Determinants of Environmental Degradation in Bangladesh: A Dynamic ARDL Framework

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Abstract: *Bangladesh, as an emerging developing country, has been using energy intensively in various industrial and socioeconomic sectors without much consideration of environmental sustainability. Therefore, this research aims to explain the impact of tourism, urbanisation, and energy consumption on carbon dioxide emissions, used here as an indicator variable of environmental degradation. A dynamic time series analysis is applied in this study by considering yearly data from Bangladesh over the period of 1995 to 2019. After confirming the stationary status of the study variables, an autoregressive distributed lag (ADRL) bounds test is applied, which reveals the long-run association among the variables. Then, following the dynamic ARDL framework, the effects of targeted variables were fixed in short and long-run periods. The findings reveal that all variables are significant positive drivers of environmental pollution over the long run, save for energy consumption. Moreover, the short-run results indicate that tourism and energy consumption are both active contributors to pollution. The empirical findings of this study will help policymakers to develop a sustainable urbanisation and tourism expansion policy to minimise pollution levels. Finally, this study also supports reducing carbon dioxide (CO_2) emissions from the sectors targeting SDG 13, Climate Action by 2030.*

Keywords: CO_2 emission, Tourism, Energy consumption, Urbanisation, ARDL bounds test
JEL Classification: JQ2, JQ3, JQ4, JQ5

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1.   Introduction

As a delta nation, Bangladesh has always been vulnerable to the effects of global warming. Greenhouse gas (GHG) emissions are a major contributor to both global warming and environmental deterioration, with carbon dioxide having the greatest environmental impact. Due to globalisation, both wealthy and developing nations now contribute to GHG emissions. The International Energy Agency (IEA) (2021) claims that carbon dioxide (CO_2) emissions increased by 6% worldwide in 2021 because of the global economic recovery following the Covid-19 pandemic. Numerous social and economic causes, including the speed of industrialisation, ease of travel, urban development, loss of forests, etc., can explain the large change in carbon emissions (Mitić et al., 2023; Nielsen et al., 2021)

Bangladesh, as a rising developing country, faces accountability for carbon emissions despite historically lower contributions compared to developed nations. Investigating current and future emissions is crucial for several reasons. Rapid economic growth, with its heavy reliance on fossil fuels for power generation, is a key driver of rising emissions (World Bank, 2024). Industries like steel and textiles contribute significantly to national emissions (CPD, 2024). Urbanisation further escalates energy demand for buildings and transportation, necessitating sustainable urban planning strategies, as emphasised by the United Nations Department of Economic and Social Affairs (UNDESA) (UN, 2012). Moreover, Bangladesh's vulnerability to climate change underscores the importance of understanding emission sources to develop targeted reduction strategies outlined in the country's Climate Change Strategy and Action Plan (Ministry of Finance Bangladesh, 2023). Investigating accountability strengthens Bangladesh's position in international climate negotiations, facilitating resource acquisition from developed nations to address climate change impacts (UNFCC, n.d.). Therefore, investigating the accountability of Bangladesh' CO_2 emissions is crucial for environmental sustainability.

The promising economic growth of Bangladesh during the past decade is indicative of expanding industries in several areas, urbanisation, and an overall rise in living conditions, all of which may affect carbon emissions either indirectly or directly. Notably, the country produces 0.21% of the world's CO_2 emissions, although the situation has been worsening quickly. According to historical data, Bangladesh's CO_2 emissions rose 7.52%

per year from 3.3 million metric tons in 1971 to 108.5 million in 2020. According to the country's amended Nationally Determined Contributions (NDCs), its GHG emissions will increase from 169.06 million metric tonnes in 2021 to 409.41 million metric tons in 2030. In addition, per capita emissions were 0.05 tonnes in 1971, 0.34 tonnes in 2010, 0.51 tonnes in 2018, and 0.64 tonnes in 2020. Bangladesh's energy consumption is increasing rapidly, and as a result, CO_2 emissions per capita are increasing at an average yearly rate of 5.48 %. The energy industry is the largest source of CO_2 emissions, with 93.09 metric tonnes, representing 55.07 % of total emissions (Haque, 2022).

Urbanisation is a prominent environmental concern in Bangladesh. Since 1970, the country's urban population has increased rapidly. A constantly rising native urban population, territorial extension of existing urban areas by converting rural areas to urban, redefinition of urban regions, and rural to urban migration cause rapid urban growth. Undoubtedly, migration has played a significant role in the growth of metropolitan areas. Implementing the United Nations (UN) Sustainable Development Goals (SDGs) is challenging due to the environmental issues caused by urbanisation. Rapid urbanisation encroaches on waterways, woods, and hills due to population growth and area expansion, directly affecting the environment. Even though such acts are illegal, the pressure is uncontrollable. Due to urbanisation and economic growth, structure demand rises (higher household income) which may also lead to pollution. In turn, this boosts the need for bricks. With current technology, the production of bricks has two disadvantages: first, it depletes topsoil from agricultural land, and second, it causes air pollution in metropolitan areas because brick kilns are located nearby. Studies have indicated that CO_2-emitting brick kilns are the primary cause of Dhaka's air pollution. Population growth and economic development both increase the demand for and supply of automobiles, which exacerbates traffic congestion and air pollution in cities. Lifestyle changes like reckless air conditioning effect city microclimates and elevate temperatures. Metropolitan regions are more likely to experience natural disasters due to climate change. In short, climate change is a huge challenge.

