control variable. It is clear that high influx of foreign investors expected to increase production as such may increase pressure in carbon dioxide emissions as well. Equation (3) expressed into econometrics model as shown in equation (4). The study utilises the semi log model by instituting natural logarithms in all variables except technological innovations.

$$LNCO2_t = C + \beta_1 LNRE_t + \beta_2 TI_t + \beta_3 LNGDP_t + \beta_4 CV_t + \varepsilon_t \quad 4$$

Where $LNCO_2$ is natural logarithm of CO_2 emissions and it is dependent variable while LNRE is natural logarithm of renewable energy, TI is technological innovations, LNGDP is natural logarithm of gross domestic product and CV stands for control variable and it is represented by foreign direct investment (FDI), ε is an error term, t is time index and β_1 to β_4 represents the coefficient of changes for independent variables. All other variables except $LNCO_2$ are independent variables. Including FDI in the equation, the study formulated equation (5).

$$LNCO2_t = C + \beta_1 LNRE_t + \beta_2 TI_t + \beta_3 LNGDP_t + \beta_4 LNFDI_t + \varepsilon_t \quad 5$$

All other variables remain the same, but LNFDI stands for natural logarithm of foreign direct investment. The choices of all these variables based on the previous studies, GDP and TI are from (Xiu et al., 2022; Zeeshan et al., 2023), RE and CO_2 are from (Ehigiamusoe, 2022; Raihan and Tuspekova, 2022) while FDI is from (Ben et al, 2019; Wang et al, 2022; Setyadharma et al, 2024) just to mention a few. However, proxy of TI can be used to measures ICT access as well, but World Development Indicators (WDI, 2024) uses the mobile subscriptions as a proxy of TI and the current study adopted the similar index.

Dynamic Ordinary Least Squares (DOLS) Model

Having specified the econometrics models, the present study employed the DOLS approach to analyse the dynamic influence of renewable energy consumption, technological innovations, economic growth and FDI on CO_2 emissions. Adoptions of DOLS are based on the advantage of being able to evaluate the variables with mixed orders of integrations. This technique has the power to determine the regressand covariate on the regressor covariate in levels lags and leads. DOLS technique handles the endogeneity by finding standard deviations employing lags and leads to the first difference separately. Combining the lags and leads tends to fix the small sample bias's problems, endogeneity and problem of autocorrelation to independent variables. Thus, the present paper utilises the DOLS approach or technique to analyse the long run coefficient amongst the variables using Equation 6.

$$LNCO2_t = \Phi_0 + \gamma_1 LNCO2_{t-1} + \gamma_2 LNRE_{t-1} + \gamma_3 TI_{t-1} + \gamma_4 LNGDP_{t-1} + \gamma_5 LNFDI_{t-1} + \sum_{i=1}^{q} \alpha_1 \Delta LNCO2_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LNRE_{t-i} + \sum_{i=0}^{q} \alpha_3 \Delta TI_{t-i} + \sum_{i=0}^{q} \alpha_4 \Delta LNGDP_{t-i} + \sum_{i=0}^{q} \alpha_5 \Delta LNFDI_{t-i} + \varepsilon_t \quad (6)$$

Robustness Check

Following the application of the DOLS technique, a robustness check was conducted to validate the reliability of the DOLS results. The FMOLS and CCR approaches were employed to appraise the robustness of the study findings. FMOLS incorporates cointegration regression estimates, addressing issues of endogeneity and serial correlation. Furthermore, it corrects misspecifications in regression models by employing standard methods, such as OLS for non-stationary variables.

Similarly, the study applied the CCR approach to further validate the DOLS results, as CCR utilizes stationary data within a cointegration framework. Additionally, the CCR method provides tests of chi-square and more efficient estimators than those of the DOLS technique. By integrating FMOLS and CCR approaches, the study ensures the asymptotic coherence and robustness of the estimated results.

Results

Descriptive Statistics

Table 2 shows a comprehensive summary of the variability and averages of the study variables. CO_2 emissions exhibit a mean value of 5.12, indicating a comparatively high level of emissions. The standard deviation of 1.26 suggests moderate volatility in CO_2 emissions across review, with a maximum value of 6.60 and a minimum of 2.40. This implies a certain degree of variation, albeit with stable emission trends over time.

