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Asymmetric Effects of Economic Growth, Fossil Fuel Consumption, and Financial Development on Carbon Emissions in Ghana

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This research analyzes the impact of economic expansion, non-renewable energy consumption (NonREC), financial sector improvement, and carbon releases in Ghana. The study used yearly data from 1971 to 2014 and applied the Nonlinear Autoregressive Distributed Lag (NARDL) method to examine the data. The NARDL approach facilitated the differentiation of variables into favorable and unfavorable adjustments by examining the short- and long-run effects. The results indicated that all the independent variables exhibited short-term asymmetries, while economic growth presented long-term asymmetry. Negative adjustments in economic expansion led to a decline in carbon releases in the long run but an increase in the short run. favorable and unfavorable adjustments in NonREC positively and negatively impact carbon releases in both the short and long term. Additionally, negative adjustments in financial development positively affected carbon releases in the long run. The cumulative dynamic multipliers graphs and impulse response function graphs illustrate the same impact pattern of the independent variables on carbon releases, confirming the findings' robustness. The study suggests implementing environmental policies in Ghana that promote renewable sources of energy and energy-conserving innovations to reduce environmental degradation. The findings recommend that the decision-maker prioritize effective environmental strategies like a green economy, renewable energy use, and energy-saving technologies. By adopting clean energy and implementing advanced technologies, sustainable economic growth can be achieved while preserving the environment and the ecosystem.

Keywords: **c**arbon emissions, financial development, fossil fuel consumption, Ghana, NARDL
JEL Classification: Q32, Q43, Q53, Q54

Environmental degradation has generally been growing due to the increase in industrial and agricultural sectors, with carbon emissions in metric tons per capita rising from 0.21 in 1960 to 0.23 in 1980 to 0.32 in 2000 to its present level of 0.36 (WDI, 2012). Climate change has resulted from the emission of greenhouse gases, such as those from fuel combustion, urbanization, industrialization, and deforestation (Babar et al., 2015). However, environmental protection policies appear to have not kept pace with economic development. Economic growth has sometimes led to reduced spending on environmental protection, hastening environmental degradation.

Ghana lacks comprehensive research on the impact economic growth has on the environment, and this could rationally account for Ghana's lack of strict environmental rules, laws, and regulations and their inconsistent enforcement (Copeland & Taylor, 2004). A rapidly growing population in a developing economy like Ghana would most likely result in high emission levels of greenhouse gases where environmental regulations are not being followed as per the Environmental Kuznets Curve (Antweiler et al., 2001).

Ghana quickly industrialized after gaining independence in 1957 through solid government ownership, government regulation of foreign trade, and a sizable government bureaucracy. Rapid industrialization was an unsuccessful strategy that led to a decline in the economy. The government implemented the Economic Recovery Program as a cure for the unfortunate economic conditions. As a result, the economy responded favorably (Asante-Addo & Weible, 2019). For instance, the agriculture sector experienced an annual growth rate of around 18.15%

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from the period of 1995 to 2001, which increased to 22.18% from 2002-2007. Similar improvements in performance have been noted over time in the industrial sector, which grew to a growth rate of 15.10% per year from 1997-2001 to 21.47% from 2002-2008 (WDI, 2012).

The Ghanaian government has outlined a policy scenario to curb environmental pollution. For instance, Ghana's GDP and demand for energy in the stated policy scenario are expected to be 9 Mtoe and 438 billion USD in 2040, respectively. Efficiency standards could allow an economy four times larger than today to require only three times more energy. Oil remains the most significant energy source, with two-thirds consumed in the transport sector, while hydropower and domestically produced gas and oil are the primary providers of electricity. According to stated policy scenarios, the electricity demand is expected to increase by about 350%, and by 2040, fossil fuel consumption[1] in Ghana is expected to be 13.4Mtoe, with an efficiency gain of -1.4Mtoe. Natural gas is replacing light crude oil in electricity generation rapidly, and by 2030, GHG emissions are expected to be reduced by 15% (unconditional) to 45% (conditional) compared to the business-as-usual scenario (around 74 Mt CO2-equivalent). Additionally, by 2040, the technological development goal is to achieve the production and processing of an anticipated 300 million barrels of oil and gas reserves.

Earlier research has extensively examined carbon dioxide emissions and their effects on nations worldwide. The neoclassical economic growth hypothesis backed the idea that increased industrial activity, population, and economic growth influenced CO2 emissions. Kraft and Kraft (1978) initially proposed the connection between energy use and economic development. They found that in the post-war period, causality was unidirectional and solely ran from GNP to energy; no causality was found towards GNP from energy. Since that groundbreaking research, legion studies have extensively probed this subject and affirmed enduring or cause-and-effect connections among economic expansion/industrialization, energy usage, and ecological pollution(Ahmad et al., 2019; Aziz et al., 2020; Jalil & Feridun, 2011; Jebabli et al., 2023; Ozturk & Acaravci, 2013; Gokmenoglu et al., 2015; Abokyi et al., 2019; Saboori et al., 2012; Aboagye, 2017; Kwakwa & Alhassan, 2018; Kwakwa et al., 2014; Twerefou et al., 2016; Khan et al., 2019). Energy use has the capacity to both threaten the environment and drive rapid economic growth. Environmental deterioration and global warming have become serious issues, and CO_2 is thought to be a key contributor to these phenomena (Paul & Bhattacharya, 2004). Specifically, in Ghana, the consumption of fossil fuels has become more important than other forms of energy. Over the years, the percentage of NonREC has significantly accelerated from 22% to 52% between 1971 and 2014 (Abokyi et al., 2019). Consumption of fossil fuels has been the highest in Ghana's energy mix since 2009. It continues to rise, while the use of other sources of energy has been declining on average (WDI, 2017).

The financial sector is critical in providing businesses with easy, affordable, and adaptable financial resources and offering investment prospects to individuals (Ji et al., 2021). There are two ideas in the literature that aim to analyze the link between financial growth and the sustainability of the environment. The first one was introduced in the 1990s, known as the Pollution Haven Hypothesis (PHH), introduced in the early 1990s by Peter Neary and Gene Grossman. According to this hypothesis, multinational corporations (MNCs) focused on maximizing their profits and minimizing their production costs tend to move their operations to countries with less strict environmental regulations and standards, particularly in developing countries. This creates "pollution havens" where the environmental regulations are not very strict. The second idea is the Pollution Halo Hypothesis (PH), which Ramanathan and Collins introduced in the late 1990s. Birdsall and Wheeler (1993), Zhang (2011), Tamazian et al., (2009), Jalil and Feridun (2011), and Sadorsky (2010) contradict the "pollution haven" theory, while Gokmenoglu et al., (2015), Musah et al., (2021), and Shahbaz et al., (2018), found that financial growth contributes to how much CO2 is emitted, hence supporting the Pollution Haven Hypothesis.

