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RESEARCH ARTICLE

The Impact of Economic Growth and Electricity Access on CO_2 Emissions in Bangladesh: An ARDL Bounds Testing Approach

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Abstract

As a rapidly developing nation, Bangladesh faces the imperative of decoupling economic expansion from environmental degradation. This study investigates the dynamic interplay between economic drivers, non-CO_2 greenhouse gases, and carbon dioxide (CO_2) emissions using annual data from 1990 to 2022. Employing the Autoregressive Distributed Lag (ARDL) bounds testing approach, the model examines the impact of GDP growth, electricity access, foreign direct investment (FDI), trade liberalization, and emissions from methane (CH_4) and nitrous oxide (N_2O). The empirical results substantiate a stable long-run cointegrating relationship among these variables. Specifically, long-term CO_2 emissions are significantly driven by GDP growth and methane output, whereas Foreign Direct Investment (FDI) is associated with a reduction in emissions. In the short run, however, expanded electricity access, industrial value added, and nitrous oxide levels contribute to rising pollution. The Error Correction Term (ECT) of -0.273 indicates a moderate adjustment speed, correcting approximately 27.3% of disequilibrium annually. These findings underscore the need for a multifaceted policy framework, including 'Green FDI' initiatives, accelerated renewable energy adoption, industrial energy efficiency, and sustainable agriculture. Implementing these measures will help Bangladesh align its development trajectory with SDGs 7, 8, and 13.

Keywords: CO_2 Emissions; ARDL Bounds Testing; Economic Growth; Pollution Halo Hypothesis; Bangladesh

Introduction

In the twenty-first century, one of the greatest issues facing policymakers has been the pursuit of fast economic expansion, with all the attendant negative effects on the environment (Sarkodie & Strezov, 2019). This is particularly apparent in Bangladesh, a South Asian nation with a population of over 170 million. The nation has emerged as one of the region's fastest-growing economies, attaining an average GDP growth rate of 6-7% per annum over the past decade [Bangladesh Bureau of Statistics (BBS), 2023]. This significant economic advancement has been propelled by industrialization, urbanization, and a flourishing ready-made garment (RMG) sector, which constitutes over 80% of the nation's export revenues (BBS, 2023).

However, this economic momentum has exacted a heavy environmental toll. Bangladesh's deep-seated reliance on fossil fuels has driven a substantial surge in energy consumption and greenhouse gas (GHG) emissions, specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Alam et al., 2012; Alam et al., 2016). Beyond contributing to global climate change, these emissions exacerbate local ecological crises, such as air pollution and soil degradation, posing a severe threat to the nation's long-term sustainability

[Intergovernmental Panel on Climate Change (IPCC), 2022]. The interplay between economic growth, energy consumption, and environmental degradation in Bangladesh is intricate and multifaceted. While CO_2 emissions may exhibit a short-term positive correlation with GDP growth, reflecting the nation's reliance on carbon-intensive industries, methane and nitrous oxide emissions appear to hinder economic performance, highlighting the high cost of unsustainable operational practices (Rahman & Kashem, 2017). Methane, derived primarily from agriculture and waste management, constitutes approximately 20% of total GHG emissions, while nitrous oxide levels have escalated alongside agricultural intensification (Wisser et al., 2024; FAO, 2023). These trends underscore the critical necessity of adopting sustainable methodologies to mitigate environmental damage. Concurrently, Bangladesh has achieved significant milestones in electrification, with over 90% of the population now having access to power (BPDB, 2023). However, the translation of electricity access into GDP growth often exhibits a time lag, necessitating accelerated investment in infrastructure and energy efficiency (Hossain, 2011). Furthermore, the energy mix remains heavily skewed toward fossil fuels, with renewables contributing less than 5% to total output (SREDA, 2023). This dependence not only compromises environmental sustainability but also exposes the economy to the volatility of global energy markets.

Foreign Direct Investment (FDI) and trade openness have also been pivotal to Bangladesh's economic trajectory. FDI inflows, particularly in manufacturing and energy, have facilitated technology transfer and industrial expansion (Islam et al., 2013). However, FDI can demonstrate a delayed negative impact on environmental sustainability, suggesting potential inefficiencies in capital absorption (Cole et al., 2011). Similarly, while trade openness drives growth, it exacerbates energy demand and emissions in export-oriented sectors like ready-made garments (Rahman & Vu, 2020). This dynamic aligns with the Pollution Haven Hypothesis, which suggests that developing nations with weaker regulations attract polluting industries, thereby complicating the trade-environment nexus (Managi et al., 2009).

The industrial sector, which includes construction and the RMG business that was discussed previously, is a crucial part of this economic growth. The value added (IND_VA) of this sector is a straightforward way to measure how much it adds to the economy. But it also uses a lot of energy and releases a lot of CO_2 (Rahaman, Chen, & Jiang, 2023), which makes its role as an engine of expansion and its environmental impact directly opposed to each other. So, for policies to be sustainable, they need to know the net effect of industrial activity.

While the individual impacts of these factors are partially understood, they are often analysed as part of the STIRPAT framework, which links population, affluence (GDP), and technology to environmental impact (York et al., 2003). However, a critical gap remains in analysing their combined and dynamic interplay (Alam et al., 2016). Most studies tend to focus on CO_2 in isolation, failing to account for the complex feedback loops between economic drivers (GDP, FDI, Trade, Industry), energy access, and the *full spectrum* of key greenhouse gases (CO_2, CH_4, and N_2O). To address this gap, the present study utilises the Autoregressive Distributed Lag (ARDL) framework, a method well-suited for examining long-run and short-run dynamics among time-series variables (Pesaran et al., 2001).

The main goal of this research is to explore the short-run and long-run dynamic relationships between Carbon Dioxide (CO_2) emissions and their key drivers in Bangladesh. Specifically, this study aims to:

I. Investigate the existence of a stable long-run (cointegrating) relationship between CO_2 emissions and its main drivers: GDP growth (GDP_GR), access to electricity (ELEC_ACCESS), foreign direct investment (FDI_NET), industrial value added (IND_VA), trade openness (TRADE_GDP), Methane emissions (CH_4_CHG), and Nitrous Oxide emissions (N_2O_CHG).

II. Measuring the short-run and long-run impacts of these variables on CO_2 emissions.

III. Determine the speed of adjustment back to long-run equilibrium following a short-term shock, using the Error Correction Model (ECM).

The significance of this study is twofold. First, it adds something new to the academic world by offering a more complete model of greenhouse gases. Innovatively including CH_4 and N_2O as predictors for CO_2 provides a more comprehensive picture of emission dynamics than the typical studies that only examine CO_2. Second, and just as importantly, the findings are crucial for policymakers in Bangladesh. By putting real numbers to the impacts of these key economic, energy, and environmental variables, this research provides a solid foundation for evidence-based policies. This can help leaders design smarter interventions that allow Bangladesh to grow its economy without destroying the environment, helping the nation meet its Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth), and SDG 13 (Climate Action).
This study provides three concrete contributions to the existing literature on emissions and economic development in Bangladesh:

- **Integrated Modelling of Greenhouse Gases (GHG):** To the best of the author's knowledge, this is the first study for Bangladesh to move beyond a CO_2-centric model. While existing studies (e.g., Rahman & Kashem, 2017; Alam et al., 2016) focus exclusively on the drivers of carbon dioxide, this paper innovatively includes Methane (CH_4_CHG) and Nitrous Oxide (N_2O_CHG) as direct independent variables. This joint modelling reveals a novel cross-gas pollution linkage, where long-run CO_2 emissions are significantly driven by methane, and short-run CO_2 emissions are driven by nitrous oxide.

- **Robust Evidence for the "Pollution Halo" Hypothesis:** Foreign investment in Bangladesh has raised a lot of questions about its effects on the environment. This study utilizes a dynamic ARDL framework to provide an exhaustive analysis of both long-term and short-term effects. The results show that FDI_NET has a big effect on lowering CO_2 emissions in both the short and long run. This discovery is a big deal since it strongly supports the "Pollution Halo" hypothesis (that FDI brings in cleaner technology) instead of the "Pollution Haven" explanation for Bangladesh.

