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Prempeh, Kwadwo Boateng

Sunyani Technical University

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Green Finance or Carbon Trap? The Role of Financial Development in Ghana's CO_2 Emissions

Kwadwo Boateng Prempeh
Faculty of Business and Management Studies, Sunyani Technical University, Ghana
Email address: prempeh.boateng@stu.edu.gh
ORCID: https://orcid.org/0000-0001-8193-6676

Abstract

Purpose – This study examines the symmetric and asymmetric effects of financial development on CO_2 emissions in Ghana, incorporating the roles of natural resource rents and economic sustainability.

Design/Methodology/Approach – Using annual data from 1990 to 2020, the study employs linear and nonlinear autoregressive distributed lag (ARDL and NARDL) models to assess long- and short-term relationships. Principal Component Analysis (PCA) is applied to construct an economic sustainability index.

Findings – The results confirm a long-run relationship between financial development and CO_2 emissions. Financial development and natural resource rents contribute to increased CO_2 emissions, whereas economic sustainability reduces emissions. The NARDL model reveals asymmetric effects: positive shocks in financial development significantly increase emissions, while negative shocks have a neutral impact. Short-term effects suggest that financial development also drives emissions growth.

Research Implications – The findings underscore the need for policies that promote financial development aligned with environmental sustainability. Policymakers should incentivize green financing, strengthen environmental regulations for resource extraction, and integrate sustainability into economic policies to mitigate emissions.

Originality/Value – This study is among the first to explore the asymmetric impact of financial development on CO_2 emissions in Ghana, while also considering natural resource rents and economic sustainability. By highlighting the nonlinear effects, the research provides new insights for policymakers and scholars examining the environmental consequences of financial sector expansion.

Keywords: Financial development, CO_2 emissions, economic sustainability, natural resource rents, ARDL, NARDL, Ghana

1. Introduction

Climate change is a pressing worldwide problem that is of utmost significance and poses a grave danger to the ongoing survival of humankind as it has dire consequences on population health (Prempeh, Frimpong, *et al.*, 2024). The primary catalyst for climate change is the escalating levels of greenhouse gases (GHGs), predominantly carbon emissions (CE). It is, therefore, imperative for nations to prioritise environmental pollution concerns to achieve their sustainable development agenda, particularly SDG 13. Several economic factors have been highlighted in the literature as significant contributors to CE, including economic growth, exploitation of natural resources, foreign direct investment (FDI), trade openness, energy consumption, industrialisation, financial development (FD), and urbanisation (Chen, Wang, *et al.*, 2023; Luqman, 2024; Mensah and Abdul-Mumuni, 2022; Omoke *et al.*, 2020; Prempeh, 2024).

In recent years, the interaction between FD and CE has been vital due to the surge in green financing (Majeed *et al.*, 2020). Green financing helps to mitigate CE by promoting ecologically friendly investments. Furthermore, FD may reduce CE by supporting research and development (R&D) efforts and encouraging capital-intensive renewable energy projects and green technology. However, FD may enhance CE by stimulating the purchase of goods and services. Rising demand for goods and services necessitates more production, which may require intensive energy usage, leading to CO_2 emissions.

Ghana is grappling with the problem of declining air quality due to the escalation of CE, as seen in Figure 1. Ghana generates approximately 66% of its electricity from thermal sources, contributing to its increasing CE. Despite contributing 25.6 million metric tonnes of CO_2 (Mt CO2e), which accounts for 0.06% of global greenhouse gas (GHG) emissions, Ghana is disproportionately affected by the effects of climate change. The annual cost of environmental deterioration in Ghana is projected to be $6.3 billion, which accounts for almost 11% of the country's GDP in 2017 (World Bank, 2020). Ghana's goal is to decrease its GHG emissions by 45% by 2030, compared to the levels recorded in 2015, as outlined in its Nationally Determined Contribution (NDC) under the Paris Agreement. Prempeh (2023) posits that economic expansion increases environmental deterioration due to FD. The Central Bank of Ghana (BoG) has implemented measures to alleviate environmental deterioration by promoting green investment projects. For example, BoG has signed an agreement with International Finance Corporation (IFC) to promote green financing. As a result, the Bank of Ghana (BoG) has introduced the Ghana Sustainable Baking Principles

(SBPs) with support from the International Finance Corporation (IFC). In addition, The Ghana Stock Exchange (GSE), in partnership with the Securities and Exchange Commission (SEC), introduced the Green and Sustainable Bond Rules to guide the listing and trading of environmentally friendly and sustainable bonds on the Ghanaian market in 2022, with the backing of IFC. This motivates the study to explore the connection between FD and CE in Ghana empirically.

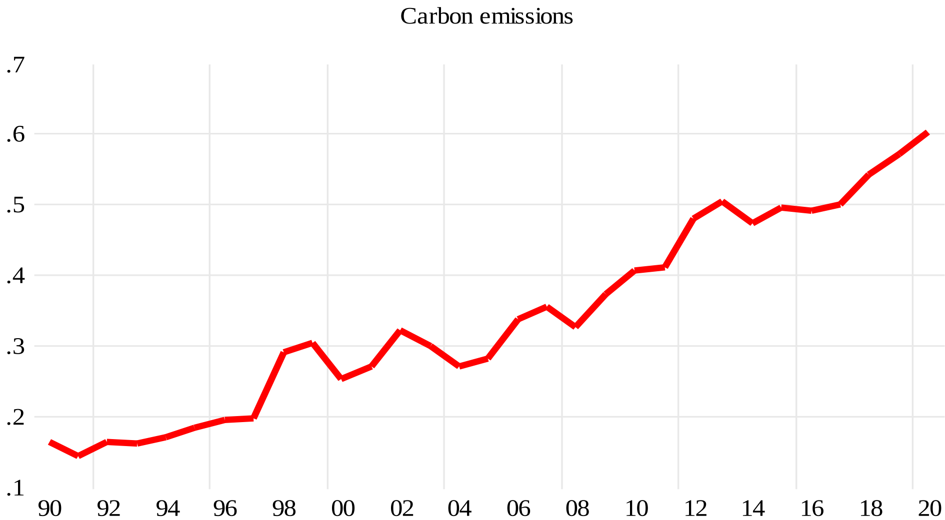

Figure. 1 A plot of CO_2 emissions (metric tons per capita) in Ghana (1990–2020)