Recent limited literature has reiterated the importance of considering asymmetries in the relationships between environmental pollution and macroeconomic indicators (see Raggad, 2020; Basu et al., 2020; Musibau et al., 2021; Shahbaz et al., 2021; Ampofo et al., 2021; Shabestari, 2018). Shabestari (2018) notes that linear relationship models may result in biased and inaccurate greenhouse gas emission projections. Additionally, Shahbaz et al., (2017) and Baz et al., (2019) pointed out the possibility of favorable and unfavorable adjustments in exogenous variables affecting endogenous variables differently. Previous studies by Abokyi et al., (2019), Aboagye (2017), Kwakwa and Alhassan (2018), Kwakwa et al., (2014), and Twerefou et al., (2016) studied the

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[1] Fossil fuel and non-renewable energy consumption are used alternatively throughout the study and abbreviated as NonREC.

relationships between environmental pollution and macroeconomic indicators using linear technics for Ghana. To this end, we aim to build on the literature by posing the following questions: Do positive or negative adjustments to economic expansion, NonREC, and financial sector improvement have asymmetric impacts on CO2 releases in Ghana in the short and long run? Ghana tends to have frequent policy changes due to political interest, which could result in frequent fluctuations in the policy variables. Thus, the assumption of symmetrical relationships can lead to biased conclusions. Based on this, this research analyzes the asymmetric influence of economic expansion, NonREC, and financial development on CO_2 releases in Ghana.

By examining the nonlinear impacts of economic expansion, the use of fossil fuel, and financial sector improvement on CO_2 emissions[2] in Ghana, this study builds on the existing works and includes a potentially meaningful non-linear relationship between economic expansion, NonREC, and financial development[3] on CO_2 releases. This aspect has not been given particular attention, especially in the Ghanaian case. Using the Nonlinear Autoregressive Distributed Lag (NARDL) model, our study is the first to consider asymmetries in this relationship, thus providing new insights into the empirical debate. To gain a better and more detailed understanding of how variables are related, the NARDL framework can help us observe how short-term and long-term adjustments occur after experiencing both positive and negative shocks. Additionally, our results are robust, as demonstrated by the consistent pattern of influence of the independent variables on CO_2 releases shown by both the cumulative dynamic multipliers graphs and impulse response function graphs. Finally, our study provides policy insights that would aid in designing relevant policy actions that could effectively reduce the environmental degradation caused by economic growth in Ghana.

Method

Data description

The study uses annual data from 1971 to 2014 to investigate the asymmetric effects of economic expansion, non-renewable energy (fossil fuel) consumption (Hereafter NonREC), and financial sector improvement on carbon releases in Ghana. Two reasons determine the timeframe of the study. First, after receiving financing from the International Monetary Fund (IMF) and instituting a structural adjustment package, fiscal discipline was restored in Ghana after 1983. Second, data availability limits the timeframe of the study. Considering data availability, carbon dioxide (CO2) intensity is used to measure carbon emissions. The CO2 intensity is determined by the ratio of kilograms of CO2 emitted to kilograms of oil-equivalent energy consumed. This is a measure of carbon emissions. Economic expansion is gauged using the real gross domestic product per capita (GDP) in 2015 US$. The consumption of fossil fuel energy, including coal, oil, petroleum, and natural gas products as a percentage of aggregate energy used, provides a measure of NonREC. The level of financial sector improvement is gauged by the percentage of private sector credit to GDP. All the data was obtained from the World Bank Development Indicators (WDI) database. Also, all the variables are transformed into natural logarithms such that LCO2, LGDP, LFEC, and LFD denote carbon releases economic growth, NonREC, and financial sector improvement, respectively. Figures 1 and 2 present the graphical visualization of the time series. All the time series displayed a positive trend after 1990, which marks the beginning of the recovery period from the turmoil that started in the early 1980s.

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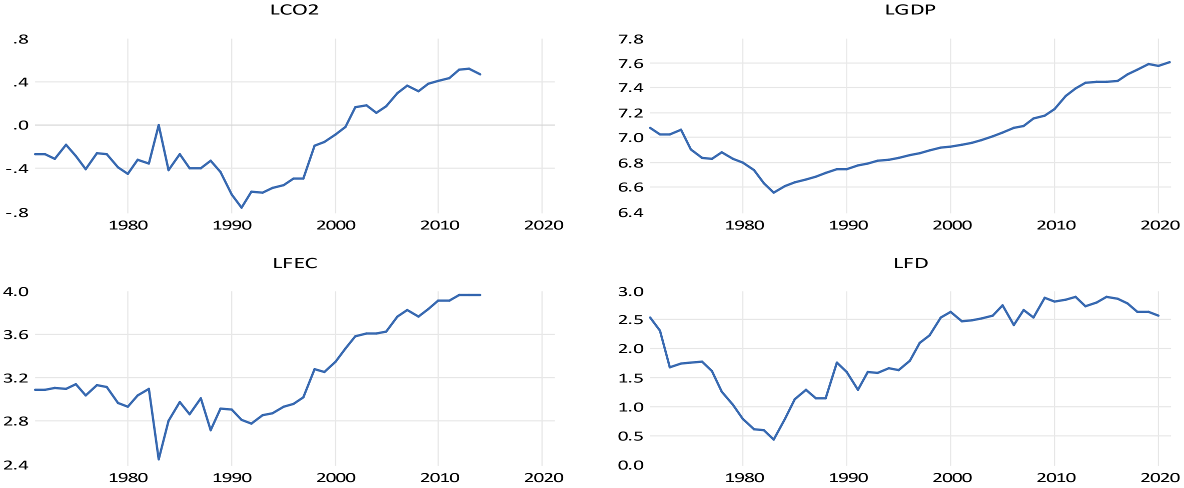
[2] Carbon emissions and carbon releases are used interchangeably throughout the study.