Renewable energy (RE) demonstrates relatively stable variability, with a mean value of 4.47 and a standard deviation of 0.11, highlighting slight fluctuations over time. The observed variation in RE suggests a significant influence on CO_2 emissions. Technological innovation (TI) and GDP exhibit proportionate high mean values of 33.03 and 23.74, respectively, underscoring their substantial contributions to CO_2 emissions. However, the high standard deviation of 34.85 for TI indicates considerable advancements in technology across the study period. In contrast, FDI reports the lowest mean value of 19.41 compared to TI and GDP, with a standard deviation of 2.87. This finding suggests lower levels of FDI inflows during the study period. Overall, the descriptive statistics provide critical clues into the distributional characteristics of the variables, offering a solid foundation for subsequent empirical analysis.

Table 2: Descriptive statistics

	$LNCO_2$	LNRE	TI	LNGDP	LNFDI
Mean	5.117214	4.468533	33.03167	23.74200	19.40848
Median	5.306542	4.504796	16.80467	23.72772	20.37914
Maximum	6.597691	4.555980	91.89985	25.09472	21.45912
Minimum	2.397986	3.961765	0.001253	22.17200	9.210340
Std. Dev.	1.256285	0.107673	34.84887	0.959763	2.869246
Observations	34	34	34	34	34

Source: Researcher's computation (2025)

Correlation Analysis Results

Table 3 provides the correlation analysis and are key insights into the association ship among variables under study. The results indicate a negative correlation (-0.5591) between emissions of CO_2 and renewable energy's consumption (RE), advocating that a rise in renewable energy usage is connected with upgrading in environmental quality. This finding aligns with Keynesian theory, which posits that increased government expenditure on renewable energy can contribute to environmental sustainability. Conversely, technological innovations (TI), GDP and FDI exhibit a positive correlation with CO_2 emissions over the study period. Specifically, the correlation coefficients for TI, GDP, and FDI are 0.6911, 0.6982, and 0.6593, respectively, indicating their potential contribution to rising carbon emissions. These results underscore the need for further investigation into the short- and long-term fluctuations of these variables in relation to CO_2 emissions.

Table 3: Descriptive statistics

	$LNCO_2$	LNRE	TI	LNGDP	LNFDI
$LNCO_2$	1.000000	-0.559092	0.691101	0.698240	0.659296
LNRE	-0.559092	1.000000	-0.749034	-0.685795	-0.340088
TI	0.691101	-0.749034	1.000000	0.915910	0.504266
LNGDP	0.698240	-0.685795	0.915910	1.000000	0.704207
LNFDI	0.659296	-0.340088	0.504266	0.704207	1.000000

Source: Researcher's computation (2025)

Augmented Dickey-Fuller (ADF) Test Results

To be certain that no variable exceeds the required order of integration, this paper performed a unit root test using the ADF test specifications. The results, depicted in Table 4, indicate that the variables exhibit stationarity at a combination of levels—that is, at level and first difference. These empirical findings justify the adoption of the DOLS approach in this study, as it provides a more robust estimation framework compared to conventional cointegration techniques like Engle-Granger residual-based cointegration and Johansen cointegration (Adebayo et al., 2021).

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Table 4: Augmented Dickey-Fuller (ADF) results

		With Intercept no Trend		With Intercept and Trend	
Variables	**Symbols**	**Level**	**1st Difference**	**Level**	**1st Difference**
Carbon Dioxide Emissions	$LNCO_2$	Non-stationary	Stationary	Non-stationary	Stationary
Renewable energy consumption	LNRE	Non-stationary	Non-stationary	Non-stationary	Non-stationary
Technological Innovations	TI	Non-stationary	Stationary	Stationary	Stationary
Gross Domestic Product	LNGDP	Non-stationary	Stationary	Non-stationary	Stationary
Foreign Direct Investment	LNFDI	Stationary	Stationary	Stationary	Stationary

Source: Researcher's computation (2025)

Dynamic Ordinary Least Squares (DOLS) Results

Table 5 presents the results of the DOLS estimation. The findings indicate that the estimated long run coefficient of consumption of renewable energy (LNRE) is negative and statistically significant at the 5% level, holding another factors constant. This suggests that a 1% increase in renewable energy lessen CO_2 emissions close to 23.07150 kilotons, highlighting its crucial role in mitigating environmental degradation. Conversely, the long run coefficient of technological innovations is positive, implying that advancements in technology contribute to increased CO_2 emissions. Specifically, a 1% rise in technological innovations is interrelated with an increase of 0.012643 kilotons in CO_2 emissions in the long run. This finding suggests that while technological progress can drive economic growth, it may also lead to adverse environmental consequences if not aligned with sustainable practices.