Numerous investigations have explored the impact of FD on CE. However, the findings of these studies have been equivocal. While some argue that FD has a beneficial effect, others argue that it has negative consequences, while others argue that there is no link. Several studies focusing on emerging countries and Sub-Saharan Africa have shown a notable adverse impact of FD on CE. See, for example, Omoke et al. (2020), Alhassan et al. (2022), Brown et al. (2022), Prempeh et al. (2023), Ashena and Shahpari (2024), and Prempeh (2024). However, some have demonstrated the positive impact of FD on CE, for example, Boutabba (2014), Ali et al. (2019), Rajpurohit and Sharma (2021) and Mukhtarov et al. (2024). Other studies, such as Abokyi et al. (2019), Cosmas et al. (2019) and Khan et al. (2021), among others, revealed no substantial connections between FD and CE. It is essential to mention that most of these studies explored the link between FD and CE in a symmetric framework. However, this study contends that there could be asymmetries in the link between FD and CE. Thus, this study contributes to the literature by examining the symmetric and asymmetric relationship between FD and CE in Ghana while accounting for the influence of natural resource rents (NR) and economic sustainability (ES) on CE, where limited or no empirical evidence exists. ES implies that an economic system or activity may endure for an extended period without degenerating the environment, society, or future generations. ES is a more comprehensive viewpoint, and economic growth and development are its dimensions (Mehmood and Kaewsaeng-on, 2024a).

The remaining sections of the paper are structured as follows: Section 2 analyses the relevant literature. Section 3 outlines the methodology, whereas Section 4 presents the empirical results. Section 5 provides the conclusion and policy implications.

2. Literature review

There has been increasing interest in the empirical link between FD and CE in recent years. However, the findings of the studies on this topic have been equivocal. Several studies have shown that increased FD is associated with decreased CE. For example, Prempeh et al. (2023) explored the impact of FD on CE in 11 ECOWAS economies using the augmented mean group (AMG) estimator and Driscoll-Kraay (D-K) panel regression. The empirical results demonstrated that the impact of FD on CE is negative and significant. Similarly, Prempeh (2024) focused on 10 ECOWAS nations and found that FD substantially dampens CE using the D-K panel regression and panel quantile regression (PQR) techniques. Later, Ashena and Shahpari (2024) examined the link between FD and CE in 30 developing countries over the period 1990-2018 by using the Panel-ARDL approach. Their empirical outcomes provide compelling evidence of the adverse effect of FD on CE. Mehmood and Kaewsaeng-on (2024b) also established a negative impact of FD on CE in the top 10 tourist economies using data spanning 1991-2021. Mensah and Abdul-Mumuni (2022) investigated the asymmetric effect of FD on CE using a sample of 31 SSA nations and the panel NARDL approach. The study revealed that both positive and adverse shock in FD hinders CE. Shang et al. (2023), using the ARDL and NARDL approaches, concluded that FD mitigates CE in China in the long term. Omoke et al. (2020) used the NARDL technique from 1971-2014 and found evidence that positive shock in FD deters CE while adverse shocks in FD induce CE. Using the three-stage least-square-square (3SLS) approach, Alhassan et al. (2022) revealed a noteworthy inverse correlation between CE and FD in Ghana. Ren et al. (2023) also adopted the pooled mean group estimator and found that FD reduces CE in China.

On the other hand, other studies have revealed the positive impact of FD on CE (Ibrahim and Ajide, 2021; Mukhtarov *et al.*, 2024; Wang, Zhou, *et al.*, 2024). Ibrahim & Vo (2021), relying on a sample of 27 countries from 1991-2014, concluded that FD promotes CE. Habiba et al. (2023) scrutinised the connection between FD and CE using the AMG estimator. The empirical studies demonstrated a positive correlation between FD and CE. Interestingly, Cosmas et al. (2019) discovered that FD had a neutral effect on CE from 1981 to 2016, as determined by the ARDL analysis. In the context of Ghana, Abokyi et al. (2019), using the ARDL technique, concluded that FD has no significant impact on CE.

Another variable that can influence CE is NR. The influence of this variable depends on the state of the country, which may either have a beneficial or detrimental effect on CE. Some studies have demonstrated that NR makes a substantial contribution to CO_2 emissions, highlighting the necessity of sustainable resource management (Alhassan and Kwakwa, 2023; Chen and Chen, 2024; Chen, Gozgor, *et al.*, 2023; Nwani and Adams, 2021; Zhao *et al.*, 2024). Huang et al. (2023) applied the AMG technique and found that NR heightened CE in BRICS economies. In their paper, Shang et al. (2023), using the System Generalised Method of Moments (SGMM) estimations, demonstrated the inducing effect of NR on CE in 36 economies. Kwakwa et al. (2020) found that NR contributed to the CE. On the contrary, some studies revealed the mitigating effects of NR on CE (Chen, Wang, *et al.*, 2023; Luqman, 2024; Shahbaz *et al.*, 2024). Li et al. (2024) found that NR hinders CE. Tufail et al. (2021), using the CS-ARDL model, found that NR dampens CE in OECD economies. In a recent study conducted by Wang, Li, et al. (2024), it was shown that NR has a neutral impact on CE. The neutral effect of NR on CE is supported by Befeke et al. (2023). Khaddage-Soboh et al. (2023) adopted the moment quantile regression (MMQR) technique to determine that lower quantiles demonstrate a negative and substantial relation between NR and CE. However, this connection turns positive and statistically insignificant at upper quantiles.

Economic sustainability can also influence CE. Scholarly interest in ES has recently increased as a result of its potential for advancing environmental quality by lowering CE (Amaliah *et al.*, 2024; Bekele *et al.*, 2024; Cao *et al.*, 2024; Prempeh, Kyeremeh, *et al.*, 2024; Subhan *et al.*, 2024; Xie and Huang, 2024). For example, Mehmood and Kaewsaeng-on (2024a), using the FMOLS, DOLS and PQR techniques, found that ES is a barrier to CE in 10 newly industrialised economies. The empirical outcomes of Zhang et al. (2022) demonstrate that sustainable ecological laws have a suppressive effect on CE in China.

The paper departs from other works in the literature in two key aspects: Firstly, it is the first to explore the symmetric and asymmetric impact of FD on CE while considering NR and ES as additional determinants of CE in Ghana. Second, the majority of studies have concentrated on economic growth as a means of elucidating CO_2 emissions and environmental concerns; nonetheless, it is critical to address economic sustainability issues, which have been overlooked in literature except for the recent panel study by Mehmood and Kaewsaeng-on (2024a).

