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Contents

Impact Assessment of Mechanized Shelling on Maize Yield Efficiency and Farm Profit in Rural Bangladesh 1–16

Prianka Basak; Farhana Yeasmin; Jannatul Ferdous; Md. Nazmus Sadekin

Development Diplomacy in Changing Political Transition: Envisioning a Developed and Prosperous Bangladesh 17–39

Razia Sultana; Fahim Shahriar

Energy Transition and Carbon Emissions in Bangladesh: A Nonlinear Analysis of Renewable and Fossil Energy Consumption 40–65

Al Amin Al Abbasi

Climate Change, Biodiversity Loss, and Livelihood Adaptation: Perspectives from *Beel* Dependent Artisanal Fishers in Bangladesh 66–87

Md. Ariful Islam; Al-Amin Sarkar; Md. Firoz Hossain; Nahid Hasan; Fuad Hasan

Attaining SDG 13: Assessing Bangladesh Scenario 88–111

Segufta Hossain

Economic Participation Without Protection: A Systematic Literature Review on Women's Vulnerability in Bangladesh's Urban Economy 112–136

Maisha Akter Trina; Md. Ariful Islam

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Vol. 7, No. 1&2, June-December 2025, (Page 40–65) ISSN: 3078-6614 (Online)

Energy Transition and Carbon Emissions in Bangladesh: A Nonlinear Analysis of Renewable and Fossil Energy Consumption

Al Amin Al Abbasi[1]

Abstract

Rapid economic expansion and industrialization in Bangladesh have intensified energy demand, triggering severe environmental degradation and escalating carbon emissions due to a heavy reliance on fossil fuels. Despite national decarbonization targets, the non-linear dynamics surrounding how shifts between fossil fuel reliance and renewable energy adoption affect carbon output remain insufficiently understood. To address this gap, this study applies the nonlinear autoregressive distributed lag (NARDL) framework to examine the asymmetric and opposing impacts of fossil fuel and renewable energy consumption on CO_2 emissions in Bangladesh. The findings reveal that changes in energy use have distinct short- and long-term environmental impacts, confirming a non-linear relationship. Specifically, each unit increase in renewable energy reduces CO_2 emissions by 0.134 units, whereas expanding fossil fuel use increases emissions. Wald tests provide proof of considerable long-term asymmetry in energy usage, but short-term asymmetry lacks statistical significance. The dynamic multiplier analysis shows persistent differences in adjustment to positive and negative energy shocks and stability tests ensure robustness of the estimates. The evidence is clear: Bangladesh needs to accelerate the rollout of renewable energy, phase out reliance on fossil fuel, improve energy efficiency, promote rooftop solar, modernize the electrical grid, develop energy storage and attract private and climate investment. Collectively, these strategies can facilitate sustained emission reductions, improve energy security, and support Bangladesh's transition to a low-carbon energy system.

Keywords: CO_2 emissions, fossil energy consumption, renewable energy consumption, NARDL, asymmetric effects, Bangladesh

JEL Classification: Q42, Q54, Q57

1. Introduction

Energy is vital to economic development, to industrialization, and to the improvement of human well-being. However, due to high carbon dioxide (CO_2)

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emissions, rising global energy consumption—primarily from fossil fuels—has severely harmed the environment. As a result, switching from conventional fossil fuel-based energy systems to renewable energy sources is generally accepted as a prerequisite for accomplishing sustainable development objectives. Comprehensive studies indicate that renewable energy enhances environmental conditions by lowering emissions, while dependence on non-renewable energy sources generally intensifies ecological issues. For instance, Omri and Saidi (2022) illustrated that the utilization of renewable energy improves environmental quality by reducing CO_2 emissions, whereas the use of non-renewable energy exacerbates environmental strain. In a similar vein, Akbar et al. (2024) validated that renewable energy diminishes emissions, whereas the use of fossil fuels escalates carbon emissions.

Although broad trends have been identified, the relationship between the use of renewable energy and environmental quality is complex and varies significantly between countries. Chen et al. (2022) shown that, particularly in countries with robust institutional frameworks, renewable energy only reduces CO2 emissions when consumption beyond a particular threshold. On the other hand, Ali et al. (2022) observed that China's carbon-emission intensity benefits in the long run from the use of both renewable and non-renewable energy. In a similar vein, Altın (2024) discovered a positive correlation between the use of renewable energy and carbon emissions in G7 nations, but stressed that energy efficiency offers long-term environmental advantages. These varied findings imply that institutional integrity, economic frameworks, technical advancements, and country-specific factors all have a major influence on how energy use affects environmental outcome.

This matter holds particular importance for Bangladesh, where rapid economic development and industrialization have resulted in considerable alterations in energy consumption trends. Notwithstanding the heightened focus on renewable energy advancement, fossil fuels persist in prevailing inside the national energy composition. Despite Bangladesh's engagement in different regional and international studies, there are few complete assessments on the interplay of renewable energy, non-renewable energy, economic growth, and CO_2 emissions at the country level. Furthermore, a significant portion of the current research presupposes a linear and symmetrical correlation between energy usage and environmental deterioration. An increase or decrease in energy use can generate different environmental outcomes, highlighting the importance of considering asymmetric relationships. Recent studies using asymmetric approaches have shown that energy-related shocks may have unequal impacts on carbon emissions (Mahapatra & Irfan, 2021; Mujtaba et al., 2022).

The Nonlinear Autoregressive Distributed Lag (NARDL) model is used to identify the asymmetric reactions of emissions to both increases and decreases in energy consumption, as well as to examine short-term and long-term correlations. This study addresses current research deficiencies by examining the unequal impacts of renewable and fossil fuel use on CO2 emissions in Bangladesh using annual data

spanning from 1990 to 2022. Empirical findings indicate that heightened fossil fuel usage markedly elevates CO_2 emissions, whilst a rise in renewable energy consumption aids in mitigating environmental deterioration. The findings further reveal significant long-run asymmetry, indicating that positive and negative changes in energy consumption yield distinct environmental outcomes. Based on these findings, policymakers in Bangladesh should prioritize accelerating renewable energy rollout, gradually phasing out reliance on fossil fuels, enhancing energy efficiency, modernizing the electrical grid, and attracting private and climate investments to support a low-carbon energy transition.

The article is structured as follows: Section 2 discusses literature on energy consumption, economic growth and environmental quality; Section 3 describes data sources, variables, methodology and econometric framework; Section 4 presents the empirical results, including NARDL estimations, asymmetric effects, dynamic multiplier analysis and model stability analysis; and Section 5 concludes with important policy implications for sustainable energy development in Bangladesh.

2. Literature Review

This systematic literature review summarizes empirical research on the connections among economic growth (GDP), renewable energy consumption (REC), non-renewable energy consumption (NREC), and carbon dioxide (CO2) emissions. The literature is structured across four analytical levels: global viewpoints, regional dynamics, national analyses, and country-specific case studies.