Bangladesh has abundant resources. The world's longest natural sea beach lies in southern Bangladesh, a tourist destination. Tea gardens, marshy forests, waterfalls, and more abound in the northeast. Low travel costs and natural resources make the country a great travel destination. Between

2018 and 2019, approximately 16.4 million visitors visited Bangladesh, 80.28% of whom were non-resident Bangladeshis and the rest foreigners. In 2019, according to the Bangladesh Bureau of Statistics (BBS), the contribution of travel and tourism was 3.02% of the GDP, with 8.07% of overall employment associated to tourism (Byron & Hasan, 2021). Though Bangladesh's travel and tourism contribution to the GDP has fluctuated significantly in recent years, it has tended to climb from 2000 to 2019. Compared to 2019, Bangladesh's tourism earnings decreased by 44.3% in December 2020, although it increased by 9.5% in 2019 (CEIC Data, 2020). Although there are several examples of the positive effects of tourism on the economy, this industry also responsible for environmental pollution—from airplane flights and boat journeys to souvenirs and hotels, several activities add to the carbon footprint of tourism.

The tourism industry, despite its economic benefits, is a notable contributor to GHG emissions, primarily through various operational aspects. In terms of transportation, commercial air travel and cruise ships heavily reliant on fossil fuels significantly contribute to emissions. Ground transportation within destinations also adds to emissions, especially in regions heavily dependent on fossil fuels (EPA, 2024; Jaz et al., 2023). Accommodation establishments such as hotels and resorts consume substantial energy, with research highlighting a correlation between hotel size and energy consumption. Additionally, adventure tourism activities and increased waste generation by tourists further exacerbate GHG emissions, directly releasing pollutants and straining waste management systems (Borowski et al., 2022). Tourism frequently exerts strain on natural resources through overconsumption, frequently in areas where resources are scarce. Tourism places a significant strain on local land use, which can result in soil erosion, increased pollution, the destruction of natural habitats, and greater pressure on endangered species (Gupta & Dutta, 2018).

Energy is the fundamental driving force behind the new contemporary way of living. Energy use also explicitly linked to environmental catastrophe (Chen et al., 2016; Yılmaz, 2023; Bildirici & Çoban, 2023). Bangladesh, being an emerging developing nation, relies heavily on energy as a fundamental resource for promoting trade and industrial development. Industrialisation has led to more pollution in developing countries because green policies were not yet adopted. Energy, of course, is essential for every nation's economy, and the industry contributes to pollution in emerging

nations (Apergis & Gangopadhyay, 2020; Sreenu, 2022). Therefore, the prices of energy may also play a significant role in overall energy use and the level of pollution in Bangladesh, which inspired this study to examine the impact of energy use on pollution.

Several studies have already been conducted to assess the impact of energy use on environmental pollution in Bangladesh, but most use electricity consumption as a proxy for energy use. Rahaman et al. (2022) finds a positive impact of electricity use on environmental pollution in Bangladesh. Recent studies have examined the impact of energy use on pollution in Bangladesh and note a significant association between energy use and pollution in long- and short-run dynamics (Raihan et al., 2022d; Islam et al., 2021). The onset of urbanisation has occurred concurrently with the acceleration of industrialisation. Over the past five decades, Bangladesh has undergone an important phase of urbanisation. The urban population of Bangladesh increased from 8.6% in 1972 to 39.7% in 2022 (Kneoma, 2022). Pollution is more significantly impacted by the substantial improvement in urbanisation (Raza et al., 2023; Kahouli et al., 2022). Energy use and urbanisation both contribute significantly to the pollution of any developing country since these are unavoidable byproducts of economic development (Kirikkaleli & Kalmaz, 2020). Rising energy demand due to urbanisation also results in pollution (Raihan et al., 2022c). Kirikkaleli and Kalmaz (2020) use fully modified ordinary least squares (FMOLS) and dynamic OLS (DOLS) to identify the effect of energy use and urbanisation on environmental pollution, which exhibit a significant positive effect of both variables on pollution. By investing in clean energy technologies and policies that promote energy efficiency, we can break this cycle and reduce our reliance on oil, leading to a healthier planet and potentially even more stable oil prices (Alam, 2023). This paper addresses these macroeconomic issues and tries to bridge the literature gap of previous studies by considering a new set of economic variables that impede sustainability in developing nations like Bangladesh.