Furthermore, growth of economy, proxied by the natural logarithm of GDP (LNGDP), exhibits a negative and statistically significant coefficient at the 5% level, suggesting that a 1% increase in economic growth reduces CO_2 emissions by 2.062005 kilotons in the long run. This finding implies that as Tanzania's economy expands, it potentially adopts cleaner and more efficient energy sources, thereby contributing to environmental sustainability. Thus, renewable energy and economic growth have the strongest impact on CO_2 reduction.

Additionally, the results reveal that LNFDI has a positive and statistically significant impact on CO_2 emissions at the 5% level. A 1% increase in FDI leads to a rise in CO_2 emissions by 0.970485 kilotons, indicating that foreign investments, particularly in emission-intensive industries, may undermine environmental quality. Overall, the empirical results suggest that consumption of renewable energy and economic growth contribute to environmental health or environmental sustainability by reducing CO_2

emissions, whereas technological innovations and FDI exacerbate quality of environmental in Tanzania. These insights underscore the need for strategies that promote green technologies and sustainable investment policies to achieve long-term environmental and economic goals.

Table 5: Dynamic ordinary least squares (DOLS) results

Variables	Coefficient	Std. Error	t-Statistic	Prob.
LNRE	-23.07150**	8.608756	-2.680004	0.0179
TI	0.012643	0.010622	1.190255	0.2537
LNGDP	-2.062005**	0.710612	-2.901733	0.0116
LNFDI	0.970485**	0.378593	2.563399	0.0225
C	139.1016**	47.03623	2.957329	0.0104

Note: Regressand variable $LNCO_2$; NB: P< 0.01; P<0.05; P<0.10. Asterisk presents statistically significant at 1% (***), 5% level (**), and 10 (*) % level

Robustness Check

Fully Modified Ordinary Least Square (FMOLS) Results

To establish the robustness of the findings, the study deployed FMOLS and CCR approaches to validate the results obtained from the DOLS estimations. Tables 6 and 7 present the long run regression coefficients emanating from the FMOLS and CCR approaches. The empirical results confirm the consistency and reliability of the DOLS estimates, bolster up the robustness of the study's findings. Notably, both FMOLS and CCR results substantiate that renewable energy and economic growth exert a negative influence on CO_2 emissions, thereby contributing to environmental sustainability. Conversely, technological innovations and foreign direct investment are identified as detrimental factors to environmental quality in Tanzania. These results align closely with the empirical findings of the DOLS approach, further strengthening the study's conclusions on the association ship between economic dynamics and quality of environment or environmental sustainability.

Table 6: Fully modified ordinary least squares (FMOLS) results

Variables	Coefficient	Std. Error	t-Statistic	Prob.
LNRE	-1.035799	2.473860	-0.418697	0.6786
TI	0.028241*	0.015338	1.841183	0.0762
LNGDP	-0.531862	0.650831	-0.817204	0.4207
LNFDI	0.238261*	0.123786	1.924775	0.0645
C	16.95269	18.09591	0.936825	0.3569

Note: Regressand variable $LNCO_2$; NB: P< 0.01; P<0.05; P<0.10. Asterisk presents statistically significant at 1% (***), 5% level (**), and 10 (*) % level

Canonical Cointegrating Regression (CCR) Results

Having estimated the FMOLS, the present study performed the CCR techniques to authenticate the results obtained from the DOLS estimation. The empirical results confirm the consistency and reliability of the DOLS estimates, reinforcing the

robustness of the study's findings. Especially, both FMOLS and CCR results substantiate that consumption of renewable energy and economic growth bring a negative effect on emissions of CO_2, thereby contributing to environmental sustainability quality. Conversely, technological innovations and foreign direct investment are pointed out as detrimental factors to environmental quality as such are harming the environmental sustainability in Tanzania. The FMOLS and CCR estimates show broadly similar coefficient signs to DOLS for key variables although statistical significance varies across methods. FMOLS concentrates on the transformation of both data and parameters whereas CCR concentrates on data transformation only while the DOLS adopts a parametric approach in estimations (Priyankara, 2018). Generally, DOLS, FMOLS and CCR results are in line with correlation results except on GDP.