2.1 Global Studies on Energy Consumption and Environmental Quality

Global studies reveal a complex link among economic growth, energy systems, and carbon emissions, as fossil fuel shocks and restricted trade increase carbon footprints (Huang et al., 2022). Across economies, relationships among GDP, energy choices, and emissions depend heavily on developmental thresholds (Caldera et al., 2024). Specifically, renewable energy cuts emissions only after surpassing consumption thresholds (Chen et al., 2022), with its impact multiplying fivefold once human capital thresholds are met (Shabani, 2024). Although GDP growth drives pollution, expanding renewables, resource management, public spending, strong institutions, building efficiency, and digital finance mitigate emissions (Achuo et al., 2022; Alam et al., 2025; Amiri et al., 2025; Hasan et al., 2026; Iqbal et al., 2025; Quoc et al., 2025). However, transitions carry systemic trade-offs: clean energy can spur growth that indirectly raises total emissions or face delays from ongoing fossil dependence (Madaleno & Nogueira, 2023; Nguyen et al., 2026). Life-cycle evaluations show renewables lower emissions relative to fossil fuels, yet full sustainability requires managing their ecological footprint (Sobczuk et al., 2025)

2.2 Region-Specific Interactions of Energy and Carbon Emissions

Regional economic partnerships and geography drive distinct decarbonization pathways. In G20 nations, fossil fuels escalate carbon emissions, whereas hydro and

renewables mitigate them; Shah et al. (2024) linked renewables to improved energy efficiency and reduced carbon footprints. In G7 countries, coal and gas generation harm environmental quality. While efficiency gains lower emissions, Altın (2024) observed an unexpected positive link between renewable usage and emissions, signaling transitional challenges. Decarbonization varies across Europe: Central and Eastern European (CEE) panel studies show renewables curb emissions growth better than non-renewables. In the EU, Chovancová et al. (2025) noted fossil fuels raise emissions while renewable impacts vary by country, making standardized policies ineffective. In OECD nations, Mujtaba et al. (2022) found capital formation and growth degrade environmental quality—a 1% renewable increase lowers emissions by 0.2%, whereas a 1% non-renewable increase raises them by 1.08%. Similarly, Işık et al. (2024) identified natural resource rents as environmental stressors, contrasting with renewables and internet usage. Elsewhere, growth conflicts with sustainability. In SAARC, non-renewables, urbanization, and development elevate emissions, while secondary education and renewables improve quality. Omri and Saidi (2022)cited industrial activity as MENA's chief polluter, offset by renewables. In the GCC, STIRPAT modeling connects fossil fuels—especially oil—to rising emissions. Finally, ASEAN's economic expansion drives emissions, requiring renewable and nuclear growth for mitigation.

2.3 National Investigations and Policy Frameworks

National development paths often align with macroecological frameworks such as the Environmental Kuznets Curve (EKC). In resource-reliant nations, Szetela et al. (2022)identified a $25,700 income threshold and found that a strong rule of law accelerates emission reductions driven by renewables. Chien (2022) affirmed the EKC in N-11 countries, where economic growth initially degrades the environment before enabling restoration. Similarly, Awan et al. (2025) validated the EKC in built environments, noting that a 1% increase in building energy efficiency reduces emissions by 0.835% to 0.913%. Administrative strategies vary across nations. In Canada, Xuan (2025) found that a 1% increase in renewables reduces carbon emissions by 1.15%, though higher power use slightly increases them. Luong et al. (2026) showed that domestic innovation, trade liberalization, and renewables jointly curb emissions in the Netherlands. However, Jie and Rabnawaz (2024) highlighted bottlenecks in developing nations, where expansion beyond domestic infrastructure capacity increases per capita emissions, underscoring the necessity of regional energy exchange unions.

2.4 Specific Country Case Studies

At the country level, researchers use local time-series models to examine the direct effects of domestic energy mixes. In China, despite massive investments in clean energy, the economy remains heavily dependent on traditional energy sources. Using dynamic ARDL simulations, Ali et al. (2022) found that both renewable and nonrenewable energy consumption had a positive long-term effect on the intensity of carbon emissions. Specifically, non-renewable sources increased emissions intensity

by 0.75%, while renewable sources contributed a 0.27% increase. These findings highlight the challenges associated with transitioning a large industrial base to clean energy.

Empirical research in Malaysia shows a clear conflict between measures to reduce carbon emissions and economic growth. According to Ahmat et al. (2025), reliance on non-renewable energy sources, economic growth, and overall energy consumption all significantly reduce carbon emissions in the short and long term. In contrast, Mohamad et al. (2026) identified an inverted U-shaped relationship between Malaysian GDP and carbon emissions from 1970 to 2021, indicating that long-term developmental maturity contributes to reducing carbon output.

In Turkey, the factors influencing carbon emissions vary between the short-term and long-term. Karaaslan and Çamkaya (2022) found that while health spending and renewable energy use consistently reduce carbon emissions, GDP and non-renewable energy use increase them over time. This long-lasting moderating impact was also validated by Mukhtarov (2024), who predicted that a 1% increase in Turkish renewable energy consumption would result in a 0.17% decrease in carbon emissions. However, imports and real GDP per capita continue to contribute to emissions.

In other specific developing economies, the local energy mix dictates ecological outcomes. In Indonesia, increases in coal and gas consumption directly lead to higher carbon emissions, whereas oil consumption increases the ecological footprint. Using an ARDL technique in Uzbekistan, Apergis et al. (2023) discovered that hydropower use lowers per capita emissions both immediately and over time. On the other hand, using coal reduces emissions only over time, whereas using natural gas and oil continuously increases emissions. Conversely, the utilization of natural gas and oil perpetually elevates emissions, whilst coal usage decreases emissions just in the long run. According to the two main sources of carbon emissions in Pakistan are the use of biomass and non-renewable energy. It was found that emissions in rural areas were negatively impacted by renewable energy, however this effect was statistically insignificant. According to Nguyen et al. (2026), GDP development in the Czech Republic boosts short-term emissions but encourages the use of renewable energy and supports long-term green growth.

2.5 Research Gap

A systematic literature review reveals five critical research gaps regarding the relationships between economic development, energy usage, institutional frameworks, and environmental quality, which this study systematically addresses through a unified analytical design.

Firstly, despite the extensive broader literature (Omri & Saidi, 2022; Amin et al., 2023; Shah et al., 2024; Ahmat et al., 2025), Bangladesh's specific structural dynamics remain notably under-researched. To address this limitation, this study conducts a dedicated, country-specific time-series analysis for Bangladesh,

delivering empirical findings that reflect the nation's precise energy structure, developmental stage, and climate vulnerabilities.

