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Investigating the Nexus between Economic Growth and Environmental Quality in Bangladesh: The Role of Renewable Energy

Prome Biswas[1] Subroto Dey[1] Md. Ariful Islam[1] Sanjoy Kumar Saha[1] Shakil Mahmood Shaon[1*]

[1]Department of Economics, Mawlana Bhashani Science and Technology University, Tangail 1902, Bangladesh

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ABSTRACT

Environmental quality and climate change have become popular topics in all scientific disciplines in recent decades due to their effect on human wellbeing and economic growth. This paper investigates the effect of urbanization, physical capital, financial development and renewable energy consumption on environmental quality in Bangladesh over the period 1990 to 2020 by utilizing the ARDL Bounds Test. This research employs secondary data sourced from the World Bank. The expected outcomes have been decided by multiple quantitative time-series evaluation techniques, including the Augmented Dickey-Fuller assessment, ARDL (Autoregressive Distributed Lag) bound test, and the Granger Causality analysis. The Augmented Dickey-Fuller test has verified that none of the series is integrated of the second order. The F-bounds test results verified the presence of a sustained connection among the analyzed variables. Empirical research demonstrates that urbanization, together with physical capital and financial development, exacerbates environmental degradation, but renewable energy usage mitigates it over the long term. The short-term findings indicate that urbanization and physical capital correlates favorably with environmental damage, while financial development and renewable energy consumption correlates negatively with the environmental damage. The Granger causality test outcomes indicate that carbon dioxide emissions and urbanization, as well as carbon dioxide emissions and renewable energy usage, mutually Granger cause each other in a bidirectional manner. All outcomes are logically coherent, and the policy recommendations are derived from our study.

1. INTRODUCTION

Bangladesh, in conjunction with all other United Nations participating countries, has overwhelmingly adopted the 2030 agenda for the achievement of Sustainable Development (Saha, 2025. This agenda prioritizes fostering harmonious relations between nations to achieve future goals that enhance human well-being while also safeguarding the environment.

Nestled amidst the fertile Ganges Delta, Bangladesh, a nation teeming with life and resilience, grapples with a burgeoning challenge: environmental pollution (Akter et al., 2024). As the 8th most populous country and among those most susceptible to climate change, Bangladesh faces the daunting task of curbing its CO_2 emissions while simultaneously propelling its economic and social development (Akhi et al., 2024). The country has seen both economic growth and environmental challenges because of urbanization and economic development. Due to rising industrialization and urbanization in the country over the past few decades, there has been significant growth in financial systems, expansion of infrastructure, and an increase in energy demand (Dey et al., 2025). Simultaneously, there has been a significant increase in concern regarding environmental damage. The swift rate of urbanization, combined with the increasing need for physical capital and energy, has exerted significant strain on its environment (Saha, 2023; Saha, 2024).

It is imperative to comprehend the intricate interaction between urbanization, accumulation of physical capital, development of financial systems, and utilization of energy from renewable sources in influencing the environmental condition of the country (Lubna et al., 2024). Comprehending these connections is essential for developing well-designed strategies that harmonize

*Corresponding Author: shakilmahmood7053@gmail.com

economic advancement with ecological sustainability.

The phenomenon of urbanization, characterized by the progressive concentration of a population in urban areas, has been a prominent and defining characteristic of the contemporary period. Bangladesh has experienced accelerated urbanization in current decades, with the urban population growing from 23.3% in 2000 to 37.4% in 2020 (World Bank, 2021). Although urbanization has provided favorable economic prospects and enhanced quality of life for several individuals, it has also resulted in escalated energy usage, production of trash, and pollution (Saha & Saha, 2023). The dense population and intensive economic operations, and industrial activities in metropolitan regions places significant pressure on natural resources and ecosystems. Urban growth and sprawl at the local level invade and diminish green spaces and habitats (Irwin & Bockstael, 2007; Saha & Jeong, 2019). Urban regions exhibit greater temperatures because of the urban heat island phenomenon (Oke, 1982). Azam & Khan (2016) reveals that the expansion of urbanization exerts a significantly adverse influence on the environment in Bangladesh and India, but a negligible positive effect in Pakistan and a substantial advantage in Sri Lanka.

Bangladesh has undergone substantial economic growth and development in recent decades, mostly by emphasizing the expansion of its physical capital (Saha, 2020; Saha, 2025). Physical capital encompasses the tangible assets such as structures, machines, instruments, and industries that are utilized in the process of manufacturing. The production and use of physical capital often involve resource extraction, energy consumption, and emissions. However, investments in more efficient and environmentally friendly capital can also lead to reduced environmental impact over time (Poly et al., 2025).

The growth of physical capital is a fundamental characteristic of economic progress (Solow, 1956). Nevertheless, this swift growth has resulted in unforeseen repercussions on the environment, resulting in heightened levels of environmental deterioration. This essay examines the diverse influence of physical capital on environmental deterioration in Bangladesh and emphasizes its significance for sustainable development.

