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An Empirical Investigation of GDP, Industrialization, Population, Renewable Energy and CO_2 Emission in Bangladesh: Bridging EKC-STIRPAT Models

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ABSTRACT

This research paper explores the presence of the Environmental Kuznets Curve (EKC) in Bangladesh, delving into the intricate relationships among GDP, industrialization, renewable energy utilization, and CO_2 emissions. Utilizing the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model, our investigation spans the 1992-2021 timeframe, offering a comprehensive analysis of the interplay between these crucial factors in the context of Bangladesh's environmental sustainability. In this study, the F-bound test is utilized to establish the cointegration relationship among variables. And the short-run and long-run elasticity of explanatory variables is investigated by employing the Autoregressive Distributed Lag (ARDL) approach. This research also employed a pairwise granger causality test to explore the direction of causality between them. Empirical results prove the existence of a cointegration relationship among CO_2 emission, GDP per capita, a quadratic form of GDP per capita, renewable energy, industrialization, and population. The findings provide strong support for the presence of the EKC in the case of Bangladesh. Besides that, significant inverse relationship was also obtained between CO_2 emission and renewable energy consumption. Additionally, the study found the detrimental long-term effects of industrialization on the environment. The EKC hypothesis argues that Bangladesh can accomplish sustainable economic development. To attain the goal country should adopt appropriate government policies and ensure their implication. This study strongly advocates using sustainable energy sources and implementing regulations on pollutant industries.

Keywords: Bangladesh; STIRPAT; Carbon dioxide emission; Renewable Energy; Industrialization; Sustainability
JEL Classifications: L9, O13, P18, Q00

1. INTRODUCTION

Economic progress drops anchor by improving energy use, infrastructure, water management, technology, etc., which harms environmental quality. Ensuring green economic growth while maintaining environmental quality is a tough challenge in the contemporary world. The impact of unplanned economic growth on biodiversity has attracted the attention of world economists, which is reflected in both the Paris Agreement in 2015 and the Kyoto Protocol in 1997 (Nathaniel and Lheonu, 2019). According to the Intergovernmental Panel on Climate Change (IPCC), global warming will rise between 1.8°C and 4°C by the end of the 21^{st} century, which is higher than the previous one. And human activity, which releases greenhouse gases (GHG) into the atmosphere, is the primary cause of global warming (Ryan-Collins et al., 2011, Zimon and Zimon, 2020, Khan et al., 2023; Khan et al., 2020). Environmental deterioration, exacerbated by global warming, catalyzes global climate change, rendering the earth uninhabitable for living being.

From the very beginning, achieving higher economic growth has been the prime goal for Bangladesh's macroeconomic stabilization policy area. In the last 50 years, Bangladesh has achieved remarkable economic progress, which is taking a toll on its environment (extreme pollution, land erosion, deforestation, depletion of resources etc.). Potential climate hazards like an increase in sea level, drought, salinity ingress, cyclone, storms, loss of habitats, destabilization of agriculture, etc., now impede the country's economic development. Bangladesh's annual average rainfall is anticipated to increase by 4%, 2.3%, and 6.7% by 2030, 2050, and 2070, respectively, while its sea level is expected to rise by at least 40 cm by 2030 (Bangladesh Economics Review, 2021). The rise in sea level can submerge up to 13% of the coastal land of Bangladesh by 2080, which is one-third of the total area of this country. There is a strong possibility that 25-30 million people will displace due to this pollution-driven flood (Daizy et al., 2021).