Secondly, empirical research offers conflicting conclusions on whether renewable energy improves environmental quality or unintentionally exacerbates emissions due to transitional bottlenecks, scale effects, or regional disparities (Ali et al., 2022; Altın, 2024; Jie & Rabnawaz, 2024; Nguyen, 2026). This study overcomes this ambiguity by isolating both short-run and long-run effects of renewable energy deployment and evaluating how domestic infrastructure limits, economic scale, and persistent reliance on fossil fuels shape environmental outcomes over time.

Thirdly, prior studies predominantly rely on linear, symmetric assumptions, ignoring the reality that positive and negative energy shocks impact emissions differently and that renewables may require minimum threshold levels of development to become effective (Huang et al., 2022; Chen et al., 2022; Shabani, 2024; Mujtaba et al., 2022). To bridge this gap, this study employs advanced econometric methods—such as Non-linear ARDL (NARDL), threshold regression, and quantile models—to capture directional asymmetries and determine critical developmental thresholds.

Fourthly, essential institutional, technological, and social indicators—such as governance quality, human capital, digital finance, and government expenditures—are typically evaluated in isolation rather than within a cohesive system (Shabani, 2024; Amiri et al., 2025; Iqbal et al., 2025; Quoc et al., 2025; Hasan et al., 2026). This study resolves this fragmentation by incorporating institutional quality, human capital, technological innovation, financial development, and urbanization into a unified empirical model, utilizing interaction terms to test whether strong institutions amplify green energy benefits.

Finally, relying on total energy consumption and aggregate CO2 emissions conceals the contrasting ecological footprints of specific fuel sources and broader ecosystem pressures (Chovancová et al., 2025; Shah et al., 2024; Sobczuk et al., 2025; Apergis et al., 2023). This study addresses this issue by disaggregating energy sources into specific fuel types (solar, hydro, biomass, coal, oil, natural gas) where data permits and incorporating complementary metrics such as ecological footprint and carbon intensity to provide a comprehensive environmental assessment.

3. Methodology

3.1 Data and Variable Definitions

Using annual time series data from 1990 to 2022—a sample period selected primarily due to the availability of consistent historical data prior to 1990 and up to the most recent reporting period in 2022—this study examines the asymmetric effects of renewable and non-renewable energy consumption on carbon dioxide (CO2) emissions in Bangladesh. Secondary data was gathered from the International Energy Agency's (IEA) database. The chosen time frame reflects Bangladesh's sluggish shift to greener energy sources, the country's increasing reliance on fossil

fuels, and the recent boom in renewable energy initiatives. The primary explanatory factors in the empirical model are the ratios of fossil and renewable energy consumption, while the dependent variable is per capita carbon dioxide emissions. Table 1 displays the variables used in the analysis.

Table 1: Definition and measurement of variables and summary statistics

Variable	Symbol	Definition	Unit	Mean	Max	Min	S.D.
Emissions of carbon dioxide per person	CO_2	Emissions of CO_2 from energy-related activities in relation to population size	Tons per capita	0.30	0.66	0.094	0.18
Share of renewable energy usage	REC	The proportion of renewable energy sources in the ultimate energy consumption	Percentage (%)	47.90	73.13	24.33	15.70
Fossil energy consumption share	FEC	Ultimate energy consumption share of fossil fuels (coal, oil, and natural gas)	Percentage (%)	49.65	59.82	34.15	7.32

Source: Author's calculations based on International Energy Agency (IEA) data and statistics

The core link between energy usage trends and carbon emissions is:

$$CO_{2t} = f(REC_t, FEC_t) \quad (1)$$

where, CO_{2t} signifies per capita CO_2 emissions, REC_tindicates renewable energy consumption, and FEC_timplies fossil energy consumption in year$t$.

3.2 Rationale for Adopting NARDL Approach

The correlation between energy use and environmental deterioration may be asymmetric, as fluctuations in energy usage could yield consequences that are not equivalent in scale or orientation. In Bangladesh, renewable energy expansion may reduce CO_2 emissions by substituting for carbon-intensive sources, while a decline in renewable adoption may not lead to an equivalent rise in emissions due to existing infrastructure and consumption patterns. Similarly, increases in fossil fuel use may create stronger environmental impacts than the benefits from equivalent reductions. In order to identify asymmetric short-term and long-term effects, Shin et al. (2014), developed the NARDL model, which is used to distinguish between positive and negative changes in energy variables. This method provides more accurate policy insights by examining whether energy expansion and contraction have distinct environmental effects, is perfect for the analysis of small sample time-series, and accommodates variables integrated at both I(0) and I(1).

3.3 Non-Linear ARDL Model Specification

Following Shin et al. (2014), renewable and fossil energy consumption variables are decomposed into positive and negative changes. The asymmetrical long-term correlation between carbon emissions and energy usage is delineated as:

$$REC_t^+ = \sum_{j=1}^{t} max(\Delta REC_j, 0)\ REC_t^- = \sum_{j=1}^{t} min(\Delta REC_j, 0) \quad (2)$$

Similarly, fossil energy consumption is decomposed as:

$$FEC_t^+ = \sum_{j=1}^{t} max(\Delta FEC_j, 0) FEC_t^- = \sum_{j=1}^{t} min(\Delta FEC_j, 0) \quad (3)$$

The asymmetric long-run relationship between carbon emissions and energy consumption is specified as:

$$CO_{2t} = \beta_0 + \beta_1 REC_t^+ + \beta_2 REC_t^- + \beta_3 FEC_t^+ + \beta_4 FEC_t^- + \varepsilon_t \quad (4)$$

where, β_1 and β_2 capture the long-run effects of positive and negative changes in renewable energy consumption, while β_3 and β_4 represent the corresponding asymmetric effects of fossil energy consumption.

3.4 Unit Root Tests

The stationarity characteristics of the variables are examined using the Phillips-Perron (PP) and Augmented Dickey-Fuller (ADF) tests before the NARDL model is estimated. These tests are useful for determining if the variables become stationary after initial differencing I(1) or are stationary at level I(0). When the variables are a combination of I(0) and I(1) processes, the NARDL technique is appropriate. Because the bounds test is ineffective in the presence of I(2) variables, we employ unit root analysis to verify the model's integration properties.

