Global Journal of Economic and Finance Research

e-ISSN: 3050-5348
p-ISSN: 3050-533X

Vol. 02(04): 179-190, April 2025

Home Page: https://gjefr.com/index.php/gjefr

The Relationship Between Carbon Emissions and Economy Growth in Sierra Leone

Emmanuel Momoh[1], David Dauda Lansana[2], Mr. Stephen Kai Kai Momoh[3], Sazib Hossain[4]

[1,2,4]School of Business, Nanjing University of Information Science & Technology, Nanjing, China

[3]Eastern Polytechnic University, Kenema

[4]ORCID: https://orcid.org/0009-0009-3578-1170

KEYWORDS: Carbon emissions, economic growth, Sierra Leone, autoregressive distributed lag (ARDL), foreign direct investment (FDI)

Corresponding Author:
Sazib Hossain

Publication Date: 09 April-2025
DOI: 10.55677/GJEFR/02-2025-Vol02E4

ABSTRACT

This study explores the dynamic relationship between carbon emissions and economic growth in Sierra Leone—a developing West African country striving to balance development and environmental sustainability. The analysis incorporates foreign direct investment (FDI), energy consumption (EC), and trade openness (TO) as key explanatory variables, reflecting the country's resource-dependent economy. Using the Autoregressive Distributed Lag (ARDL) model and time-series data from 1980 to 2021, the study examines both short- and long-term relationships. Stationarity of variables is confirmed via the Augmented Dickey-Fuller test, validating the model's reliability. Findings reveal a long-run co-integrating relationship among CO_2 emissions, economic growth, FDI, EC, and TO. Granger causality tests indicate a unidirectional causality from FDI to CO_2 emissions, suggesting that foreign investment—especially in energy-intensive sectors—plays a pivotal role in shaping environmental outcomes. Variance decomposition further shows that energy consumption is the most significant driver of emissions, followed by economic growth, with trade openness having a moderate effect. Policy recommendations emphasize aligning FDI with green practices, promoting low-carbon technologies, and transitioning to renewable energy sources like solar, hydro, and wind. Strengthening environmental regulations and offering incentives for sustainable business practices are also advised. This research provides critical insights for policymakers to pursue strategies that foster economic growth while minimizing environmental degradation.

INTRODUCTION

Understanding the intricate relationship between carbon emissions and economic growth is critical for countries like Sierra Leone as they strive to achieve sustainable development. Positioned in West Africa with a growing economy and a rich, diverse ecological landscape, Sierra Leone presents a unique context to explore the dual challenges of economic advancement and environmental conservation (Sampa & Hossain, 2024). This study examines the complex interplay between carbon dioxide (CO_2) emissions and economic development in Sierra Leone, focusing on how this relationship shapes the country's developmental trajectory. Like many other emerging economies, Sierra Leone stands at a developmental crossroads where the pursuit of economic growth often carries environmental consequences, particularly in terms of carbon emissions. The country's economy, which relies heavily on sectors such as agriculture, mining, and light manufacturing, is vital to its gross domestic product (GDP). However, these sectors also contribute significantly to environmental degradation (World Bank, 2020). As foreign direct investment (FDI) continues to flow into Sierra Leone and economic activities expand, it becomes increasingly important to understand the implications for the country's environmental footprint. Past research in similar contexts suggests a complex correlation between economic growth and environmental quality, with varying results depending on the level of industrialization and regulatory frameworks in place.

A widely discussed framework in this discourse is the Environmental Kuznets Curve (EKC) hypothesis, which proposes that environmental degradation increases during the early stages of economic development but decreases as income levels rise and societies demand cleaner environments (Grossman & Krueger, 1995). However, the relevance of this theory in the context of Sierra Leone—characterized by limited industrialization, a post-conflict economy, and infrastructure challenges—requires empirical validation. Energy consumption plays a central role in this economic-environmental nexus. Sierra Leone's energy sector is primarily dependent on non-renewable sources and traditional biomass, which account for a substantial share of the country's emissions (International Energy Agency, 2019). Limited access to modern energy systems has led to the use of environmentally harmful alternatives that hinder both productivity and ecological sustainability. Therefore, exploring the relationship between energy consumption and CO_2 emissions is vital to ensuring that energy-driven economic growth does not exacerbate environmental challenges. This study also considers the role of FDI in Sierra Leone's carbon emissions. While foreign investment is a key driver of economic expansion, especially in capital-intensive sectors like mining, it can also lead to increased emissions if not managed within a sustainable framework. On the other hand, FDI can facilitate the transfer of cleaner technologies and environmental best practices. Understanding whether FDI exacerbates or alleviates environmental stress is essential for designing effective policy interventions. Trade openness (TO) is another important variable under examination. As Sierra Leone becomes increasingly integrated into the global economy, its trade volume and diversity have expanded. Trade can stimulate economic growth and technology diffusion, but it may also lead to increased pollution from industrial activities and transportation. The net impact of trade openness on environmental quality in Sierra Leone remains unclear and warrants detailed empirical investigation.

Given these interlinked dynamics, this research is structured around several core objectives:

- To analyze the short-run and long-run relationship between CO_2 emissions and economic growth, assessing whether economic expansion correlates with environmental degradation or supports ecological sustainability.
- To investigate the impact of FDI on carbon emissions, exploring whether increased foreign investment is associated with pollution-intensive growth or cleaner development paths.
- To assess how energy consumption contributes to CO_2 emissions, particularly in light of Sierra Leone's heavy reliance on non-renewable energy sources and limited electricity access.
- To examine the influence of trade openness on environmental outcomes, evaluating whether increased trade fosters pollution or promotes environmental efficiency through technology transfer and international standards.
- To offer policy recommendations that support sustainable development by aligning economic growth strategies with environmental preservation.

The context of Sierra Leone adds significance to this study. Rich in natural resources like diamonds, gold, and rutile, the country's economy has long been dominated by extractive industries. While these sectors contribute to GDP and employment, they also present significant environmental risks. The aftermath of a prolonged civil war (1991–2002) and the Ebola crisis left the nation with weakened infrastructure and environmental governance, further complicating the development-environment balance. Sierra Leone also faces environmental challenges characteristic of rapidly urbanizing and resource-dependent economies. Deforestation, water pollution, and biodiversity loss have been exacerbated by insufficient environmental regulations and unsustainable land-use practices. While the country's overall contribution to global carbon emissions is relatively small due to its low level of industrialization, the localized environmental impacts are significant and pose long-term risks to public health and agricultural productivity.