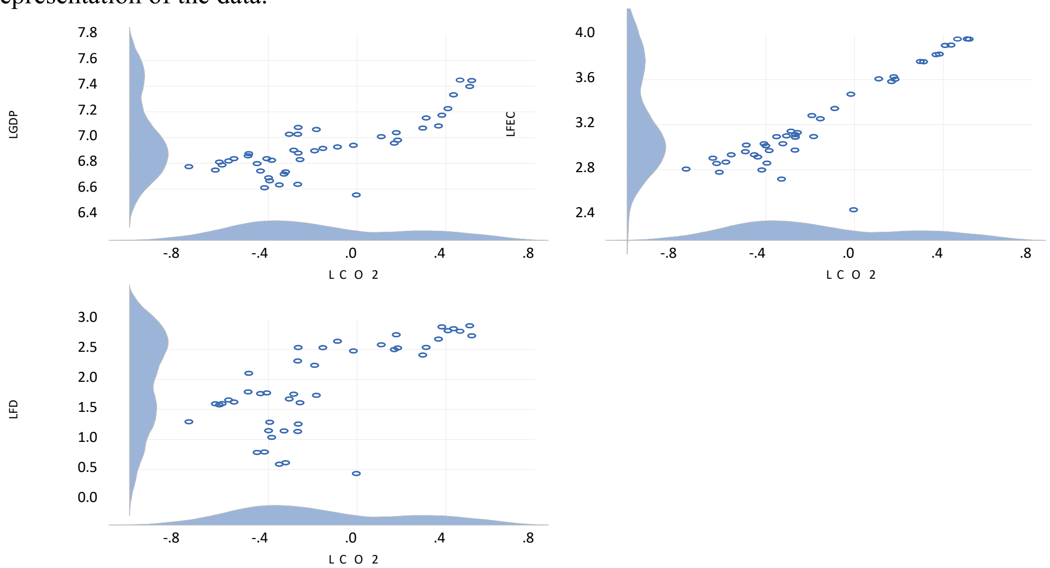
[3] Financial sector improvement and financial development are used interchangeably throughout the study.

Figure 1
Time series graphical representation



Source: Authors' creation

Figure 2
Scatter plot representation of the data.



Source: Authors' creation

The summary statistics and the correlation matrix are displayed in Table 1 for all the time series. It is shown that the greatest mean, median, maximum, and minimum figures are recorded for GDP per capita (LGDP). However, the highest standard deviation is observed for the LFD time series. Additionally, the Jaque-Bera test recorded for all the time series is insignificant, showing that the time series has a normal distribution feature. Also, in Table 1, the correlation matrix is recorded, which shows that the correlation coefficient between all the explanatory variables and the dependent variable is positive, and the highest correlation coefficient is recorded for NonREC (LFEC).

Table 1

Summary statistics + correlation matrix

Time series	LCO2	LGDP	LFEC	LFD
Mean	-0.1567	6.9264	3.2347	1.8960
Median	-0.2674	6.8892	3.0951	1.7704
Maximum	0.5167	7.4476	3.9630	2.8943
Minimum	-0.7602	6.5545	2.4448	0.4332
Std. Dev.	0.3619	0.2196	0.4084	0.7249
Skewness	0.4782	0.7004	0.4860	-0.2841
Kurtosis	2.0264	3.0427	2.0708	1.9119
Jarque-Bera	3.4148	3.6011	3.3151	2.7626
LCO2	1.0000			
LGDP	0.7915	1.0000		
LFEC	0.9063	0.8778	1.0000	
LFD	0.7088	0.8397	0.8356	1.0000

Source: Authors' creation

Empirical Methodology

This study adopts Abokyi et al., (2019) empirical model for Ghana in the Nonlinear Autoregressive Distributed Lag (NARDL) framework put forward by Shin et al., (2014) to assess the short and long-run nonlinear influence of economic expansion(LGDP), NonREC (LFEC) and financial sector improvement (LFD) on carbon releases for Ghana. The method offers a more thorough understanding of the potential short- and long-term asymmetric effects on Ghana's CO_2 releases (LCO2) of changes in the real gross domestic product (LGDP), NonREC (LFEC), and financial sector improvement (LFD). According to Granger and Yoon (2002), the NARDL not only allows the measurement of the favorable and unfavorable impacts of the explanatory variables through partial totals but also uncovers any concealed cointegration. Nevertheless, as in our current study, the NARDL can yield robust results when data observations are limited.

The framework of NARDL is a variation of the ARDL cointegration model that considers asymmetry. Originally, the unrestricted error-correction framework from the symmetrical ARDL model (Pesaran et al., 2001) does not have asymmetry for the short- /long-term. We represent it as in equation 1:

$$\Delta y_t = \alpha + \theta y_{t-1} + \delta x_{t-1} + \sum_{i=1}^{p-1} \pi_i \Delta y_{t-i} + \sum_{i=0}^{q-1} \mu_i \Delta x_{t-i} + \varepsilon_t \qquad (1)$$

where α connotes the intercept. μ_i and π_i, and δ and θ, and ε_t stand for the short- and long-term coefficients and error term, respectively. The NARDL model utilizes a nonlinear long-run cointegrating model to examine the asymmetric impact. It is structured as:

$$y_t = \sigma^+ x_t^+ + \sigma^- x_t^- + u_t \qquad (2)$$

where the symbols σ^+ and σ^- stand for the coefficients of x_t in the long term, as it has been divided as; $x_t = x_0 + x_t^+ + x_t^-$. This division of the independent variable is represented by equation 3, which describes the process of breaking down x_t into its increases (Δx_t^+) and decreases (Δx_t^-) changes.

$$x_t^+ = \sum_{i=1}^{t} \Delta x_i^+ = \sum_{i=1}^{t} \max(\Delta x_i, 0) \text{ and } x_t^- = \sum_{i=1}^{t} \Delta x_i^- = \sum_{i=1}^{t} \min(\Delta x_i, 0) \qquad (3)$$

By combining equation 1 and 2, we can obtain the nonlinear asymmetric model with error correction in the long run, as follows:

$$\Delta y_t = \alpha + \theta y_{t-1} + \delta^+ x_{t-1}^+ + \delta^- x_{t-1}^- + \sum_{i=1}^{p-1} \pi_i \Delta y_{t-i} + \sum_{i=0}^{q-1} (\mu_i^+ \Delta x_{t-i}^+ + \mu_i^- \Delta x_{t-i}^-) + \varepsilon_t \qquad (4)$$

where $\delta^{-} = -\theta\sigma^{-}$ and $\delta^{+} = -\theta\sigma^{+}$.The symbols, $\mu_i^{+}$and μ_i^{-} connotes the favorable and unfavorable short-term adjustments of the independent variable, x_t. The model illustrates the short-term and long-term asymmetric impact of the variables LGDP, LFEC, and LFD on carbon emissions in Ghana. As noted in Shin et al., (2014) work, the nonlinear ARDL approach estimation involves five steps. First, to prevent the event of having I(2) series among the series, unit root tests need to be performed. Second, equation 4 is estimated using the ordinary least square approach. Third, the bounds test approach, utilizing F-statistics $(\mathrm{F_{PSS}})$ proposed by Pesaran et al., (2001) and t-statistics $(\mathrm{t_{BDM}})$ proposed by Banerjee et al.,(1998), are employed to investigate the asymmetric long-term relationship between the levels of the series $\mathrm{y_t}$, and $\mathrm{x_t}$. We then state the null (no cointegration) and alternative (cointegration) hypotheses in Equation 5 using the $\mathrm{F_{PSS}}$.