3.5 NARDL Bounds Testing and Error Correction Model

Following the confirmation of the integration orders, we employ the NARDL bounds testing framework to examine the long-run equilibrium relationships among the variables. The asymmetric error correction model is specified as follows:

$$\Delta CO_{2t} = \alpha_0 + \sum_{i=1}^{p-1} \gamma_i \Delta CO_{2t-i} + \sum_{i=0}^{q} \beta_i^+ \Delta REC_{t-i}^+ + \sum_{i=0}^{q} \beta_i^- \Delta REC_{t-i}^- + \sum_{i=0}^{q} \delta_i^+ \Delta FEC_{t-i}^+ + \sum_{i=0}^{q} \delta_i^- \Delta FEC_{t-i}^- + \rho CO_{2_{t-1}} + \varphi_1^+ REC_{t-1}^+ + \varphi_1^- REC_{t-1}^- + \varphi_2^+ FEC_{t-1}^+ + \varphi_2^- FEC_{t-1}^- + \lambda ECM_{t-1} + \varepsilon_t \quad (5)$$

Where,$\lambda_1, \sum_{i=0}^{p} \beta_i^+$, $\sum_{i=0}^{p} \beta_i^-$, $\sum_{i=0}^{q} \delta_i^+$ and $\sum_{i=0}^{q} \delta_i^-$ represent the short-term effects, with one capturing the positive and the other the negative impact. On the other hand, the terms ρ, φ_i^+, and φ_i^-account for the long-term negative and positive effects of *REC* and *FEC* respectively. ECM_{t-1} represents the lagged error correction term. A statistically significant and unpleasant coefficient for the error correction term shows the existence of long-term convergence. The error term ε is expected to exhibit an independent normal distribution, holding a mean of zero and a stable variance. The critical values outlined by Pesaran et al. (2001) are compared with the F-statistic obtained from the limits test. If the F-statistic is greater than the upper critical value, this result shows that the variables are cointegrated. The limits test's collective null hypothesis is stated as follows:

$$H_0 = \rho = \varphi_1^+ = \varphi_1^- = \varphi_2^+ = \varphi_2^- = 0 \quad (6)$$

3.6 Asymmetric Effects and Wald Test

We employ Wald tests to evaluate short- and long-run asymmetries. The null hypothesis for long-run symmetry in fossil energy use is specified as follows:

$$H_0: \beta_1 = \beta_2 \quad (7)$$

and for renewable energy consumption:

$$H_0: \beta_3 = \beta_4 \quad (8)$$

The rejection of these theories suggests that there are statistical differences in the effects of rising and falling energy usage on CO2 emissions.

4. Result and Discussion

4.1 Unit Root Test

Unit root tests are utilized to ascertain the integration order of the variables before estimating the NARDL model. The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are applied at both the level and the initial differences.

Table 2: Unit root test

Variable	ADF (Level)	ADF (1st Difference)	PP (Level)	PP (1st Difference)
CO2	0.085	-5.421***	-0.794	-12.243***
REC	-4.662***	-4.615***	-2.848*	-9.843***
FEC	-2.188	-6.114***	-1.977	-6.363***

Source: Author's calculations based on International Energy Agency (IEA) data and statistics
*Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively*

Table 2 shows the results of the unit root tests. The results indicate that CO_2 emissions are non-stationary at the level**,** as both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test statistics are statistically insignificant. However, both tests become highly significant at the 1% level after taking the first difference, confirming that CO_2 emissions are integrated of order one, or I(1)**.** While the ADF test indicates stationarity at the level for renewable energy consumption (REC)**,** the PP test provides weaker evidence. Consequently, REC exhibits a mixed integration structure of I(0) and I(1) since its first-difference results are also highly significant. Similarly, final energy consumption (FEC) is non-stationary at the level due to insignificant test statistics but becomes stationary after first differencing, confirming its I(1) classification. Overall, the unit root test findings confirm that none of the variables are integrated of order two, or I(2), and all variables are either I(0) or I(1). Satisfying this prerequisite explicitly validates the application of the NARDL model**,** permitting a rigorous examination of the asymmetric short- and long-term interactions among the variables.

4.2 Non-Linear ARDL Bound Tests

The NARDL limits test for cointegration results. For K = 4 explanatory variables, the expected F statistic value of 11.768 is much higher than the upper critical values at all traditional significance thresholds, which are 3.52 (10%), 4.01 (5%), 4.49 (2.5%), and 5.06 (1%). Regardless of whether the variables under consideration are integrated of order I(0) or I(1), the limits testing approach indicates that the null hypothesis of no long-run cointegrating connection is rejected when the calculated F-statistic is greater than the upper bound critical value. The null hypothesis can be categorically rejected because the F-statistic (11.768) is

significantly greater than the upper critical value at the 1% significance level. This outcome offers strong statistical proof that the dependent variable and its explanatory variables have a stable long-term equilibrium relationship.

In addition to testing the NARDL model specification and cointegration between the variables, the rejection of the null hypothesis (Equation 6) permits an asymmetric response to both positive and negative changes in the explanatory variables. Therefore, the estimation of long-run asymmetric coefficients and the corresponding error correction model (ECM) is made easier by econometric principles. Cointegration suggests that any short-term departures from long-term equilibrium are transient and will eventually be fixed by the error correction procedure. Future studies on both long-run asymmetric impacts and short-run dynamic adjustments in the NARDL framework will have a solid econometric foundation thanks to the limits test results, which offer strong empirical support for a long-run asymmetric equilibrium relationship among the variables.

Table 3: Bound test

Test Statistic	Value	K
(1)	(2)	(3)
F-statistic	11.768	4
Bounds Critical Values for F-statistics		
Significance	Lower Bound I(0)	Upper Bound I(1)
(1)	(2)	(3)
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Source: Author's calculations based on International Energy Agency (IEA) data and statistics

4.3 Short-Term and Long-Term Coefficients from the NARDL Model

The NARDL model estimations (Table 4) indicate that both fossil energy consumption (FEC) and renewable energy consumption (REC) have asymmetric effects on per capita carbon dioxide (CO2) emissions in the short and long run. Analyzing FEC and REC by separating them into positive and negative partial-sum factors empowers the model to identify if variations in energy use result in different consequences for environmental quality.

The short-term coefficient, ΔFEC^{+}, linked to the increase in fossil energy consumption is statistically significant and negative (β = -0.005, p = 0.006). This suggests that a reduction in CO2 emissions is correlated with a favorable short-term disruption in the use of fossil fuels. Even though this result deviates from conventional expectations, it might point to short-term changes in fuel composition, energy efficiency, or manufacturing structure. On the other hand, ΔFEC^{-} is positive but statistically insignificant (β = 0.001, p = 0.786), indicating that short-term reductions in fossil fuel consumption have little effect on CO2 emissions. There is a stronger short-term association between emissions and the use of renewable energy. An increase in the use of renewable energy leads to a short-term decrease in CO2

emissions, according to the statistically significant and negative ΔREC^{+} coefficient ($\beta = -0.033$, $p < 0.01$). Similarly, ΔREC^{-} is statistically significant and negative ($\beta = -0.010$, $p < 0.01$). A decrease in the use of renewable energy is associated with an increase in CO2 emissions, according to the REC^{-} measure, which represents the overall negative changes in renewable energy consumption.