This analysis regresses urbanisation, energy consumption and tourism to explain environmental degradation. In addition, the % age-based yearly growth of the study variables is displayed in Figure 1, which illustrates the simultaneous growth of urbanisation, energy consumption and tourism activities along with CO_2 emission. In this study, CO_2 emission is used as an indicator variable to represent environmental pollution. CO_2 is commonly

acknowledged as the most prominent GHG resulting from human activities (EPA, 2023). Hence, the primary aims of this research are to substantiate the accountability of the rapid urbanisation, energy consumption, and the tourism industry in Bangladesh for environmental degradation by examining of both long- and short-run associations.

Figure 1: Growth of Variables, 1995-2019 (%)
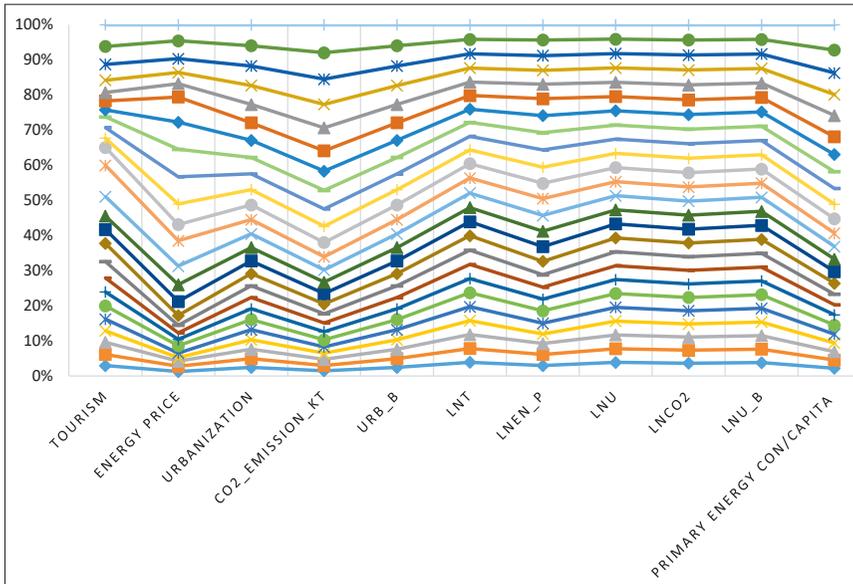
2.   Literature Review

In 1950, focus on environmental pollution started with the establishment of the environment Kuznets curve (EKC) hypothesis by Simon Kuznets. This EKC hypothesis holds an inverted-U relationship between environmental pollution and income. Later, empirical investigation into the association between economic development and energy consumption began in the late 1980s, led by Kraft and Kraft (1978). They investigated the causal association between GNP and gross energy use and found a unidirectional causality from economic growth to energy use. Moreover, Shafik and Bandyopadhyay (1992) also examine environmental quality and economic growth. With the 1997 Kyoto Protocol, the world focused on mitigating

environmental pollution and was concerned about the effect of GHGs. As a result, in the last two decades, the world has been intensely concerned about environmental pollution. Researchers also significantly contributed to pollution-based research works where they had considered other macroeconomic variables. Zou (2018) examines the impact of energy prices on environmental pollution using data on crude oil prices, CO_2 emissions, and GDP in the United States from 1983 to 2013 and discovers that oil price fluctuations have a significant impact on CO_2 emissions both in the long and short run. Amin and Atique (2021) conducted a panel study across South Asia regarding the impact of urbanisation and tourism together on environmental degradation and assert that urbanisation and tourism both have a positive influence on carbon emissions in the long run. According to Abbasi et al. (2021), energy prices are a significant factor in increasing environmental pollution. They conducted a panel dynamic analysis of 18 top complexity indexed countries, taking into account the effects of tourism, economic complexity, and energy prices on pollution. By using the autoregressive distributed lag (ARDL) method, they confirm that the price of energy has a positive effect on pollution.

Kahouli and Chaaben (2022) investigate the link among energy consumption, environmental degradation, trade, FDI, and economic growth of GCC countries by adopting the ARDL framework, and their findings support the significant effect of all study variables towards environmental degradation. Uzair Ali et al. (2022) conducted a panel ARDL analysis considering CO_2 emissions, fossil fuel consumption, economic growth, and population density in Bangladesh, Pakistan, and India. Their findings suggest that population density, and fossil fuel consumption accelerated CO_2 emissions in the long run. Usman et al. (2022) investigated the effect of urbanisation and energy consumption on environmental pollution, considering some other macroeconomic variables such as trade and economic growth in G7 countries. Using an ARDL model, they reveal that trade and urbanisation have a positive impact on pollution in the long run. Martial et al. (2023) investigate the impact of tourism, GDP, renewable energy, and electricity consumption on environmental pollution in 26 low-income countries, including Bangladesh, by adopting the generalized method of moments (GMM). They show that due to increasing economic growth, tourism is not harmful to the environment. Voumik et al. (2024) investigate the impact of tourism on environmental pollution along with

other macro-economic variables (GDP, renewable energy, energy intensity, and urbanisation) in 40 Asian countries using cross-sectional ARDL (CS-ARDL) method, which reveals that tourism can help mitigate CO_2 emissions, unlike urbanisation. Akther et al. (2024) examine the role of agriculture production, fertiliser use, tourism, and renewable energy on CO_2 emissions in South Asia using GMM, over the time span of 1991 to 2019. They find that all variables are responsible for increasing CO_2 emissions, except for the use of renewable energy.