$$\mathrm{H_0}: \theta = \delta^{+} = \delta^{-} = 0 \qquad \text{versus} \quad \mathrm{H_1}: \theta \neq \delta^{+} \neq \delta^{-} \neq 0 \tag{5}$$

In addition to the $\mathrm{F_{PSS}}$, the $\mathrm{t_{BDM}}$ is also performed to search for cointegration relationships. The hypothesis are jointly tested as; $\mathrm{H_0}: \theta = 0$ versus $\mathrm{H_1}: \theta < 0$. Four, we execute the Wald test on the null hypotheses of $\sum_{i=0}^{q-1} \mu^{+} = \sum_{i=0}^{q-1} \mu^{-}$ and $\delta^{+} = \delta^{-}$ to investigate short- and long-run symmetry, respectively. At the end of the test, rejection of both nulls will imply nonlinearities, and our model will then take the following form;

$$\Delta \mathrm{y_t} = \alpha + \theta \mathrm{y_{t-1}} + \delta x_{t-1} + \sum_{i=1}^{p-1} \pi_i \Delta \mathrm{y_{t-i}} + \sum_{i=0}^{q-1} (\mu_i^{+} \Delta \mathrm{x_{t-i}^{+}} + \mu_i^{-} \Delta \mathrm{x_{t-i}^{-}}) + \varepsilon_t \tag{6}$$

$$\Delta \mathrm{y_t} = \alpha + \theta \mathrm{y_{t-1}} + \delta^{+} \mathrm{x_{t-1}^{+}} + \delta^{-} \mathrm{x_{t-1}^{-}} + \sum_{i=1}^{p-1} \pi_i \Delta \mathrm{y_{t-i}} + \sum_{i=0}^{q-1} \mu_i \Delta x_{t-1} + \varepsilon_t \tag{7}$$

Equations 6 and 7 imply nonlinear specifications of the NARDL model in a cointegrating environment, respectively. Finally, the impact of favorable and unfavorable aggregate dynamic multipliers associated with unit adjustments in $\mathrm{x_t^{+}}$ and $\mathrm{x_t^{-}}$ on the dependent variable $\mathrm{y_t}$ is given as;

$$\mathrm{m_h^{+}} = \sum_{j=0}^{h} \frac{\partial \mathrm{y_{t+j}}}{\partial \mathrm{x_t^{+}}}, \text{ and } \mathrm{m_h^{-}} = \sum_{j=0}^{h} \frac{\partial \mathrm{y_{t+j}}}{\partial \mathrm{x_t^{-}}} \tag{8}$$

where $(\mathrm{h} = 0,1,2 \ldots .)$. In equation 8, if $\mathrm{h} \to \infty$, then $\mathrm{m_h^{+}} \to \sigma^{+}$and $\mathrm{m_h^{-}} \to \sigma^{-}$, the long-run coefficients ($\sigma^{+}$and σ^{-}) concerning the favorable and unfavorable adjustments of the explanatory variables are computed as $\sigma^{+} = -\frac{\delta^{+}}{\theta}$ and $\sigma^{-} = -\frac{\delta^{-}}{\theta}$.

Estimation Results and Discussions

Unit Root Testing

The Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979) together with Phillips and Perron (1988) (PP) tests are utilized to check the unit root properties of the time series data to ensure that none of them are I(2). This aims to ensure that the NARDL cointegration approach employed in the study remains valid. The Zivot and Andrews (2002) (ZA) test is also conducted to control the robustness of the prior two tests' outcomes in the presence of an endogenous structural change. The outputs of all three tests confirm that all the time series have an I(1) integration property, thereby providing the basis for the application of the nonlinear ARDL framework (Shahbaz et al., 2017) to search for the validity of asymmetric cointegration between CO2 releases and LGDP, LFEC, and LFD. The next section presents the Wald test and bounds cointegration test.

Table 2
ADF, PP, and ZA unit root test results

Series	Test Statistics				Outcome
	Intercept (Level)	**Intercept (1st difference)**	**Trend & intercept (Level)**	**Trend & intercept (1st difference)**	
ADF test					
LCO2	0.063753	-8.637251***	-1.739671	-8.917452***	I(1)
LGDP	0.555610	-4.506547***	-2.218142	-5.425998***	I(1)
LFEC	0.698189	-9.070769***	-1.387315	-7.435281***	I(1)

LFD	-1.023102	-6.361505***	-3.235638*	-6.419758***	I(1)
PP test					
LCO2	-0.245713	-8.622571***	-1.561688	-8.983125***	I(1)
LGDP	0.768148	-4.458889***	-2.805444	-5.306963***	I(1)
LFEC	0.056011	-9.236689***	-1.746401	-10.36755***	I(1)
LFD	-1.153233	-6.348850***	-3.223210*	-6.410101***	I(1)
ZA test					
LCO2	-3.246234	-10.17267***	-4.357448	-10.11792***	I(1)
LGDP	-3.071854	-6.885847***	-3.985376	-7.241525***	I(1)
LFEC	-3.311102	-8.120690***	-3.992323	-8.413846***	I(1)
LFD	-4.052334	-8.377218***	-3.380518	-8.404519***	I(1)

*** indicates the significance level at a 1% level.

* Indicates the significance level at a 10% level.

Source: Authors' creation

Wald Test and NARDL Bounds Cointegration Test

In this section, by utilizing the bounds test, we assess the validity of a cointegration relation among LCO2, LGDP, LFEC, and LFD in the NARDL setting. In Table 3, panel A, F_{PSS} and t_{BDM} are reported as 4.46 and -4.03, respectively. The F_{PSS} exceeds the upper critical bound of 4.35 for k = 3 at a 5% significance level. This implies an asymmetric cointegration between LCO2 and LGDP, LFEC, and LFD. Additionally, the absolute estimated value of t_{BDM} is over the table critical value in Banerjee et al., (1998) at a 5% significance level, implying cointegration between the LCO2 and the independent variables.