3. Methodology

3.1 Theoretical associations

An advanced financial system facilitates businesses in acquiring cash for investment at lower costs. The industrial production process necessitates significant energy consumption, resulting in a subsequent rise in CE due to Ghana’s heavy reliance on unclean energy sources, namely fossil fuels. Financial development is one of Ghana’s primary catalysts for economic growth (Prempeh and Frimpong, 2024). Therefore, a resilient financial system will result in a rise in the consumption of goods and services. Certain items and services in question possess environmentally sustainable qualities and have the potential to impede CE. Nevertheless, products and services that lack environmental sustainability will release CO_2 into the atmosphere. FD may enhance loan accessibility, enabling investments in clean energy technology and energy-efficient projects, ultimately reducing carbon emissions (Prempeh, 2024). The resource curse hypothesis posits that societies with copious natural resources may have challenges in attaining long-term economic and ecological sustainability. Nations possessing vast natural resources, especially renewable resources such as minerals or oil, often have difficulties effectively managing their use while minimising environmental impacts. Rapidly pursuing the exploitation of resources may result in negative consequences, including deforestation, destruction of habitats, pollution, and a rise in CE. Endowed with abundant natural resources, Ghana is plagued by weak institutional frameworks, corruption, lack of transparency, and the detrimental impact of ‘*galamsey*’ activities, aggravating the undesirable outcomes of abundant natural resources. Economic sustainability is the attainment of enduring economic development via the effective utilisation of resources, the reduction of environmental implications, and the advancement of social well-being (Bekele *et al.*, 2024). A meticulous equilibrium is necessary between economic advancement, environmental preservation, and social fairness.(Subhan *et al.*, 2024) At this stage, nations prioritise the environmental consequences of their activities and hence implement policies and strategies to enhance environmental quality by decreasing CO_2 emissions. This stage aligns with the declining phase of the U-shaped environmental Kuznets (EKC) hypothesis.

3.2 Data

This paper used annual time series data from 1990-2020 to quantify the dynamic impact of financial development on CO_2 emissions while controlling for natural resource rent and economic sustainability. The observations of both the predictor and dependent variables were sourced from the World Development Indicators (WDI) database. The predictor variables are financial development (FD), natural resource rent (NR), economic sustainability (ES), and carbon emissions (CE), which symbolise the target variable. Table 1 presents the variables' notations, measures and sources.

Table 1. Variable and data sources

Variable	Notation	Measure	Data source
Carbon emissions	CE	CO_2 emissions (metric tons per capita)	WDI
Financial development	FD	Domestic credit to private sector (% of GDP)	WDI
Natural resource rent	NR	Total natural resources rents (% of GDP)	WDI
Economic sustainability (PCA)	ES	Trade (% of GDP)	WDI
		Population growth (annual %)	WDI
		Final consumption expenditure (current US$)	WDI
		Inflation, consumer prices (annual %)	WDI

3.2.1 Principal Component Analysis (PCA)

The economic sustainability index is developed using PCA. It considers variables such as population, inflation, final consumption expenditure and trade (P-I-F-T) inspired by Mehmood and Kaewsaeng-on (2024a). The outcomes of the PCA are provided in Table 1, while the graphical representation of the PCA, known as the Biplot, is shown in Figure 2. The eigenvalues of the PCA represent the amount of variation explained by each component. PC 1 is picked based on its eigenvalue of 3.477, which exceeds 1 and reflects 86.9% of the total variance in the specified measures.

Table 2. Principal component analysis

Component	Eigenvalue	Percentage of Variance	Cumulative
1	3.477	0.869	0.869
2	0.455	0.114	0.983
3	0.066	0.017	1.000
4	0.001	0.000	1.000

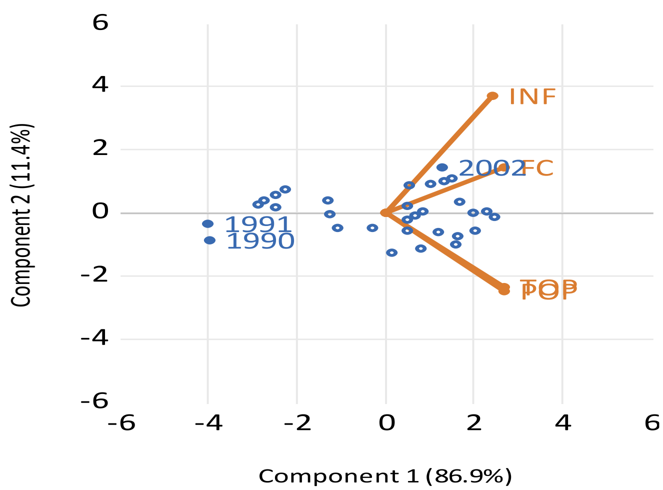

Figure 2. Biplot of principal component analysis.

3.3 Model specification

The study aims to explore the impact of FD on CE in Ghana. The general form of CE function is developed as follows.

$$CE_t = \int FD_t \tag{1}$$

Consistent with prior studies, the current study has accounted for a list of confounding variables such as NR and ES in Equation (1). The resulting Equation (2) is as defined below:

$$CE_t = \int FD_t, NR_t, ES_t \tag{2}$$

Where t symbolises the period. To normalise the time data, improve the reliability of estimates and facilitate the interpretation of the results in terms of elasticities, we transform all the variables excluding ES, which is an index, into their natural logarithm (*ln*) form. The empirical model is designed as follows:

$$lnCE_t = \beta_0 + \beta_1 lnFD_t + \beta_2 lnNR_t + \beta_3 ES_t + \varepsilon_t \tag{3}$$

Where ε_t is the residual term in the model. β_0 denotes the intercept of the model. β_1, β_2 and β_3 are the coefficients of FD, NR and ES, respectively.

3.4 Econometric strategy

Unit root test

Before executing the autoregressive distributed lag (ARDL) and nonlinear autoregressive distributed lag (NARDL) tests, it is essential to ascertain the correct order of integration by carrying unit root checks since these econometric approaches are founded on the premise that no series is $I(2)$. Considering this, we employ the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Lee and Strazicich (2003) unit root checks. The Lee and Strazicich (2003) unit root test accounts for structural breaks in the series. The unit root tests are crucial since they verify if an appropriate model has been chosen and prevent erroneous estimate outcomes.