Carbon dioxide (CO_2) is the dominant contributor to this global warming, as it is liable for 58.8% of GHG (greenhouse gas) emissions (Bacon and Bhattacharya, 2007; Ghosh et al., 2014). This paper investigates the driving force of CO_2 emission in Bangladesh. The relationship between carbon dioxide emissions and GDP per capita has been empirically analyzed using the environmental Kuznets curve (EKC) theory in the context of the STIRPAT model. According to the concept of EKC, a country's growth increases environmental degradation primarily, and after achieving a sufficient income level, the association turns negative (Suki et al., 2020). Growth in GDP or per capita income directly reduces environmental quality by raising carbon emissions in the country (Mansoor and Sultana, 2018; Menyah and Wolde-Rufael, 2010; Saboori and Sulaiman, 2013; Shahbaz et al., 2013, Zimon et al. 2022, Walasek et al. 2023, Zimon, 2016). Population density has a colossal concussion on the environment which should be considered eruditely. Researchers have found unidirectional causality between CO_2 emission and population growth (Cole et al., 1997; Sadorsky, 2014; Huang et al., 2008). Over the past few decades, Bangladesh has been walking on the path of economic development under the umbrella of rapid Industrialization. Population density and growing Industrialization have weaved alarming environmental crises in this country.

According to the EKC hypothesis, the consequence of GDP growth or rising per capita income on an economy's environmental quality involves three stages: scale, structural, and composite effects. The scale effect, in the first stage, degrades the environmental quality. After achieving a certain level of GDP growth (which can be different for different economies) due to advanced technology and increased environmental awareness, environmental quality begins to recover. Eco-friendly technology abates environmental degradation (Farooq et al., 2022). In an economy, increased income proposes innovation of green technology, green city project, etc. However, as a developing nation with a high poverty rate, the nation must recognize the need for economic growth and Industrialization. Therefore, using energy effectively is essential to continuing growth efforts. Bangladesh's energy usage has risen over time. Compared to 1973, when it was 93.93 kg of oil equivalent per person, it increased to 229.25 kg of oil equivalent per person in 2014, a 144% increase (WDI, 2022). The use of renewable energy as a percentage of overall energy use decreased from 0.45% in 1973 to only 0.15% in 2014, a decrease of 65.74% (WDI, 2022). Undoubtedly, the bulk of energy in Bangladesh is produced using fossil fuels or other non-renewable energy sources, which results in higher CO_2 emissions and environmental damage. However, this study focuses on the influence of renewable energy usage and CO_2 emission in Bangladesh and recommend essential policy to mitigate CO_2 emission.

This study investigated the relationship between environmental quality and economic affluence in Bangladesh. Here, carbon dioxide emission proxies for degradation of the environment and GDP per capita represent economic affluence. This research utilized the autoregressive distributed lag model to observe the long-run and short-run dynamics and causal relationship between CO_2 emission and population, GDP per capita (a proxy for economic affluence) and Renewable energy consumption and Industrialization (a proxy for technology).Our main objectives of this study are as under:

i. To find out the existence of the Environmental Kuznet Curve (EKC) in the framework of the STIRPAT model in Bangladesh
ii. To explore the short-run and long-run relationship between CO_2 emission and GDP per capita, renewable energy consumption, Industrialization and population in Bangladesh
iii. To detect the causal relationship between CO_2 emission and GDP per capita, population, Industrialization and renewable energy consumption in Bangladesh

The main contributions of this research are: (1) Variable selection is theoretically and conceptually justified about Bangladesh; (2) This study used the most up-to-date and comprehensive data accessible; (3) The results were obtained using appropriate econometric approaches, which were then examined using various diagnostic tests; (4) To our best knowledge, this is the first empirical study that considers Current education expenditure, tertiary (% of total expenditure in tertiary public institutions) as a proxy variable for technology in the context of Bangladesh. This will help understand the need for more effective policies for research and development; (5) The research findings are applicable and coherent with the theories and present context of the country; (6) This study will help conducive to the policymakers to make beneficial policies in Bangladesh as well as worldwide.

The remainder of the paper is formatted as follows: Sect. 2 represents the detailed review of relevant literature. Section 3 briefly outlines the data, theoretical framework, and econometrics methodology of this study. The results from the econometric analyses are presented and explained in the "Results and discussion" section, with proper literature support in sections 4 and 5. Finally, Sections 6 and 7 describe the conclusion and provides some policy implications. At last, section 8 provides limitations and future researches.