Table 4: Short-run and long-run co-efficient from NARDL model

Variables	Coefficient	Std. Error	t-Statistic	Prob.
Short-run				
C	-0.008**	0.004	-2.520	0.019
ΔFEC^{+}	-0.005***	0.008	-3.053	0.006
ΔFEC^{-}	0.001	0.002	0.274	0.786
ΔREC^{+}	-0.033***	0.008	-4.027	0.000
ΔREC^{-}	-0.010***	0.008	-6.239	0.000
Long-run				
CO_2(-1)*	-0.181*	0.088	-2.044	0.053
FEC^{+}(-1)	-0.006**	0.002	-2.772	0.011
FEC^{-}(-1)	0.003*	0.002	1.973	0.061
REC^{+}(-1)	-0.024***	0.007	-3.440	0.002
REC^{-}(-1)	0.006**	0.002	2.763	0.011
EC	-0.181***	0.021	-8.369	0.000
Adjusted R-squared	0.998260			
Sum squared resid	0.001103			
Akaike info criterion	-6.760882			
Schwarz criterion	-6.298305			
Durbin-Watson stat	1.324613			
F-statistic	1913.480***			0.000

Source: Author's estimation based on International Energy Agency (IEA) data and statistics
*Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively*

The rate of adjustment toward the long-run equilibrium is reflected in the long-term coefficient of CO2 (-1), which is -0.181 and statistically significant. After a deviation from equilibrium, lagged CO2 emissions change by 18.1% every interval. Additionally negative and statistically significant is the coefficient of FEC^{+}(-1), which is 0.006. According to this research, there is a 0.006 unit long-term decrease in CO2 emissions for every unit increase in fossil fuel energy use over the previous era. This unforeseen adverse correlation could be ascribed to enhancements in energy efficiency, technical progress, or alterations in energy use patterns. The coefficient of FEC^{-}(-1) = 0.003 is both positive and statistically significant. Long-term CO2 emissions decrease by 0.003 units when fossil fuel energy use is reduced by one unit during the previous period. These conflicting outcomes show that changes in fossil fuel usage, whether favorable or unfavorable, have distinct long-term implications on CO2 emissions. Regarding renewable energy, REC^{+}(-1) is statistically significant ($\beta = -0.024$, $p = 0.002$) and negative, indicating that prior increases in the use of renewable energy lead to lower current CO2 emissions. This outcome highlights the enduring ecological benefits of augmenting renewable energy. In contrast, REC^{-}(-1) is both positive and statistically significant ($\beta = 0.006$,

p = 0.011), indicating that reductions in renewable energy consumption correlate with diminished CO_2 emissions. The contrasting indications and intensities of these elements suggest a nonlinear long-term correlation between energy usage and academic and environmental well-being.

The NARDL model exhibits an excellent match, with an adjusted R^2 of 0.9983, (The F-statistic=1913.480, $p < 0.01$), explaining 99.83% of the variability in CO_2 emissions. A diminished residual sum of squares indicates negligible unaccounted variation. The Durbin-Watson value of 1.325 suggests that the residual serial correlation necessitates additional scrutiny. The varying indicators and intensities of positive and negative energy shocks demonstrate considerable long-term nonlinearity in the correlation between energy use and CO_2 emissions.

4.4 Long-Run Estimation at Level

Fossil and renewable energy consumption have notable asymmetrical effects on CO2 emissions, according to the long-run level estimations (Table 5). A nonlinear link between energy use and emissions is confirmed by the distinct ecological effects of both positive and negative energy shocks. This implies that variations in energy use should be examined individually, taking into account their source and path.

Table 5: Long-run coefficient level

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FEC^+	0.035***	0.008	4.171	0.000
FEC^-	0.020**	0.009	2.173	0.041
REC^+	-0.134**	0.063	-2.116	0.046
REC^-	-0.036***	0.006	-5.891	0.000

Source: Author's estimation based on International Energy Agency (IEA) data and statistics
*Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively*

There is a significant and positive correlation ($\beta = 0.035$, $p < 0.01$) between the affirmative aspect of fossil energy consumption (FEC^+) and rising CO2 emissions throughout time. This result is consistent with fossil fuels' high carbon content and implies that a greater reliance on conventional energy sources leads to a decline in environmental quality. The coefficient of FEC^- is both positive and statistically significant ($\beta = 0.020$, $p = 0.041$). Since FEC^- represents cumulative negative changes in fossil energy consumption, this positive coefficient indicates that reductions in fossil energy use are linked to lower CO_2 emissions. Additionally, the greater magnitude of FEC^+ compared to FEC^- suggests that the negative impact of fossil-energy expansion exceeds the positive effect of an equivalent reduction, thereby providing evidence of long-run asymmetry.

The environmental effects of using renewable energy are the opposite. Because the coefficient for REC^+ is negative and statistically significant ($\beta = -0.134$, $p = 0.046$), there is a constant decrease in CO2 emissions as more renewable energy is used. These results demonstrate how renewable energy can facilitate decarbonization by substituting carbon-intensive energy sources. Additionally, the coefficient on REC^- is statistically significant and negative ($\beta = -0.036$, $p < 0.01$). An increase in

CO2 emissions is linked to a cumulative decrease in the use of renewable energy, as indicated by the negative value of REC−. Furthermore, the fact that the absolute magnitude of REC^{+} is significantly greater than that of REC^{-} suggests that the impact of renewable energy growth on reducing emissions is significantly greater than the impact of renewable energy decline on raising emissions.

When taken as a whole, these findings offer compelling proof that there are enduring nonlinearities in the relationship between energy use and emissions. The findings highlight the need to increase renewable energy and reduce the usage of fossil fuels in order to achieve long-term reductions in CO2 emissions. Our findings emphasize the necessity of distinguishing between the consequences of positive and negative energy shocks since a traditional symmetric model can obscure these disparate long-term effects.

4.5 Asymmetrical Impacts on Extended and Immediate Duration (Wald Test)

The findings of the Wald test reveal significant long-term asymmetry in the association between CO_2 emissions and both fossil energy usage (FEC) and renewable energy usage (REC).

Table 6: Wald test: long-run linear relationship CO_2 and FEC

Test Statistic	Value	df	Probability
t-statistic	2.930	22	0.007
F-statistic	8.585	(1, 22)	0.007
Chi-square	8.585	1	0.003

Source: Author's estimation based on International Energy Agency (IEA) data and statistics
*Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively*

The null hypothesis of long-run symmetry (Equation 7) for fossil energy consumption (FEC) as shown in Table 6 is dismissed at the 1% significance threshold. This is shown by t-statistic of 2.930 (p=0.007), F-statistic of 8.585 (p=0.007) and chi-square statistic of 8.585 (p=0.003). These findings indicate that both favorable and unfavorable alterations in fossil energy usage have significantly different long-term impacts on CO_2 emissions.