Table 3

Wald test for asymmetries and bounds cointegration test.

Panel A: Asymmetric cointegration test with Bounds			
Variable	F-test (F_{PSS})	t-test (t_{BDM})	Results
	4.46	-4.03	Evidence of cointegration
Panel B: Asymmetry in the short run with the Wald tests			
LCO2 =f (LGDP, LFEC, LFD)	LGDP on $LCOI$	LFEC on $LCOI$	LFD on $LCOI$
Variables	WSR_{LGDP}	WSR_{LFEC}	WSR_{LFD}
	6.247** (0.021)	18.810*** (0.000)	3.188* (0.089)
Panel C: Asymmetry in the long run with the Wald tests			
Variables	WLR_{LGDP}	WLR_{LFEC}	WLR_{LFD}
LCO2 =f (LGDP, LFEC, LFD)	3.344* (0.082)	0.061 (0.807)	1.366 (0.256)

Source: Authors' creation

Then, making use of the Wald test the short- and long-run asymmetry are investigated. Panel B of Table 3 reports the short-run nonlinearity test. Using the Wald test, the null hypothesis is stated as $\sum_{i=0}^{q-1} \mu^+ = \sum_{i=0}^{q-1} \mu^-$(meaning no validity of short-run asymmetry) is tested against the alternative hypothesis stated as $\sum_{i=0}^{q-1} \mu^+ \neq \sum_{i=0}^{q-1} \mu^-$ (meaning validity of short-run asymmetry). The Wald test statistics calculated for LGDP, LFEC, and LFD are reported as 6.247, 18.810, and 3.188, respectively. The null is rejected at 5%, 1%, and 10%, respectively. It implies a short-run asymmetry between LCO2 and all the independent variables. In Panel B of Table 3, the Wald test outcome is reported to test the null; i.e., $\delta^+ = \delta^-$ (meaning no validity of long-run asymmetry) against the alternative; $\delta^+ \neq \delta^-$ (meaning validity of long-run asymmetry). 3.344, 0.061, and 1.366 are the Wald test statistics calculated for LGDP, LFEC, and LFD, respectively. No validity of long-run asymmetry is rejected for the LGDP at a 10% significance level. On the other hand, we are not able to reject the lack of validity of the long-run asymmetry hypothesis for LFEC and LFD, meaning that only the LGDP exerts a long-run nonlinear influence on LCO2 releases.

Long Run and Short Run Analysis

Before the analyses, the necessary diagnostic tests must be conducted on the estimated model. The Portmanteau (χ^2_{SC}), Breusch/Pagan (χ^2_{HT}), Ramsey Reset (χ^2_{FF}) and Jarque-Bera (χ^2_{NORM}) tests for testing serial correlation, heteroskedasticity, functional form, and normality, respectively, are conducted with respective null hypotheses: no serial correlation, homoskedasticity, misspecification-free, and normality. The empirical results for these diagnostics are displayed at the bottom section of Table 4, which indicates the failure to reject the pre-stated null hypotheses. Nonetheless, the cumulative sums (CUSUM) and cumulative sum of squares (CUSUMSQ) test plots, as in Figure 3, ratify the parameter stability of the estimations.

In what follows, the estimation results, as displayed in Table 4, correspond with the mode specified in Equation 4. From the table, the long-run output shows that favorable and unfavorable adjustments in economic expansion (LGDP) impact CO2 emissions (LCO2) negatively, implying long-run asymmetries, but only the negative adjustments have a statistically significant impact. A percentage decrease in the LGDP decreases LCO2 by 1.18%. Additionally, the first lag of unfavorable adjustments in the LGDP has a statistically significant increasing effect (i.e., the estimated coefficient is 1.040) on LCO2, meaning that a decrease in economic growth in Ghana significantly reduces environmental degradation. It can be inferred from the study that Ghana's environment was not negatively affected by the country's economic expansion and improvement during the period examined. Ampofo et al., (2021) reported similar results for Bangladesh, Iran, and Turkey. For India, Akadiri and Adebayo (2022) also noted a similar effect of negative adjustments in economic expansion on CO_2 releases. In the short-run, the output indicates that favorable adjustments in economic expansion insignificantly decline LCO2 whilst negative adjustments significantly increase LCO2 for Ghana. For example, a 1% rise will decrease LCO2 by 0.75%, while a 1% fall will raise LCO2 by 2.19%. Our results support the short-run observations made by Abdul-Mumuni et al. (2022) for Ghana. The overall findings for LGDP corroborate previous findings (Abokyi et al., 2019; Twerefou et al., 2016), where the empirical output discovered that expansion in industrial production and gross domestic product, respectively, decreases LCO2 emissions in Ghana. Contrary to our results, an adverse influence of economic expansion on LCO2 emissions using linear techniques (Aboagye, 2017; Kwakwa & Alhassan, 2018; Kwakwa et al., 2014).

Additionally, in the long run, favorable and unfavorable adjustments in fossil consumption have positive and negative impacts on LCO2, respectively, as theoretically expected. A percentage change in positive and negative adjustments led to 1.149% and 1.219% increases and decreases in LCO2 in Ghana, respectively. Our results show that the negative adjustment exerts a stronger effect than the favorable adjustments for long-run considerations. Notwithstanding, the first lag for favorable and unfavorable adjustments in LFEC exerts an increasing impact on LCO2 in Ghana with estimated coefficients of 1.015 and 1.076, respectively. The results may imply that the efficient utilization of energy resources that are non-renewable can reduce the pollution of the environment in Ghana since negative adjustments have a greater impact. This was expected from the theoretical point of view as increases in NonREC are expected to increase environmental deterioration in Ghana as the economy heavily depends on obsolete technologies and non-renewable energy, such as crude oil, for growth. Additionally, the results suggest that alternative energy sources should be devised to mitigate environmental degradation in Ghana. The same pattern of LFEC's influence on LCO2 is observed for the case of the short run. For instance, positive adjustments increase LCO2 by 1.52% (1.516) per unit percentage increase at the 1% significance level, whereas negative adjustment decreases CO_2 emissions by 0.58% (-0.584) per unit percentage decrease at the 1% significance level. This also affirms the assertion that efficient use of non-renewable energy can hinder environmental degradation. The favorable result regarding the influence of using fossil fuels on LCO2 supports previous research on Ghana (such as; Abokyi et al., 2019; Kwakwa & Alhassan, 2018; Twerefou et al., 2016). In several other researches, similar positive impacts of NonREC on environmental deterioration have been evidenced (see; Al-Mulali & Ozturk, 2016; Chen & Lei, 2018; Danish et al., 2017; Dogan & Seker, 2016).