- **Specific Short-Run vs. Long-Run Policy Insights:** The ARDL-ECM framework improves upon static models by isolating short-run from long-run effects. This study contributes to the field by mapping these distinct temporal drivers: while ELEC_ACCESS and IND_VA drive emissions in the short term, GDP_GR and CH_4_CHG are significant long-term factors. Recognizing this dichotomy allows policymakers to move beyond one-size-fits-all solutions and instead deploy targeted measures that address both immediate fluctuations and structural trends.

Literature Review

The literature regarding environmental sustainability and economic growth provides a solid theoretical foundation for analyzing the complex nexus between these two fields. Utilizing predominantly secondary data, this body of work can be categorized into four primary strands: 1) the dynamic between economic expansion and energy consumption; 2) the inherent trade-offs between development and environmental degradation; 3) the ecological implications of globalization, specifically regarding trade and Foreign Direct Investment (FDI); and 4) the contribution of renewable energy to long-term sustainability. This thematic organization facilitates a comprehensive understanding of the challenges involved in reconciling economic objectives with environmental preservation.

Economic Growth and Energy Consumption

The nexus between economic expansion and energy usage remains a central debate within energy economics (Apergis & Payne, 2012). Empirical evidence is far from uniform, often diverging based on the specific country and methodology employed. In emerging economies like India (Alam et al., 2011; Sarkar & Singh, 2010) and China (Lin & Moubarak, 2014), studies frequently support the 'energy-led growth' hypothesis, identifying energy as a critical driver of development. In contrast, research from OECD nations suggests a different trajectory, where strategic investments in efficiency allow for the 'decoupling' of economic progress from energy demand (IEA, 2022). In Bangladesh, the evidence is mixed. The research conducted by Alam et al. (2012) and Sharif Hossain (2011) identified energy consumption as a primary factor influencing economic growth; however, studies by Rahman & Kashem (2017) emphasised the more substantial impact of industrial expansion. A prevalent limitation in numerous studies is the neglect of the substantial time lag between investments in energy infrastructure and the subsequent economic benefits. This study helps fill that gap by using the dynamic, lagged structure of the ARDL model.

Environmental Emissions and Economic Growth

While the Environmental Kuznets Curve (EKC) hypothesis successfully predicts an inverted U-shaped pollution trajectory in countries like Sweden and Vietnam (Grossman & Krueger, 1991; Stern, 2004; Managi et al., 2009), it often fails to describe trends in the Global South. In South Asia, and Bangladesh specifically, studies consistently show that emissions continue to rise with growth, with no turning point in sight (Shahbaz et al., 2012; Alam et al., 2016; Islam et al., 2021). Moreover, existing research suffers from a significant blind spot: an almost exclusive focus on CO_2 (Cole et al., 2011). For agrarian nations like Bangladesh, excluding methane (CH_4) and nitrous oxide (N_2O) leads to an incomplete picture of environmental impact (FAO, 2021; Lgwe, 2024). By incorporating these non-CO_2 gases, this study provides a comprehensive analysis that standard models miss.

Trade, FDI, and Their Environmental Impact

The ecological impact of globalization is defined by two competing theories. The 'Pollution Haven Hypothesis' argues that weak regulations in developing nations like Bangladesh attract polluting industries (Walter & Ugelow, 1979; Raihan et al., 2022). Alternatively, the 'Pollution Halo Hypothesis' posits that FDI transfers cleaner technology and improves environmental standards (Zhu et al., 2016; Liu et al., 2018).
Bangladeshi literature has produced inconsistent results, though many studies support the Haven hypothesis. For example, trade openness has been linked to higher emissions in export industries (Rahman & Vu, 2020; Zhang et al., 2017), and Hossain (2011) found a direct link between FDI and CO_2. Crucially, however, previous research often fails to account for temporal delays. This study fills that gap by using an ARDL approach to model the dynamic, time-dependent effects of trade and FDI on the environment.

Renewable Energy and Sustainable Development

Renewable energy transition is universally accepted as a cornerstone of sustainable growth (Balsalobre-Lorente et al., 2020). Experiences in Germany and India confirm that renewables can reduce emissions without hindering the economy (Tseng et al., 2019; IEA, 2022).

Within Bangladesh, solar home systems have expanded significantly in rural zones (SREDA, 2023). However, the sector grapples with formidable challenges, notably grid reliability issues, high installation costs, and limited land resources (BPDB, 2023; Mondal & Denich, 2010). Despite the clear potential for renewables, there is limited research on how policy interventions can expedite their uptake. This study addresses this limitation by analyzing the impact of environmental regulations and the EPS Index on energy transition.

Drivers of Non-CO_2 Emissions (CH_4 and N_2O)

Existing research suffers from a major blind spot: an almost exclusive focus on carbon dioxide. This study fills that gap by explicitly modeling Methane (CH_4_CHG) and Nitrous Oxide (N_2O_CHG). Understanding the drivers of these gases is crucial for Bangladesh. Methane output is heavily tied to the agrarian economy, particularly rice paddies and livestock (Alam et al., 2016; Habib et al., 2023), though urban landfills also contribute significantly due to poor waste processing (IPCC, 2022).
Nitrous Oxide, on the other hand, tracks closely with fertilizer application (Wisser et al., 2024; FAO, 2023). Consequently, mitigating these emissions requires a shift toward sustainable farming and better waste management. By capturing these agricultural and urban drivers, our analysis moves beyond the standard industrial models to provide a complete picture of the country's emissions profile.

Gaps in the Literature and This Study's Contribution

- Most prior studies have restricted their analysis to CO_2 emissions, failing to account for the significant environmental impact of methane (CH_4) and nitrous oxide (N_2O) (Sarkodie & Strezov, 2019; Lawe, 2025).
- The delayed (lagged) consequences of energy investments, FDI, and trade are frequently neglected, as they cannot be represented in static models.
- There is insufficient research on the measurable effectiveness of environmental policies in promoting renewable energy in Bangladesh.

This study addresses these gaps by

- Including CO_2, CH_4, and N_2O emissions in a single, integrated analysis.
- Using the Autoregressive Distributed Lag (ARDL) model to study both the short-run and long-run dynamic effects of all variables.
- Evaluating how policies like the EPS Index can promote sustainable development in Bangladesh.

Methodologies

Data and Variables

This study uses a quantitative, longitudinal approach to look at the things that affect carbon dioxide emissions in Bangladesh. The research utilises annual time-series data spanning from 1991 to 2023, obtained from the World Bank's World Development Indicators (WDI) database. The model chooses Carbon Dioxide (CO_2) Emissions (total, excluding LULUCF, Mt CO_2e) as the dependent variable (CO_2_TOT), functioning as the main indicator of environmental degradation. Table 1 shows a summary of all the variables that were used in this analysis. The independent variables were chosen because they are related to economic activity and environmental impacts in theory:

Table 1. Variable Descriptions

Variable	Description
	Dependent Variable
CO_2_TOT	Carbon Dioxide (CO_2) Emissions (total) excluding LULUCF (Mt CO_2e)
	Independent Variables
CH_4_CHG	Methane (CH_4) Emissions (% change)
ELEC_ACCESS	Access to Electricity (% of population)
FDI_NET	Foreign Direct Investment, net inflows (% of GDP)
GDP_GR	GDP Growth (annual %)
IND_VA	Industry (including construction), value added (% of GDP)
N_2O_CHG	Nitrous Oxide (N_2O) Emissions (% change)
TRADE_GDP	Trade (% of GDP)

Theoretical Rationale for Variable Selection

Table 2. Variable Justifications with References

Variable	Justification	Selected References
CO_2_TOT	Key driver of climate change. Bangladesh's emissions have grown significantly with industrialisation.	(Alam et al., 2016; IPCC, 2022; Stern, 2004)
GDP_GR	GDP growth reflects economic health and is central to the energy-environment trade-off. Critical for SDG alignment.	(World Bank, 2023; Rahman & Kashem, 2017; Barro, 1996; Hossain, 2011)
ELEC_ACCESS	Electrification is a primary driver of industrialisation, social equity, and economic activity.	(IEA, 2022; Tseng et al., 2019; BPDB, 2023; SREDA, 2023)
FDI_NET	FDI influences technology transfer (Pollution Halo) or can attract polluting industries (Pollution Haven).	(Islam et al., 2013; Cole et al., 2011)
IND_VA	Industrialisation (e.g., the RMG sector) is a major contributor to GDP but also a primary source of emissions.	(BBS, 2023; Rahman & Kashem, 2017; Lin & Moubarak, 2014)
CH_4_CHG	Methane (mainly from agriculture/waste) accounts for ~20% of Bangladesh's GHG emissions.	(IPCC, 2022; FAO, 2021; SREDA, 2023; Rahman & Alam, 2021)
N_2O_CHG	Nitrous oxide (N_2O) emissions from fertilisers have increased with agricultural intensification.	(FAO, 2021; Rahman & Alam, 2021; Smith et al., 2008)
TRADE_GDP	Trade openness drives energy demand and emissions in export-oriented economies (e.g., the RMG sector).	(WTO, 2023; Rahman & Vu, 2020; Managi et al., 2009; Shahbaz et al., 2015)