2. LITERATURE REVIEW

Existing literature asserts that human activities are accountable for the environment's continued deterioration, but the dynamics of the driving variables still need to be entirely determined. In the empirical literature, two major analytical models are often utilized. One is the Environmental Kuznets Curve (EKC) hypothesis, which stresses the importance of economic growth. And another one is the STIRPAT model, which describes environmental degradation as a function of affluence, population, and technology (Nwani and Omoke, 2020; York et al., 2023).

From 1970 to 2015, an empirical study (ARDL) on the impact of urbanization and economic progress on carbon dioxide emissions in Singapore concluded that economic growth had a positive and significant impact on carbon emissions (Ali et al., 2017). For the same period in Malaysia, bidirectional causality is observed between GDP and CO_2 emission (Bekhet and Othman, 2017). Using the STIRPAT model, Appiah et al. (2018) observed that technology is a vital driving force for CO_2 emissions in Ghana. In this study (1990-2016), technology proxies by residential energy efficiency, access to electricity and clean cooking. The environmental Kuznets curve (EKC) in Pakistan is supported by empirical research using the same model, in which the industrial sector's share in GDP is used as a reference variable for technology (Faridi et al., 2018). Using the ARDL technique, Ilu (2019) investigated the relationship between carbon emissions in metric tons per capita GDP, energy use, and access to electricity as a percentage of the total population in Nigeria from 1990 to 2018. This research did not discover the existence of Kuznet's Curve throughout the inquiry. In the short run, however, access to electricity was found to be adversely and significantly associated with carbon emissions, whereas energy use is the opposite. In the prolonged run, energy consumption was found to be adversely and significantly associated with carbon emissions, although access to power was the polar opposite. Wang et al. (2011) argued that in China's population, economic growth and technology increased CO_2 emissions in both the long and short run using the IPAT model and ARDL bound test approach. Using ARDL simulation, Nwani and Omoke (2020) examined an empirical model in Brazil (1971-2014). According to the estimations, economic growth and the intensity of consumption of fossil fuels have a considerable long-run growing impact on CO_2 emissions.

In Nigeria, the years 1970 through 2017 were considered for conducting a trend analysis about the relationship between economic growth and CO_2 emission. The study discovered that economic growth significantly and positively impacts both long- and short-run CO_2 emissions (Akorede and Afroz, 2020). By using Log Mean Divisia Index (LMDI) decomposition techniques, Majeed et al. (2020) obtained that in Pakistan, while the compound annual growth rate increases the emission growth, the technological effect does the opposite significantly. In their study, Shaari et al. (2021) analyzed the role of energy usage, economic growth, and rural population growth on CO_2 emissions in nine developing nations from 1990 to 2015, spanning different geographical regions. Using the panel ARDL method, they proved that higher energy consumption and economic growth could increase CO_2 emissions over time in the long run. In Chile, researchers obtained environmental degradation from economic growth by utilizing data from 1990 to 2018. Using a nonlinear ARDL model, the study discovered that technological innovation is unsuccessful at reducing consumption-based carbon emissions (Adebayo et al., 2021).

In the example of Peru, a study was undertaken to explain the combined influence of economic globalization, financial growth, and fossil fuel intensity consumption on carbon emission, where it was discovered that fossil fuel consumption could enhance environmental degradation (Okere et al., 2022; Salehi et al., 2022). This study verified the inverted U-shaped hypothesis between economic growth and carbon emissions by utilizing dynamic ARDL counterfactual simulation and kernel-based regularized least squares within the context of the STIRPAT model (1971-2017). Islam et al. (2013) investigated the EKC hypothesis for Bangladesh using data from 1971 to 2010. By utilizing the ARDL approach, they obtain that energy consumption and urbanization worsen the quality of the environment, but trade openness improves it. The same dynamics are observed between urbanization and CO_2 emission in a study from 1973 to 2013, where ARDL bound test technique was adopted (Rayhan and Islam, 2015). The association between environmental deterioration (with carbon emission standing as a proxy for environmental deterioration), economic growth, total energy consumption, and an increase in the industrial production index was investigated (1998-2013). The study shows a significantly positive association between industrial production, GDP per capita, and carbon emission (Islam et al., 2017; Kashem and Rahman, 2019) urged that GDP growth and urbanization are Bangladesh's primary sources of CO_2 emissions. Islam et al. (2022) The relationship between capital formation, urbanization, trade openness, energy consumption, technological innovation, and economic growth on Bangladesh's ecological footprint was analyzed using the (ARDL) simulations method and annual frequency data from 1972 to 2017. They concluded that the formation of capital, urbanization and the use of energy all hurt the quality of the environment, whereas the opening of markets to commerce and the development of new technologies had a positive impact.