Table 4

Short-run and long-run analysis

Variable	Coefficient	Std. Errs.	t	p>t
$LCO2(-1)$	-0.883***	0.219	-4.030	0.001
$LGDP^{+}(-1)$	-0.261	0.295	-0.890	0.385
$LGDP^{-}(-1)$	1.040*	0.521	2.000	0.059
$LFEC^{+}(-1)$	1.015**	0.381	2.670	0.014
$LFEC^{-}(-1)$	1.076***	0.242	4.450	0.000
$LFD^{+}(-1)$	-0.099	0.143	-0.690	0.497
$LFD^{-}(-1)$	-0.310**	0.132	-2.360	0.028
$\Delta LCO2(-1)$	-0.015	0.120	-0.130	0.902
$\Delta LGDP^{+}$	-0.745	0.698	-1.070	0.298

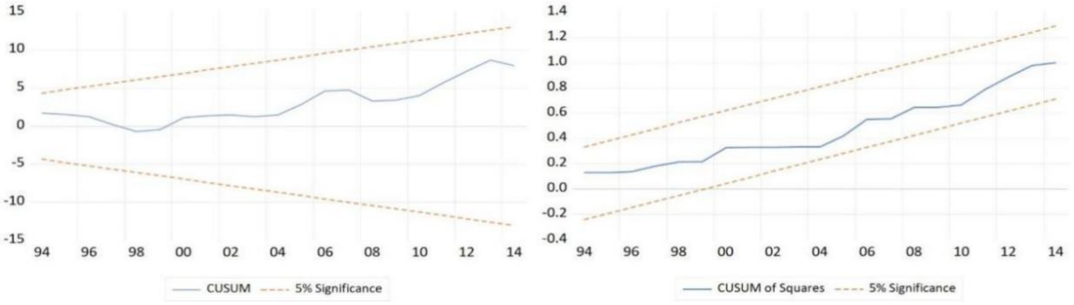
$\Delta LGDP^{+}(-1)$	-0.028	0.919	-0.030	0.976
$\Delta LGDP^{-}$	2.190**	0.777	2.820	0.010
$\Delta LGDP^{-}(-1)$	0.900	0.572	1.570	0.130
$\Delta LFEC^{+}$	1.516***	0.247	6.140	0.000
$\Delta LFEC^{+}(-1)$	0.314	0.209	1.500	0.148
$\Delta LFEC^{-}$	-0.584***	0.136	-4.290	0.000
$\Delta LFEC^{-}(-1)$	-0.127	0.337	-0.380	0.710
ΔLFD^{+}	0.042	0.125	0.330	0.741
$\Delta LFD^{+}(-1)$	-0.114	0.110	-1.040	0.310
ΔLFD^{-}	0.081	0.106	0.760	0.455
$\Delta LFD^{-}(-1)$	0.328*	0.158	2.080	0.050
Cons.	-0.181*	0.098	-1.840	0.079
Long run coefficients				
Variables	Coef.	F-stat	P>F	
$LGDP^{+}$	-0.296525	0.719	0.406	
$LGDP^{-}$	-1.177*	4.075	0.056	
$LFEC^{+}$	1.149***	24.640	0.000	
$LFEC^{-}$	-1.219***	85.060	0.000	
LFD^{+}	-0.112	0.567	0.460	
LFD^{-}	0.351**	4.563	0.045	
Diagnostics and statistics				
Test	Stat.	Prob	Test	Stat.
χ^2_{SC}	23.92	0.1992	R-squared	0.880
χ^2_{HT}	.7744	0.3789	Adj. R-squared	0.7659
χ^2_{FF}	.8793	0.4703	F-statistics	7.71***
χ^2_{NORM}	.2594	0.8784	Obs	42
CUSUM and CUSUMQ		Stable		

“*” “**” and “***” indicate significance levels at 10%, 5%, and 1% respectively. χ^2_{SC}, χ^2_{HT}, χ^2_{NORM} and χ^2_{FF} denotes the Portmanteau test for serial correlation, the Breusch/Pagan heteroskedasticity test, the Jarque-Bera test on normality, and the Ramsey Reset test for functional form, respectively.

Source: Authors’ creation

Further, we inquire the long-run case for financial sector improvement (LFD). Favorable and unfavorable adjustments to LFD negatively and positively impact LCO2. However, only the unfavorable adjustments have an impact at the 5% significance level. For instance, a 1% decrease in the LFD increases the LCO2 by 0.35% in the long run for Ghana contemporaneously. Additionally, a period lag of the negative adjustment of the LFD also enters the NARDL model with a significant estimate at a 5% level with an adverse impact. A 1% reduction of LFD causes a decrease of the LCO2 by 0.31% in the one-period lag. However, the contemporaneous impact of LFD negative adjustments is greater than the lagged effects. Though the coefficient of LFD positive adjustment is insignificant, our results partially support the findings in the previous literature. Our findings corroborate the findings of Jalil and Feridun (2011), Sadorsky (2010), Birdsall and Wheeler (1993), and Tamazian et al., (2009). On the contrary, Abdul-Mumuni et al., (2022), Shahbaz et al., (2016), Zhang (2011), Gokmenoglu et al., (2015), Musah et al., (2021), and Shahbaz et al., (2018) reported a likewise favorable impact of financial sector improvement on CO_2 releases. Our results for the short-run, however, depict that both the favorable and unfavorable adjustments have insignificant positive impacts, with the estimates being 0.042 and 0.081, respectively. The overall results suggest that decreased financial development (LFD) can significantly increase pollution levels in the long term, thus supporting the Pollution Halo Hypothesis. It emphasizes developing the Ghanaian financial sector to balance economic expansion with ecological preservation. The existing body of research agrees that the progress seen in Ghana’s financial environment over the past thirty years has contributed to domestic investment, reduced financial risk, and improved capital accumulation. As a result, it has attracted increased foreign direct investment and the embracement of contemporary friendly environmental innovations, causing a hindrance of ecological degradation (Abokyi et al., 2019). Additionally, developing the financial sector will enable corporations and production units to adopt friendly environmental technology and invest in environmental protection.