Estimation and Methods

The Autoregressive Distributed Lag (ARDL) model is employed to examine the impact of globalisation and economic factors on population growth in Bangladesh. This method considers both short-term fluctuations and long-term equilibrium points. It has a process for fixing mistakes (ECM) that must be negative and statistically significant. This demonstrates how quickly variables get to their long-term equilibrium. The primary advantage of the ARDL approach lies in its flexibility regarding the order of integration. Unlike standard cointegration techniques, it yields robust results whether the underlying variables are purely I(0), purely I(1), or a combination of both. This framework is designed to simultaneously capture short-term dynamic adjustments and long-term equilibrium relationships, providing a holistic view of the variables' interactions. The existence of a valid long-run relationship is rigorously confirmed via the Bounds testing procedure. Moreover, the ARDL framework is superior to static models for analyzing complex economic systems. By explicitly incorporating lags of both the dependent and independent variables, the model inherently captures the dynamic nature of the data. This structure helps to mitigate potential endogeneity problems, such as reverse causality, offering more reliable estimates than static alternatives (Pesaran et al., 2001).

Model Specification

To assess the relationship between Annual Economic growth (GDP_GR) and its determinants, the subsequent econometric model is formulated:

$$CO_2\_\mathrm{TOT}_t = \alpha_0 + \alpha_1 CH_4\_CHG_t + \alpha_2 ELEC\_ACCESS_t + \alpha_3 FDI\_NET_t + \alpha_4 GDP\_GR_t + \alpha_5 IND\_VA_t + \alpha_6 N_2O\_CHG_t + \alpha_7 TRADE\_GDP_t + +\mathcal{E}_t \quad (1)$$

Where:

α_0= Constant term, and $\alpha_1 \dots \dots \alpha_7$ are the long-term coefficients of CO_2 Emission the explanatory variables and the error term (ε_T)

Unit Root Test

To avoid spurious regression, the stationarity of the time series is tested using the Augmented Dickey-Fuller (ADF) in intercept and intercept and trend (Dickey & Fuller, 1979). To determine stationarity and the order of integration, the has been tested applied is Augmented Dickey-Fuller (ADF) test. Suppose a series is stationary at its level (eg, cap Z sub t, cap Z sub t). In that case, it is referred to as I(0) or integrated of order zero if it is stationary after the first difference (e.one. ($Z_t - Z_t - 1Z_t - Z_t - 1$), it is classified as I(1) or integrated of order 1.

The ADF test examines whether each variable has a unit root. The ADF test equation is specified as:

$$\Delta Y_t = \beta_0 + \beta_{1t} + \delta Y_{t-1} + \sum_{j=1}^{m} \phi j \, \Delta Y_{t-j} + \mu_t \quad (2)$$

Where:

Y_t = Variable under investigation (e.g., *GDP_GRt*, *ELEC_ACCESSt*, etc.).

ΔY_t= First difference of Y_t

β_0 = Constant term.

Y_{1t} = Time trend.

δ = Coefficient of the lagged level of *Yt*.

Φ_j = Coefficients of lagged differences.

μ_t = Error term

If θ is 0, the variable is I. To make sure the results are correct. By proving stationarity and avoiding false regression results, these tests make sure that the analysis is reliable.

ARDL Bounds Test for Cointegration Test

When two or more time series are not stationary, the cointegration test is used to see if there is a stable long-term connection between them. When all the variables in a model remain constant after differencing, this test is used to determine if they all follow the same order of integration. For cointegration to exist, two conditions must be met:

1. Each series must have the same integration order.
2. A linear combination of the series must be stationary at their respective levels (Thome, 2014).

To examine long-run equilibrium relationships, the maximum likelihood approach is used. (Johansen & Juselius, 1990). Two likelihood ratio tests—the maximum eigenvalue and trace test—are employed to identify the number of cointegrating vectors. The test can be summarised as follows:

$$\Delta X_t = IIX_{t-1} + \sum_{i=1}^{p-1} \Gamma X_{t-1} + \mathcal{E}_t \qquad (3)$$

Where:

Xt= Vector of endogenous variables (e.g., CO_{2t}, CH_4, *GDP_GRt*, *ELEC_ACCESSt*, etc.). .Π: Matrix of long-run coefficients.

Γ*i*= Matrix of short-run coefficients.

ϵt= Error term.

The rank of Π (denoted as *r*) determines the presence of cointegration:

- If r=0*r*=0, no cointegration exists, and the model reduces to a VAR of order p*p*.
- If 0<*r*<*n*, there are *r* cointegrating vectors, and Π=*αβ*′. Here, α*α* measures the strength of the relationship, and *β* represents the cointegrating vector. Even if W*t* is I(1), *β*′W*t* is I(0).

Bound Test Equation

To assess the short-run and long-run dynamics, the Autoregressive Distributed Lag (ARDL) model is applied. The bound test equation is specified as:

$$CO_2\_\text{TOT}_t = \alpha_0 + \sum_{i=1}^{p} \beta_{1i}\, CH_4\_\text{CHG}_{t-1} + \sum_{i=1}^{p} \beta_{2i}\, \text{ELEC\_ACCESS}_{t-1} + \sum_{i=1}^{p} \beta_{3i}\, FDI\_NET_{t-1} + \sum_{i=1}^{p} \beta_{4i}\, GDP\_GR_{t-1} + \sum_{i=1}^{p} \beta_{5i}\, \text{IND\_}VA_{t-1} + \sum_{i=1}^{p} \beta_{6i}\, N_2\text{O\_CHG}_{t-1} + \sum_{i=1}^{p} \beta_{7i}\, \text{TRADE\_GDP}_{t-1} + \phi_1 CH_4\_\text{CHG}_{t-1} + \phi_2 \text{ELEC\_ACCESS}_{t-1} + \phi_3 FDI\_NET_{t-1} + \phi_4 GDP\_GR_{t-1} + \phi_5 \text{IND\_VA}_{t-1} + \phi_6 N_2\text{O\_CHG}_{t-1} + \phi_7 \text{TRADE\_GDP}_{t-1} + \varepsilon_t \quad (4)$$

Where:

- (β_1 …… β_7), & (θ_1…... θ_7): Short-run coefficients.
- ϕ_1 to ϕ_7: Long-run coefficients.
- ϵ_t: Error term.

Criteria of Lag Selection

The Akaike Information Criterion (AIC) in EViews-12 automatically found the lag structure for the model with a maximum lag length set to 2. The AIC is a common, standard and robust way to choose a model selection as it effectively balances model fit with parsimony, that is, it statistically penalises the inclusion of unnecessary lags. The chosen ARDL (2, 0, 1, 0, 2, 0, 1, 2) specification has the lowest AIC value.

The selected model was then evaluated using the diagnostic tests (for serial correlation, heteroskedasticity, and normality) and stability tests (CUSUM and CUSUM-SQ). Table 7 shows that the model passed all diagnostic tests successfully, which means that statistically valid and robust.

Diagnostic and Stability Tests

Finally, a series of diagnostic tests are run on the chosen ARDL model to make sure it is strong and dependable. The tests for Serial Correlation (Breusch-Godfrey LM test), Heteroskedasticity (Breusch-Pagan-Godfrey test, 1979), and Normality (Jarque-Bera test) are also part of this. The Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUM-SQ) tests (Brown et al., 1975) show that the model is stable.