Moreover, the energy deficit in Sierra Leone is a critical concern. With one of the lowest electricity access rates in West Africa, most households and industries depend on biomass and diesel generators. This not only limits productivity and access to modern services but also intensifies carbon emissions and air pollution. A shift toward renewable energy sources such as solar, hydro, and wind could simultaneously support economic development and reduce environmental degradation. The relationship between economic growth and CO_2 emissions has been widely explored in economic literature, but findings vary across countries and contexts. Some studies suggest a linear relationship where emissions increase with growth, while others indicate a decoupling effect in which economies grow without proportionate increases in emissions (Khan et al., 2015; Shahbaz et al., 2013). However, most of this research has focused on larger economies, leaving a gap in understanding how these dynamics unfold in smaller, low-income countries like Sierra Leone. By incorporating variables such as GDP, FDI, energy consumption, and trade openness, this study contributes to filling that gap. It uses an econometric framework to determine the existence of co-integration and causality among these variables, offering evidence-based insights into Sierra Leone's development path. The findings are intended to inform policymakers, environmental agencies, and development partners, enabling them to craft targeted interventions that ensure economic development does not come at the cost of environmental sustainability.

LITERATURE REVIEW

2.1 CO_2 Emissions and Economic Growth

The interplay between economic growth and environmental degradation has received considerable attention, particularly through the lens of the Environmental Kuznets Curve (EKC) hypothesis. Originating from the work of Grossman and Krueger (1991), the EKC posits an inverted U-shaped relationship between environmental degradation and income per capita. The hypothesis suggests that pollution increases with economic growth during early stages of development, but beyond a certain income level—where cleaner technologies and stricter regulations are adopted—environmental degradation begins to decline. Stern (2004) and Dinda (2005) provided theoretical and empirical validation of the EKC, reinforcing the idea that economic growth can eventually coincide with environmental improvement.

Empirical studies provide nuanced insights into this dynamic. Panayotou (1993) found that higher-income countries tended to show improved environmental quality (Hossain et al., 2024), lending further support to the EKC theory. However, country-specific variations challenge its universality. For example, Shahbaz et al. (2013), in a study on Pakistan, identified that increased energy consumption initially raised CO_2 emissions but noted eventual environmental improvement due to economic expansion. Coondoo and Dinda (2007) highlighted that income inequality across countries affects emissions significantly, while Akbostancı et al. (2008) did not find EKC evidence in Turkey, suggesting that developmental phases and policy measures matter.

Ozturk and Acaravci (2010) confirmed a long-run causal relationship among economic growth, energy consumption, and emissions in Turkey, and similar mechanisms could be expected in developing nations like Sierra Leone. Khan et al. (2015) used FMOLS methods to reveal a positive correlation between CO_2 emissions and economic growth in China, Japan, and the U.S., though India demonstrated a negative linkage. This suggests that developmental context, energy policies, and industrial profiles are critical mediators in the growth-emissions relationship. In the EU context, Kasperowicz (2015) observed a long-term negative correlation between economic growth and CO_2 emissions among 18 member states, but also reported short-term positive effects, indicating transitional dynamics (Hossain, 2025). Cederborg and Snobohm (2016) analyzed 69 developed and 45 developing countries and found a consistent positive correlation between per capita GDP and emissions, contradicting EKC predictions and emphasizing regional disparities. Meanwhile, Aslan et al. (2018) confirmed the EKC's inverted-U pattern across various U.S. sectors, validating the hypothesis at the disaggregated level. Studies from the African context offer additional insights. Khan et al. (2020) applied the ARDL approach in Pakistan and found that both energy use and economic growth significantly influenced CO_2 emissions in the long and short run (Hossain & Nur, 2024). Similarly, Olubusoye and Musa (2020) found that in 79% of 43 African countries studied, CO_2 emissions positively correlated with economic growth. Osadume (2021) conducted a panel econometric analysis for six West African nations, revealing strong short-term positive impacts of economic growth on emissions. Shikwambana et al. (2021) applied the Sequential Mann-Kendall test in South Africa and established a robust linear relationship between emissions and GDP.

2.2 CO_2 Emissions and Foreign Direct Investment (FDI)

Foreign Direct Investment (FDI) plays a complex and often contested role in environmental outcomes. The Pollution Haven Hypothesis (PHH) argues that FDI gravitates toward countries with lax environmental regulations, thereby increasing emissions. However, others propose that FDI brings cleaner technologies and managerial efficiencies, mitigating environmental damage. Balsalobre-Lorente et al. (2018) highlighted that the relationship between FDI and emissions is multifaceted and conditional upon regulatory and technological contexts. Pao and Tsai (2011), focusing on Brazil, found that FDI increased CO_2 emissions due to industrial intensification. Similarly, Tang and Tan (2015) applied Granger causality techniques in Vietnam, concluding that FDI spurred emissions growth. Zhang and Zhou (2016) offered sector-specific insights from China, demonstrating that certain industries received pollution-intensive FDI. Other studies provided a more nuanced perspective. Ren et al. (2014) noted that when paired with sound policies, FDI in oil-exporting countries could lower emissions. Omri et al. (2015) showed in MENA countries that FDI and economic growth co-evolve with environmental degradation. Liang (2006) similarly found that FDI in China was linked to polluting sectors, while Solarin and Al-Mulali (2018) proposed that FDI initially degrades the environment but improves it as host economies mature. In BRIC countries, Tamazian et al. (2009) identified that while economic growth raised emissions, higher FDI improved environmental standards through technology spillovers. Seker et al. (2015) confirmed this dynamic in Turkey, with FDI's negative short-term but positive long-term environmental effects. Furthermore, Xing and Kolstad (2002) linked lax environmental laws to increased FDI and emissions. Dechezleprêtre and Sato (2017) and Zugravu-Soilita (2017) investigated the regulatory angle, finding that environmental standards shape FDI flows and subsequent emissions.