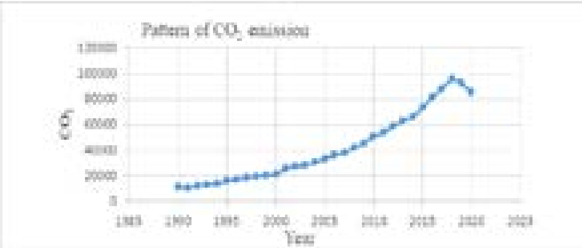
In addition, the development of infrastructure, including the construction of roads, highways, and power plants, has resulted in deforestation, the destruction of habitats, and the decline of biodiversity. The rapid expansion of metropolitan areas and industries has led to widespread deforestation, causing the destruction of crucial ecosystems and the endangerment of wildlife species. In addition, the discharge of wastewater from power plants and industrial activity has polluted water bodies, causing harm to aquatic organisms, and worsening environmental deterioration. The utilization of fossil fuel-driven machinery, automobiles, and electricity production has resulted in a rise in emission of greenhouse gases (Intergovernmental Panel on Climate Change, 2014).The process of deforestation (clearing forests for croplands) and industrial pollution harm ecosystem significantly. These activities lead to a decline in biodiversity, meaning the variety of plant and animal species in an area is reduced. This reduction can destabilize ecosystems, affecting their health and resilience (Czech, 2008).

Financial development, shown by the expansion and complexity of financial markets and institutions, significantly influences environmental results. On the one hand, it can enable investments in environmentally friendly technologies and sustainable solutions. Conversely, technology can also facilitate heightened consumption and manufacturing activities that, if not adequately controlled, might have detrimental effects on the environment. Saud et al., (2019) shows environmental quality is enhanced by financial development, foreign direct investment, and trade openness; conversely, environmental quality is degraded by electricity consumption and economic expansion. Shoaib et al., (2020) demonstrate that financial development exerts a favorable and statistically substantial long-term impact on carbon emissions at a level of significance of 1% in both panels. In the D8 and G8 nations, the results of financial growth and energy use are notably more substantial. Utilization of energy and openness in trade positively influence carbon emissions, but a 1% statistical reduction in carbon emissions is significantly attributed to GDP.

Utilization of renewable energy has become essential in alleviating environmental damage. A plethora of countries is transitioning from fossil fuels to clean energy resources including solar, wind, and hydropower, geothermal energy, and biodiesel. Renewable energy sources possess the capacity to offer environmentally friendly and sustainable energy, with much reduced negative effects on the environment compared to fossil fuels (Jacobson & Delucchi, 2011). To attain the sustainable development goals (SDGs) of 2030 and emerge as a developed country by 2041, the nation must increase energy consumption while lowering CO_2 emissions. The country is most vulnerable to climate change. In this case, renewable energy might be extremely important for maintaining environmental protection while also supporting economic growth. However, increased efforts are required to diminish carbon dioxide releases and mitigate the impacts of climate change.

While a consistent energy supply is commonly considered essential for promoting overall growth, there is sometimes a trade-off between increased economic success and decreased environmental well-being (Murshed et al., 2021) .This is mostly because of the dominating use of fossil fuels to fulfill the global energy demand. The burning of these energy supplies leads to significant environmental problems. For example, when people choose to consume fossil fuels, it leads to the release of pollutants into the atmosphere, which in turn causes a decline in environmental quality. On the other hand, it has been suggested that using renewable energy resources as a substitute could enhance the condition of environmental characteristics (Murshed et al., 2021a; Shoron et al., 2025). Therefore, it is crucial to discover the potential methods by which the reliance on fossil fuels worldwide might be reduced to attain a state of equilibrium by effectively reconciling economic expansion with the conservation of the environment.

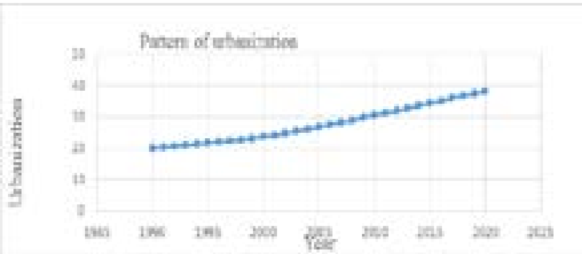
Figure 1: Pattern of CO_2 emission



Source: World development indicators.

Figure 1 shows that, with sporadic minor variations, CO_2 emissions increased gradually between 1990 and 2020. This suggests that industrial activity and our reliance on fossil fuels are growing, which is causing climate change.