Substantial research has been conducted on Bangladesh's environmental pollution, with several macroeconomic variables used to explain the pollution in early 1990s. Initially, Khan and Qayyum (2007) examined time series data for South Asia from 1972 to 2004 using ARDL to find a causal relationship between energy consumption and GDP in all economies. Later, Ahamad and Islam (2011) studied the energy consumption-growth nexus of Bangladesh using the vector error correction model (VECM) and discover a bidirectional relationship flowing from electricity consumption to economic growth in the long-run. Many studies have since been conducted on the environmental crisis. If we look back to the most recent studies on Bangladesh, researchers have concentrated their attention on explaining this environmental crisis by more associated macro-economic variables. Kashem and Rahman (2019) examine data from 1975 to 2015 in Bangladesh investigate the impact of urbanisation, GDP, and population density on CO_2 emissions. They discover a long-term equilibrium relationship and a bidirectional causal link between urbanisation and CO_2 emissions. Murshed et al. (2021) investigate the impact of renewable energy, energy use, and economic growth on the environmental pollution of Bangladesh between 1972 and 2015 and find a significant long-term association. Islam et al. (2021) examine the impact of globalisation, FDI and energy consumption on carbon emissions, while also taking into account other macroeconomic variables such as trade, innovation, etc. Rahman and Alam (2021) include urbanisation in their dynamic econometric model to assess its effect on environmental pollution in Bangladesh along with some other macroeconomic variables. Adopting an ARDL framework, they reveal that urbanisation has a detrimental effect on pollution. Using ADRL bounds testing and DOLS, Raihan et al. (2022a) investigate the nexus between some macroeconomic variables, including urbanisation and economic growth, and environmental pollution in Bangladesh. Taking the time series data from

1992 to 2019, they find that urbanisation and economic growth are both responsible for increasing CO_2 emissions. Rahaman et al. (2022b) also study the effects of FDI, tourism, electricity consumption, and economic growth on CO_2 emissions in Bangladesh, and reveal that except for tourism, other study variables have a positive effect on CO_2 emissions in the long run.

Due to different time limits and different macroeconomic variables set for separate mathematical methods, the output of studies varies. Islam et al. (2023) reinvestigate the EKC hypothesis for Bangladesh, considering economic growth and pollution along with other macroeconomic variables, but find no evidence of an EKC, and that urbanisation does not mitigate pollution. Raza et al. (2023) examine the contribution of economic growth, urbanisation and energy consumption on environmental pollution between 1980 and 2020, and find that all variables contribute to pollution.

Though different researchers have considered different sets of macro-economic variables in investigating environmental pollution in Bangladesh, the proposing variable set was not considered together. As rapid urbanisation requires intense energy use, and since the promising tourism sector may contribute towards environmental pollution, the present study tries to minimise the gap and explores the nexus among the variables using econometric analysis. In particular, this research considers the change in environmental degradation due to the variation of the selected set of independent variables: energy consumption, urbanisation, and tourism.

3.   Data Description, Model Specification and Methodology

3.1   Data description

This study uses yearly time series data on energy consumption, tourism, urbanisation, and CO_2 emissions, covering the period between 1995 to 2019. Here, the number of international tourist arrivals is applied as a proxy variable for tourism (Amin et al., 2020); urban population is an indicator variable for urbanisation (Al-Mulali, 2015); primary energy consumption per capita is a reference variable for energy consumption; and CO_2 emissions is used as a proxy variable for environmental pollution (Raza et al., 2023; Islam et al., 2023; Rahman and Alam, 2021). More specifications of our selected variables are given in the following table:

Table 1: Descriptions of Variables

Variables	Description	Indicator	Source
CO$_2$ emission	Carbon dioxide emissions (Kt)	$lnCO_2$	WDI, World Bank
International tourism, number of arrivals	International inbound tourists (overnight visitors, thousands of individuals)	$lnTO$	WDI, World Bank
Urban population	Urban population (thousands of individuals)	$lnUR$	WDI, World Bank
Energy consumption	Primary energy consumption per capita (kWh/person)	$lnEC$	US Energy Information Administration

Note: ln refers the natural logarithm of study variables.

The analysis uses the following ordinary experimental model:

$$lnCO2 = f(lnT, lnU, lnEC) \tag{1}$$

Where *lnCO2* refers to the logarithm of CO$_2$ emissions, the dependent variable; and *lnT*, *lnU*, *lnEC* represent the logarithm of international tourism, number of arrivals, urban population and energy consumption respectively, the independent variables. The major problem of time series data is its non-stationary status, and basic dynamic econometric analysis starts with confirming the unit root test. Considering the unit root status of the variables, this study proceeded with further time series analysis. The model specification procedure is shown in Figure 2.