Research Hypotheses

This study tests the following hypotheses based on the theoretical and empirical literature:

I. H1: Economic growth has a positive and significant impact on CO_2 emissions.
   - *Rationale:* Economic activity in Bangladesh is heavily reliant on fossil fuels and carbon-intensive industries (Rahman & Kashem, 2017). Therefore, expect a positive relationship between GDP_GR and CO_2_TOT.

II. H2: Access to electricity has a positive and significant impact on CO_2 emissions.
   - *Rationale:* As Bangladesh's energy grid is primarily fossil-fuel-based (SREDA, 2023), expanding ELEC_ACCESS is expected to increase CO_2_TOT, particularly in the short run.

III. H3: Foreign Direct Investment has a significant impact on CO_2 emissions.
   - *Rationale:* This hypothesis tests the competing "Pollution Haven" (positive impact) vs. "Pollution Halo" (negative impact) theories. This study will determine which effect is dominant in Bangladesh.

IV. H4: Non-CO_2 greenhouse gases have a positive and significant impact on CO_2 emissions.
   - *Rationale:* This is the study's novel hypothesis: Emissions from agriculture (CH_4_CHG and N_2O_CHG) are linked to the same economic development model that drives industrial CO_2 emissions and will have a positive, compounding effect on CO_2_TOT.

Results and Discussion

Statistical Characterization

Table 3 shows descriptive data for the eight variables utilized in this analysis for Bangladesh from 1991 to 2023. Key economic indicators show strong GDP growth (mean = 5.65% each year), although Bangladesh's economy was very unpredictable during this time, with growth rates between 3.45% and 7.88%. The industrial value-added sector made up a consistent part of the economy (mean = 25.85% of GDP). Net foreign direct investment (FDI) inflows as a percentage of GDP were also erratic, ranging from 0.004% to 1.74%.

The data highlights a stark transformation in Bangladesh's environmental landscape. It is observe a sharp surge in CO_2 emissions, rising from 14.07 to 124.79 Mt CO_2e. Alongside this, fluctuations in Methane (CH_4) and Nitrous Oxide (N_2O) signal shifting dynamics in agricultural practices. Social indicators are equally telling. The electricity access data, ranging from a low of 9.91% to a near-universal 99.99%, captures the country's aggressive electrification efforts, averaging 52.34% over the period. Additionally, trade openness (mean = 32.49%) points to increased global connectivity. Statistical validity was confirmed via the Jarque-Bera test, which indicated normal distribution across all variables. These findings emphasize that Bangladesh's development trajectory is inextricably linked to both economic stability and environmental volatility. These results illustrate how crucial it is for Bangladesh to have particular policies that deal with these concerns in order to reach its national sustainability objective.

Table 3. Descriptive Statistics

Variable	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Prob.
CO_2_TOT	57.397	46.20	124.793	14.068	35.493	0.5356	1.9340	3.1401	0.2080
CH_4_CHG	7.787	5.436	24.642	-4.643	9.879	0.1511	1.4754	3.3218	0.1899
ELEC_ACCESS	52.342	50.50	99.990	9.905	28.301	0.2734	1.9093	2.0467	0.3594
FDI_NET	0.612	0.525	1.735	0.004	0.490	0.5897	2.3978	2.4110	0.2995
GDP_GR	5.648	5.572	7.882	3.448	1.170	-0.1321	2.1422	1.1077	0.5747
IND_VA	25.847	24.50	34.594	21.120	4.235	0.9210	2.3532	5.2406	0.0728
N_2O_CHG	57.322	62.80	108.506	5.122	29.302	-0.1365	2.0290	1.3989	0.4969
TRADE_GDP	32.490	30.98	48.111	18.890	7.873	0.4509	2.3245	1.7456	0.4178

Graphs of the Variables

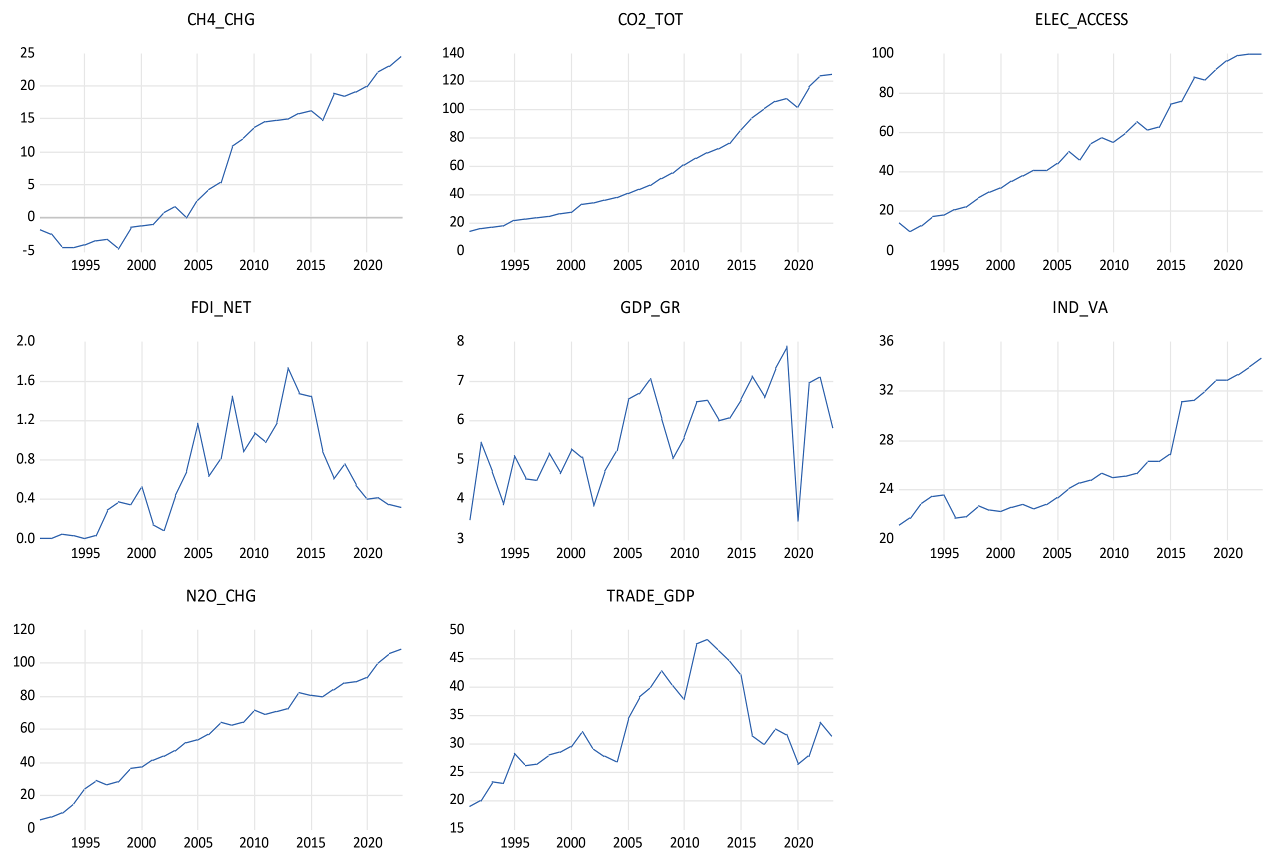

Figure 1. Graphs of the variables with time, from 1991 to 2023

Unit Root Test Result

Table 4. Stationary Test

Variable	Test Specification	At Level I(0)	At 1st Difference I(1)	Conclusion
		t-Stat (Prob.)	t-Stat (Prob.)	
CO_2_TOT	Intercept	1.923 (0.9997)	-5.025 (0.0003)***	I(1)
	Trend & Intercept	-1.477 (0.8167)	-5.891 (0.0002)***	
CH_4_CHG	Intercept	0.706 (0.9904)	-5.999 (0.0000)***	I(1)
	Trend & Intercept	-3.086 (0.1266)	-6.249 (0.0001)***	
ELEC_ACCESS	Intercept	0.376 (0.9785)	-8.142 (0.0000)***	I(1)
	Trend & Intercept	-3.339 (0.0782)*	-8.042 (0.0000)***	
FDI_NET	Intercept	-1.900 (0.3285)	-6.4914 (0.0000)***	I(1)
	Trend & Intercept	-1.5796 (0.7787)	-6.6556 (0.0000)***	
GDP_GR	Intercept	-4.009 (0.0041)***	-7.352 (0.0000)***	I(0)
	Trend & Intercept	-5.520 (0.0004)***	-7.216 (0.0000)***	
IND_VA	Intercept	0.793 (0.9923)	-5.163 (0.0002)***	I(1)
	Trend & Intercept	-5.163 (0.0002)***	-5.505 (0.0005)***	
N_2O_CHG	Intercept	-0.430 (0.8921)	-6.489 (0.0000)***	I(1)
	Trend & Intercept	-3.082 (0.1275)	-6.424 (0.0001)***	
TRADE_GDP	Intercept	-6.424 (0.0001)***	-8.142 (0.0000)***	I(0)
	Trend & Intercept	-3.339 (0.0782)*	-8.042 (0.0000)***	