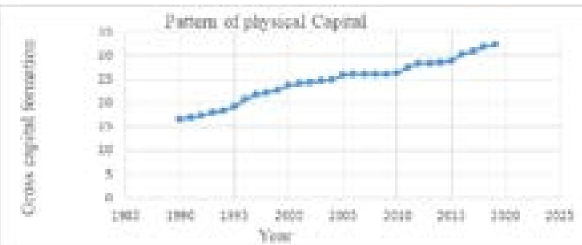
Figure 2:Pattern of Urbanization



Source: World development indicators.

As seen in figure 2, the rate of urbanization increased steadily from 19.81% in 1990 to 38.17% in 2020.Because of infrastructural development and industrialization, more people are relocating to cities, which frequently results in higher energy emissions and consumption.

Figure 3:Pattern of Physical Capital



Source: World development indicators.

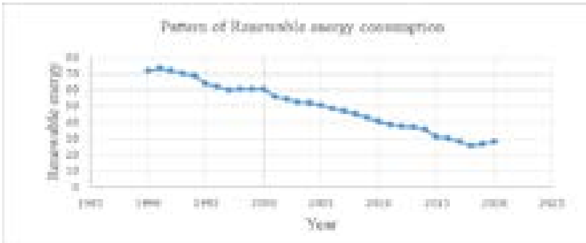
Figure 3 illustrates the steady rise in gross capital formation, or investments in tangible assets like infrastructure, between 1990 and 2020.Investments and economic growth are increasing, which probably increases productivity but also puts more burden on the environment.

Figure 4: Pattern of Financial Development

Source: World development indicators.

Figure 3 illustrates the steady rise in gross capital formation, or investments in tangible assets like infrastructure, between 1990 and 2020.Investments and economic growth are increasing, which probably increases productivity but also puts more burden on the environment.

Figure 5: Pattern of Renewable Energy Consumption



Source: World development indicators.

Renewable energy consumption dropped sharply from about 71.68% in 1990 to roughly 28% by 2020, as shown in Figure 5, and then stabilized at this lower level. This trend highlights a lack of transition to sustainable energy sources despite the growing need to reduce fossil fuel reliance.

Keeping the above background and significance in mind the objectives are as follows:

1. To assess the short-term and long-term connection between the relevant variable and its overall effect on carbon dioxide emissions.

2. To show the causal relationship among urbanization, physical capital, financial development, renewable energy consumption for CO_2 emission in Bangladesh.

1.1 LITERATURE REVIEW

Satterthwaite (2008) shows urbanization has significant impacts on climate, biogeochemistry, and biodiversity, particularly at larger scales. Urban energy use and garbage creation are significant factors in the production of greenhouse gas emissions. According to Glaeser &

Kahn (2008),urbanization on the other hand, offers the chance to achieve economies of scale in transportation and energy-efficient structures, which can help reduce emissions.

Azam & Khan (2016) reveals that the expansion of urbanization exerts a significantly adverse influence on the environment in Bangladesh and India, but a negligible positive effect in Pakistan and a substantial advantage in Sri Lanka. Ghosh & Kanjilal (2014) investigates the cointegrating relationship among economic activity, urbanization, and energy consumption in India by employing threshold cointegration tests in conjunction with ARDL.

Alom et al., (2017)illustrates the interrelationship between energy use, CO_2 emissions, urbanization, and financial development in Bangladesh with a Vector Error Correction Model. The causality test indicates that unidirectional causality exists among the variables. Boutabba, (2014) indicates that the financial system in India should take environment into consideration in its present activity. Financial development causes carbon emission and energy use in India.

Ali Bekhet et al., (2017) analyze the interconnections between financial development, carbon dioxide pollutants, the expansion of urban areas, the utilization of energy, gross domestic product (GDP), and internal capital investment. The correlation between urbanization and CO_2 elasticity is originally positively elastic but then transitions to negatively inelastic as urbanization advances.

Rahman & Ahmad (2019) examines the correlation between carbon dioxide (CO_2) emissions and gross capital formation (GCF) in the context of Pakistan using NARDL model. The result validates the existence of an immediate and sustained asymmetry in the effect of GCF disturbances on CO_2 emissions. The results also indicate that the utilization of coal and oil contributes substantially to carbon dioxide (CO_2) emissions, both in the immediate and extended periods. Additionally, the findings provide substantial proof for the EKC hypothesis's existence in both the immediate and long term.

Adebayo & Kirikkaleli (2021) shows evidence gathered from wavelet modeling demonstrate that in Japan, advances in technology, growth in the economy, and modernization contribute to increased CO_2 emissions. However, the utilization of renewable energy sources effectively reduces CO_2 emissions in the short- and medium-term.

Sahoo & Sahoo (2022) suggests that hydro energy consumption promotes CO_2 emissions; however, this effect is not statistically significant. However, it is evident that the implementation of nuclear energy has an adverse effect on carbon dioxide emissions. Adebayo & Rjoub et al., (2022)examine the significant connection between emissions of carbon and sustainable energy use, openness to trade and economic expansion in Sweden using QQ approach. It is found that all variables have a negative influence on CO_2 levels at various quintiles.