As an environmentally benign substitute for conventional fuels like gasoline, coal, and oil, renewable energy sources, including air, tidal power, solar, and many more, have exploded in popularity. Renewable energy sources may lessen greenhouse emissions in the air while providing clean energy at levels comparable with carbon-based sources. Numerous studies have been undertaken over the last several years to determine how and how much renewable energy can cut CO_2 emissions. For instance, Raihan et al. (2022) explored the relationship between renewable energy and Carbon emissions by employing data from 1980 to 2019 in Bangladesh. In doing so, the study applied ARDL bound test to observe the association among the variables. The study also applied Dynamic Ordinary Least Squares (DOLS) estimation approach to determine the long-run interaction among the variables. The study's findings indicated that renewable energy has a significant inverse relationship with carbon emissions. Similarly, Sharmin (2021) examined the association between renewable and non-renewable energy usage and CO_2 emission in Bangladesh. The study employed ARDL and DOLS estimation approach, and the findings showed that renewable energy remarkably contributes to mitigating CO_2 emission.

Moreover, Voumik and Sultana (2022) scrutinize the existence of the EKC hypothesis in the context of Bangladesh by considering the role of economic growth, energy consumption, and population. The study employed time series data over the period 1971 to 2020. By employing the ARDL method, the study found the long-term existence of EKC and observed that renewable energy significantly reduces CO_2 emissions. Furthermore, Rahman and Alam (2022) examine the role of renewable energy usage in reducing the emission of CO_2 in Bangladesh. The study utilized time series data for Bangladesh from 1990 to 2018. The study also employed Pooled Mean Group (PMG) and nonlinear autoregressive distributive (NARDL) approach to observe the long-run relationship among the variables used. The study's findings observe that renewable energy contributes to mitigating CO_2 emissions in Bangladesh.

The research reviewed above reveals significant arguments about the influence, either positive or negative, of technical components on the environmental deterioration that occurs in different countries. In the case of Bangladesh, there need to be more studies regarding the existence of EKC and the effects of technological factors on CO_2 emission. Most existing literature on this issue needed to consider the well-known and commonly used STIRAT model to examine the dynamics. As there is a lack of information about technological factors in Bangladesh, different variable types are used as a proxy in different studies. Renewable energy consumption and Industrialization as a proxy of technological factors and environmental degradation have not been studied in Bangladesh using the ARDL bound test approach to investigate the existence of the EKC hypothesis. Because Bangladesh has been at the forefront of the significant threat posed by environmental degradation and increased demands for ecological resources over the past few decades, this linkage must be considered. Thus, based on the above literature review and to achieve the objective of the current paper, we have formulated the following hypotheses:

H_1: Significant EKC influence exists in Bangladesh

H_2: Significant long- and short-run relationships exist between CO_2 and its determinants in Bangladesh

3. MODEL AND DATA

3.1. Data and Correlation Matrix

In this study, the variables' range is from 1992 to 2021. Table 1 exhibits the definition of variables, log form, variable name, year range, and sources.

The summary data in Table 2 have been log-transformed. To better evaluate the dependent variable, log transformation was performed. This table provides summary statistics for five different variables: $\ln CO_2$, lnGDP, lnPOP, lnINDUS, and lnREN. The number of observations for each variable (N) is also provided. The mean, standard deviation, minimum, and maximum values are given for each variable. The results show that mean value of lnINDUS is the highest and mean value of lnREN is the lowest.