Note: *, *, and * denote significance at the 1% and 5% levels, respectively.*

Table 4 illustrates the results of the Augmented Dickey-Fuller (ADF) test for all variables, which were looked at at both Level I(0) and 1st Difference I(1) using "Intercept" and "Trend & Intercept" settings. If its p-value is significant ($p < 0.10$) in at least one of the level tests, it is classified as I(0). If a variable fails all level checks, it is then tested at its 1st Difference (The p-values are from the MacKinnon (1996) one-sided p-values). The results show that most of the variables, such as ELEC_ACCESS, FDI_NET, GDP_GR, IND_VA, N_2O_CHG, and TRADE_GDP, are stationary at the I(0) level. The factors CO_2_TOT (the dependent variable) and CH_4_CHG were found to be non-stationary at the I(0) level but became stationary after the first difference.
Crucially, all variables were confirmed to be either I(0) or I(1), and no variable was found to be integrated of order two, I(2). This heterogeneous mix of I(0) and I(1) variables confirms that the ARDL bounds testing approach is the most appropriate and valid methodology for this analysis (Pesaran et al., 2001).

Results of the ARDL Bounds Test

The ARDL bounds test, shown in Table 5, rejects the null hypothesis of no cointegration at the 1% significance level. The F-test statistic of 7.6461 exceeds the crucial I(1) upper bound (3.90, $p < 0.01$). Therefore, the model parameters display a specific cointegrating relationship, and that variation in all of these variables influences CO_2 emissions in Bangladesh.

Table 5. Results of the ARDL Bounds Test

Test Statistic	Value	k
F-statistic	7.6461	7
Significance Level	Critical Bounds	
	I(0)	I(1)
10%	1.92	2.89
5%	2.17	3.21
2.5%	2.43	3.51
1%	2.73	3.90

ARDL Short-run and Long-run Estimation

Table 6. ARDL Short-run and Long-run Estimation

Variables	Long-run Coefficient	Std. Error	t-Statistic	Short-run Coefficient	Std. Error	t-Statistic
CH_4_CHG	2.702392*	1.346146	2.007503	D(CH_4_CHG)	*Not included in ECM*	
ELEC_ACCESS	-0.018612	0.498242	-0.037355	D(ELEC_ACCESS)	0.687510***	0.063089
FDI_NET	-22.12260*	12.49538	-1.770462	D(FDI_NET)	-2.479029**	0.839928
GDP_GR	7.287908**	3.330141	2.188468	D(GDP_GR)	*Not included in ECM*	
IND_VA	1.157943	2.285713	0.506600	D(IND_VA)	1.952474***	0.273289
				D(IND_VA(-1))	-2.706800***	0.343829
N_2O_CHG	0.117439	0.389064	0.301849	D(N_2O_CHG)	0.805704***	0.060723
TRADE_GDP	0.660752	0.691414	0.955654	D(TRADE_GDP)	-0.108639	0.065345
				D(TRADE_GDP(-1))	-0.413326***	0.061552
ECT (CoinEq(-1))				-0.272619*	0.026216	-10.39896
Constant	-56.17657	55.45685	-1.012978	D(CO_2_TOT(-1))	0.241410***	0.062735
R-squared				0.911346		
Adj. R-squared				0.879109		
F-statistic				12.00 (Prob. 0.0000)		
Durbin-Watson				2.118158		

*******p < 0.01, **p < 0.05, p < 0.10***

Table 6 presents the results for the selected ARDL (2, 0, 1, 0, 2, 0, 1, 2) model, which was chosen based on the Akaike Information Criterion (AIC). The above table utilises the ARDL framework to illustrate how GDP_GR,

FDI_NET, IND_VA, ELEC_ACCESS, CH_4_CHG, N_2O_CHG, and TRADE_GDP on CO_2_TOT in Bangladesh in the short-term and long-term.

In the long run, a 1-percentage-point rise in GDP_GR (GDP Growth) leads to a 7.288-unit (Mt CO_2e) increase in CO_2_TOT emissions. This result suggests that Bangladesh's economic growth is still energy-intensive, largely because of fossil fuel use and industrial production. As GDP grows, so does the need for electricity, transportation, and infrastructure, which are all strongly linked to carbon emissions. These results support the view that unregulated or carbon-heavy growth strategies can significantly contribute to environmental degradation. This trend aligns with previous findings by Rahman and Kashem (2017) regarding Bangladesh and Sarkodie and Strezov (2019) for developing economies. When examining foreign investment, the coefficients for FDI_NET reveal a distinct negative correlation with CO_2_TOT. Specifically, a 1-percentage-point increase in FDI leads to an immediate emissions reduction of 2.479 units (significant at the 5% level) and a long-term decrease of 22.122 units (significant at the 10% level).

These results lend credence to the 'Pollution Halo' hypothesis. The mechanism suggests that foreign entities transfer cleaner, more efficient technologies and rigorous environmental standards, which then spill over into the domestic economy. While this contradicts the 'Pollution Haven' narrative where capital seeks lax regulations (Cole et al., 2011), it strongly corroborates Zhu et al. (2016), who similarly identified FDI as a driver for environmental improvement.

Furthermore, IND_VA (Industrial Value Added) has a significant positive relationship with CO_2 emissions in the short term. A 1-percentage-point increase in industrial value-added results in an immediate increase in CO_2_TOT of 1.952 units (M_tCO_2e). The heavy reliance on energy-intensive processes in industrialisation, particularly in the ready-made garment (RMG) sector, results in a significant release of greenhouse gases. This finding is reinforced by the highly significant short-run coefficient for ELEC_ACCESS (+0.687), which shows that the expansion of the current energy grid is directly linked to higher emissions. A similar outcome was reported by Rahaman, Chen & Jiang (2023), who linked industrial activity and energy consumption directly to emissions in Bangladesh.

The influence of non-CO_2 greenhouse gases is a particularly new finding of this study. The CH_4_CHG (Methane) coefficient demonstrates that over time, a 1% rise in methane emissions ($MtCO_2e$) causes a 2.702 unit rise in CO_2_TOT emissions (at the 10% significance level). In the same way, a 1% rise in N_2O_CHG (Nitrous Oxide) emissions leads to a 0.806 unit ($MtCO_2e$) rise in CO_2_TOT emissions in the short term. This shows a very critical effect of pollution. These gases, mainly from agriculture (rice cultivation and fertilizer use) and waste, are not just separate problems; they are also linked to the same economic and agricultural activities that produce CO_2. These findings are corroborated by Alam et al. (2016) and FAO (2023), which highlight the environmental impact of unsustainable agricultural intensification occurring alongside industrial expansion.

Finally, the error correction term (CoinEq(-1)) shows that this entire model is stable. The coefficient of -0.272619 is highly significant with p=0.0000, which means that the system is stable and adjusts back to its long-run equilibrium at a speed of 27.3% per year following any short-term shock.

Diagnostic and Stability Tests

Table 7. Diagnostic and Stability Tests

Test	Null Hypothesis (H_0)	Test Statistic	Value	Probability	Conclusion
Serial Correlation	No serial correlation	Breusch-Godfrey LM (F)	1.763186	0.2131	Fail to Reject H_0
Heteroskedasticity	Homoskedasticity	Breusch-Pagan-Godfrey (F)	0.688871	0.7645	Fail to Reject H_0
Normality	Residuals are normally distributed	Jarque-Bera	1.096605	0.577930	Fail to Reject H_0

Table 7 shows the findings of the diagnostic test. The results from these tests indicate a well-specified model. For every diagnostic check, the null hypothesis was upheld, reinforcing the conclusion that the model is robust.