1.2 Research Gap

Upon reviewing the literature, it is obvious that numerous scholars have conducted substantial research on the effects of various variables, including economic expansion, impact of industrialization, population volume and trade liberalization on environmental conditions. In Bangladesh, there is insufficient research that delineates the connections between urbanization, physical capital, financial development, renewable energy consumption, and emissions of carbon dioxide.

In terms of our research, we have examined the causal connections between urbanization, physical capital, financial development, renewable energy use, and environmental degradation in Bangladesh for first time. The correlation between the variables has been established using yearly data over a period of 31 years (1990-2020).

2. METHODOLOGY

2.1 SOURCES AND DESCRIPTION OF DATA

This analysis utilized secondary data from the World Development Indicators encompassing the years 1990 to 2020. CO_2 emission (Kt) is used as a dependent variable and urbanization (total population), physical capital (gross fixed capital formation), financial development (domestic credit to private sector) and renewable energy consumption (total energy consumption) are included as independent variables.

The study employs the Auto-Regressive Distributed Lag (ARDL) methodology, initially developed by Pesaran et al. (2001), to examine co-integration relationships among variables. This approach is preferred over conventional methods such as those proposed by Engle and Granger (1987) and Johansen and Juselius (1990) due to its ability to simultaneously estimate both long- and short-run parameters while addressing issues related to endogeneity, omitted variables, and autocorrelation. A key advantage of the ARDL model is that it does not require pre-testing for unit roots or determining the order of integration for variables. Instead, it allows for stationarity at levels (I(0)), first differences (I(1)), or fractional integration. However, ensuring that the dependent variable is first-difference stationary is crucial for maintaining co-integration validity. One of the strengths of the ARDL model is its flexibility, as it can be applied to data series with mixed integration orders—whether I(0), I(1), or fractionally co-integrated (Pesaran & Pesaran, 1997).

Pesaran et al. (2001) emphasized that the dependent variable should exhibit first-difference stationarity to uphold the co-integrating relationship. Additionally, Rahman and Islam (2020) caution that the presence of I(2) variables could destabilize the system, necessitating robust unit root tests to confirm their absence. According to Pesaran et al. (2001), the ARDL model provides reliable and efficient parameter estimates, particularly in studies with small sample sizes. In contrast, traditional techniques like those by Engle and Granger, as well as Johansen and Juselius, often yield inconsistent and inefficient results in such cases. Nguyen (2020) also highlights that the ARDL bounds testing approach performs significantly better when sample sizes are limited. Another key benefit of this methodology is its ability to incorporate an optimal number of lags within a general-to-specific modeling framework, as noted by Laurenceson and Chai (2003). This feature mitigates endogeneity concerns, as it enables the inclusion of both dependent and independent variables through lagged values. Nonetheless, the inclusion of I(2) variables should be avoided to prevent system instability, making efficient unit root testing essential.

Pesaran et al. (2001) assert that the ARDL technique remains reliable and effective, especially for small-sample studies. Nguyen (2020) further supports the ARDL bounds testing method as superior to traditional multivariate co-integration techniques when working with limited observations. Additionally, the model's adaptability allows researchers to incorporate various explanatory variables and different lag structures, making it more advantageous than vector autoregressive (VAR) models.

To analyze the impact of the refugee crisis on economic growth, this study employs the Engle-Granger causality test within the ARDL framework. Furthermore, diagnostic tests, including the CUSUM and CUSUMQ tests, are conducted to assess model stability by verifying coefficient constancy and detecting potential structural breakpoints. These measures enhance the robustness and reliability of the findings.

2.2 MODEL SPECIFICATION

The purpose of this study is to examine the impact of urbanization, renewable energy, physical capital, and financial development on deterioration of the environment in Bangladesh. Environmental degradation frequently manifests in the following manner:

$LnCO_2$ = f (LnUR, LnPC, LnFD, LnREC)

$LnCO_{2t} = \beta_0 + \beta_1 LnUR_t + \beta_2 LnPC_t + \beta_3 LnFD_t + \beta_4 LnREC_t + \varepsilon t$

Where, $LnCO_2$=Natural log of carbon emission as a proxy for environmental degradation, LnUR= Natural log of urban population as a proxy for urbanization, LnPC= Natural log of gross fixed capital formation as a proxy of physical capital, LnFD= Natural log of domestic credit to private sector as a proxy for financial development, LnREC=Natural log of renewable energy consumption, β_0 β_1, β_2, β_3, β_4=parameters to be estimated, t = 1,2,3, ….31(Time Period from 1990-2020), ε= Stochastic term.