The correlation coefficients among $\ln CO_2$, lnREN, lnINDUS, lnGDP, and lnPOP are displayed in the Table 3 below. Each variable has a perfect correlation with itself, as shown by the diagonal values which are all 1.000. Triangular matrices display the correlation coefficients, with the diagonal showing the correlations between the individual variables. $\ln CO_2$ has a strong negative correlation with lnREN (−0.976), a strong positive correlation with lnINDUS (0.991), a strong positive correlation with lnGDP (0.997) and a strong positive correlation with lnPOP (0.944). lnREN has a strong negative correlation with lnINDUS (−0.948), a strong negative correlation with lnGDP (−0.963) and a strong negative correlation with lnPOP (−0.989). lnINDUS has a strong positive correlation with lnGDP (0.998) and a strong positive correlation with lnPOP (0.858). lnGDP has a strong positive correlation with lnPOP (0.880).

3.2. Theoretical Model (EKC-IPAT Bridging)

The IPAT model is one of the most concentrated ones that may be used to investigate the effect of economic activity on the amount of energy consumed and the environment. The model postulates that the environmental effect, denoted by the letter "I," is the product of three factors: the population (P), the level of wealth (A), and the level of technological advancement (T) (Ehrlich and Holdren, 1971).

This can be written as an Equation (1)

$$I = P\,A\,T \tag{1}$$

Where I represents the influence, P demonstrates demographics, A represents economics, and T represents technological considerations, respectively. The fact that the known values of some factors in this model determine the value of the missing term does not allow the hypothesis to be tested (York et al., 2003). Dietz and Rosa (1997) suggested using the STIRPAT model to overcome this limitation.

The model can be written as Equation (2)

$$I_t = \alpha P_t^b A_t^c T_t^d \,\varepsilon_t \tag{2}$$

Taking logarithms (ln) allows the nonlinear Equation (2) to be changed into a linear form, as demonstrated in Equation (3).

$$\ln(I_t) = \alpha + b\ln(P_t) + c\ln(A_t) + d\ln(T_t) + \epsilon \tag{3}$$

Here, a, b, c, and d stand in for the coefficients term, ε stands in for the error term, and the subscripts t display time in the appropriate order. The IPAT model makes it possible to evaluate various factors impact on the environment (CO_2).

To investigate the presence of the EKC, GDP per capita (GDPPC) and GDP per capita square ($GDPPC^2$) are employed. On the other hand, to confirm the STIRPAT model, GDP, technological improvement (renewable energy and industrialization) variables,

Table 1: Definition of variables, frequency and sources

Variable	Log Form	Definition	Year	Source
Carbon dioxide Emission	lnCO_2	CO_2 emissions (kt)	1992-2021	WDI (2023)
Gross Domestic Product Per Capita	lnGDPPC	GDP per capita (constant 2015 US$)		
Gross Domestic Product Per Capita²	lnGDPPC²	GDP per capita² (constant 2015 US$)		
Population	lnPOP	Population, total		
Renewable Energy	lnREN	Renewable energy consumption (% of total final energy consumption)		
Industrialization	lnINDUS	Industry (including construction), value added (constant 2015 US$)		

Source: WDI, World bank

Table 2: Summary statistics

Variables	n	Mean	SD	Min	Max
lnCO_2	30	10.37	0.665	9.290	11.42
lnGDP	50	6.519	0.428	5.995	7.447
lnPOP	50	18.54	0.288	18.01	18.93
lnINDUS	50	23.35	1.015	21.36	25.21
lnREN	30	3.867	0.318	3.209	4.293

Source: Authors' computations

Table 3: Correlation matrix

Variables	lnCO_2	lnREN	lnINDUS	lnGDP	lnPOP
lnCO_2	1.000				
lnREN	−0.976***	1.000			
lnINDUS	0.991***	−0.948***	1.000		
lnGDP	0.997***	−0.963***	0.998***	1.000	
lnPOP	0.944***	−0.989***	0.858***	0.880***	1.000

***P<0.01, **P<0.05, *P<0.1, Source: Authors' computations

population and environmental pollution (CO_2 emission) are considered.