- **Normality Test:** The Jarque-Bera (JB) assessment (Jarque & Bera, 1980), with a p-value of 0.5779, means the distribution is normal.
- **Serial Correlation Test:** The Breusch-Godfrey (LM) examination (Breusch, 1978; Godfrey, 1978) reveals no serial correlation in the residuals, with an F-statistic p-value of 0.2131.
- **Heteroskedasticity Test:** The Breusch-Pagan-Godfrey test (Breusch & Pagan, 1979) implies no evidence of heteroscedasticity in the residuals, reporting an F-statistic p-value of 0.7645.

Stability Checking by CUSUM & CUSUM Square Test of the Model

The Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUM-SQ) tests proposed by Brown et al. (1975) were used to determine if the model's parameters remained constant during the sample period. As seen in the statistics, the test results for both metrics remain well inside the 5% threshold limit. This indicates that the model can be used to examine long-term policy because the estimated parameters are fundamentally stable and consistent.

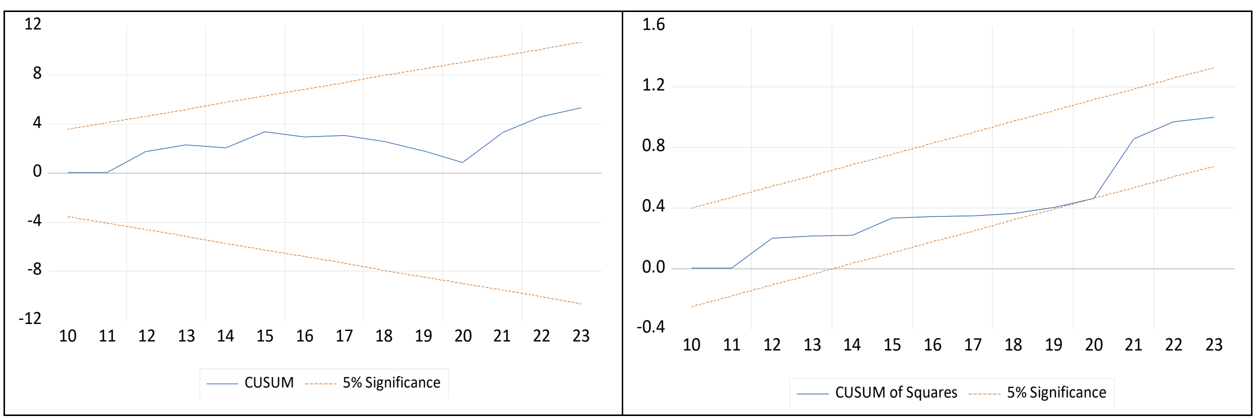

Figure 2. CUSUM & CUSUM Square Test

Discussion and Policy Implications

This study employed the ARDL framework to investigate the intricate nexus linking energy consumption, economic expansion, and environmental degradation in Bangladesh. The empirical results reveal a nuanced dynamic. In the long run, both economic growth (GDP_GR) and methane output (CH_4_CHG) act as significant drivers of CO_2 emissions, underscoring the environmental cost of current agricultural and developmental practices. Conversely, Foreign Direct Investment (FDI_NET) exerts a negative impact on emissions; this finding supports the 'Pollution Halo' hypothesis, suggesting that foreign capital facilitates the transfer of greener technologies. In the short run, however, the expansion of electricity access (ELEC_ACCESS), industrialization (IND_VA), and nitrous oxide emissions (N_2O_CHG) all contribute to immediate spikes in carbon output. The ARDL bounds test confirms a stable long-run cointegration among these variables. Furthermore, the Error Correction Term (ECT) is negative and highly significant (-0.272619, $p < 0.01$), indicating that the system self-corrects at a speed of approximately 27.3% annually following a shock. The findings of this study underscore the critical requirement for policies that strike a balance between the preservation of the environment and the promotion of energy efficiency and growth, with the ultimate goal of steering Bangladesh in the direction of reaching its Sustainable Development Goals (SDG) objectives 7, 8, and 13.

Specific Actions and Implementation

To tackle the identified challenges, Bangladesh can adopt clear and effective policies based on the successful experiences of other countries. The following strategies are directly informed by the sign and significance of the model's coefficients.

It is important to note that while this econometric model identifies the *direction* and *magnitude* of the problem, it cannot generate specific political targets. Therefore, the numeric goals (e.g., MW of solar, number of farmers) mentioned in the implementation plans are presented as illustrative examples of the scale of action required, not as direct outputs of the model.

Table 8: Policy Recommendations Based on ARDL Findings

Policy Recommendation	Result Alignment (Based on ARDL Model)	Recommended Action (Global Example)	Illustrative Implementation Strategy
1. Green FDI Framework	Justified by the negative and significant long-run coefficient (-22.122, $p < 0.10$) of FDI_NET. This suggests that for every 1-percentage-point rise in FDI, CO_2 emissions *decrease* by 22.12 units, supporting the Pollution Halo hypothesis.	Attract foreign investment in renewable energy and eco-tourism, inspired by Costa Rica's model, which generates over 98% of its electricity from renewables (UNIDO, 2023).	Offer tax breaks and streamline regulatory processes specifically for green FDI projects that involve verified technology transfer.
2. Carbon Pricing & Energy Efficiency	Justified by the positive and significant coefficients of GDP_GR (long-run: +7.288, $p < 0.05$) and IND_VA (short-run: +1.952, $p < 0.01$). These results confirm that both long-run growth and short-run industrial activity significantly increase emissions.	Develop mandatory energy efficiency standards and implement a carbon pricing mechanism, inspired by Japan's Top Runner Program (IEA, 2022) and Sweden's carbon tax (World Bank, 2023).	*Illustrative Target:* Set an initial carbon tax rate of \$10/ton of CO_2 for high-emitting sectors (e.g., textiles, cement). Use revenue to subsidise energy-efficient appliances.
3. Sustainable Agriculture Practices	Justified by the positive and significant coefficients of CH_4_CHG (long-run: +2.702, $p < 0.10$) and N_2O_CHG	Promote organic farming and modern agricultural techniques to reduce Methane and Nitrous	*Illustrative Target:* Train 50,000 farmers in organic farming and alternate wet-drying

	(short-run: +0.806, $p < 0.01$). This novel finding confirms a cross-gas pollution linkage.	Oxide emissions, following India's Zero Budget Natural Farming (ZBNF) initiative (FAO, 2021).	(AWD) techniques for rice. Support the setup of biogas plants to capture methane from waste.
4. Decarbonising the Grid	Justified by the positive and significant short-run coefficient (+0.687, $p < 0.01$) of ELEC_ACCESS. This result shows that expanding the grid with its current carbon-intensive fuel mix directly increases CO_2 emissions.	Aggressively expand off-grid and grid-tied renewable energy, drawing inspiration from Germany's *Energiewende* policy (IEA, 2022) and Kenya's success with solar home systems (World Bank, 2023).	*Illustrative Target:* Partner with the private sector to install 5,000 MW of solar capacity by 2030. Install 2 million new solar home systems by 2025.
5. Green Industrial Zones & Circular Economy	This policy directly targets the positive short-run coefficient of IND_VA (+1.952, $p < 0.01$). Since industrial activity is a major immediate driver of emissions, dedicated green zones are a logical intervention.	Promote a circular economy in the RMG sector and develop eco-industrial parks, following the example of China's Suzhou Industrial Park (UNIDO, 2023) and the Netherlands' approach (EU, 2023).	*Illustrative Target:* Create three green industrial zones by 2027, offering tax incentives. Establish 10 textile recycling hubs in major industrial zones by 2026.

Limitations of the Study

The author acknowledges several limitations in this study that provide avenues for future research. The first limitation is the relatively small sample size. The analysis is based on 33 annual observations (1991-2023). While the selected ARDL (2, 0, 1, 0, 2, 0, 1, 2) model was chosen based on the robust Akaike Information Criterion (AIC) and passed all diagnostic and stability tests (as shown in Table 7 and Figure 2), a small sample size can increase the risk of overfitting. The findings should therefore be interpreted with this constraint in mind.