Figure 2: Flow Chart of Model Selection Criteria
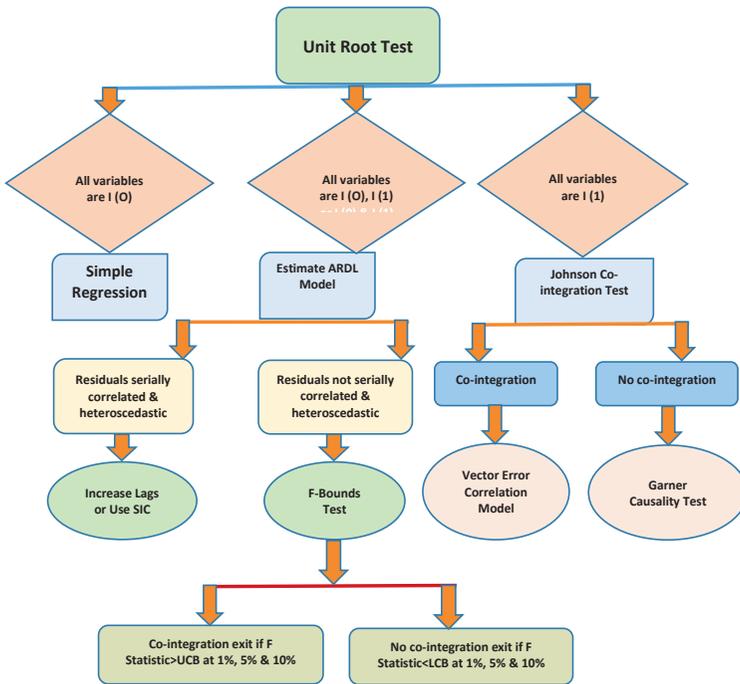
3.2 *ARDL model structure*

To scrutinise the impact of tourism, urbanisation, and energy prices on CO_2 emissions, we used the symmetric ARDL method (Pesaran et al. 1997; 2001). The ARDL methodology has several benefits over other cointegration techniques. This method is suitable whether the regressors are purely $I(0)$, $I(1)$, or mutually integrated, but for $I(2)$ series this approach is inapplicable (Ilyas et al., 2010; Meo et al., 2018). Therefore, to ensure order of integration of the involved variables, we employ the augmented Dickey-Fuller (ADF) stationary test (Dickey & Fuller, 1979). Further, as reported by Jalae et al. (2019) and Nkoro and Uko (2016), this model provides better results with small samples. Moreover, the ARDL approach is a single equation framework, and it allows uneven lag orders for different variables. To capture the relationship amongst variables the following ARDL framework is incorporated:

$$\Delta lnCO2_t = \beta_0 + \sum_{j=1}^{p} \beta_1 \Delta lnCO2_{t-1} + \sum_{j=0}^{p} \beta_2 \Delta lnTO_{t-1} + \sum_{j=0}^{p} \beta_3 \Delta lnUR_{t-1}$$

$$+ \sum_{j=0}^{p} \beta_4 \Delta lnEC_{t-1} + \gamma_1 lnCO2_{t-1} + \gamma_2 lnTO_{t-1} + \gamma_3 lnUR_{t-1} \quad (1)$$

$$+ \gamma_4 lnEC_{t-1} + \epsilon_t$$

Where $lnCO2$, lnT, lnU and $lnEC$ represent the logarithm of CO_2 emissions, international tourism, number of arrivals, urban population and energy consumption respectively; Δ represents the first difference operator; p represents the lag length; ϵ_t represents stochastic error correction term; and βs & γs indicate short run and the long-run parameters. The Schwarz Bayesian criterion (SBC) is used for optimal lag structure. To ascertain the appearance of a long-run relationship, we applied ARDL bounds testing procedure for co-integration (Pesaran et al., 2001). The bounds test methodology is founded on the joint F statistic of all lagged regressors, and null hypothesis of no linear relationship is present among variables, i.e., $\gamma_i = 0$, is carried out against the alternative hypothesis, i.e., $\gamma_i \neq 0$, i=1,2,3,4. The following error correction model estimates the short-run dynamics once co-integration has been achieved.

$$\Delta lnCO2_t = \beta_o + \sum_{j=1}^{p} \beta_1 \Delta lnCO2_{t-1} + \sum_{j=0}^{p} \beta_2 \Delta ln\,TO_{t-1} + \sum_{j=0}^{p} \beta_3 \Delta lnUR_{t-1}$$

$$+ \sum_{j=0}^{p} \beta_4 \Delta lnEC_{t-1} + \varphi ECM_{t-1} + \varepsilon_t \quad (2)$$

Where ECM_{t-1} is the lagged error correction term and φ is the component of ECM_{t-1} and other study variables ($lnCO2$, lnT, lnU and $lnEC$) are symbolised by the previously defined indicator. Subsequently, we applied several diagnostic tests to check the reliability of the dynamic model.