2.3 CO_2 Emissions and Energy Consumption

Energy consumption is arguably the most direct driver of CO_2 emissions. Empirical literature has repeatedly validated this relationship across regions and developmental contexts.

Soytas et al. (2006), using U.S. data, confirmed energy use as a primary driver of emissions, without finding a long-term link between income and CO_2. Halicioglu (2008), in Turkey, found both short- and long-run correlations between energy use, trade, and emissions. Zhang and Cheng (2009) demonstrated in China that energy use leads emissions, and economic growth drives energy demand—emphasizing a cascading relationship. Apergis and Payne (2009) showed bidirectional causality between emissions and energy use across Central America. Pao and Tsai (2011), examining Brazil, validated the EKC while confirming that energy-intensive industrial growth exacerbates pollution. Similarly, Li et al. (2017) identified a dual causal relationship among fossil fuel consumption types and emissions in China. Using the ARDL model, Cetin et al. (2018) confirmed long-run relationships among trade, energy use, and CO_2 in Turkey. Khoshnevis and Dariani (2019) found in Asian economies that trade openness, urbanization, and energy use mutually reinforce emissions trends. Vo and Le (2019) explored ASEAN nations and uncovered country-specific variations—Indonesia and Myanmar, for instance, exhibited unidirectional causality among energy use and CO_2 emissions. Mathieu et al. (2019) applied similar methods in Togo, validating the long-term linkage among energy, GDP, and emissions. Osobajo et al. (2020) also verified these associations in 70 countries from 1994–2013. Fong et al. (2022) found that among Greater Bay Area cities, energy inefficiency contributed to emissions except for technologically advanced cities like Shenzhen and Hong Kong.

2.4 CO_2 Emissions and Trade Openness

Trade liberalization's environmental implications are complex. While global trade can spread cleaner technologies, it may also exacerbate pollution due to increased industrial activity.

Between 1990 and 2011, simultaneous equation models used in MENA countries showed an insignificant or negative correlation between trade openness and pollution. However, Shahbaz et al. (2017) found an inverted U-shaped relationship across income groups, supporting EKC dynamics in trade contexts. Shahbaz et al. (2013) similarly argued that trade boosts R&D, which in turn reduces emissions. Managi et al. (2009) found that trade lowers emissions in advanced economies but worsens them in poorer countries. Jayanthakumaran et al. examined Chinese industrial data, showing that trade improves environmental quality by promoting income growth and eco-conscious spending (Hossain & Hena, 2024; Hossain et al., 2024). The UK-based study revealed both short- and long-term causality between CO_2 and trade openness, while Akin reported a positive relationship across income and trade variables. Ozturk and Acaravci (2013) identified a strong positive correlation in Turkey, whereas Boutabba found trade openness reduced emissions in India. Omri et al. (2011) reported unidirectional causality from trade openness to emissions, confirming that globalization affects environmental quality. Al Mamun et al. (2014) revealed that a 1% rise in trade could reduce emissions by 0.3%, albeit inconsistently across income levels.

2.5 Study Hypotheses

Based on the above literature, the following hypotheses are proposed:

- H_1: There exists a significant long-run and short-run relationship between CO_2 emissions and economic growth.
- H_2: FDI positively influences CO_2 emissions through energy-intensive activities.
- H_3: Energy consumption significantly contributes to CO_2 emissions.
- H_4: Trade openness significantly affects CO_2 emissions, either positively or negatively.
- H_5: FDI Granger-causes CO_2 emissions.
- H_6: CO_2 emissions do not Granger-cause FDI inflows.

2.6 Literature Gap and Novelty

While global literature on the EKC, FDI, energy consumption, and trade openness is vast, a glaring gap remains in the context of low-income, resource-dependent countries like Sierra Leone. This study is among the first to apply ARDL models, Granger causality tests, and variance decomposition to Sierra Leone, offering a country-specific evaluation of its economic trajectory and its alignment with EKC theory. Moreover, this research delves into the Pollution Haven Hypothesis, assesses the role of fossil fuel dependency, and explores renewable energy potential. The empirical evidence will inform green investment strategies, stricter regulations, and policy frameworks tailored to Sierra Leone's developmental goals.

METHODOLOGY, DATA SOURCE

This study utilizes secondary time-series data from 1980 to 2021 to analyze the long-run relationship between economic growth and carbon emissions in Sierra Leone. Data on CO_2 emissions and energy consumption (EC) per capita are sourced from *Our World in Data*, while gross domestic product (GDP) per capita, foreign direct investment (FDI), and trade openness (TO)—measured as the sum of exports and imports as a percentage of GDP—are obtained from the *World Bank*. CO_2 emissions per capita serve as the dependent variable, reflecting environmental degradation. The independent variables include GDP per capita as a proxy for economic growth, FDI inflows representing external investment, EC indicating reliance on energy sources, and TO capturing trade integration. The study employs the Autoregressive Distributed Lag (ARDL) model to explore both short- and long-run dynamics among these variables, and uses pairwise Granger causality tests to examine the directional influence, particularly between FDI and CO_2 emissions. This approach provides a comprehensive view of the economic-environmental nexus in Sierra Leone, offering valuable insights for sustainable policy development.

Table 1: Variables Description

Variables	Unit	Source
CO_2	Per capita Co_2 (kt)	Our World in Data
Energy Consumption	Per capita (Kwh/person)	Our World in Data
GDP	Per capita (Current US dollars)	World Bank
FDI	Inflows (Current US dollars)	World Bank
TO	(Trade % of GDP)	Our World in Data

Table 1 outlines the variables used in the study for Sierra Leone from 1980 to 2021. CO_2 emissions (kt) and energy consumption (kWh per capita) are sourced from *Our World in Data*, allowing for cross-country comparisons. GDP per capita, FDI inflows (in USD), and trade openness (% of GDP) are obtained from the *World Bank*. These indicators capture key aspects of economic activity and integration, while their per capita and monetary measurements help assess their environmental impact. The data supports analyzing the relationship between economic growth and CO_2 emissions in a measurable and comparative framework.