3.5 Linear and nonlinear ARDL models

This paper applied the ARDL bounds testing procedure by Pesaran et al. (2001) to investigate cointegrating associations among the variables. The ARDL limits testing approach may be used regardless of the order of integration, meaning that the variables can have a combination of both $I(0)$ and $I(1)$ orders of integration. This distinguishes it from traditional cointegration tests. This strategy can generate dependable results in studies that include small sample figures since it reduces biases. Furthermore, the ARDL model enables concurrent estimates of both the long and short-term parameters. The ARDL procedure is well recognised for its extensive scope, robustness, and efficacy, making it a preferred method for academics who want to examine persistent connections and derive relevant policy ramifications from empirical outcomes (Prempeh, 2023; Qamruzzaman, 2024). Based on model 3, we formulate the linear ARDL model as follows:

$$\Delta lnCE_t = \varphi_0 + \delta_1 lnCE_{t-1} + \delta_2 lnFD_{t-1} + \delta_3 lnNR_{t-1} + \delta_4 ES_{t-1} + \sum_{i=1}^{p} \varphi_{1i} \Delta lnCE_{t-i} + \sum_{i=1}^{p} \varphi_{2i} \Delta lnFD_{t-i} + \sum_{i=1}^{p} \varphi_{3i} \Delta lnNT_{t-i} + \sum_{i=1}^{p} \varphi_{4i} \Delta ES_{t-i} + \varepsilon_t \tag{4}$$

In Model 4, φ and δ represent the coefficients of the long and short-term parameters, respectively. Δ is the first difference operator, and p denotes the maximum lag length. The optimal lag length is obtained by applying the appropriate information criteria such that the residual term ε is free from serial correlation, non-normality, heteroscedasticity and model misspecification issues. The bound testing technique necessitates an assessment of the null hypothesis, stating that there is no cointegration. ($H_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$) in opposition to the alternative hypothesis that cointegration exists ($H_1 = \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0$). The decision to endorse or refute the null hypothesis hinges on the *F*-statistics. Pesaran et al. (2001) demonstrated that cointegration between variables exists when the computed *F*-statistics value exceeds the upper bound {*F*-statistic< $I(1)$ critical}. However, the finding is inconclusive when the computed *F*-statistic is within the $I(0)$ and $I(1)$ boundaries. The ARDL, which integrates the error correction term, is described in model 5 as:

$$\Delta lnCE_t = \varphi_0 + \sum_{i=1}^{p} \varphi_{1i} \Delta lnCE_{t-i} + \sum_{i=1}^{p} \varphi_{2i} \Delta lnFD_{t-i} + \sum_{i=1}^{p} \varphi_{3i} \Delta lnNT_{t-i} + \sum_{i=1}^{p} \varphi_{4i} \Delta ES_{t-i} + \Psi_1 ECT_{t-1} + \varepsilon_t \quad (5)$$

Where ECT_{t-1} is the error correction term. Furthermore, it is anticipated that the symbol ψ, which represents the coefficient of ECT, will have a negative value and be statistically significant. This indicates that any temporary divergence from the established long-term equilibrium will eventually return to it.

The NARDL model developed by Shin et al. (2014) extends the conventional ARDL model. The NARDL model is capable of capturing the nonlinear relationship between the dependent variable and the determinants, unlike the ARDL model. The long and short-term asymmetric influence of FD on the CE may be estimated using this approach. The use of the NARDL in empirical modelling remains widespread and demonstrates superior performance when dealing with small samples that exhibit a varied structure of integration. In the same way, it provides both short-term and long-term results along with significant insights for policy-making. The NARDL method can identify asymmetries in a single equation model inside a nonlinear framework.

According to Shin et al. (2014), we may derive the asymmetric cointegration equation by integrating the positive and negative shocks of *ln*FD in the symmetric Model. The asymmetric variables of *ln*FD are obtained using the following partial sum equation.

$$\begin{cases} lnFD_t^+ = \sum_{j=1}^{t} lnFD_j^+ = \sum_{j=1}^{t} MAX(\Delta lnFD_j, 0) \\ lnFD_t^+ = \sum_{j=1}^{t} lnFD_j^- = \sum_{j=1}^{t} MIN(\Delta lnFD_j, 0) \end{cases} \quad (6)$$

Taking into consideration the asymmetric impacts of FD on CE in the ARDL representation in model 4, the NARDL is formulated following Shin et al. (2014):

$$\begin{aligned} \Delta lnCE_t = \phi_0 &+ \sum_{i=1}^{p} \phi_{1i} \Delta lnCE_{t-i} + \sum_{i=0}^{p} \phi_{2i} \Delta lnNR_{t-i} + \sum_{i=0}^{p} \phi_{3i} \Delta ES_{t-i} + \sum_{i=0}^{p} (\phi_{4i} \Delta lnFD_{t-i}^+ + \phi_{5i} \Delta lnFD_{t-i}^-) + \Pi_1 lnCE_{t-1} \\ &+ \Pi_2 lnNR_{t-1} + \Pi_3 ES_{t-1} + \Pi_4 lnFD_{t-1}^+ + \Pi_5 lnFD_{t-i}^- + \varepsilon_t \end{aligned} \quad (7)$$

Where ϕ and Π represent the magnitudes of the short and long-term parameters, correspondingly. An analysis is conducted to see whether there is cointegration among the variables. Like the ARDL model, the estimated *F*-statistic is compared to the *I*(0) and *I*(1) critical bounds. The rejection of H_0 ($H_0 = \Pi_1 = \Pi_2 = \Pi_3 = \Pi_4 = \Pi_5 = 0$) validates long-run associations among the variables. After conducting model 8 estimation, we use the symmetry (Wald) test to analyse the presence of both short- and long-term asymmetries. The error correction model for the NARDL is expressed as follows:

$$\begin{aligned} \Delta lnCE_t &= \phi_0 + \sum_{i=1}^{n} \phi_{1i} \Delta lnCE_{t-i} + \sum_{i=0}^{n} \phi_{2i} \Delta lnNR_{t-i} + \sum_{i=0}^{n} \phi_{3i} \Delta ES_{t-i} + \sum_{i=0}^{n} (\phi_{4i} \Delta lnFD_{t-i}^+ + \phi_{5i} \Delta lnFD_{t-i}^-) + \Omega ECT_{t-1} \\ &+ \varepsilon_t \end{aligned} \quad (8)$$

Where Ω, the coefficient of ECT must be negative and substantial to demonstrate that any disequilibrium will be corrected in the long term. Furthermore, the "asymmetric cumulative dynamic multiplier effect" resulting from a percentage shift in $lnFD_t^+$ and $lnFD_t^-$ is expressed as:

$$KlnFD_z^+ = \sum_{j=0}^{z} \frac{\vartheta lnCE_{t+j}}{\vartheta lnFD_{t-1}^+}, KlnFD_z^- = \sum_{j=0}^{z} \frac{\vartheta lnCE_{t+j}}{\vartheta lnFD_{t-1}^-}, z = 1, 2, 3, \dots n \quad (9)$$

It is important to note that $z \to \infty, K_z^+ \to \beta_1^+, \& \; K_z^- \to \beta_1^-$. The estimated dynamic multipliers illustrate the adjustment process from the initial equilibrium to the new equilibrium after a shock to *ln*FD.