Table 7: Wald test: long-run non-linear relationship CO_2 and REC

Test Statistic	Value	df	Probability
t-statistic	-3.907	22	0.000
F-statistic	15.266	(1, 22)	0.000
Chi-square	15.266	1	0.000

Source: Author's estimation based on International Energy Agency (IEA) data and statistics
*Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively*

The usage of renewable energy shows a similar tendency (Table 7). The null hypothesis (Equation 8) on the long-term symmetry between renewable energy consumption (REC) and CO2 emissions is firmly dismissed based on a t-statistic of -3.907, an F-statistic of 15.266, and a Chi-square statistic of 15.266, all statistically significant at the 1% threshold. The findings support the long-term asymmetric impact of both positive and negative shocks to the use of renewable energy on CO2

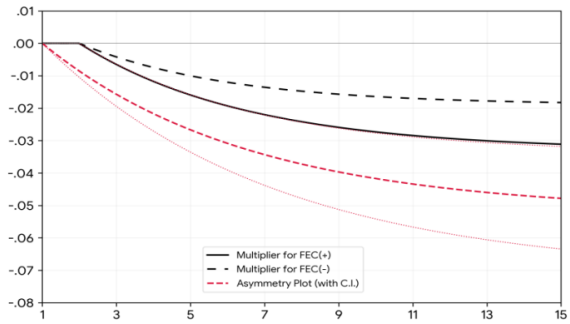
emissions. The extent of long-term asymmetry in renewable energy consumption appears to be greater than in fossil energy consumption, according to the higher Wald statistics of REC.

The findings collectively endorse the nonlinear configuration of the NARDL framework and suggest that the long-term reaction of CO_2 emissions depends on the directional shifts in both fossil and renewable energy usage. This outcome is significant because a conventional linear specification may mask such heterogeneous responses by enforcing a symmetric adjustment process. On the other hand, the null hypothesis of symmetry is not rejected by the short-run Wald tests. As a result, neither fossil energy consumption (FEC) nor renewable energy consumption (REC) exhibits a statistically significant short-term asymmetrical association with CO2 emissions. The evidence thus indicates that asymmetric adjustment is predominantly a long-run phenomenon, whereas short-run responses remain statistically symmetric.

4.6 Dynamic Asymmetric Multiplier Effects

The asymmetric multiplier effects of fossil energy consumption (FEC) and renewable energy consumption (REC) on CO2 emissions are shown in Figures 1 and 2. CO2 emissions are the dependent variable, while FEC and REC are calculated as a percentage of total energy use. By breaking down changes in energy consumption into positive and negative partial sums, the asymmetric dynamic multiplier technique makes it easier to assess whether changes in the consumption of fossil and renewable energy sources have distinct long-term effects on carbon emissions.

Figure 1: Multiplier effect of FEC

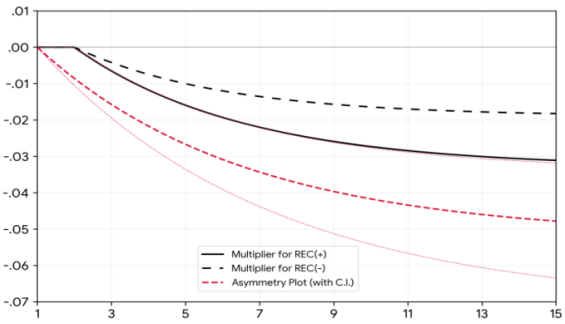


Source: Author's calculations based on International Energy Agency (IEA) data and statistics

In Figure 1, the solid black line (Multiplier for FEC+) illustrates the cumulative response of CO_2 emissions to positive shocks in fossil energy consumption. This downward trend suggests that rises in FEC correlate with a progressive decrease in CO_2 emissions during the investigated timeframe, with the impact stabilizing over the long run. The dashed black line (Multiplier for FEC-) captures the response to negative shocks in fossil energy consumption, showing a weaker adjustment effect as the response remains closer to zero. This implies that reductions in fossil energy dependence may not immediately translate into equivalent emission reductions due

to energy system rigidity, existing carbon-intensive infrastructure, and delayed substitution effects. The red solid and red dotted lines represent the upper and lower limits of the asymmetry graph with confidence intervals, respectively. The central red dashed line illustrates the disparity between the cumulative impacts of positive and negative fossil energy consumption (FEC) disturbances. The persistent negative asymmetry trajectory suggests that fluctuations in fossil energy usage exert unequal impacts on CO_2 emissions. The widening gap between the confidence bounds over the long-run horizon indicates increasing uncertainty and supports the persistence of asymmetric adjustment mechanisms in the fossil energy–emission relationship.

Figure 2: Multiplier effect of REC



Source: Author's calculations based on International Energy Agency (IEA) data and statistics

Figure 2 (solid black line, multiplier for REC+) shows the total reaction of CO2 emissions to positive shocks in the usage of renewable energy. The initial adverse reaction suggests that short-term emissions reduction may occur with renewable energy development. The increasing trend in the multiplier over time demonstrates that the persistent effects of renewable energy expansion are affected by large-scale structural reforms, technical absorption and shifting conditions of the energy market. The dash black line (Multiplier for REC-) shows the negative effects on renewable energy consumption (close to zero), indicating that the decline in renewable energy consumption will not cause significant increases in CO2 emissions in the short term. This is attributed to inertia of the energy system, efficiency improvements and continuance of existing renewable energy resources.

The crimson solid and crimson dashed lines in the REC asymmetry diagram define the limits of the confidence interval, whilst the middle crimson dashed line signifies the aggregate disparity between positive and negative REC shocks. The positive and increasing asymmetry response indicates that positive and negative changes in renewable energy utilization have differing effects on CO2 emissions. Furthermore, the widening confidence interval over time implies that the long-term environmental impacts of changes in renewable energy become more pronounced.

The results validate the existence of nonlinear and asymmetric correlations between energy consumption patterns and CO_2 emissions. Dependence on fossil energy demonstrates persistent asymmetric effects on emissions, while the expansion

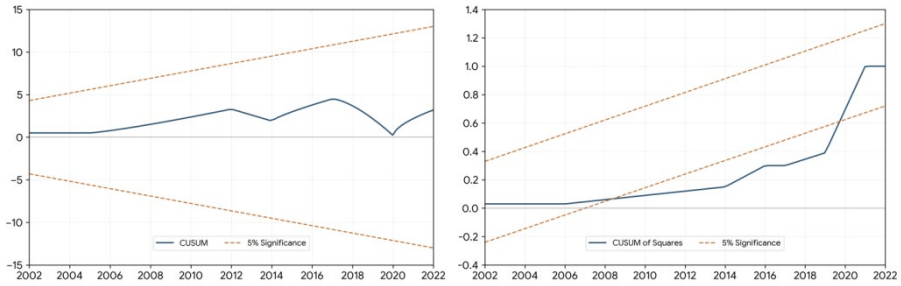
of renewable energy creates a distinct adjustment pathway linked to energy transition dynamics. These findings highlight the importance of considering asymmetric reactions in energy-environment assessments and advocate for policies that encourage the adoption of renewable energy, enhancements in energy efficiency, and the progressive replacement of fossil fuels to meet long-term decarbonization objectives.