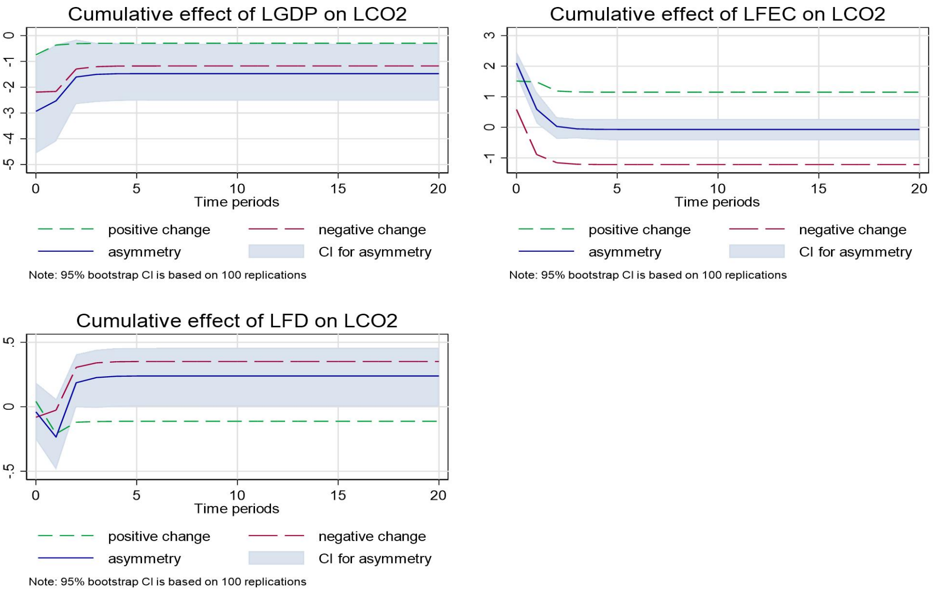
Figure 3.
CUSUM and CUUSMSQ test Plots



Source: Authors' creation

The cumulative dynamic multipliers are shown in Figure 4 after we implemented a variety of dynamic adjustments. These multipliers show how carbon emissions respond to a positive or negative shock in economic growth, fossil fuel usage, and financial sector improvement separately as it moves toward a new long-term balance. Figure 4 shows positive economic growth (LGDP) increments do not impact CO2 emissions significantly. Negative shocks significantly impact CO_2 emissions and dominate the effect of positive shocks. Hence, LGDP has an overall adverse influence on LCO2. Further, the consumption of fossil fuel exerts an overall adverse impact on LCO2 because negative shocks have dominant effects, which confirms the earlier documented estimates for the favorable and unfavorable shocks of LFEC for the long term (i.e., 1.149 vs. -1.219). Additionally, positive shocks of financial development (LFD) exert a temporary unfavorable impact on LCO2 (confirming the insignificant coefficient recorded for positive adjustments in Table 4), while negative shocks exert a dominant permanent influence on LCO2. Hence, the overall impact of LFD is favorable. This conclusion is coherent with the recorded coefficients for favorable and unfavorable adjustments, supporting the dominant positive effects in Table 4.

Figure 4
Cumulative effects of independent variables on carbon emissions (LCO2)