2.3 UNIT ROOT TEST

A non-stationary series of times is a random phenomenon characterized by unit roots or structural breakdowns. In contrast, roots of units predominantly induce non-stationary behavior. The existence of a unit root denotes that the investigated time series is non-stationary, whereas its absence shows stationarity (Nkoro & Uko, 2016). Nelson and Plooser (1982) assert that many economic time series necessitate differencing to attain stationarity. Numerous economic factors show a pattern they are usually not stagnant. Therefore, it was crucial to verify the stationarity of the parameters before moving further with any analysis. The Augmented Dickey-Fuller (ADF) test for unit root was used in this investigation appraisal (Dicky and fuller,1979,1981). Autocorrelation is eliminated via the ADF test by adding more lagged components to the independent and dependent variables, specifically carbon emissions, urbanization, physical capital, financial development, and renewable energy use.

2.4 ARDL MODEL SPECIFICATION

The ARDL (Autoregressive Distributed Lag) method is appropriate for investigating the nexus between economic growth, environmental quality, and renewable energy in Bangladesh due to several key advantages. First, it accommodates variables with mixed orders of integration (I(0) and I(1)), which is common in macroeconomic time series, making it suitable even when variables like GDP, CO_2 emissions, and renewable energy consumption are not uniformly stationary. Second, ARDL performs well with small sample sizes, a typical feature in single-country studies using annual data. Third, it enables simultaneous estimation of both short-run dynamics and long-run equilibrium relationships, providing a comprehensive view of the interactions among the variables. Additionally, the model includes an error correction term (ECT) to capture the speed of adjustment toward long-run equilibrium following short-run shocks. Its flexibility in selecting optimal lag lengths for each variable enhances model accuracy and reduces bias. Overall, ARDL's robustness and clarity in distinguishing short- and long-run effects make it a suitable empirical approach for policy-relevant research on the environmental and economic implications of renewable energy in Bangladesh.

The cointegration evaluation technique assesses whether the endogenous variable affects the cointegration of the model's key parameters. The main benefit of this model lies in its capacity to identify long-term correlations between variables, irrespective of their stationarity at first difference, level, or a combination thereof, given that no factor may remain stationary at the second difference. The ideal latency for each model was determined utilizing the Akaike Information Criterion, or AIC. The study encompasses the development of the subsequent instance.

Dependent variable: $LnCO_2$:
Independent variable: LnUR, LnPC, LnFD, LnREC

$$\Delta LnCO_{2t} = \alpha_0 + \sum_{i=1}^{p} \beta_{1i} \Delta LnCO_{2t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta LnUR_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta LnPC_{t-i} + \sum_{i=i}^{q} \beta_{4i} \Delta LnFD_{t-i}$$

$$+ \sum_{i=1}^{q} \beta_{5i} \Delta LnREC_{t-i} + \gamma_i LnCO_{2t-1} + \gamma_2 LnUR_{t-1} + \gamma_3 LnPC_{t-1} + \gamma_4 LnFD_{t-1} + \gamma_4 LnREC_{t-1} + \varepsilon_t$$

The F-bounds test (Pesaran et al., 2001) was employed with the ARDL model to validate a long-term correlation between the variables. Long-term associations among the variables are confirmed by F-statistics exceeding the critical values of both the top and bottom boundaries. The F-bound approach was employed to obtain long-run values. The model for error correction exhibited the short-run coefficients, and the error correction term as follows:

$$\Delta LnCO2t = \alpha o + \sum_{t=1}^{p} \delta_{li} LnCO_{2t-i} + \sum_{i=1}^{q} \delta_{2i} \Delta LnUR_{t-i}$$

$$+\sum_{i=1}^{q} \delta_{3i} \Delta LnPC_{t-i} + \sum_{i=1}^{p} \delta_{4i} LnFD_{t-i} + \sum_{i=1}^{q} \delta_{5i} \Delta LnREC_{t-i} + \theta_1 ECT_{t-i} + \mu t$$

Short-term causality is confirmed by the considerable coefficients of the other explanatory variables, while permanent causality is evidenced by the substantial coefficient of the error correction term (ECT) θ.

3. RESULT ANALYSIS AND DISCUSSION

Table 1: Result of Augmented Dicky Fuller Test

Variables	With Intercept						
	At Level			At First Difference			Remarks
	t-statistics	5% critical value	P- value	t-statistics	5% critical value	P- value	I(d)
LnCO2	-1.522	-1.706	0.0700	-2.625	-1.708	0.0073***	I(1)
LnUR	0.178	-1.706	0.5700	-2.139	-1.708	0.0212**	I(1)
LnPC	-2.358	-1.706	0.0131**	-2.940	-1.708	0.0035***	I(0)
LnFD	-1.401	-1.706	0.0865	-3.932	-1.708	0.0003***	I(1)
LnREC	-0.384	-1.706	0.3519	-3.116	-1.708	0.0023***	I(1)

Source: Authors Estimation.

Symbols (**), and (***) denote statistical significance at the 5% and 1% levels, respectively.