4. Results and interpretation

4.1 Descriptive statistics and correlation matrix

Table 3 reports the descriptive statistics and pairwise correlation between CE and its determinants. It can be observed that all the variables have a positive mean except CE. ES recorded the highest standard deviation, followed by FD, CE and NR, respectively. The shape of the distribution, as shown by the skewness, suggests that all the variables are negatively skewed. Furthermore, the kurtosis measure demonstrates that all the variables have a platykurtic distribution. In addition, we do not reject the null hypothesis in the Jarque-Bera test for all the variables, indicating that all the variables adhere to a normal distribution. The correlation analysis shows that CE is positively correlated with NR and FD but negatively correlated with ES. Correlation measures the degree of relationship between variables, although it does imply cointegration. Hence, it is imperative to test for cointegration among variables.

Table 3. Descriptive statistics and correlation matrix

Variables	*ln*CE	*ln*FD	*ln*NR	ES
Mean	-1.165	2.399	2.372	0.001
Median	-1.135	2.569	2.381	0.126
Maximum	-0.506	2.894	2.777	2.606
Minimum	-1.949	1.297	1.855	-2.921
Std. Dev.	0.433	0.483	0.248	1.419
Skewness	-0.252	-0.955	-0.262	-0.297
Kurtosis	1.876	2.492	2.233	2.559
Jarque-Bera	1.961	5.042	1.114	0.708
Probability	0.375	0.080	0.573	0.702
Correlation matrix				
*ln*CE	1.000			
*ln*FD	0.876	1.000		
*ln*NR	0.103	0.295	1.000	
ES	-0.679	-0.319	0.316	1.000

4.2 Unit root tests

We executed three stationarity assessments to investigate the unit root traits of the economic series. The stationarity of variables is crucial for eliminating the risk of erroneous estimations. The outcomes of the ADF, PP and Lee and Strazicich (2003) LM tests suggest that all the variables are $I(1)$ even after accounting for structural changes (see Table 4). Intriguingly, structural changes are detected in all of the variables. For instance, the test demonstrates structural changes in CE in 1996 and 2000. This suggests that Ghana witnessed substantial shocks in CE following the Financial Sector Adjustment Programme (FINSAP)-2, which covered the period 1992-1995 and the numerous economic policies that were implemented after the Provisional National Defence Council (PNDC) initiated steps to transition Ghana from military authority to democratic administration in 1992. The unit root analyses suggest that the ARDL, NARDL, and other econometric approaches used in this study are suitable since none of the chosen variables is $I(2)$.

Table 4. Unit root analysis

Variables	ADF test	PP test	Lee Strazicich LM unit root test	
	T-statistic	*T*-statistic	*T*-statistic	Break dates
*ln*CE	-0.763	-0.191	-5.269	1996, 2000
*ln*FD	-2.067	-1.704	-4.822	1997, 2013
*ln*NR	-1.153	-1.119	-5.469	2000, 2009
ES	-0.494	-0.470	-5.0473	2001, 2010
ΔlnCE	-6.707***	-9.484***	-8.267***	1995, 2003
ΔlnFD	-7.712***	-7.341***	--9.391***	1994, 2000
ΔlnNR	-6.572***	-6.573***	-7.843***	2003, 2008
ΔES	-5.645***	-6.687***	-12.246***	2003, 2010

Note: *** denotes significance at 1% level.

4.3 Cointegration tests

The ARDL bounds test is recognised for its sensitivity to lag selections; therefore, the appropriate lag structure must first be identified. As displayed in Table 5, all the information criteria suggest an optimum lag length of one. After establishing the optimum lag length, we execute the ARDL and NARDL bounds test for cointegration.

Table 5. Lag selection test.

	Information Criteria					
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-28.950	NA	0.0001	2.354	2.544	2.412
1	38.580	110.942*	3.17e-06*	-1.327*	-0.376*	-1.036*
2	47.807	12.522	5.56E-06	-0.843	0.869	-0.320
3	70.149	23.938	4.37E-06	-1.296	1.178	-0.540

*Denotes the lag order chosen by the criteria.

Table 6 presents the results of *F*-statistics for the ARDL (symmetric) and NARDL (asymmetric) models. The NARDL model decomposes FD into positive and negative partial sums to determine the nonlinear effect of FD on CE. The outcomes of the linear and nonlinear specifications fail to confirm the null hypothesis of no cointegration at the 5% level of significance, suggesting that long-run causal associations exist in series in Ghana.

Table 6. The results of ARDL and NARDL cointegration tests

Estimation	Symmetric model		Asymmetric model	
F-statistic	6.307**		6.163**	
Critical values (T= 30)	*I*(0)	*I*(1)	*I*(0)	*I*(1)
1%	5.333	7.063	4.768	6.670
5%	3.710	5.018	3.354	4.774
10%	3.008	4.150	2.752	3.994

Note: ** indicates the rejection of H_0: no levels relationship at 5%. Selected model: ARDL (1,1,1,0) and ARDL (1,1,0, 0) for the symmetric and asymmetric model, respectively.

To ascertain the validity of the outcomes of the ARDL tests, we rely on the Bayer and Hanck (2013) combined cointegration test, which is suitable for investigating cointegration association in small finite samples. Additionally, we use the Gregory and Hansen (1996) cointegration test, which considers structural changes in the series. The outcomes of these two tests are reported in Table 7. The results of the Bayer and Hanck (2013) combined and Gregory and Hansen (1996) cointegration tests support the outcome of the ARDL bounds test as both procedures fail to confirm the H_0 of no cointegration even in the presence of structural changes at least at the 5% level of significance. The linear and nonlinear ARDL approaches are both viable for exploring the long- and short-run impacts, as the documented cointegration serves as a solid basis.

Table 7. The outcome of Bayer-Hanck and Gregory-Hansen cointegration tests

Bayer-Hanck test for Cointegration		
Test	Fisher Type Test statistics	5% critical value
EG-JOH	55.615	10.637
EG-JOH-BO-BDM	56.533	20.486
Gregory-Hansen cointegration test		
ADF	Zt	Za
-5.38** (1998)	-5.48**(1998)	-31.38(1998)

4.4 ARDL analysis

We determine the long- and short-term effects of *ln*FD, *ln*NR, and *ln*ES on *ln*CE, as the long-term nexus between the variables has been verified. The long and short-term evaluations are highlighted in Table 8. In Part A, we observe that the coefficient of *ln*FD is positively linked to *ln*CE, and it is statistically significant at the 1% level, highlighting its crucial contribution to environmental deterioration. Keeping other determinants constant, environmental deterioration might worsen due to a 1% increase in *ln*FD, leading to a 0.624% surge in *ln*CE. A possible reason is that the *ln*FD triggers a corresponding rise in investment in energy-intensive industries, stimulating production, mining and fossil fuel extraction (Prempeh, 2023).