3.1 Model Specification

This study is grounded in three key theoretical frameworks: the Environmental Kuznets Curve (EKC) hypothesis, the Pollution Haven Hypothesis (PHH), and the Energy-Led Growth Hypothesis to explore how economic activities impact carbon emissions in Sierra Leone. The EKC suggests an inverted U-shaped link between income and pollution, where emissions rise during early development but fall as income increases and cleaner technologies emerge; this study investigates whether Sierra Leone fits this pattern. The PHH posits that countries with weak environmental regulations attract pollution-intensive FDI, potentially raising emissions—a concern for developing nations like Sierra Leone. Conversely, FDI may also introduce cleaner technologies. Lastly, the Energy-Led Growth Hypothesis highlights how increased energy use—especially fossil fuels—drives economic growth but also raises emissions, a pattern evident in many low-income countries. This study tests these theories within Sierra Leone's context to assess the roles of growth, FDI, and energy use in shaping environmental outcomes.

3.2 Empirical Model Specification

To empirically investigate the relationship between carbon emissions and economic growth in Sierra Leone, the study adopts the Auto regressive Distributed Lag (ARDL) model, which is well-suited for analyzing both short-run and long-run relationships among variables. The general functional form of the model is:

$$CO_{2t} = \alpha_o + \alpha_1 FDI_t + \alpha_2 GDP_t + \alpha_3 EC_t + \alpha_4 TO_t + \varepsilon_t \quad (1)$$

CO_{2t} = Carbon dioxide emissions per capita (kt)
FDI_t = Foreign direct investment inflows (current US$)
GDP_t = Gross domestic product per capita (current US$)
EC_t= Energy consumption per capita (kWh/person)
TO_t= Trade openness (exports + imports as a percentage of GDP)
α_o = Constant term
$\alpha_1, \alpha_2, \alpha_3, \alpha_4$ = Estimated coefficients
ε_t = Error term

The ARDL model: It is applicable for variables with mixed levels of stationarity (i.e., I(0) or I(1)) (Pesaran et al., 2001).It allows for short-run and long-run coefficient estimation in a single equation framework. It is well-suited for analyzing small sample sizes, which is relevant for Sierra Leone's economic data. To confirm the existence of a long-term relationship, the Bounds Testing approach is employed, where the F-statistic is compared against critical values at different significance levels.