Then, Equation (3) is extended as in Equation (4).

$$lnCO_{2t} = \beta + \alpha_1 lnGDPPC_t + \alpha_2 lnGDPPC_t^2 + \alpha_3 lnREN_t + \alpha_5 lnINDUS_t + \alpha_4 lnP_t + \psi_t \quad (4)$$

Where β is the intercept and t is the period, ψ_t stands for a error term with constant variance and zero means, which is assumed to be normally distributed, and $\alpha_i S$ (i = 1,…., 4) are the coefficients of the variables.

The EKC hypothesis between the degree of economic growth and CO_2 emissions (inverted U-shape) acknowledges that GDP per capita (GDP) has both favorable and adverse effects on the natural environment.

This is consistent with the positive and negative impacts of GDP per capita (GDPPC) on CO_2 emissions cancelling each other out. Hence the assumptions regarding GDP per capita (GDPPC) and CO_2 emissions in Bangladesh are accepted if $\alpha_1 > 0$ and $\alpha_2 < 0$, respectively.

3.3. Empirical Model and Method of Analysis

3.3.1. Autoregressive distributed lag model

An econometric model was developed based on theoretical and empirical literature to reveal the existence of EKC and the impact of "Renewable energy consumption and Industrialization" on CO_2 emission. Thus, the following, Adeleye et al. (2018) and Kripfganz and Schneider (2016), the generalized autoregressive distributive lag (ARDL) model:

$$\ln CO_2 = \omega_{0i} + \sum_{i=1}^{p} \alpha_i lnCO_{2_{t-i}} + \sum_{i=0}^{q} \beta_i lnGDP_{t-i} + \sum_{i=0}^{q} \gamma_i lnGDP^2{}_{t-i} + \sum_{i=0}^{q} \delta_i lnREN_{t-i} + \sum_{i=0}^{q} \Pi_i lnINDUS_{t-i} + \sum_{i=0}^{q} \theta_i p_{t-i} + \varepsilon_t \quad (5)$$

In Equation (5), ω is the constant term, β_i, γ_i, δ_i, π_i, and θ_i are the parameters. The dependent and explanatory variables can be purely I (1) or co-integrated, and q is the optimal lag order. Here, t refers to time, and ε_t stands for the vector of the error term, which is an unobservable zero mean white noise vector process (serially uncorrelated or independent). The Equation (5) addresses whether "renewable energy consumption and industrialization" plays a role in determining CO_2 emissions in Bangladesh between 1971 and 2020. In addition, it addresses the problem of EKC being present in Bangladesh.

3.3.2. Error correction model and cointegration test

3.3.2.1. Bound cointegration test

Inferential data analysis approaches were utilized in this investigation. It encompasses the unit root test, ARDL bound test, diagnostic tests, and the Granger causality test. In this study, time series data are employed. Hence it is required to determine whether the variables are stationary. To determine the order of integration of the variables, we employ the Augmented Dickey–Fuller or ADF (Dickey and Fuller, 1979), Phillips–Perron or PP (Phillips and Perron, 1988), and KSSUR (Kwiatkowski et al., 1992) unit root tests in this inquiry.

After determining the order of integration of the variable, this study used the ARDL bound cointegration technique to assess whether there is a long-run relationship between independent and dependent variables.

Compared to the conventional cointegration method, the ARDL bounds cointegration method has several advantages (Pesaran et al., 2001). While it does not accommodate I(2) or high-order variables, it does permit mixed-order variables, particularly I(0), I(1), fractionally integrated variables, or mixed [I(0) or I(1)] (Ozturk and Karagoz, 2012;Shahbaz and Faridul, 2011). The second benefit is that while the conventional cointegration techniques required a significant sample observation, the ARDL bounds cointegration technique can be applied to small and finite samples (N < 50). It has the potential to address omitted variables, serial correlation concerns, and endogeneity issues because the long-run model produces unbiased estimates. The last advantage of the ARDL bounds cointegration method is that it enables simultaneous long-run and short-run dynamics in a single reduced form of the Equation (Harris and Sollis, 2003).