4.7 Recursive Residual-Based Stability Test

The results of the CUSUM and CUSUM of Squares stability tests, which examine the dependability of the computed regression model, are shown in the illustrations. These tests utilize recursive residuals and are commonly employed to determine whether model coefficients remain stable over time and to identify any structural changes during the study period.

In the CUSUM test, the solid blue line illustrates the cumulative sum statistic, while the dashed orange lines indicate the 5% significant thresholds. The CUSUM line stays within the crucial thresholds throughout the whole sample duration, although some variations noted between 2012 and 2017 and around 2020. As the statistic does not cross the confidence boundaries, these results suggest no significant parameter instability or structural breaks.

Figure 3: CUSUM test and CUSUM of square test



Source: Author's calculations based on International Energy Agency (IEA) data and statistics

In a comparable manner, the CUSUM of Squares test assesses model stability by examining the cumulative squared recursive residuals. The blue line stays within the 5% upper and lower significance thresholds for the entire duration.

The CUSUM and CUSUM of Squares tests both validate that the estimated model maintains structural stability at the 5% significance threshold. The coefficients exhibit stability over time, indicating that the long-term associations among the variables are dependable and that the model is suitable for additional empirical examination and policy evaluation.

4.8 Discussion

Fossil energy consumption and renewable energy consumption have unequal effects on per capita CO2 emissions in both the short and long term, according to

empirical results from the NARDL model. The analysis shows that the disaggregation of fluctuations in energy use into positive and negative components results in varied environmental impacts of resultant increases and drops in energy use. This non-linear relationship highlights the need for considering the direction of energy shocks in the analysis of energy-environment nexus. Prior studies have similarly noted that energy–environment relationships are not inherently linear, and that positive and negative shifts in energy variables may produce divergent impacts on carbon emissions. Mahapatra and Irfan (2021) confirmed that changes in energy efficiency had uneven long-term effects on carbon emissions, suggesting that environmental responses vary depending on whether energy conditions improve or deteriorate.

Adoption of renewable energy significantly reduces CO2 emissions, according to the short-term analysis. An affirmative surge in REC^{+} yields a negative and markedly significant coefficient, indicating that a prompt escalation in renewable energy utilization leads to environmental enhancement through emission reduction. Similarly, the negative component of REC^{-} is also significant, indicating that reductions in renewable energy use are associated with changes in emission dynamics. The findings indicate that the development of renewable energy has a significant impact in the short-term trajectories of emission reduction. Prior empirical research robustly corroborates this association. Singh et al. (2025) shown that the utilization of renewable energy markedly decreases CO_2 emissions and has a more substantial beneficial effect on the environment than non-renewable energy sources. Similarly, Akbar et al. (2024) indicated that the utilization of renewable energy markedly reduces carbon emissions, while the use of fossil fuels leads to heightened emissions. Evidence from Turkey reinforces the assertion that the utilization of renewable energy lowers CO_2 emissions, especially in the long run (Karaaslan & Çamkaya, 2022; Khan et al., 2025).

The transient correlation between fossil fuel usage and CO_2 emissions displays a convoluted structure. Contrary to the widely held notion that increased use of fossil fuels would result in increased emissions, the coefficient of positive fossil energy consumption shocks is negative and statistically significant. This discovery could suggest temporary alterations in energy efficiency, variations in fuel composition, or structural changes within the energy system. On the other hand, negative changes in the use of fossil fuels do not have a statistically significant immediate impact, indicating that reducing reliance on fossil fuels may need a longer period of time to yield measurable ecological benefits. Mahapatra and Irfan (2021) found that Energy efficiency has asymmetric long-run effects on carbon emissions across economies. In established economies, a 1% increase in energy efficiency reduces emissions by 1.24%, whereas in developing economies, it reduces emissions by 1.19%. On the other hand, 1% unfavorable shock causes emissions to increase by 0.37% in developed countries and by 1.06% in developing countries. Prior research has similarly recognized differences between short-term and long-term energy effects. Similar distinctions between short-term and long-term energy impacts have been

identified by earlier studies. Renewable and non-renewable energy sources have distinct short-term and long-term effects on CO2 emissions, as demonstrated by (Apergis et al., 2023). Energy derived from fossil fuels often elevates emissions, whereas renewable energy sources provide ecological advantages.

Long-term assessments present stronger validation of the environmental ramifications associated with modifications in the energy system. Investigation into the disparate factors of fossil fuel energy use shows that rises and declines in fossil fuel usage influence CO_2 emissions in various ways. Remarkably, advantageous shifts in fossil fuel utilization are connected to a lasting reduction in CO_2 emissions. This surprising outcome might be clarified by enhancements in energy efficiency, technological advances, the introduction of cleaner fossil fuel technologies, or alterations in energy consumption structures (Almulhim et al., 2025; Dissanayake et al., 2023; Voumik et al., 2023). Reductions in fossil energy consumption contribute to emissions reductions; however, the magnitude of this effect differs from that observed during fossil fuel expansion. The discrepancy implies that variations in fossil energy utilization yield inconsistent long-term environmental repercussions. These results are in agreement with other investigations that reveal non-renewable energy usage considerably heightens CO_2 emissions. In opposition, some studies assert that the employment of non-renewable energy does not statistically significantly aid in the reduction of CO_2 emissions(Ali et al., 2025; Singh et al., 2025).

The utilization of renewable energy exhibits a negative long-term correlation with CO_2 emissions. Elevated utilization of renewable energy markedly diminishes CO_2 emissions, substantiating the enduring ecological advantages of broadening renewable energy resources. This discovery suggests that replacing carbon-heavy energy sources with renewable alternatives can aid in decarbonization. Reductions in the use of renewable energy, on the other hand, are associated with higher emissions, underscoring the need of maintaining and expanding renewable energy capacity for effective long-term emission control. These findings are in line with other studies that showed non-renewable energy worsens environmental deterioration whereas renewable energy enhances environmental quality by lowering CO2 emissions(Mujtaba et al., 2022; Naseem et al., 2024; Yang et al., 2026). Szetela et al. (2022) shown that the utilization of renewable energy markedly decreases per capita CO_2 emissions, particularly in nations with superior institutional quality.

These results are further supported by the long-term estimates based on levels. CO2 emissions are significantly and favorably impacted by reliance on fossil fuels, demonstrating the carbon-heavy characteristics of this dependency. The greater magnitude of the positive fossil energy component, compared to the negative component, demonstrates that environmental damage from fossil fuel expansion surpasses the environmental improvements achieved through equivalent reductions. Conversely, renewable energy expansion results in significant emission reductions, and the larger magnitude of REC^{+} compared to REC^{-} indicates that renewable

energy development yields greater environmental benefits than the losses incurred from its contraction. Substantial proof shows that more consumption of renewable energy diminishes CO_2 emissions, but growing use of non-renewable energy considerably amplifies emissions(Chen et al., 2023; Sugiharti et al., 2025).