Nevertheless, this might heighten carbon emissions, which presents obstacles to achieving ecological sustainability. Moreover, improved financial services and expanded credit options may lead customers to diversify their spending habits, leading to a higher demand for items and services that contribute to environmental degradation (Jiang and Ma, 2019). Also, it can be argued that the underdeveloped nature of the Ghanaian financial sector makes it difficult to channel funds towards green (i.e., renewable) projects, which require huge investments at the initial stages (Prempeh, 2023). This finding challenges the works of Mehmood and Kaewsaeng-on (2024b), Prempeh et al. (2023) and Prempeh (2024), which conclude that *ln*FD mitigates *ln*CE. This discovery further contradicts studies conducted by Abokyi et al. (2019) and Alhassan et al. (2022) in the context of Ghana. The discrepancy in the results might be ascribed to the control variables utilised, the measurement of variables, the time frame of the study, or the econometric methodologies applied. However, the present finding is analogous to the findings of Ibrahim and Vo (2021), Samour et al. (2022) and Habiba et al. (2023), which endorse that increases in ln*CE* are associated with rises in *lnFD.*

In terms of the impact of *ln*NR on *ln*CE, the results suggest a detrimental effect of *ln*NR on the environment as a positive association prevails between *ln*NR and *ln*CE, which is marginally significant at the 10% level. More precisely, a 1% rise in *ln*NR lessens environmental quality by increasing *ln*CE by 0.255%. This discovery confirms the *"resource curse hypothesis*", which posits that abundant natural resource endowment impacts economic growth and increased energy use, primarily from fossil fuels, leading to environmental degradation. This discovery is consistent with the conclusions that were drawn by Kwakwa et al. (2020), Huang et al. (2023), Shang et al. (2023) and Lin et al. (2024) but deviates from the conclusions of Tufail et al. (2021) and Li et al. (2024). Extraction of natural resources often necessitates high energy-consuming procedures that lead to environmental deterioration due to increased CO_2 emissions. Furthermore, the income derived from the exploitation of natural resources may inadvertently support energy-intensive industries, which support carbon-intensive economic activities. The usage of hazardous chemicals such as cyanide and Mercury in mining operations in Ghana has been mentioned in the media throughout the years. The rise in CO_2 emissions and decline in the quantity and quality of Ghana's cocoa production may be attributed to the increase in irresponsible mining, activities of illicit mining, and deforestation (Alhassan and Kwakwa, 2023). Although Ghana has seen some financial benefits from its natural resources, the findings indicate that the government may have been unable to effectively address the environmental problems caused by mining these resources in the nation. Unsurprisingly, CO_2 emissions are increasing with Ghana's exploitation of natural resources.

Findings also suggest that ES promotes long-term environmental quality by reducing *ln*CE. Based on the outcomes, it has been established that an increase of 1% in ES results in a comparable reduction of 0.149% in *ln*CE. This outcome is expected due to the study's emphasis on the decreasing phase of the U-shaped Environmental Kuznets Curve (EKC), marked by high-income levels and ES. The study concentrated on ES rather than economic development. During the sustainability phase, efforts are made to tackle environmental concerns. ES drives the nation to transition from renewable energy to cleaner energy sources. As nations adopt environmentally friendly technologies and processes, CO_2 emissions may be inhibited. This outcome aligns with the EKC theory, which suggests that heightened environmental deterioration, such as increased CO_2 emissions, is likely during the early phases of economic growth. However, as nations advance and achieve sustainability, they emphasise environmental conservation and sustainability. This transition is characterised by a decrease in pollution and other forms of degradation to the environment (Prempeh, 2024). ES aligns with the latter stages of the EKC, during which the focus shifts towards bolstering sustainability and decreasing environmental deterioration. A recent study by Mehmood and Kaewsaeng-on (2024a) also presents comparable evidence in the case of newly industrialised countries (NICs).

The short-term estimates derived from the parsimonious ARDL model are showcased in Part B of Table 8. The outcomes demonstrate that in the short term, a 1% rise in *ln*FD heightens *ln*CE by 0.262%. The coefficient of l*n*NR is positive but statistically insignificant, suggesting that in Ghana, *ln*NR positively but insignificantly influence *ln*CE in the short term. ECT_{t-1} has a negative coefficient that is significant at the 1% level. In theory, a negative coefficient is anticipated, indicating the reestablishment of long-term equilibrium after an external disruption. The validity and model specification issues are addressed through diagnostic checks (See Part C). The normality of the model residuals is evaluated using the Jarque-Bera test, and the outcome suggests that the residuals are normally distributed. The findings further illustrate that the model exhibits homoscedasticity and lacks serial correlation and functional misspecification. Lastly, the stability of long- and short-run parameters is indicated by the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) depicted in Figure 3. In this paper, we implement fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and canonical cointegrating regression (CCR) methodologies to assess the resiliency of the ARDL test. The outcomes of these assessments are provided in Table 9.

Table 8. The outcome of long- and short-run ARDL estimation.

Variable	Coefficient	Standard error	*p*-value
Part A: Long-run analysis			
*ln*FD	0.624***	0.056	0.000
*ln*NR	0.255*	0.128	0.057
ES	-0.149***	0.019	0.000
Part B: Short-run analysis			
ΔlnFD	0.262***	0.086	0.005
ΔlnNR	-0.010	0.070	0.889
Constant	-2.184***	0.417	0.000
ECT_{t-1}	-0.679***	0.127	0.000
R-squared	0.573		
F-statistics	5.153***		
Part C: Stability Checks			
Test	*F*-statistic	*p*-value	
Normality (Jarque-Bera)	0.675	0.714	
Serial correlation	1.856	0.181	
Heteroskedasticity	0.951	0.479	
Ramsey RESET	0.708	0.409	

Note: *** and * denote significance at 1% level and 10% level, respectively.