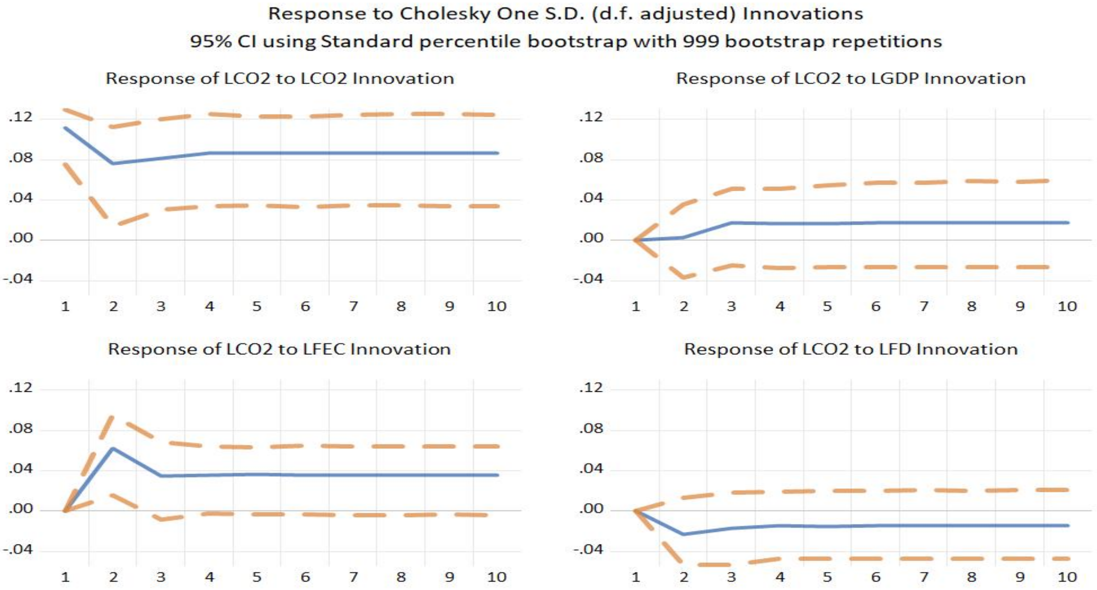


Source: Authors' creation

Robustness Check Results

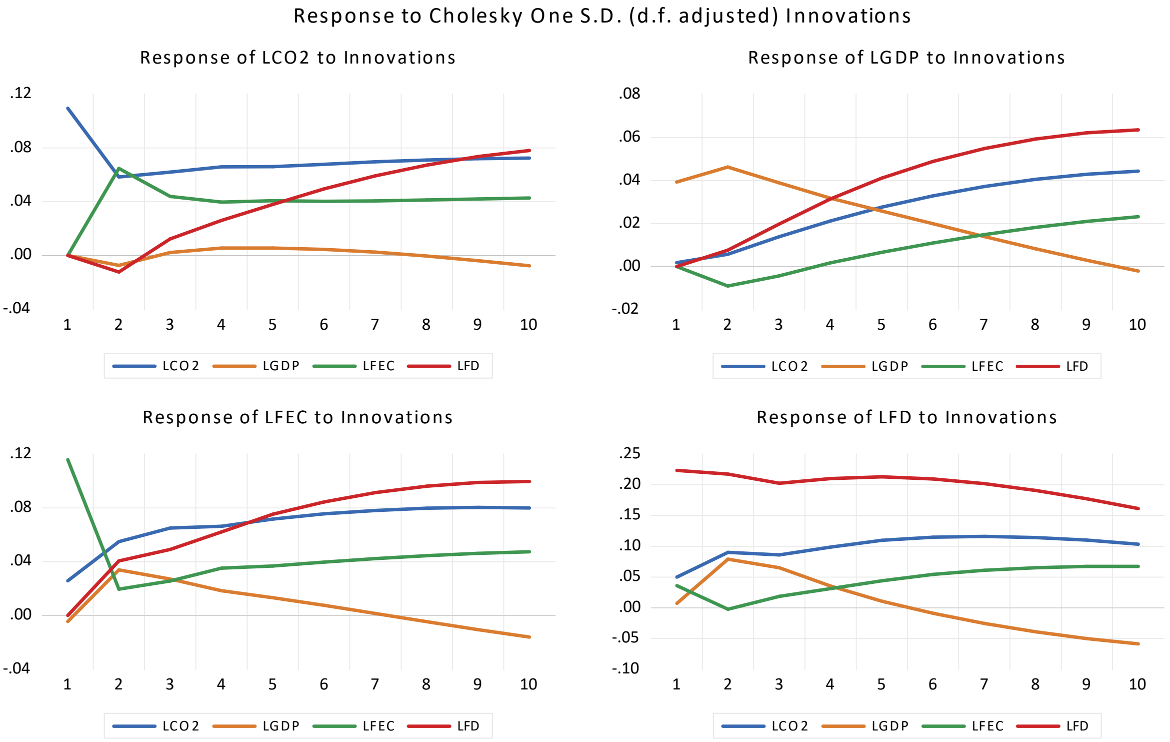
We conduct further analysis to ascertain robustness. The vector error correction model (VECM) framework with Schwarz Information Criterion (SIC) for lag choosing procedure was used to conduct the impulse response analysis. Figures 5 and 6 show the reaction of CO2 emissions to unit standard deviation shocks of LGDP, LFEC, and LFD over a 10-year horizon. LCO2 emissions respond negatively to LGDP at first, positively to LFEC, and negatively to LFD initially before becoming positive through the forecast horizon. These responses are consistent with the NARDL model in Table 5, which recorded negative coefficients for positive and negative adjustments to LGDP, positive adjustments to LFEC, and negative and positive adjustments to LFD. The results suggest that economic expansion and financial sector improvement affect CO2 emissions differently. While LGDP and LFD initially negatively affect LCO2 emissions, fossil LFEC has a favorable effect. However, the influence of LFEC declines after the second forecast horizon.

Figure 5
Impulse response functions



Source: Authors' creation

Figure 6
Impulse response functions combined graphs



Source: Authors' creation

Conclusion and Policy Implications

Ecological deterioration has become a grave concern in the context of the Ghanaian economy. Previous literature considered the linear relationship between CO_2 releases and their determinants for Ghana. However, using linear relationship models to predict future greenhouse gas emissions might produce somewhat biased and imprecise outcomes. This study explored the asymmetric influence of economic expansion, NonREC, and financial sector improvement on CO_2 releases for Ghana using the Nonlinear Autoregressive Distributed Lag (NARDL) model with annual data ranging between 1971 and 2014. The NARDL approach enables the separation of variables into favorable adjustments (shocks) and unfavorable adjustments (shocks), allowing us to grasp both the long- and short-run equilibrium alterations trends preceding favorable and unfavorable shocks and the sophisticated equilibrium dynamics among indicators, hence providing a more detailed and nuanced understanding of the interactions between the indicators. Therefore, the novelty of our study stems from taking care of potentially biased conclusions emanating from the assumption of symmetrical relationships between the considered variables, as favorable and unfavorable changes in exogenous indicators can affect endogenous indicators differently. The bounds test results indicate a cointegration between economic growth, NonREC, financial sector improvement, and CO_2 releases. The Wald test results indicate the existence of a short-run asymmetrical influence of economic expansion, NonREC, and financial sector improvement on CO2 releases. However, asymmetrical long-run impact exists only in the case of economic growth. The NARDL output indicates that negative adjustments to economic growth significantly decrease (increase) CO2 releases for the long run (short run), while positive adjustments do not significantly impact them. Positive adjustments and negative adjustments of NonREC have increasing and decreasing effects on CO_2 releases, respectively, in runs. The negative adjustments, however, have a larger effect than the positive adjustments, suggesting that the optimal utilization of NonREC has the prospect of decreasing environmental pollution in Ghana, which aligns with theoretical expectations and previous studies. The Ghanaian economy's heavy dependence on NonREC, such as crude oil, for growth, implies that increasing NonREC could result in more significant environmental degradation. This may also imply that both short-run and long-run measures can effectively reduce CO_2 emissions by reducing the consumption of fossil fuels. Therefore, we emphasize the importance of embracing environmental policies that promote the optimal utilization of NonREC in the 1-District, 1-Factory agenda. The findings suggest to the decision-maker the need to prioritize effective environmental strategies like a green economy, reusable energies, and energy-efficient innovations, specifically in the transportation sector. In the One District One Factory agenda, Ghana should also diversify the energy complexity, with a greater weight towards all forms of renewable energy, such as solar, hydroelectricity, and wind. Furthermore, the government should encourage investors to invest more in firms focusing on environmental quality so that increases in carbon emissions will not accompany economic growth. Additionally, negative adjustments of financial environment improvement increase CO_2 releases in the long run, meaning long-term measures to enhance the financial environment can effectively address Ghana's environmental degradation issues. This highlights the importance of developing Ghana's financial sector to balance economic growth with environmental preservation. Providing financial aid to investors who intend to launch projects that advance environmental sustainability is crucial. Such support will play a significant role in enhancing public awareness about energy security and environmental protection. Financial policies are necessary to assist fossil fuel-oriented businesses in transitioning into eco-friendly operations. The dynamic multiplier graphs and the impulse response function plots largely support the conclusions from the NARDL model.

The study has a few limitations that are worth pointing out. Firstly, the study was conducted solely in Ghana; hence, only Ghanaian data was utilized for the analysis. Secondly, the sample range ended in 2014 due to limited data availability for the variables in the model. We recommend that future research explore this relationship further by utilizing methodologies that can account for structural breaks in the sample range. Furthermore, we suggest that researchers consider using data from sub-Saharan African regions to understand this relationship better and improve policy formulation in the subregion of Africa.

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