Additionally, to evaluate the robustness of the ADRL model, this study uses the DOLS regression technique (Stock & Watson, 1993). When the sample size is small, DOLS performs better because it encompasses the first difference of nonstationary regression coefficients along with the leads

and lags of the first difference regressors, which eliminates endogeneity and serial correlation among the parameters (Kalmaz & Kirikkaleli, 2019; Abumunshar et al., 2020). The main advantage of the DOLS technique is that it also considers the mixed order of integration of study variables (Raihan & Tuspekova, 2022a; Pattak et al., 2023).

4   Empirical Findings

4.1   Findings from ARDL framework

Prior to utilising ARDL approaches to examine the influence of the study variables on environmental contamination, Table 2 provides descriptive statistics and variance inflation factor (VIF) results. As the values of VIF are all below 10, they provide evidence that our independent variables do not exhibit multicollinearity.

Table 2: Descriptive Statistics and VIF Results

Variable	*lnCO2*	*lnTO*	*lnUR*	*lnEC*
Number of observations	25	25	25	25
Mean	10.56	12.19	17.50	7.32
Standard deviation	0.54	0.33	0.28	0.35
Minimum	9.71	11.55	17.05	6.81
Maximum	11.38	13.05	17.95	7.97
VIF	-	1.01	1.76	1.72

ARDL does not involve the pre-testing of variables (Nkoro & Uko, 2016). However, to ensure the integration level of the variables, we employed the ADF stationary test because the estimated F-statistic will be improper in the presence of the $I(2)$ variable. The results of the ADF test are displayed in Table 3. The null hypothesis of the ADF test is there is a unit root, and the alternative hypothesis implies its absence. The results indicate that all the variables involved hold a unit root at levels but become stationary at the first difference. Thus, this result assists us in performing the ARDL bounds testing procedure for co-integration to check the long-run association among the variables.

Table 3: Results of ADF Unit Root Test

	lnCO2	*lnTO*	*lnUR*	*lnEC*
Level	0.72306	-1.9514	-1.3739	3.7898
	(0.9897)	(0.3047)	(0.5749)	(1.0000)
1st difference	-4.1064	-4.0452	-24.9082	-5.3115
	(0.0191)**	(0.0216)**	(0.0001)**	(0.0023)**
Decision	I(1)	I(1)	I(1)	I(1)

Note: ** refers to significance at 5% levels.

The results of co-integration are reported in Table 4. As the F-statistic value of 14.61 is greater than the upper critical bound (UCB) of 3.67 at the 5% significance level, we can therefore state that there exists a long-run connection among variables. The summary of estimated long run and short run coefficients shown in panel A and panel B, respectively, of Table 4.

Table 4: Summary of ARDL Bounds Test for Co-Integration Based on Schwarz Bayesian Criterion

Model	F-Statistic	Critical value		Significance	Summary
		LCB	UCB	level	
F_{CO2}	7.25	2.79	3.67	5%	Co-integration

The long-run results of the ARDL assessment are displayed in Panel A of Table 5. The study identifies tourism, urbanisation, and energy consumption as significant variables for CO2 emissions in Bangladesh. At the 1% level, the long-run coefficients of urbanisation and tourism are both significant and positive. The findings indicate that tourism and urbanisation have a detrimental impact on the ecological sustainability of Bangladesh. Conversely, the long-run coefficient of energy consumption exhibits a statistically significant negative relationship at the 1% level, suggesting that it contributes to green sustainability in Bangladesh by reducing emissions of CO2.

In terms of tourism, CO2 emissions in Bangladesh rise by 0.223 units for every unit change in tourism activity, similar to the results obtained by Jayasinghe and Selvanathan (2021), Selvanathan et al. (2021), and Raihan et al. (2022a), and contradicting Rahaman (2022). Increased tourism activities have a detrimental effect on the climate as it accelerates

environmental damage. The tourism sector has the potential to contribute to environmental contamination by emitting nitrogen oxides into the atmosphere and releasing methane because of inefficient disposal methods. However, transportation associated with tourism, especially air travel, is a major source of CO_2 emissions that contribute to climate change and have consequences for regional as well as international ecosystems. Moreover, tourism infrastructure may also emit CO_2 through deforestation or land use adjustments. Tourism in Bangladesh is an expanding sector. Thus, ecologically conscious travel, green technology, and destination management are essential for reducing CO_2 emissions from tourism.

The findings suggest that urbanisation has a greater long-term impact on the deterioration of Bangladesh's environmental sustainability compared to tourism, as seen by its higher coefficient value of 2.581. This observation clarifies the potential negative impact of the swift expansion of urban populations on the long-term prospects of sustainable environmental goals. The agglomeration of business, industrial, and residential activities within metropolitan regions of Bangladesh typically leads to heightened energy requirements. To fulfil the energy requirements of various sectors such as construction, transportation, and manufacturing, the combustion of fossil fuels, notably coal, oil, and natural gas, is commonly employed, resulting in the release of CO_2 into the atmosphere. The findings of our study align with previous studies conducted in Bangladesh, e.g., Kashem and Rahman (2019), Rahman and Alam (2021), Islam et al. (2021), and Raihan et al. (2022b; 2022c). However, our research outcomes do not align with the results reported by Raza et al. (2023), who reveal significant adverse effects of urbanisation on CO_2 emissions. Moreover, the results of the current investigation align with the outcomes reported by Adebayo and Kalmaz (2021), Amin and Atique (2021), Raihan (2022a; 2022b; 2022c), Sufyanullah et al. (2022), and Voumik et al. (2023).