A second limitation is the potential for endogeneity, particularly reverse causality, between CO_2 emissions and key drivers like GDP growth. For instance, while GDP growth impacts CO_2 emissions, climate policies designed to *reduce* CO_2 could in turn affect GDP growth. This study attempts to mitigate this issue by using a dynamic ARD-ECM framework, which is more robust to endogeneity than a static OLS model. However, this remains a key consideration.

Future Research Direction

I. Because the sample size was so small, future studies could use data from every three or four months, if that's possible, to get more information.
II. To deal with endogeneity more clearly, future studies should use different estimators, such as Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS), that are made for cointegrated models and are used to do robustness checks. These ways might help make sure that the long-term coefficients are correct.

III. To build on the model's results, one useful way to do more research would be to use the non-linear ARDL (NARDL) method to look at the different effects, both good and bad, that these economic factors have on CO_2 emissions.

Declaration

The author affirms that this content is wholly original and has not been submitted or published elsewhere. The author was solely responsible for the research, composition, and final approval of the paper.

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Author's contribution: Saikat Pande: Conceptualisation, Methodology, Software, Validation, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Writing – Review & Editing, Visualisation.

References

Alam, M. J., Begum, I. A., Buysse, J., & Van Huylenbroeck, G. (2012). Energy consumption, carbon emissions and economic growth nexus in Bangladesh: Cointegration and dynamic causality analysis. *Energy policy*, *45*, 217-225. https://doi.org/10.1016/j.enpol.2012.02.022

Alam, M. J., Begum, I. A., Buysse, J., Rahman, S., & Van Huylenbroeck, G. (2011). Dynamic modeling of causal relationship between energy consumption, CO_2 emissions and economic growth in India. *Renewable and Sustainable Energy Reviews*, *15*(6), 3243-3251. https://doi.org/10.1016/j.rser.2011.04.029

Alam, Md. M., Murad, Md. W., Noman, A. H. Md., & Ozturk, I. (2016). Relationships among carbon emissions, economic growth, energy consumption, and population growth: Testing the Environmental Kuznets Curve hypothesis for Brazil, China, India, and Indonesia. *Ecological Indicators*, *70*, 466–479. https://doi.org/10.1016/j.ecolind.2016.06.043

Ali, W., Gohar, R., Chang, B. H., & Wong, W. K. (2022). Revisiting the impacts of globalization, renewable energy consumption, and economic growth on environmental quality in South Asia. *Advances in Decision Sciences*, *26*(3), 1-23.

Aliyu, M. A. (2005). Foreign direct investment and the environment: Pollution haven hypothesis revisted. https://ageconsearch.umn.edu/record/331376

Apergis, N., & Payne, J. E. (2012). Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel of OECD countries. *Energy Economics*, *34*(3), 733-738. https://doi.org/10.1016/j.eneco.2011.04.007

Balsalobre-Lorente, D., & Leitão, N. C. (2020). The role of tourism, trade, renewable energy use and carbon dioxide emissions on economic growth: evidence of tourism-led growth hypothesis in EU-28. *Environmental Science and Pollution Research*, *27*(36), 45883-45896. https://doi.org/10.1007/s11356-020-10375-1

Barro, R. J. (1996). *Determinants of economic growth: A cross-country empirical study*. https://doi.org/10.3386/w5698

BBS (Bangladesh Bureau of Statistics-Government of the People's Republic of Bangladesh). (2023). *Statistical yearbook of Bangladesh*. Dhaka. Retrieved from https://bbs.gov.bd/

BPDB (Bangladesh Power Development Board). (2023). *Annual report 2022-2023*. Dhaka. Retrieved from https://bpdb.gov.bd/

Breusch, T. S. (1978). Testing for autocorrelation in dynamic linear models. *Australian Economic Papers*, *17*(31), 334–355. https://doi.org/10.1111/j.1467-8454.1978.tb00635.x

Breusch, T. S., & Pagan, A. R. (1979). A simple test for heteroscedasticity and random coefficient variation. *Econometrica*, *47*(5), 1287–1294. https://doi.org/10.2307/1911963

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for testing the constancy of regression relationships over time. *Journal of the Royal Statistical Society: Series B (Methodological)*, *37*(2), 149–163. https://doi.org/10.1111/j.2517-6161.1975.tb01532.x

Christoforidis, T., & Katrakilidis, C. (2022). Does foreign direct investment matter for environmental degradation? Empirical Evidence from Central–Eastern European Countries. *Journal of the Knowledge Economy*, *13*(4), 2665-2694. https://doi.org/10.1007/s13132-021-00820-y

Cole, M. A., Elliott, R. J. R., & Zhang, J. (2011). Growth, foreign direct investment, and the environment: Evidence from Chinese cities. *Journal of Regional Science*, *51*(1), 121–138. https://doi.org/10.1111/j.1467-9787.2010.00674.x

Copeland, B. R., & Taylor, M. S. (2017). North-South trade and the environment. In *International trade and the environment* (pp. 205-238). Routledge. https://doi.org/10.4324/9781315201986-17

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*(366a), 427–431. https://doi.org/10.1080/01621459.1979.10482531

EU (European Commission). (2023). *Circular economy action plan*. Brussels: European Commission. Retrieved from https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

FAO (Food and Agriculture Organization). (2021). *Model description | Global Livestock Environmental Assessment Model (GLEAM)*. Retrieved from https://www.fao.org/gleam/model-description/en/

FAO (Food and Agriculture Organization). (2023). *Pathways towards lower emissions*. https://doi.org/10.4060/cc9029en

Godfrey, L. G. (1978). Testing against general autoregressive and moving average error models when the regressors include lagged dependent variables. *Econometrica*, *46*(6), 1293–1301. https://doi.org/10.2307/1913829

Görg, H., & Greenaway, D. (2004). Much ado about nothing? Do domestic firms really benefit from foreign direct investment?. *The World Bank Research Observer*, *19*(2), 171-197. https://doi.org/10.1093/wbro/lkh019

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement*. https://doi.org/10.3386/w3914

Habib, M. A., Islam, S. M., Haque, M. A., Hassan, L., Ali, M. Z., Nayak, S., ... & Gaihre, Y. K. (2023). Effects of irrigation regimes and rice varieties on methane emissions and yield of dry season rice in Bangladesh. *Soil Systems*, *7*(2), 41. https://doi.org/10.3390/soilsystems7020041

Harun, M. A. (2015). *The role of Solar Home System (SHS) in socio-economic development of rural Bangladesh* (Doctoral dissertation, Brac University). http://hdl.handle.net/10361/5049

Hossain, M. F., Hossain, S., & Uddin, M. J. (2017). Renewable energy: Prospects and trends in Bangladesh. *Renewable and Sustainable Energy Reviews*, *70*, 44-49. https://doi.org/10.1016/j.rser.2016.11.197

Hossain, M. S. (2011). Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. *Energy policy*, *39*(11), 6991-6999. https://doi.org/10.1016/j.enpol.2011.07.042

IEA (International Energy Agency). (2022). *Energy efficiency analysis*. Paris: IEA. Retrieved from https://www.iea.org/reports/energy-efficiency-2022

IPCC (Intergovernmental Panel on Climate Change). (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. Retrieved from https://www.ipcc.ch/report/ar6/wg2/

Islam, F., Shahbaz, M., Ahmed, A. U., & Alam, Md. M. (2013). Financial development and energy consumption nexus in Malaysia: A multivariate time series analysis. *Economic Modelling*, *30*, 435–441. https://doi.org/10.1016/j.econmod.2012.09.033

Islam, M. M., Khan, M. K., Tareque, M., Jehan, N., & Dagar, V. (2021). Impact of globalization, foreign direct investment, and energy consumption on CO_2 emissions in Bangladesh: Does institutional quality matter?. *Environmental Science and Pollution Research*, *28*(35), 48851-48871. https://doi.org/10.1007/s11356-021-13441-4

Jarque, C. M., & Bera, A. K. (1980). Efficient tests for normality, homoscedasticity and serial independence of regression residuals. *Economics Letters*, *6*(3), 255–259. https://doi.org/10.1016/0165-1765(80)90024-3

Johansen, S., & Juselius, K. (1990). Maximum likelihood estimation and inference on cointegration—with appucations to the demand for money. *Oxford Bulletin of Economics and statistics*, *52*(2), 169-210.

Kraft, J., & Kraft, A. (1978). On the relationship between energy and GNP. *Journal of Energy and Development*, *3*(2), 401-403.