Table 7: Canonical cointegrating regression (CCR) results

Variables	Coefficient	Std. Error	t-Statistic	Prob.
LNRE	-2.441240	12.84352	-0.190076	0.8506
TI	0.026295	0.023366	1.125342	0.2700
LNGDP	-0.546825	0.659849	-0.828713	0.4143
LNFDI	0.249754**	0.102785	2.429872	0.0218
C	23.45592	63.87659	0.367207	0.7162

Note: Regressand variable $LNCO_2$; NB: P< 0.01; P<0.05; P<0.10. Asterisk presents statistically significant at 1% (***), 5% level (**), and 10 (*) % level

Discussion

The current study revealed a significant link between consumption of renewable energy and CO_2 emissions in Tanzania. As anticipated, consumption of renewable energy has a negative effect on CO_2 emissions, meaning that an increase in government spending on renewable energy technologies, like solar energy, Ocean energy, wind energy, hydroelectric power, bioenergy power and geothermal power, improves environmental quality. These findings align with those of Setyadharma et al. (2024), Zwane et al. (2023), Raihan et al. (2022), Raihan and Tuspekova (2022b), and Ben et al. (2019), who conducted studies in various regions, including Africa, BRICS countries, Malaysia, Turkey, and Central and South American countries, and confirmed the negative influence of renewable energy on CO_2 emissions. Conversely, consumption of energy from fossil fuel sources is detrimental to environmental quality, as confirmed by Leitão (2021) in Portugal.

Similarly, growth of economy, measured by GDP, has a negative influence on CO_2 emissions in Tanzania, suggesting that economic activities do not necessarily harm environmental sustainability. This is happening due to fact that Tanzania uses the renewable energies in the production process including hydroelectric power, bioenergy power and geothermal power as such it improves environmental quality. This finding is important to be adopted by other countries to use the renewable energies so as to improve the quality of environment. This finding contrasts with the views of Raihan and Tuspekova (2022b), who argued that economic growth give rise to environmental deterioration in Kazakhstan. The study demonstrates that economic growth can increase human activities, such as societal production and consumption, successively lead to higher CO_2 emissions. Economic growth also

drives increased production across sectors such as manufacturing, agriculture, tourism, and construction, give rise to higher levels of waste and environmental degradation. These findings corroborate studies by Raihan et al. (2024), Raihan et al. (2022), Raihan and Tuspekova (2022c), Begum et al. (2020), and Ben et al. (2019), which found that economic growth adversely affects the quality of environment in Bangladesh, Malaysia, Turkey, and other regions.

In contrast, technological innovations and foreign direct investments (FDI) significantly harm environmental quality. Technological innovations, while enhancing production capacity, exert additional pressure on the environment, raising carbon dioxide emissions. This study's findings contrast with those of Raihan et al. (2022), who found that technological innovations improve quality of environment in Malaysia. Nevertheless, it is possible that the adoption of sophisticated technologies in production processes in Tanzania, similar to Malaysia, could reduce carbon emissions. Moreover, this study confirms that FDI negatively impacts environmental quality in the long run. Foreign direct investments are generally associated with higher production levels for both domestic and foreign trade, which tend to elevate carbon emissions. To mitigate carbon emissions, countries need to implement advanced technologies and sophisticated production methods. This recommendation could benefit other developing countries, aiming to promote economic growth while ensuring environmental sustainability. These findings are congruent to Wang et al. (2022), who identified FDI as a major contributor to environmental degradation in China. However, this study's empirical results contrast with those of Setyadharma et al. (2024) and Ben et al. (2019), who found that FDI had a weak correlation with CO_2 emissions in BRICS countries and Central and South American countries, indicating that FDI inflows in these regions are environmentally friendly and support economic growth.

Furthermore, the present study employed the DOLS technique deploying data spanning from 1990 to 2023 to assess the influence of growth of economy, technological innovations, renewable energy's consumption, and FDI on CO_2 emissions in Tanzania. The ADF unit root test was used in this paper to assess data stationarity, while robustness checks were conducted using FMOLS and CCR techniques. The ADF results showed that the variables under study exhibited mixed orders of integration, I(1) and I(0), at levels and first differences. The analysis revealed that renewable energy's consumption and economic growth negatively influence carbon dioxide emissions, whereas technological innovations and FDI adversely affect emissions. The results from FMOLS and CCR regressions authenticated the findings generated by DOLS model.