Table (1) illustrates that not all variables display stationarity in their original form. This denotes that the variables LnC02, LnUR, LnFD, and LnREC are integrated of order one, I (1), but LnPC is integrated of order zero, I (0).

Table 2: Estimated ARDL Model Dependent Variable: Lnco2, ARDL (1,2,0,2,0)

Variables	Coefficients	Standard error	t statistic	P value
LnCO2(-1)	-0.2249468	0.1495316	-1.50	0.149
LnUR(-1)	-17.56787	6.392708	-2.75	0.013
LnUR(-2)	6.033046	3.225378	1.87	0.077
LnPC	0.6720991			
	0.1562951	4.30	0.000	
LnFD(-1)	0.0395988	0.0831569	0.48	0.639
LnFD(-2)	0.1567826	0.696736	2.25	0.036
LnREC	-1.093842	0.1223627	-8.94	0.000
Constant	10.10752	1.134467	8.91	0.000

Source: Authors Estimation.

The table shows the results of an ARDL (Autoregressive Distributed Lag) model with the dependent variable being. The lag structure for the model is specified as ARDL (1, 2, 0, 2, 0) which indicates how many past values of the dependent and independent variables are considered in the model. The lags are important in ARDL models for capturing dynamic relationships between the variables. Specifically,1 means one past value of the dependent variableLnCO$_2$ is included means two lags of independent variables (UR, FD) are included.0 means PC, REC has no lag (only current values are included).

This lag structure is often determined by statistical criteria like Akaike Information Criterion (AIC) or Schwarz Bayesian Criterion (SBC) during the ARDL model estimation.

Table 3: Result of Bound F-Test

Model: LnCO2=F (UR, PC, FD, REC)	**ARDL (1,2,0,2,0)**	
F-statistics =27.776	**Number of independent variables. K=4**	
Critical values	**Lower bounds, I(0)**	**Upper bounds, I(1)**
10%	2.45	3.52
5%	2.86	4.01
2.5%	3.25	4.49
1%	3.74	5.06

Source: Authors Estimation.

H_0: No levels relationship.

The ARDL bounds test results indicate the value of the f-statistic is 27.776. At the 1% significance level, the calculated F-statistic of our model exceeds the maximum bound. Consequently, the null hypothesis may be rejected, and the results indicate a persistent correlation between the variables in our study.

Table 4: Estimated Long Run Coefficient of the ARDL model

Dependent variable: LnCO2, ARDL (1,2,0,2,0)				
Variables	Coefficients	Standard error	t-statistics	p-value
LnUR	O.7589247	0.2537318	2.99	0.008***
LnPC	0.5486761	0.0867146	6.33	0.000***
LnFD	O.3731069	0.0619029	6.03	0.000***
LnREC	-O.8929709	0.1155805	-7.73	0.000***
R-squared=0.9060, Adj R-squared=0.8614				

Source: Authors Estimation.Note: (*), (**), and (***) denote significant levels of 10%, 5%, and 1%, respectively.

The results demonstrate that a 1% increase in urbanization is connected to a long-term growth in CO_2 emissions of 0.75%. Thus, urbanization, which results in heightened CO_2 emissions, contributes to the degradation of our ecosystem. Gross fixed capital formation, an essential metric of physical capital, demonstrates a statistically significant positive association with CO_2 emissions in Bangladesh. Our research determined that a 1% augmentation in gross fixed capital formation leads to a 0.54% increase in CO_2 emissions over the long term. Our analysis indicates that a 1% increase in the ratio of domestic credit to the private sector, a measure of financial development, results in a long-term rise of 0.37% in CO_2 emissions. Moreover, it illustrates that a mere 1% increase in the utilization of renewable energy sources will result in a persistent reduction of 0.89% in carbon dioxide emissions, a critical indicator of environmental degradation. The data indicates a robust statistical association between heightened utilization of renewable energy and diminished carbon dioxide emissions.

Table 5: Short Run Estimation from ECM

Dependent Variable: LnCO2, ARDL (1,2,0,2,0)				
Variables	**Coefficients**	**Standard error**	**t-statistic**	**p-value**
ΔLnUR	11.53482	3.430731	3.36	0.003***
ΔLnUR(-1)	-6.033046	3.225378	-1.87	0.077*
LnPC	0.6720991	0.1562951	4.30	0.000***
ΔLnFD	-0.1963813	0.830813	-2.36	0.029**
ΔLnFD(-1)	-0.1567826	0.0696736	-2.25	0.036**
Ln REC	-1.093824	0.1223627	-8.94	0.000***
ECT (-1)	-1.224947	0.1495316	-8.19	0.000***
Constant	10.10752	1.134467	8.91	0.000***
R-squared=0.9060 Adj R-squared=0.8614				

Source: Authors Estimation. Note: (*), (**), (***) indicates significance for 10%, 5% and 1% respectively.