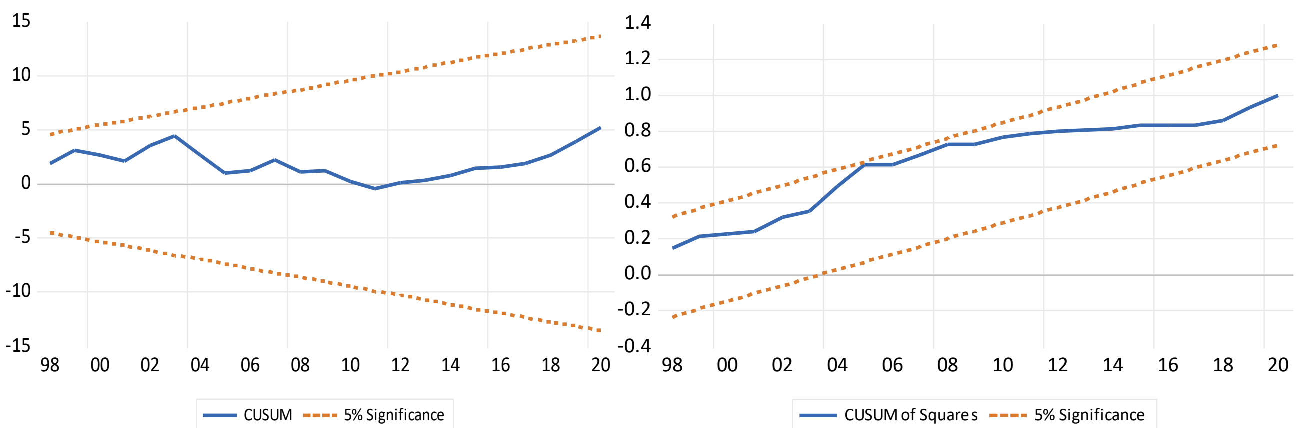

Figure 3. Cumulative sum of squares (CUSUM) and Cumulative sum of squares (CUSUMsq) for ARDL model

The results obtained through the FMOLS, DOLS and CCR estimations confirm a similar pattern to that found for the ARDL long-run estimations presented in Table 8, albeit the coefficient of *ln*NR is insignificant in all three cointegrating regression models. The DOLS, FMOLS, and CCR outcomes identify the positive impact of *ln*FD and *ln*NR on l*n*CE, whereas ES is negatively associated with *ln*CE.

Table 9. Robustness test: FMOLS, DOLS, & CCR

Methods	lnFD	lnNR	ES	Constant
	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)	Coef. (s.e.)
FMOLS	0.657 (0.039) ***	0.062 (0.081)	-0.140 (0.014) ***	-2.870 (0.182) ***
DOLS	0.633 (0.046) ***	0.103 (0.122)	-0.126 (0.015) ***	-2.910 (0.273) ***
CCR	0.655(0.039) ***	0.066 (0.081)	-0.142 (0.014) ***	-2.875 (0.178) ***

Note: *** Denotes significance at 1% level.

4.4.2 Nonlinear ARDL analysis

Focusing on the NARDL, Table 10 reports the estimated long and short-run coefficients. The long-run estimates in Part A confirm that *ln*NR increases *ln*CE while ES reduces *ln*CE in Ghana., validating the estimations derived from the ARDL model exhibited in Table 8. Table 10 demonstrates a 0.221% spike in *ln*CE linked to a 1% rise in *ln*NR. Meanwhile, a 0.079% reduction in *ln*CE is linked to a 1% increase in ES. Regarding the short-run coefficients, the parsimonious NARDL estimates suggest that none of the determinants significantly influence *ln*CE in the short term. ECT is rightly signed (-) and significant at the 1% level, indicating strong evidence of cointegrating interactions among the variables. The long-run estimates suggest that positive shocks in *ln*FD have a positive coefficient at a 1% level. Also, adverse developments in *ln*FD favourably impact *ln*CE. However, this effect is not statistically significant. $ln\text{FD}^+$ and $ln\text{FD}^-$ have long-run coefficients of 0.457 and 0.119, respectively. The magnitude of positive shocks in *ln*FD on *ln*CE in Ghana is more pronounced than the effect of unfavourable shocks in *ln*FD, while the latter is not statistically significant. The dynamic multiplier chart in Figure 5 confirms that the positive shock in *ln*FD has a greater impact on *ln*CE than adverse shocks in *ln*FD which is negligible.

The findings in Part C of Table 10 provide evidence of long-term asymmetry by rejecting the null hypothesis with a significance level of 5%. Nevertheless, the Wald test did not provide proof of short-term asymmetry in the model. The findings further indicate that the residuals exhibit homoscedasticity, normal distribution, and lack of serial correlation since the *p*-values for the Jarque-Bera, Heteroskedasticity, and Serial correlation LM tests are not statistically significant at standard thresholds. The model is accurately fitted using the Ramsey functional form. The CUSUM and CUSUMsq graphs also reinforced the model's stability (see Figure 4).

Table 10. Results of long- and short-run NARDL estimation.

Variable	Coefficient	Standard error	*p*-value
Part A: Long run-analysis			
*ln*NR	0.221*	0.116	0.068
ES	-0.079**	0.037	0.044
$ln\text{FD}^+$	0.457***	0.079	0.000
$ln\text{FD}^-$	0.119	0.216	0.586
Part B: Short-run analysis			
$\Delta ln\text{NR}$	-0.034	0.059	0.571
Constant	-1.692***	0.289	0.000
ECT_{t-1}	-0.735***	0.122	0.000
R-squared	0.598		
F-statistics	20.102***		
Part C: Stability Checks			
Test	*F*-statistic	*p*-value	
Wald_{LR} Asymmetry X^2	3.876	0.042	
Normality (Jarque-Bera)	4.424	0.109	
Serial correlation	1.076	0.359	
Heteroskedasticity	1.336	0.281	
Ramsey RESET	0.626	0.437	