Based on the empirical results, it is recommended that carbon dioxide emissions, along with all other forms of emissions, should be reduced to achieve environmental quality in Tanzania. To attain environmental sustainability, it is essential to address all sources of emissions and implement solutions, particularly in areas prone to high carbon emissions. Strengthening policies, legislative frameworks, and environmental awareness initiatives are vital in reducing carbon dioxide emissions. Environmental policy issues should focus on land degradation, deterioration of water sources, loss of wildlife habitats and biodiversity, deterioration of aquatic

ecosystems, deforestation, environmental pollution, climate change and safe use of modern biotechnology as well as cross cutting issues like gender in the environmental management, good governance and resource mobilizations. Policymakers can use these findings to formulate and implement interventions aimed at reducing CO_2 emissions. The Tanzanian government should prioritize the promotion of innovative technologies to mitigate CO_2 emissions and strengthen the quality of environment. Technological innovations play a pivotal role to lessen carbon dioxide emissions, and policymakers must invest in renewable energy sources like solar energy, geothermal, wind energy, biomass and hydroelectric power to support this transition. Public-private partnerships should be fostered to encourage the economic activities to use renewable energy in production process. Moreover, tax incentives and financial instruments, such as green financing, should be promoted to facilitate the uptake of renewable energy technologies. More developing countries could adopt similar strategies to reduce CO_2 emissions and achieve environmental sustainability.

This study acknowledges two key limitations. Firstly, it focuses exclusively on Tanzania, meaning that the findings may not be generalizable to other countries, including those in the East African region or other developing nations. Future studies could expand the dataset to include other countries to provide a broader understanding of carbon emissions. Additionally, further research could explore other variables, such as the impact of tourism, the agricultural sector, industry structure and urbanization to strengthen the understanding of carbon dioxide emissions in developing countries. Again, future study may consider reliance on biomass, new renewable policies, infrastructure constraints and how including technological innovation offers insights beyond the typical GDP-energy-emissions model.

Practical Implications for Asian Business

The present study offers valuable insights into the influences of growth of economy, renewable energy, and technological innovations on CO_2 emissions, particularly in developing countries. In recent years many emerging economies countries experiencing rapid economic growth and development as well. Thus, the current study's empirical findings provide several significant practical implications for Asian businesses. First, the study confirms the importance of renewable energy to give promotion to sustainable business practices in Asian countries. As the world strives to achieve sustainable economic development, renewable energy plays a critical role to lessen carbon dioxide emissions (Setyadharma et al., 2024; Zwane et al., 2023; Raihan et al., 2022; Raihan and Tuspekova, 2022c). Asian business managers should prioritize using energies from non-fossils energies such as renewable energy from various sources like wind energy, solar energy, hydroelectric, ocean energy, geothermal power and bioenergy, to mitigate carbon emissions and contribute to sustainable business practices. Making a use of fossil fuels as an energy source compromises environmental quality and could negatively affect long-term business viability. Thus, empirical finding from this study shed the light to Asian business managers to give the informed decisions regarding source of energy to use in their business so as to achieve the environmental sustainability in their respective areas.

Second, unlike many previous studies that assert economic growth increases carbon emissions (Raihan et al., 2024; Raihan et al., 2022; Raihan and Tuspekova 2022a; Begum et al., 2020 and Ben et al., 2019), the current study finds that economic growth in Tanzania does not adversely impact environmental quality. This implies that it is possible to achieve economic growth without harming the environment (Camila et al., 2024). Managers in Asian businesses can adopt strategies to expand their business activities while maintaining environmental sustainability, as evidenced by the findings in this study. Third, the study indicates that technological innovations and foreign direct investment (FDI) can deteriorate environmental quality (Raihan et al., 2022b). Business managers should be cautious when adopting new technologies and foreign investments to ensure that these do not lead to increased carbon emissions. Harmful technological innovations and unsustainable forms of foreign direct investment could endanger the environment and jeopardize future business prospects. The current study highlights the importance of considering user-friendly technology in the production process so as to avoid jeopardizing the quality of the environment. Similarly, suitable forms of foreign direct investment are imperative in attaining environmental sustainability in Asian businesses. In this context, the Asian business managers can adopt the proper strategies that will enhance the environmental quality in their businesses.

Finally, business managers must carefully select the types of foreign direct investments to adopt in their regions to avoid environmental degradation (Wang et al., 2022). The proper form of investment can enhance both business growth and environmental quality. The findings from this study provide a foundation for business managers to make informed decisions regarding environmental sustainability. Additionally, at the national level, policymakers as well as stakeholders can employ these findings to formulate policies and interventions that support carbon emissions reduction and environmental quality enhancement, contributing to sustainable economic development. Effective environmental policies will guide business managers in making responsible decisions that foster long-term growth and environmental protection.

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