Eventually, our research reveals that energy consumption exerts a deleterious influence on CO_2 emissions. If energy consumption rises by one unit, it will cut CO_2 emissions by 0.463 units in the long run. This indicates that an increase in energy consumption is improving the ecosystem of Bangladesh. The present study's result aligns with the research conducted by Tvinnereim and Mehling (2018) as well as Umar et al. (2021). However, it contradicts the conclusions reported by Raza et al. (2023) with regard to the context of Bangladesh.

Additionally, Panel B of Table 5 shows the results of short-run dynamics. The coefficient is -0.87, which is less than one, negative, and significant at the 5% significance level. Therefore, it is a sign of long-run adjusted equilibrium among the involved variables. Hence, it indicates that 87% of the disequilibrium of the previous year has converged to equilibrium in the present year. From Panel B, we notice that in the short run, tourist arrivals and energy prices are significantly positive and related to CO_2 emissions.

Table 5: Summary of ARDL Estimation

Panel A: Long run coefficient		Panel B: Short run coefficient	
Dependent Variable: *lnCO2*		Dependent Variable: Δ *lnCO2*	
Variables	**Coefficient**	**Variables**	**Coefficient**
lnTO	0.223 (0.0041)	Δ*lnTO*	0.123 (0.0000)
lnUR	2.581 (0.0000)	Δ*lnUR*	0.178 (0.0031)
lnEC	-0.463 (0.0015)	Δ*lnEC*	0.254 (0.0263)
		ECM_{t-1}	-0.855 (0.0000)
		R^2a	0.87
Panel C: Diagnostic test of residuals			
χ^2_{Norm}	1.70 (0.426)	χ^2_{Het}	0.538 (0.837)
χ^2_{LM}	2.55 (0.131)	χ^2_{R-R}	4.05 (0.068)

Note: **p**-values are in brackets.

**Table 6**: Summary of DOLS Technique

Variables	Coefficient	Standard error	*p*-value
lnTO	0.152	0.0954	0.0033
lnUR	2.241	0.1141	0.0134
lnEC	-0.781	0.0481	0.0391

Table 6 presents the results of DOLS techniques. The results are similar to the ARDL findings. To uphold the reliability of our model, we have utilized the Jarque-Bera test (Jarque & Bera, 1987) for normality, the Breusch-Godfrey test (Breusch, 1978) for autocorrelation, and the autoregressive conditional heteroskedasticity (ARCH) test (Engle, 1982) of lag 1 for heteroscedasticity. Additionally, the Ramsey regression equation specification error test (RESET) test (Ramsey, 1969) adopted in a study to

confirm the model specification. The findings report in panel C of Table 4 and suggest that there is no problem of non-normality of residuals, serial correlation, heteroscedasticity, or misspecification of the model.

In addition, we have applied cumulative sum (CUSUM) methods to check the parameter stability of our dynamic model. From Figure 3, it can be concluded that the estimated parameters are stable as the CUSUM lines remain within the upper and lower bounds of the graph.

Figure 3a: CUSUM Approach for Parameter Stability
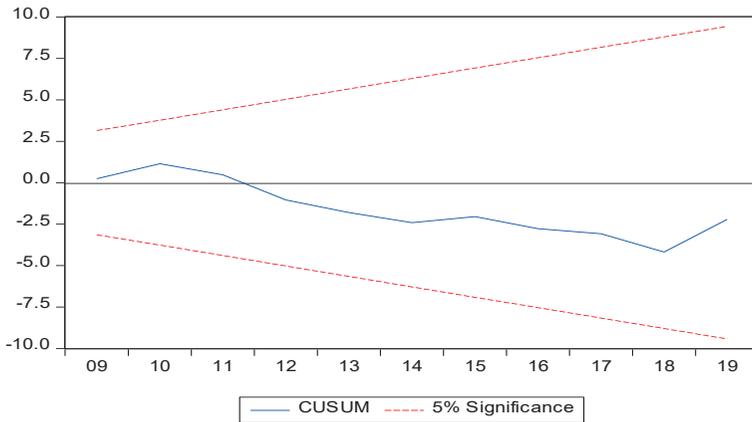
Figure 3b: CUSUMSQ Approach for Parameter Stability
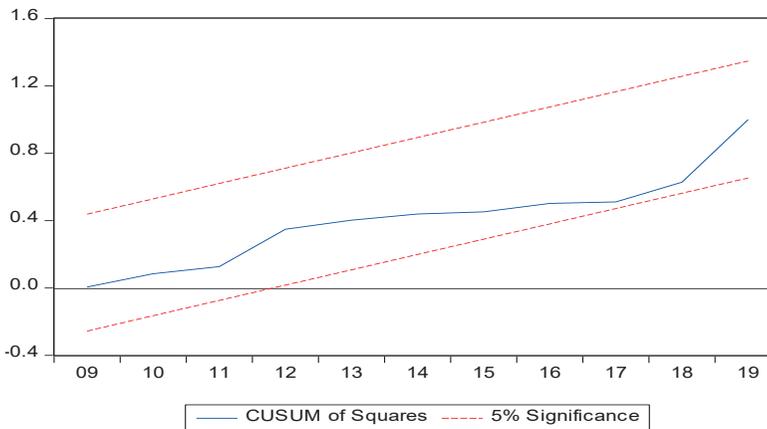
5.   Discussion and Conclusion