Lange, G. M., Wodon, Q., & Carey, K. (2018). *The changing wealth of nations 2018: Building a sustainable future*. World Bank Publications.

Lin, B., & Moubarak, M. (2014). Renewable energy consumption – Economic growth nexus for China. *Renewable and Sustainable Energy Reviews*, *40*, 111–117. https://doi.org/10.1016/j.rser.2014.07.128

Liu, Q., Wang, S., Zhang, W., Zhan, D., & Li, J. (2018). Does foreign direct investment affect environmental pollution in China's cities? A spatial econometric perspective. *Science of the total environment*, *613*, 521-529. https://doi.org/10.1016/j.scitotenv.2017.09.110

MacKinnon, J. G. (1996). Numerical distribution functions for unit root and cointegration tests. *Journal of applied econometrics*, *11*(6), 601-618. https://doi.org/10.1002/(SICI)1099-1255(199611)11:6<601::AID-JAE417>3.0.CO;2-T

Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality? *Journal of Environmental Economics and Management*, *58*(3), 346–363. https://doi.org/10.1016/j.jeem.2009.04.008

Mondal, M. A. H., & Denich, M. (2010). Assessment of renewable energy resources potential for electricity generation in Bangladesh. *Renewable and sustainable energy reviews*, *14*(8), 2401-2413. https://doi.org/10.1016/j.rser.2010.05.006

Mosier, A. R., Duxbury, J. M., Freney, J. R., Heinemeyer, O., & Minami, K. (1996). Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation. *Plant and soil*, *181*(1), 95-108. https://doi.org/10.1007/BF00011296

Nasir, M., & Ur-Rehman, F. (2011). Environmental Kuznets curve for carbon emissions in Pakistan: An empirical investigation. *Energy Policy*, *39*(3), 1857-1864. https://doi.org/10.1016/j.enpol.2011.01.025

Nasreen, S., & Anwar, S. (2014). Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. *Energy policy*, *69*, 82-91. https://doi.org/10.1016/j.enpol.2014.02.009

Ohlan, R. (2015). The impact of population density, energy consumption, economic growth and trade openness on CO_2 emissions in India. *Natural Hazards*, *79*(2), 1409-1428. https://doi.org/10.1007/s11069-015-1898-0

Olanrewaju, B. T., Olubusoye, O. E., Adenikinju, A., & Akintande, O. J. (2019). A panel data analysis of renewable energy consumption in Africa. *Renewable energy*, *140*, 668-679. https://doi.org/10.1016/j.renene.2019.02.061

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. https://doi.org/10.1002/jae.616

Rahaman, S. H., Chen, F., & Jiang, G. (2023). The asymmetric impact of renewable energy consumption on the economic growth of emerging South and East Asian countries: A NARDL approach. *Heliyon*, *9*(8). https://doi.org/10.1016/j.heliyon.2023.e18656

Rahman, M. M., & Alam, K. (2021). Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. *Renewable Energy*, *172*, 1063–1072. https://doi.org/10.1016/j.renene.2021.03.103

Rahman, M. M., & Kashem, M. A. (2017). Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. *Energy Policy*, *110*, 600–608. https://doi.org/10.1016/j.enpol.2017.09.006

Rahman, M. M., & Vu, X.-B. (2020). The nexus between renewable energy, economic growth, trade, urbanisation and environmental quality: A comparative study for Australia and Canada. *Renewable Energy*, *155*, 617–627. https://doi.org/10.1016/j.renene.2020.03.135

Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. *Energy and Climate Change*, *3*, 100080. https://doi.org/10.1016/j.egycc.2022.100080

Reay, D. S., Davidson, E. A., Smith, K. A., Smith, P., Melillo, J. M., Dentener, F., & Crutzen, P. J. (2012). Global agriculture and nitrous oxide emissions. *Nature Climate Change*, *2*(6), 410-416. https://doi.org/10.1038/nclimate1458

Sarkar, A., & Singh, J. (2010). Financing energy efficiency in developing countries—lessons learned and remaining challenges. *Energy Policy*, *38*(10), 5560-5571. https://doi.org/10.1016/j.enpol.2010.05.001

Sarkodie, S. A., & Strezov, V. (2019). A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. *Science of the total environment*, *649*, 128-145. https://doi.org/10.1016/j.scitotenv.2018.08.276

Shahbaz, M., Lean, H. H., & Shabbir, M. S. (2012). Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. *Renewable and Sustainable Energy Reviews*, *16*(5), 2947-2953. https://doi.org/10.1016/j.rser.2012.02.015

Shahbaz, M., Nasreen, S., Abbas, F., & Anis, O. (2015). Does foreign direct investment impede environmental quality in high-, middle-, and low-income countries? *Energy Economics*, *51*, 275–287. https://doi.org/10.1016/j.eneco.2015.06.014

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., & Smith, J. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), 789–813. https://doi.org/10.1098/rstb.2007.2184

SREDA, (Sustainable and Renewable Energy Development Authority)-Power Division; Ministry of Power, Energy & Mineral Resources. (2023). Retrieved from https://sreda.gov.bd/

Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development*, *32*(8), 1419–1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Tapio, P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of transport in Finland 1970–2001. *Transport Policy*, *12*(2), 137-151. https://doi.org/10.1016/j.tranpol.2005.01.001

Thome, H. (2015). Cointegration and error correction modelling in time-series analysis: A brief introduction. *International Journal of Conflict and Violence (IJCV)*, *9*(1), 199-208. https://doi.org/10.4119/IJCV-3055

Tseng, M.-L., Islam, M. S., Karia, N., Fauzi, F. A., & Afrin, S. (2019). A literature review on green supply chain management: Trends and future challenges. *Resources, Conservation and Recycling*, *141*, 145–162. https://doi.org/10.1016/j.resconrec.2018.10.009

UNIDO (United Nations Industrial Development Organization). (2023). *Eco-industrial parks: A pathway to sustainable industrial development*. Vienna: UNIDO. Retrieved from https://www.unido.org/

United Nations Development Programme. (n.d.). *Documentation and downloads*. Retrieved October 9, 2025, from https://hdr.undp.org/data-center/documentation-and-downloads

Walter, I., & Ugelow, J. L. (1979). Environmental Policies in Developing Countries. *Ambio*, *8*(2/3), 102–109. [suspicious link removed].

Wang, L., Mehmood, U., Agyekum, E. B., Uhunamure, S. E., & Shale, K. (2022). Associating renewable energy, globalization, agriculture, and ecological footprints: implications for sustainable environment in South Asian countries. *International Journal of Environmental Research and Public Health*, *19*(16), 10162. https://doi.org/10.3390/ijerph191610162

Wisser, D., Grogan, D. S., Lanzoni, L., Tempio, G., Cinardi, G., Prusevich, A., & Glidden, S. (2024). Water use in livestock agri-food systems and its contribution to local water scarcity: A spatially distributed global analysis. *Water*, *16*(12), 1681. https://doi.org/10.3390/w16121681

World Bank. (2023). *Bangladesh: Development news, research data*. Retrieve from https://www.worldbank.org/en/country/bangladesh

WTO (World Trade Organization). (2023). *World trade report 2023*. Geneva: WTO. Retrieved from https://www.wto.org/english/res_e/publications_e/wtr23_e.htm

York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, *46*(3), 351–365. https://doi.org/10.1016/S0921-8009(03)00188-5

Zhang, S., Liu, X., & Bae, J. (2017). Does trade openness affect CO_2 emissions: Evidence from ten newly industrialized countries? *Environmental Science and Pollution Research*, *24*(21), 17616–17625. https://doi.org/10.1007/s11356-017-9392-8

Zhou, Y., Liu, Y., Wu, W., & Li, Y. (2015). Effects of rural–urban development transformation on energy consumption and CO_2 emissions: A regional analysis in China. *Renewable and Sustainable Energy Reviews*, *52*, 863-875. https://doi.org/10.1016/j.rser.2015.07.158

Zhu, H., Duan, L., Guo, Y., & Yu, K. (2016). The effects of FDI, economic growth and energy consumption on carbon emissions in ASEAN-5: evidence from panel quantile regression. *Economic Modelling*, *58*, 237-248. https://doi.org/10.1016/j.econmod.2016.05.003