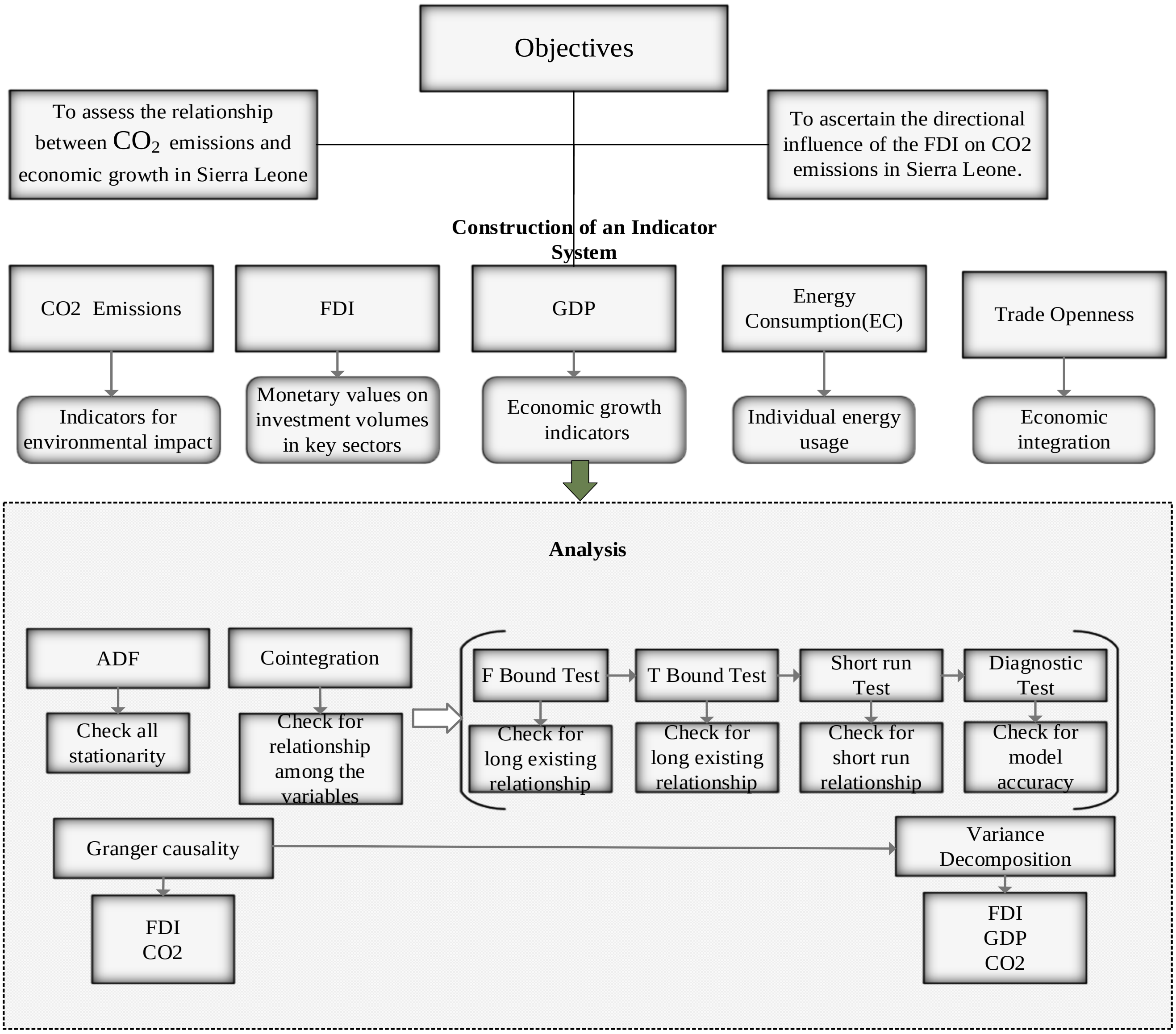

Figure 1: Framework of the study

Figure 1, provides a concise overview of the critical elements of this research framework, outlining the progression from initial inquiries to the final discussion of conclusions. Synthesize the findings of the analysis to arrive at a coherent and logical conclusion. The research structure on the relationship between CO_2 emissions and economic growth in Sierra Leone is developed to attain two goals. The primary objective is to assess the correlation between CO_2 emissions and economic variables, including GDP, FDI, energy consumption, and trade openness. Furthermore, it aims to comprehend the specific impact of FDI on CO_2 emissions. The study utilizes many econometric methodologies, beginning with the Augmented Dickey-Fuller test to determine stationarity and conducting co integration tests to examine long-term correlations. Subsequently, it employs the Bounds Testing methodology to validate these enduring connections and carries out short-term assessments to capture immediate interactions. Diagnostic tests confirm the model's resilience, while variance decomposition and Granger causality tests analyze and examine the connections between FDI and CO_2 emissions in more detail. This comprehensive framework enables a thorough examination of the connections between the economy and the environment in Sierra Leone.

RESULTS AND ANALYSIS

4.1 Augmented Dickey-Fuller Test

The results of the Augmented Dickey-Fuller (ADF) test indicate that all the variables—CO_2 emissions, energy consumption (EC), foreign direct investment (FDI), gross domestic product (GDP), and trade openness (TO)—are stationary at their first differences, I(1). This conclusion is drawn from the test statistics, which are significantly lower than the critical values at the 1%, 5%, and 10% levels, leading to the rejection of the null hypothesis of a unit root. The p-values for all variables are 0.0000, further confirming stationary at the first difference. This suggests that the time series data exhibit non-stationary at levels but become stationary after first differentiating, implying the presence of a long-term equilibrium relationship among the variables, which is crucial for further econometric modeling such as co integration analysis and error correction models.

Table 2: Augmented Dickey-Fuller Test

Variable	ADF Test Statistic	P-Value	Level stationary	Critical Value at 1%	Critical Value at 5%	Critical Value at 10%	Results
CO_2	-7.320101	0.0000	I (1)	-3.605593	-2.936942	-2.606857	Reject Null
EC	-7.050211	0.0000	I (1)	-3.605593	-2.936942	-2.606857	Reject Null
FDI	-6.971551	0.0000	I (1)	-3.605593	-2.936942	-2.606857	Reject Null
GDP	-6.530553	0.0000	I (1)	-3.615588	-2.941145	-2.609066	Reject Null
TO	-7.381508	0.0000	I (1)	-3.605593	-2.936942	-2.606857	Reject Null

4.2 Correlation Matrix

Theirs a positive relation between co2 emissions and GDP which indicates that as GDP increases, there is a possibility of an increase in CO_2 emissions. Similarly, there is a positive connection between FDI and CO_2 emissions, indicating that higher levels of FDI may be linked to higher CO_2 emissions. There is a direct correlation between energy consumption and CO_2 emissions, indicating that an increase in CO_2 emissions typically accompanies an increase in energy consumption. A positive link between trade openness and CO_2 emissions suggests that increased trade openness will likely result in higher CO_2 emissions. The article reveals a moderate positive association between GDP growth and FDI, a substantial positive correlation with increased trade openness, and a very low negative correlation indicating no significant relationship between trade openness and energy use. These correlations indicate the magnitude and orientation of a linear association between pairs of variables. The correlation matrix offers an initial insight into the degree of association between each economic indicator and CO_2 emissions in Sierra Leone.

Table 3: Correlation Matrix

Variables	CO2	GDP	FDI	EC	TO
CO2	1	0.09195	-	-	0.22645
GDP	-	1	0.28671	-0.24087	-
FDI	0.13166	-	1	-0.34521	0.71122
EC	0.29275	-	-	1	-
TO	-	0.23845	-	-0.10871	1

4.3 ARDL F Bound test

The F-statistic Resulted in 7.178139. The quantity of independent variables present in the ARDL model represent the sign k, which, in this particular instance, is equal to 4. The supplied critical value bounds apply to significance levels of 10%, 5%, 2.5%, and 1% for I(0) and I(1). The F-statistic (7.178139) exceeds the upper threshold of the I(1) critical value at all significance levels. These findings indicate that the null hypothesis can be excluded and infer that there is a sustained connection between the variables in the ARDL model for the economic and environmental data about Sierra Leone. This conclusion is of maximum importance for the study, as it provides confirmation of a stable and enduring link between the variables.

Table 4: ARDL F Bound test

Test Statistic	Value	Signif.	I (0)	I (1)
F-statistic	7.178139	10%	1.9	3.01
k	4	5%	2.26	3.48
		2.5%	2.62	3.9
		1%	3.07	4.44

4.4 ARDL F Bound test

The obtained t-statistic value from the test is -6.562685. The specified critical value bounds apply to various significance levels (10%, 5%, 2.5%, and 1%) for both I (0) and I (1) levels of integration. The t-statistic (-6.562685) is more negative than the minimum critical value for I (0) and less negative than the maximum critical value for I(1) at all levels of significance. These findings indicate that you can exclude the null hypothesis and infer that there is a persistent connection between the variables in the ARDL model for the economic and environmental data about Sierra Leone. This finding aligns with the expectations of an ARDL Bounds Testing approach to co integration, confirming the presence of a long-term equilibrium relationship between the variables of interest.

Table 5: ARDL T Bound test

Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-6.562685	10%	-1.62	-3.26
		5%	-1.95	-3.6
		2.5%	-2.24	-3.89
		1%	-2.58	-4.23

4.5 ADRL Short Run

The Delayed variable coefficient of CO_2 emissions displayed statistical significance, indicating that past levels of CO_2 emissions possess a statistically significant immediate association with present CO_2 emissions. The delayed FDI displayed a notable relationship with CO_2 emissions in the immediate term, suggesting that alterations in FDI have an immediate effect on CO_2 emissions. There was a substantial link between energy consumption and CO_2 emissions in the short term, as indicated by the significant lagged energy consumption. The lagged GDP variables, GDP (-1), GDP (-2), and GDP (-3), yielded varied outcomes. Certain lags exhibited significance, suggesting a short-term association for those particular lags. TO (-2): The trade openness variable from a previous period has a p-value slightly below the 0.05 threshold for one of the time lags, indicating a possible short-term connection at that lag. However, this connection is less robust than it is for other variables.