The estimation indicates that the resulting coefficient of the lagged error correction term (ECT) in short-run patterns with relationships over time is negative and highly significant at the 1% level. The value is -1.224947. The statistics demonstrate a consistent relationship among our variables, and the annual error of 122.5% will be corrected or realigned with the long-term equilibrium. Here ΔlnUR indicate that a 1% increase in urbanization increases CO2 emissions by approximately 11.53% in the short run. Again, ΔlnUR(-1) shows that a 1% increase in lagged urbanization reduces CO2 emissions by approximately 6.03%. As noted by LnPC, there is a 0.67% increase in CO2 emissions for every 1% increase in physical capital. ΔlnFD suggests that there is a 0.20% reduction in CO2 emissions for every 1% growth in financial development. CO2 emissions are reduced by 0.16% for every 1% increase in lagged financial development (ΔlnFD(-1)). As stated by LnREC, CO2 emissions are reduced by roughly 1.09% for every 1% increase in the use of renewable energy in the short run.

Table 6: Granger causality between variables (Lnco2,LnUR,LnPC,LnFD,LnREC)

Equation	Excluded	chi2	df	prob>chi2
LnCO2	LnUR	6.5279	2	0.038
LnCO2	LnPC	3.9625	2	0.138
LnCO2	LnFD	22.065	2	0
LnCO2	LnREC	45.363	8	0
LnCO2	ALL	12.317	2	0.002
LnUR	LnCO2	12.521	2	0.002
LnUR	LnPC	0.29452	2	0.863
LnUR	LnFD	0.40959	2	0.815
LnUR	LnREC	80.855	8	0
LnUR	ALL	8.0927	2	0.017
LnPC	LnCO2	4.9079	2	0.086
LnPC	LnUR	8.5931	2	0.014
LnPC	LnFD	0.57198	2	0.751
LnPC	LnEEC	5.7413	2	0.057
LnPC	ALL	32.706	8	0
LnFD	LnCO2	4.6541	2	0.098
LnFD	LnUR	5.4022	2	0.067
LnFD	LnPC	1.8075	2	0.405
LnFD	LnREC	16.527	2	0
LnFD	ALL	35.819	8	0
LnREC	LnCO2	19.23	2	0
LnREC	LnUR	9.4117	2	0.009
LnREC	LnPC	22.224	2	0
LnREC	LnFD	20.91	2	0
LnREC	ALL	54.801	2	0

Source: Authors Estimation.

The Granger causality analysis indicates that, holding other variables constant, carbon dioxide emission and urbanization, carbon dioxide emission and renewable energy consumption, urbanization and physical capital, as well as renewable energy consumption and financial development, exhibit bidirectional causality with one another. But there is no causal link between Carbon emission and financial development, urbanization and financial development, as well as financial development and physical capital. From the estimated table 6 we can see that physical capital Granger-causes carbon emission, but carbon emission does not Granger-cause physical capital. Urbanization Granger-causes renewable energy consumption but renewable energy consumption does not Granger-cause urbanization. Again, physical capital Granger-causes renewable energy consumption but renewable energy consumption does not Granger-cause physical capital. This indicates the existence of unidirectional causality among the variables.

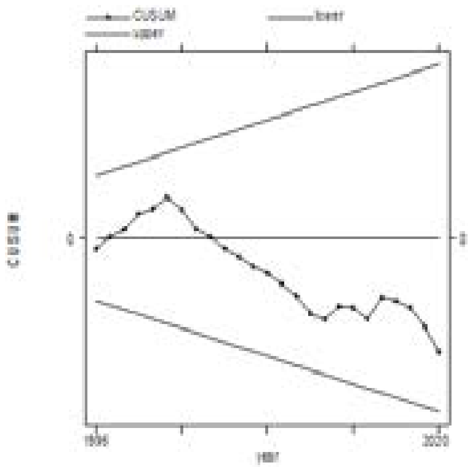
Table7: Residual Diagnostic Test

Test Name	Test statistic	Value obtained	P value	Remarks
Jarque-Bera Test	JB-statistic	0.0626	0.9692	Normally distributed
Serial correlation test (Brusch -Godfrey Serial Correlation LM tests)	F-statistic	0.181	0.6709	No serial correlation
Heteroscedasticity test (Breusch Pagan Godfrey test)	chi^2	0.24Test	0.6259	Homoscedastic

Source: Authors Estimation.

Table 7 indicates that our prediction has a normal distribution and is free from autocorrelation and heteroscedasticity concerns. The rationale for this is that the p-values of all tests surpass the 5% significance threshold. The null hypothesis is affirmed under these conditions.