***, ** and * denote significance at 1% level, 5% level and 10% level, respectively.

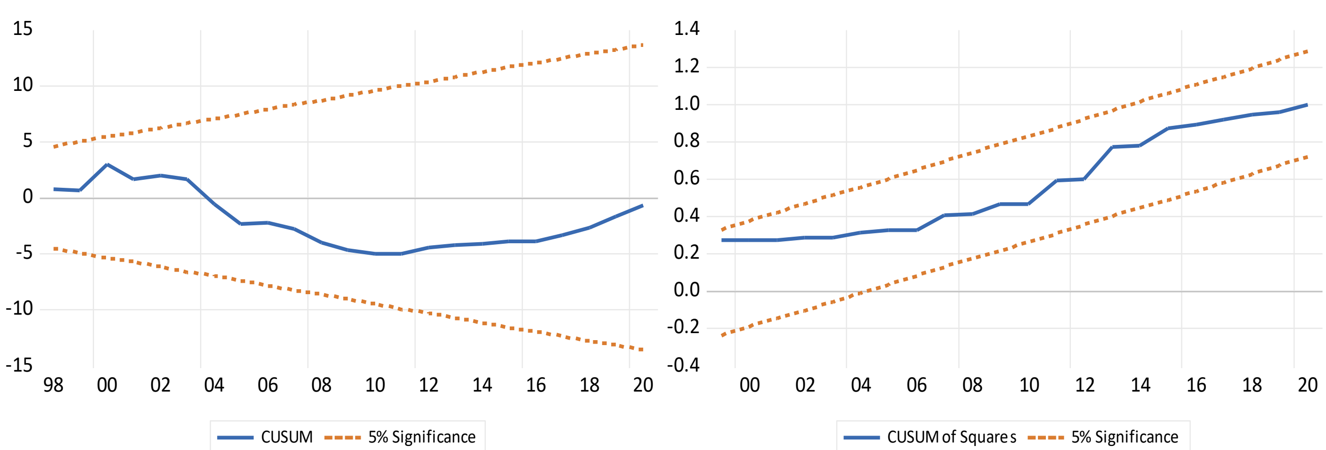

Figure 4. Cumulative sum of squares (CUSUM) and Cumulative sum of squares (CUSUMsq) for the NARDL model

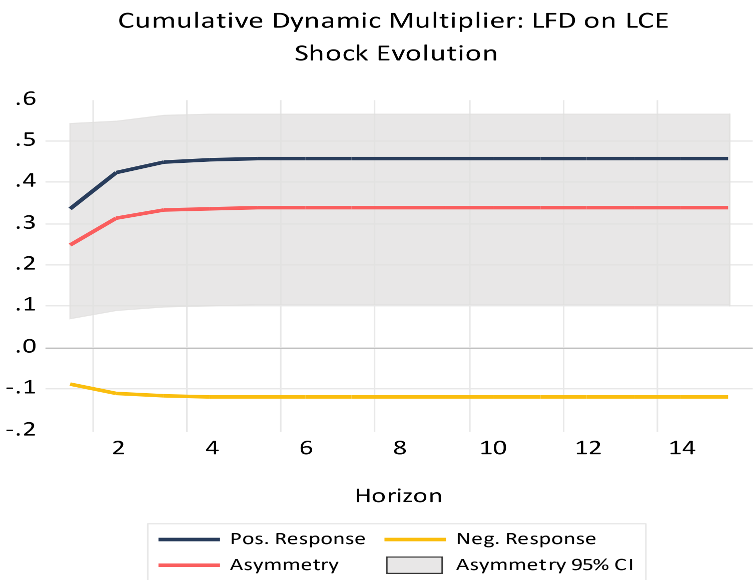

Figure 5. Dynamic multiplier graph for NARDL model

Conclusion and policy implications

The study explores the association between FD and CO_2 emissions while controlling for economic sustainability and natural resource rents from 1990-2020. The empirical investigation is conducted using ARDL and NARDL models. The NARDL model distinguished FD into positive and negative partial sums to investigate the potential asymmetric effects of FD on CO_2 levels in Ghana. The intent for examining the asymmetric impacts of FD is to investigate the consequence of both favourable and adverse shocks in FD on CO_2 emissions in the nation. The ARDL and NARDL cointegration tests support long-run associations between FD, natural resource rents, economic sustainability and CO_2 emissions. At the same time, we discover evidence of asymmetric effects of FD on CO_2 emissions in the long run.

The ARDL model results reveal that financial development and natural resource rents positively influence CO_2 emissions in the long run. However, it has been shown that achieving economic sustainability is a viable approach to lowering CO_2 emissions in Ghana. This outcome further corroborates the falling stage of the U-shaped EKC, which is established by the interplay between economic sustainability and environmental quality. The FMOLS, DOLS, and CCR estimations also substantiate the findings. Concomitantly, FD induces CO_2 emissions in the short run. The NARDL results demonstrate an asymmetric connection between FD and CO_2 emissions in the long run. In the long run, positive shocks in FD substantially increase CO_2 emissions. At the same time, adverse shocks in FD have a neutral impact on CO_2 emissions.

The asymmetric and symmetric inquiry findings have uncovered the following policy ramifications for Ghanaian policymakers. These ramifications aim to promote environmental sustainability by focusing on FD, natural resource rent, and economic sustainability. First, policymakers in Ghana should contemplate implementing regulations and guidelines to prevent financial development activities from exacerbating environmental degradation in recognition of the beneficial effects of financial development on CO_2 emissions. Policymakers should promote FD that aligns with ecological sustainability. By prioritising low-carbon investment, advocating for eco-friendly technology, and providing capital for eco-friendly projects, financial institutions can contribute to environmental sustainability. Second, in light of the detrimental effects of natural resource rent on environmental quality, policymakers in Ghana must advocate for sustainable management of resources. This entails adopting strategies that guarantee eco-responsible resource extraction and utilisation of natural resources. This encompasses using environmentally friendly technologies, reducing the production of waste products, and encouraging responsible management of resources to lessen the adverse environmental effects of extracting resources. Lastly, the study's demonstration of economic sustainability in Ghana suggests that prioritising sustainability in economic policies can enhance environmental quality by reducing CO_2 emissions. Consequently, policymakers should incorporate an economic sustainability agenda into national development strategies to guarantee that economic growth is pursued in a manner that is economically and environmentally sustainable in the long run. Sustainable development is essential for achieving an equitable balance between economic development, environmental protection, and social well-being. CO_2 emissions can have dire consequences on the environment and population health. Mitigating environmental deterioration often includes using renewable energy sources, implementing energy efficiency measures, carbon pricing systems, and afforestation and reforestation efforts. This is consistent with the UN Sustainable Development Goals (SDGs), including SDG 8, which focuses on fostering sustainable economic growth.

Like many empirical studies, this study has shortcomings that should be acknowledged and resolved in future investigations. The study concentrates solely on Ghana; therefore, the results may not apply to economies with varying economic and FD patterns. The study addresses FD, natural resource rent, and economic sustainability. The quality of governance, institutions, energy blend, and urbanisation all impact CO_2 emissions. Future studies should include more determinants to understand better the nuanced association between FD and CO_2 emissions. Finally, future studies might investigate the threshold impacts of FD on CO_2 emissions for Ghana and other countries using innovative econometric techniques. This approach can significantly improve the existing corpus of literature.

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