Table 6: ADRL Short Run

Variable	Coefficient	Std. Error	t-Statistic	Prob.
CO2 (-1)	-0.275055	0.066633	-4.127889	0.0005
FDI (-1)	9.25e-11	2.87e-11	3.225928	0.0042
EC (-1)	5.23e-05	1.73e-05	3.020709	0.0067
GDP (-1)	-0.001841	0.000673	-2.735400	0.0127
GDP (-2)	-0.000967	0.000527	-1.833102	0.0817
GDP (-3)	-0.000709	0.000333	-2.131108	0.0457
TO (-2)	-0.000459	0.000218	-2.105294	0.0481

In summary, the model's short-term dynamics indicate that previous levels of CO_2 emissions have an inverse relationship with current levels. In contrast, FDI has a positive relationship, even though to a small extent. There is a positive relationship between historical energy consumption and current emissions. The inverse correlation between GDP and emissions implies that, in the short term, an increase in economic output in the past is linked to a decrease in emissions in the present. This could be attributed to enhanced efficiency or a fundamental shift in the economic structure. The adverse consequences of previous trade liberalization may stem from an adjustment to more effective trade methods or modification in trade items that result in reduced CO_2 emissions.

4.6 ARDL Diagnostics test

The F-statistic of 1.648067, along with a p-value of 0.1444, indicates that there is not enough substantial evidence to support the presence of heteroskedasticity at commonly accepted levels of significance, such as 0.05. This indicates that the null hypothesis of homoskedasticity, which assumes a constant variance of residuals, cannot be invalidated. This indicates that the error terms of the model remain consistent regardless of the values of the independent variables, which is a favorable characteristic for obtaining precise standard errors and test statistics. The F-statistic is 1.639913, and the equivalent probability of obtaining this value or a more extreme value under the null hypothesis is 0.2217. The obtained p-value exceeds the commonly accepted significance level (often 0.05 or 0.10), indicating insufficient evidence to reject the null hypothesis. Hence, we lack substantial evidence of serial association at the 5% or 10% significance levels. A high Jarque-Bera statistic provides strong evidence against the null hypothesis that the data follows a normal distribution. The p-value for the Jarque-Bera statistic is 0.508741, which exceeds the standard criteria of 0.05 or 0.10. The high p-value indicates insufficient statistical evidence to reject the null hypothesis that the residuals follow a normal distribution.

Table:7 ARDL Diagnostics test

Residual Diagnostics	F-statistics	Prob.
Heteroskedasticity Test: Harvey	1.648067	0.14444
Bruesch-Godfred LM Test	1.639913	0.2217
Jarque-Bera	1.351362	0.508741

4.7 Variance Decomposition of CO2

In period 1, shocks cause all the estimated error variances of co2. Over time, the influence of its disturbances diminishes, indicating that other factors contribute to the variability in the prediction inaccuracy of CO2 emissions. The relationship between GDP and the forecast error variance of CO2 emissions is initially negligible but gradually increases to around 1.53% by period 10. This indicates a modest, although progressively stronger, influence of GDP on the fluctuation of CO2 emissions over time. FDI: The influence of FDI on CO2 emissions begins at a baseline level of 0 but experiences a notable rise over time. By period 10, FDI accounts for approximately 18% of the discrepancy in projected CO2 emissions, highlighting its significant contribution to the variability of CO2 emissions. The influence of EC on the forecast error variance of CO2 emissions likewise rises gradually over time, reaching around 15.74% by period 10. This suggests that energy consumption has a substantial and increasing impact on the variability of CO2 emissions. The relationship between TO and CO2 emissions exhibits an initial value of 0, which gradually rises and reaches its highest point in period 7. Subsequently, there is a minor decline in CO2 emissions by period 10, amounting to around 6.84%. This indicates a moderate level of influence on the variability of CO2 emissions.

Table 8: Variance Decomposition of CO_2

Period	S.E.	CO2	GDP	FDI	EC	TO
1	0.018318	100.0000	0.000000	0.000000	0.000000	0.000000
2	0.021924	94.57845	0.144546	2.731885	0.455429	2.107688
3	0.026673	82.31686	0.807670	11.39894	0.315103	5.161428
4	0.029828	76.65565	0.852893	13.69109	0.495668	5.604704
5	0.032245	72.63786	1.304811	18.65003	1.189991	6.217307
6	0.034204	68.96807	1.595121	19.59640	3.105012	6.735399
7	0.035770	66.04256	1.626116	19.56154	5.722263	7.047516
8	0.037090	63.25413	1.611478	19.11978	8.900604	7.114002
9	0.038249	60.48089	1.577801	18.57553	12.33195	7.033826
10	0.039269	57.86355	1.530491	18.02439	15.73660	6.844965

4.8 Variance Decomposition of GDP

The proportion of the variation in GDP's forecast errors that can be due to CO2 grows gradually over time, beginning at approximately 4.86% in the initial period and reaching around 5.22% by the tenth period. The forecast error variance of GDP is primarily attributed to its past values, decreasing from 95.13% to 73.75% over time. Foreign Direct Investment FDI: Initially, FDI has little impact on the variability in GDP's forecast errors. However, as time progresses, the contribution of FDI to predicting the future variability of GDP increases, indicating its growing significance. The impact of energy consumption on the forecast error variance of GDP begins at zero. However, it progressively increases over time, signifying a growing influence of energy consumption on the future variance of GDP. The impact of trade openness on the prediction error variance of GDP is initially tiny and remains reasonably stable over time, suggesting a consistent but moderate effect on the future variation of GDP. Essentially, this variance decomposition reveals that GDP is mainly influenced by its past values. However, other factors like CO2 emissions, FDI, energy consumption, and trade openness also contribute to the fluctuations in GDP over time, with their impact generally growing or remaining stable.