This study addresses the question of whether tourism, urbanisation, and energy consumption are responsible for environmental pollution in Bangladesh. The empirical evidence in the long run shows a significant impact of all study variables on environmental pollution. As tourism becomes more common and accessible to all, as urbanisation becomes a more prominent factor, and as energy consumption increases, CO_2 emissions will increase at a significant rate. This result also supports the claims of several previous studies that urbanisation and tourism cause CO_2 emissions.

However, it is apparent that urbanisation is an inclusive term for a country's advancement in several aspects. With the economic and social advancement of a country, many people tend to concentrate in certain areas, which results in the transformation of the land for residential, commercial, industrial, and transportation purposes. Hence, CO_2 emissions increase in more urbanised areas. On the other hand, people tend to use more and more energy with the development of living standards. Initially, people may utilise energy in unsustainable ways. However, when economic progress occurs, there will be an increasing awareness regarding the environment, as depicted in the EKC hypothesis. So, after a certain period, users will be concerned about environmental sustainability and search for alternative sources of energy that may depend on renewable energy, which may reduce CO_2 emissions in the long run. This also help Bangladesh to achieve SDG 7, which is affordable and clean energy. However, in the short run, energy consumption has a substantial positive influence on CO_2. We assume that for users, it may be difficult to switch suddenly to alternative energy. That may contribute to rising CO_2 emissions. Hence, with the change in energy prices, CO2 emissions change in both cases.

In this age of globalisation, tourism has become a prolific sector. The development of the industry and the influx of tourists require many accommodation setups and transportation facilities, which leads to a sufficient amount of energy use and indirectly affects CO_2 emissions. Based on these outcomes, this study suggests that policymakers focus their attention on constructing an organised and eco-friendly urban area. They can focus on spreading the scope to build sustainable industries and other facilities in rural areas that may reduce massive, unplanned urbanisation. Tourism also contributes a lot to pollution, so policymakers should be

concerned with making a tourism policy that is good for the environment. Bangladesh has a highly dense population, explaining why urbanisation is increasing drastically and increasing CO_2 emission levels. At the same time, the number of local tourists also rising dramatically as their socioeconomic condition is improving. Therefore, government should plan properly how to impose carbon neutrality, or a carbon tax based that would help us to have some polity measures for Climate Action, which is our target by 2030.

6.   Policy recommendations

Considering the study's findings, the following are some policy recommendations to address environmental pollution caused by tourism, urbanisation, and energy consumption in Bangladesh. To promote sustainable urban development, eco-friendly city planning with green spaces, public transportation systems, and energy-efficient buildings should be encouraged. This can be achieved through tax breaks for developers who follow these principles. Eco-friendly tourism practices can be promoted, such as responsible waste management, homestays in rural areas, and minimising transportation emissions. This could involve certification programs for eco-friendly tourism businesses.

There should be greater investment in renewable energy sources like solar, wind, and hydro power to reduce reliance on fossil fuels and CO_2 emissions. This could involve subsidies or tax breaks for renewable energy projects. The government should also consider implementing a carbon tax or carbon neutrality policies for specific sectors. This would put a price on CO_2 emissions and incentivise businesses to reduce their carbon footprint, which may secure sustainable environment and mitigate the adverse impact of climate change. Public education campaigns are also crucial to raise awareness about environmental issues and encourage sustainable living practices.

The implementation of sustainable urban development and carbon pricing measures can promote the establishment of a sustainable environment. Ensuring a sustainable environment helps reduce the detrimental impact of climate change, which aligns with SDG 13. Hence, these suggestions also contribute to the attainment of the SDG objectives in the foreseeable future.

7.   Limitations

The study has been conducted with few macroeconomic variables such as tourism, urbanisation and energy prices. However, there is a wider scope to consider other relevant macroeconomic variables which accelerate environmental pollution. Further, this study has considered CO_2 emissions as a proxy of environmental degradation. Other responsible GHGs (sulphur dioxide, nitrogen dioxide, etc.) also can be considered as indicator of environmental pollution. Moreover, uniform dataset for carbon neutrality and carbon tax for climate action is missing in Bangladesh. The government has no concrete policy to follow for the extension of urbanisation and tourism sector. Therefore, Bangladesh is still far from achieving the Climate Action (SDG 13) target by 2030.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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