The Wald test results offer more proof that long-run imbalance exists. Positive and negative fossil energy shocks have statistically different consequences on CO2 emissions, according to the rejection of the symmetry hypothesis in fossil energy consumption. Renewable energy consumption also exhibits significant long-run asymmetry, as reflected by even higher Wald statistics, suggesting that changes in renewable energy use produce more pronounced asymmetric environmental impacts. The lack of significant short-run asymmetry implies that asymmetric adjustment primarily occurs over the long term, rather than immediately following changes in energy consumption. This outcome corresponds with the observations of Mahapatra and Irfan (2021), who noted that asymmetric effects become more pronounced over time since energy systems necessitate a period for adjustment to structural and technological transformations.

The examination of the dynamic asymmetric multiplier provides additional understanding of the adjustment mechanism. In the realm of fossil fuel usage, favorable disturbances elicit a progressive reaction in CO_2 emissions, while unfavorable disturbances produce a diminished adjustment effect. These findings suggest that existing energy infrastructure, technological limitations, and system rigidity can delay the realization of environmental benefits from fossil fuel reduction (Akram et al., 2020; Bergougui, 2024). The persistent difference between positive and negative fossil energy responses confirms the existence of long-term asymmetric adjustment mechanisms. Similar adjustment patterns have been identified in previous energy studies, where changes in energy efficiency and energy structure generated delayed environmental responses (Mahapatra & Irfan, 2021).

The multiplier effects associated with renewable energy consumption reveal a distinct adjustment pathway. Because of energy system inertia and clean energy supplies, a fall in the use of renewable energy does not immediately result in an increase in emissions. In contrast, the initial expansion of renewable energy leads to a decrease in emissions. However, the observed asymmetry in response implies that the long-term effects on environmental quality of renewable energy expansion and contraction are not equivalent. Prior studies suggest that the ecological advantages of embracing renewable energy are amplified when paired with technology progress and strong institutional capability (Amiri et al., 2025; Han et al., 2025).

The results verify that there is an asymmetric and nonlinear link between the structure of energy use and CO2 emissions. Dependence on fossil energy generates persistent environmental pressures, while the expansion of renewable energy offers a viable pathway for emission reduction and energy transition. The findings indicate that to achieve sustainable decarbonization, energy policy should concentrate on lowering fossil fuel use while simultaneously encouraging the use of renewable

energy, energy efficiency, and progressive fossil fuel replacement. This conclusion aligns with previous studies that identify renewable energy expansion, improvements in energy efficiency, and fossil fuel substitution as essential strategies for achieving environmental sustainability (Addis, 2026; Idroes et al., 2024; Zuo & Ren, 2025).

5. Conclusion

Empirical evidence reveals the nonlinear and unbalanced relationship between energy use and CO2 emissions. Changes in the utilization of renewable and fossil fuels have varying degrees of environmental impact. The findings of NARDL analyzes show that the short- and long-term effects of fossil fuel and renewable energy usage on per capita CO2 emissions are different. While reductions in the use of renewable energy typically result in higher emissions, increases in the use of renewable energy are frequently linked to improvements in environmental quality. These results show the significance of both the composition and direction of changes in energy use as crucial factors of Bangladesh's long-term decarbonization pathway.

The transient findings demonstrate an intricate adaptation mechanism. Positive gains in renewable energy use significantly reduce CO2 emissions, indicating that the growth of renewable energy has benefits even in the short term. Conversely, the immediate impacts of fossil fuel utilization are more ambiguous. The negative coefficient associated with a positive fossil-energy shock may reflect temporary changes in energy efficiency, fuel composition, production structure, or other adjustment mechanisms, rather than suggesting that fossil-energy expansion is environmentally beneficial. Formal Wald tests do not identify statistically significant short-run asymmetry. Consequently, short-run estimates should be interpreted with caution, particularly when informing policy decisions regarding fossil-fuel use. The long-run results provide more robust evidence for policy formulation. Estimates suggest that persistent rises in fossil fuel use elevate CO_2 emissions, whereas decreases in fossil energy usage facilitate reductions in emissions. Importantly, the adverse effect of fossil-energy expansion exceeds the environmental benefit of an equivalent contraction. Conversely, the proliferation of renewable energy markedly decreases emissions, and its capacity to cut emissions is considerably more potent than the detrimental impact of a decline in renewable energy. These results suggest that the proliferation of renewable energy can yield significant ecological benefits and that mitigating reliance on fossil fuels is more efficacious than trying to undo such dependence once carbon-heavy infrastructure is in place.

Overall, the findings indicate that Bangladesh cannot achieve sustained emissions reductions solely through periodic reductions in fossil energy consumption. A fundamental overhaul of the energy framework is necessary, wherein renewable energy progressively supplants carbon-heavy sources, energy efficiency is improved across the economy, and investment choices avert prolonged reliance on fossil fuels. This comprehensive approach can simultaneously advance environmental sustainability, energy security, and Bangladesh's transition toward a lower-carbon development pathway.

Bangladesh should put into action a comprehensive energy transition strategy that gradually reduces dependency on fossil fuels while accelerating the growth of renewable energy. Priority should be given to solar, wind, biogas, and other viable renewable sources, in alignment with the Renewable Energy Policy 2025 targets of achieving 20% renewable electricity by 2030 and 30% by 2040. Due to limited land availability, rooftop and distributed solar systems for industrial, commercial, educational, healthcare, governmental, and residential sectors should receive increased policy support through streamlined approval processes, improved financing mechanisms, and effective net-metering arrangements. Simultaneously, fossil-fuel substitution should proceed gradually to maintain electricity affordability, reliability, and energy security, while avoiding the construction of additional carbon-intensive infrastructure and long-term carbon lock-in.

Improving transmission and distribution infrastructures, integrating smart-grid technologies, installing energy storage systems, and implementing methods to reduce system losses are all necessary to support the growth of renewable energy. Energy efficiency should be prioritized as a central component of decarbonization, particularly in sectors such as textiles, garments, cement, steel, ceramics, buildings, appliances, and industrial equipment. Bangladesh should further encourage private investment through transparent procurement processes, predictable tariffs, green bonds, concessional climate finance, and blended-finance mechanisms. Fiscal incentives should increasingly favor renewable energy, storage, and efficiency, while ensuring protection for low-income households from adverse energy-price impacts. Finally, SREDA, the Power Division, and other relevant agencies should integrate asymmetric energy responses into long-term planning, recognizing that renewable expansion and fossil-fuel reduction may produce different environmental effects depending on the direction and magnitude of energy changes.

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