Table 9: Variance Decomposition of GDP

Period	S.E.	CO2	GDP	FDI	EC	TO
1	6.867579	4.862562	95.13744	0.000000	0.000000	0.000000
2	7.533535	4.329058	90.90103	0.871198	2.773351	1.125363
3	8.040408	4.761982	81.76421	4.434115	6.942355	2.097343
4	8.119584	4.759394	80.87821	4.455378	7.576669	2.330354
5	8.237934	4.638220	78.57142	5.058333	9.456902	2.275121
6	8.334441	4.664309	76.76520	5.168770	11.12081	2.280908
7	8.397905	4.688978	75.69624	5.214620	12.15269	2.247478
8	8.443806	4.729695	74.91191	5.254383	12.76750	2.273518
9	8.480554	4.994303	74.26481	5.231552	13.19825	2.311078
10	8.510467	5.220423	73.74621	5.202182	13.46323	2.367953

4.9 Variances Decomposition of FDI

The proportion of the variation in FDI that can be attributed to CO2 grows from 0.188070% in period 1 to 1.479476% in period 10. The effect of GDP on the variability of FDI begins at 0.452165% and gradually rises to 5.142555% by the tenth period, indicating a progressively stronger influence.FDI: At first, the vast majority (over 99%) of the discrepancy between the predicted and actual values of FDI can be attributed to the impact of its unexpected events. The level of self-explanation diminishes to approximately 70.53% by period 10, suggesting that as time progresses, other factors become increasingly influential in explaining the variability of FDI.The impact of EC shocks on the forecast error variance of FDI starts at 0% and gradually increases to become statistically significant, reaching 20.49539% by period 10.TO shocks account for a growing proportion of the variation in FDI, but it is still relatively minor, reaching 2.349258% by period 10.The variance decomposition reveals that in the short term, the majority of FDI's forecast error variance can be attributed to its shocks. However, as time progresses, the influence of other variables, particularly energy consumption and, to a lesser extent, GDP, becomes more significant.

Table 10: Variances Decomposition of FDI

Period	S.E.	CO2	GDP	FDI	EC	TO
1	1.47E+08	0.188070	0.452165	99.35976	0.000000	0.000000
2	1.79E+08	0.174849	0.753518	96.37568	0.606056	2.089894
3	1.97E+08	0.279133	5.315214	90.30585	1.628378	2.471425
4	2.05E+08	0.377771	6.212537	86.11914	5.016962	2.273594
5	2.10E+08	0.373659	5.994372	82.67226	8.749880	2.209832
6	2.15E+08	0.417458	5.771079	79.27960	12.35998	2.171884
7	2.19E+08	0.553799	5.567941	76.36056	15.38589	2.131807
8	2.22E+08	0.765340	5.398253	74.04085	17.64452	2.151041
9	2.25E+08	1.074082	5.259408	72.14071	19.29151	2.234289
10	2.28E+08	1.479476	5.142555	70.53332	20.49539	2.349258

4.10 Discussion

This study reveals a strong, positive relationship between economic growth, FDI, energy consumption, and CO_2 emissions in Sierra Leone, highlighting a pattern of development that intensifies environmental degradation. While economic expansion is linked to rising emissions, there is no evidence of the Environmental Kuznets Curve (EKC), suggesting the country remains in a pollution-intensive growth phase. FDI shows a unidirectional causal impact on emissions, supporting the Pollution Haven Hypothesis, as investments are primarily channeled into energy- and resource-intensive sectors. Energy consumption emerges as the strongest driver of emissions, largely due to Sierra Leone's reliance on fossil fuels and biomass. These findings underscore the need for policy interventions promoting renewable energy, environmentally responsible investment, and sustainable growth strategies.

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study provides a comprehensive analysis of the relationship between economic growth, CO_2 emissions, foreign direct investment (FDI), energy consumption, and trade openness in Sierra Leone using ARDL modeling, Granger causality tests, and variance decomposition. The findings reveal a strong positive relationship between GDP and CO_2 emissions, indicating that Sierra Leone's growth is heavily reliant on fossil fuels and energy-intensive industries. Contrary to the Environmental Kuznets Curve (EKC) hypothesis, there is no evidence of a turning point where increased income leads to lower emissions, suggesting that emissions will likely continue rising without targeted policy reforms. The study also finds unidirectional causality from FDI to CO_2 emissions, supporting the Pollution Haven Hypothesis, as foreign investments—particularly in extractive sectors—are linked to environmental degradation rather than sustainable development. Energy consumption emerges as the most significant driver of emissions, emphasizing the urgent need to transition from non-renewable energy sources to cleaner alternatives such as solar, wind, and hydro power. While trade openness currently shows a moderate impact, its environmental influence may grow with deeper global integration. These results call for urgent policy interventions, including stricter environmental regulations, incentives for clean energy investments, and environmentally conscious trade policies to align growth with sustainability. The study not only bridges a critical research gap on Sierra Leone's economic-environmental dynamics but also contributes to the broader discourse on sustainable development in low-income economies. It underscores the importance of strategic shifts toward green investment, innovation, and robust governance to ensure that long-term economic advancement does not come at the cost of environmental degradation.

5.2 Policy Recommendation

1 Green Investment Guidelines: The strong Causality between FDI and CO_2 emissions highlights the need for the establishment of a comprehensive framework for environmentally-friendly investments. Sierra Leone ought to implement rigorous environmental regulations for foreign investments, guaranteeing that incoming cash promotes sustainable growth and the adoption of environmentally friendly technologies.

2 Energy Reform Policy: Due to the correlation between energy use and CO_2 emissions, it is imperative to implement policy changes in the energy industry. The government ought to give priority to investments in renewable energy sources and provide incentives for the use of energy-efficient technologies in various businesses.

3 Economic Diversification: The correlation between economic growth and CO_2 emissions necessitates the need to diversify the economy by shifting towards sectors that have lower carbon intensity. Promoting service-oriented companies and high-tech sectors can help mitigate the environmental impact caused by economic growth.

4 Trade Policy Adjustments: While the direct influence of trade openness on CO_2 emissions remains inconclusive, the adoption of green trade policies can effectively address and minimize any potential adverse environmental consequences. This includes the promotion of the export and import of commodities that are environmentally sustainable, as well as the adoption of Eco-labeling.

5 **Carbon Accounting and Reduction Targets:** Develop a resilient carbon accounting system to effectively track and establish targets for reducing CO_2 emissions. This approach would facilitate openness and accountability, enabling the monitoring of progress towards emission reduction objectives.