Fig 6: Plot of CUSUM test



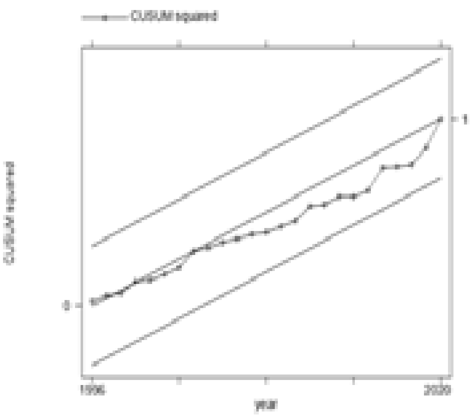


Figure 7: Plot of CUSUM Square Test, source: Authors Estimation.

The empirical findings demonstrate that both evaluation diagrams fall within the critical range at a five percent significance level. This indicates the stability of both immediate and distant factors.

4. CONCLUSION AND POLICY SUGGESIONS

The present research examines the identified cointegration, long-term and short-term dynamics and causal relationships among urbanization, physical capital, sustainable energy consumption, and financial development and CO2 emissions within the framework of Bangladesh. The cointegration was assessed utilizing the ARDL Bound Test methodology, and the Error Correction Model (ECM) to examine both long-term and short-term dynamics. The actual data illustrate the correlation, both in the short and long term, among the factors we have employed.

The data from the study undergo stationarity testing using the Augmented Dickey-Fuller tests. The study's findings indicate that the series, consisting of I (0) and I (1), exhibit a mixed order and are not stationary at I (2). The ARDL model is more convenient to employ due to the presence of time series properties with a combination of integrating orders. The research employs many diagnostic techniques to demonstrate the absence of issues related to heteroscedasticity, abnormality and autocorrelation.

The results indicate that the proportion of urbanization as shown in our study is positively correlated with environmental degradation. This correlation holds true both in the long term and in the short term, with elasticities of 0.75% and 11.53% respectively. Additionally, our study reveals a positive correlation between gross fixed capital formation and environmental degradation both short run and long run. This association has an elasticity of around 0.67% 0.54% respectively. Financial development in the study, has a favorable long-term effect on CO_2 emissions. However, in the short term, it has a negative effect due to investments in cleaner technologies that help reduce emissions. The elasticity of these impacts is measured at 0.37% and 0.20% respectively. Moreover, the investigation indicates a short term and long-term negative correlation between renewable energy consumption and CO_2 emissions and the value is 1.09% 0.89% respectively. We must be aware to reduce the CO_2 emission in Bangladesh. The empirical investigation's conclusions have significant policy implications for developing countries such as Bangladesh.

1. Our findings suggest that urbanization leads to an extension of environmental degradation, both in the short term and long term. To mitigate the ill effects of urbanization, it is imperative to implement sustainable urbanization planning through the implementation of integrated urban planning strategies that prioritize sustainable transportation, energy efficiency and ecological spaces. Establish and enforce stringent building codes that require the use of energy-efficient materials and designs. Invest in the improvement of informal settlements by implementing appropriate sanitation,

refuse management and green infrastructure.

2. CO_2 emissions in Bangladesh are generated by all equipment acquisitions, machinery, land enhancements and governmental investments which are categorized as gross fixed capital or physical capital. There is a need for increased investment in Research and Development (R&D) initiatives, specifically focusing on eco-friendly technologies, within this country. This country should actively implement capital formation oversight, specifically by adopting state-of-the-art technology that mitigates CO_2 emissions.

3. The results of our study indicate a strong and significant correlation between the level of financial development and the amount of CO_2 emissions per person. This suggests that as financial development increases, it also leads to an increase in environmental deterioration. Our policy recommendation is for the financial industry to incorporate environmental considerations into its ongoing activities. By providing interest rate concessions and implementing restrictions related to carbon emissions in their financial offers, such as term loans for commercial vehicles and real estate, the banking system's conventional practices can encourage investment in environmentally friendly technologies. Establishing a system of effective regulation and incentives that promote increased finance for low carbon emissions is essential for the development of Bangladesh's resource-conserving society.

4. According to the study using renewable energy sources helps to minimize the amount of carbon dioxide emission into the environment does it is strongly advised that effective regulations to promote renewable energy sources like a solar hydrogel nuclear power must be in placed by decision makers to address the increasing demand for energy by diminishing reliance on traditional energy sources such as oil, gas, and coal. Therefore, it is imperative for the government to enforce these restrictions to significantly enhance the environment. To increase the use of renewable energy, it is necessary to provide subsidies and tax breaks for household and business investing in renewable energy system. Therefore, it is imperative for the government to enforce these restrictions to significantly enhance the environment.

5. To mitigate the detrimental impact of urbanization, physical capital, and financial development on the environment, it is imperative to implement a nationwide environmental awareness campaign that emphasizes sustainable practices.

The absence of data that is also associated with the factors of interest is one of the limitations of this investigation. The environment can be influenced by a variety of factors. Although it analyses urbanization, physical capital, financial development, and renewable energy consumption, it neglects to consider other critical variables, including economic growth, population, FDI inflows, and trade openness.

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