6 **Incentives for Low-Carbon Practices:** Offer fiscal incentives such as tax rebates, subsidies, or other financial rewards to enterprises that adopt environmentally friendly practices with minimal carbon emissions. This could motivate corporations to allocate resources towards cleaner technology and mitigate their carbon footprints.

7 **Capacity Building:** Allocate resources towards enhancing the capabilities of local organizations to effectively oversee and enforce environmental regulations. This encompasses providing training to regulatory authorities, financial institutions, and the judiciary to enhance their capacity to implement environmental laws with utmost effectiveness.

8 **Public Awareness Campaigns:** Implement public awareness initiatives to instruct individuals and enterprises on the significance of diminishing carbon emissions and the contribution they may make towards attaining a sustainable future.

REFERENCES

1. World Bank. (2020). Sierra Leone economic outlook. World Bank Database.
2. Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American Free Trade Agreement. National Bureau of Economic Research (NBER) Working Paper No. 3914.
3. Sampa, P. and Hossain, S., 2024. Innovation and Intellectual Property Rights: A Case Study of Zambia. *Management*, *4*(6), pp.186-194.
4. Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. Quarterly Journal of Economics, 110(2), 353-377.
5. International Energy Agency (IEA). (2019). Sierra Leone energy profile. IEA Database.
6. Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. World Development, 32(8), 1419-1439.
7. Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. International Labour Organization.
8. Hossain, S., Akon, T. and Hena, H., 2024. Do creative companies pay higher wages? Micro-level evidence from Bangladesh. *Finance & Accounting Research Journal*, *6*(10), pp.1724-1745.
9. Khan, M. A., Zhao, M., Zhang, X., & Khan, M. M. (2015). Investigating the impact of carbon emissions on economic growth: Empirical evidence from panel data. International Journal of Environmental Science and Technology, 12(11), 3745-3760.
10. Hossain, S. and Nur, T.I., 2024. Gear up for safety: Investing in a new automotive future in China. *Finance & Accounting Research Journal*, *6*(5), pp.731-746.
11. Shahbaz, M., Lean, H. H., & Farooq, A. (2013). Natural gas consumption and economic growth in Pakistan. Renewable and Sustainable Energy Reviews, 18, 87-94.
12. Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. Review of Economics and Statistics, 87(1), 85-91.
13. Cole, M. A. (2006). Does trade liberalization increase energy use? Economics Letters, 92(1), 108-112.
14. Dinda, S. (2005). A theoretical basis for the Environmental Kuznets Curve. Ecological Economics, 53(3), 403-413.
15. Omri, A., Daly, S., Rault, C., & Chaibi, A. (2015). Financial development, environmental quality, trade, and economic growth: What causes what in MENA countries. Energy Economics, 48, 242-252.
16. Solarin, S. A., & Al-Mulali, U. (2018). The impact of foreign direct investment on indicators of environmental degradation. Environmental Science and Pollution Research, 25(9), 8795-8810.
17. Ren, S., Yuan, B., Ma, X., & Chen, X. (2014). The impact of FDI on CO_2 emissions in oil-exporting countries. Energy Economics, 42, 1-9.
18. Tang, C. F., & Tan, B. W. (2015). The impact of energy consumption, income, and foreign direct investment on carbon dioxide emissions in Vietnam. Energy, 79, 447-454.
19. Zhang, C., & Zhou, X. (2016). The impact of foreign direct investment on CO_2 emissions in China: A sector analysis. Energy Economics, 58, 264-271.
20. Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? American Economic Review, 91(4), 877-908.
21. Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for overaggressive time series with a unit root. Econometrica, 49(4), 1057-1072.
22. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16(3), 289-326.
23. Osadume, R. (2021). Economic growth and carbon emissions in West African countries: Panel econometric analysis. African Journal of Economic Policy, 28(1), 43-65.

24. Shikwambana, L., & Tsoanamatsie, N. (2021). The relationship between emissions and economic growth in South Africa. Energy Reports, 7, 451-459.
25. Olubusoye, O., & Musa, I. (2020). Investigating the relationship between CO_2 emissions and economic growth in African countries. Energy Policy, 143, 111595.
26. Kasperowicz, R. (2015). Economic growth and CO_2 emissions: The ECM analysis. Journal of International Studies, 8(3), 91-98.
27. Hossain, S., 2025. Singapore Role in Advancing Global Low-Carbon Economy: A Joint Effort for Sustainability and Climate Commitments. *American Journal of Business Science Philosophy (AJBSP)*, *2*(1), pp.36-47.
28. Cederborg, J., & Snobohm, S. (2016). Is there an Environmental Kuznets Curve for CO_2 emissions? Environmental and Resource Economics, 64(1), 59-77.
29. Pao, H. T., & Tsai, C. M. (2010). Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. Renewable and Sustainable Energy Reviews, 15(5), 2392-2398
30. Apergis, N., & Payne, J. E. (2009). CO_2 emissions, energy usage, and output in Central America. Energy Policy, 37(8), 3282-3286.
31. Hossain, S., Hossen, M.S.B., Zim, S.K. and El Hebabi, I., 2024. Cultural dynamics and consumer behavior: An in-depth analysis of Chinese preferences for western imported products. *GSC Advanced Research and Reviews*, *20*(3), pp.158-167.
32. HOSSAIN, S. and HENA, H., 2024. The study explores the correlation between cultural influence and community engagement in fostering social safety for tourists.
33. Halicioglu, F. (2008). An econometric study of CO_2 emissions, energy consumption, income, and foreign trade in Turkey. Energy Policy, 36(3), 1156-1164.
34. Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality? Journal of Environmental Economics and Management, 58(3), 346-363.
35. Elliott, R. J., & Zhang, J. (2011). Growth, foreign direct investment, and the environment: Evidence from Chinese cities. Journal of Regional Science, 51(1), 121-138.
36. Dechezleprêtre, A., & Sato, M. (2017). The impacts of environmental regulations on competitiveness. Review of Environmental Economics and Policy, 11(2), 183-206.
37. Sazib Hossain, H.H. and Sampa, P., Decoding Consumer Habits: Analyzing Retail Patterns Across Demographics.