There are two sets of crucial values at each significance level to test the long-term link between the variables. One set of critical values assumes that all regressors are I(0) and stands for the lower bound critical value, whereas other sets assume that all regressors are I(0) and signify the upper bound critical value (1). If the estimated F-statistic is greater than the upper limit critical value (UBC) (F > FUBC), the null hypothesis can be rejected, and it can be stated that the variables utilized in this study are co-integrated. In contrast, the null hypothesis cannot be rejected if the estimated F-statistic is smaller than the lower bound critical value (LBC) (F < FLBC). This indicates that the variables employed in this study are not co-integrated if the estimated F-statistic falls between the upper and lower boundary critical values (FLBC < F < FUBC), it is impossible to draw any conclusions regarding the cointegration position of the variables utilized in this study.

In this study, the event of long- and short-run dynamics are investigated using error correction representations specified as:

$$\Delta \ln CO_2 = \mu_{01} + \lambda \begin{pmatrix} b_1 lnCO_{2_{t-i}} + b_2 lnGDP_{t-i} + b_3 lnGDP^2{}_{t-i} \\ +b_4 lnREN_{t-i} + b_5 lnINDUS_{t-i} + b_6 lnP_{t-i} \end{pmatrix} + \sum_{i=1}^{p} a_1" \, lnCO_{2_{t-i}} + \sum_{i=0}^{q_1} a_2" \, lnGDP^2{}_{t-i} + \sum_{i=0}^{q_2} a_3" \, lnGDP_{t-i} + \sum_{i=0}^{q_3} a_4" \, lnREN_{t-i} + \sum_{i=0}^{q_4} a_5" \, lnINDUS_{t-i} + \sum_{i=0}^{q_5} a_6" \, lnP_{t-i} + \epsilon_{1t} \quad (6)$$

Regarding the unrestricted error correction model (ECM) given in Equation (6), the joint null hypothesis is that there is no long-run relationship between the variables used in this study.

[H_0: $b_1=b_2=b_3=b_4=b_5=b_6=0$] was tested against the alternative hypothesis that there is a long

run relationship between the variables used in this study [H_0: $b_1 \neq b_2 \neq b_3 \neq b_4 \neq b_5 \neq b_6$].

The hypothesis that there is a long-run link between the variables investigated in this study was verified by comparing the results of the F-test statistic produced to the critical values suggested by Pesaran et al. (2001). In Equation (6), λ represents the coefficient of error correction term (speed of adjustment coefficient), which should be negative, less than one, and statistically significant to have the long-run equilibrium.

3.3.2.2. Diagnostics test

This study confirmed the validity of the estimated ARDL model by using the Durbin-Watson autocorrelation test (Durbin and Watson, 1971), the Breusch–Godfrey serial correlation LM test (Breusch, 1978; Godfrey, 1978), the ARCH heteroscedasticity test (Engle et al., 1985), the white homoscedasticity test (White, 1980), the Jarque–Bera normality test (Bera and Higgins, 1992; Jarque and Bera, 1987), and the Ramsey RESET specification test (Ramsey, 1969). All of these tests were used to examine the distribution of the data. In addition, the cumulative sum of square recursive residual tests, also known as CUSUM and CUSUMsq tests, were utilized to validate the estimated model's stability.

3.3.2.3. Pairwise granger causality test

The concept of Granger causality between two variables states that the conditional forecast for the second variable can be significantly improved by including the lagged first variable in the information set. The pairwise Granger causality test was used in the study to determine whether or not there was a short-run causal relationship between the variables. Causality is defined as Xt is said not to Granger cause Yt if

$$E\left(Y_{t+h} | J_{t,} X_t\right) = E\left(Y_{t+h} | J_t\right) \quad (7)$$

Jt denotes the information sets considering the past observation of X_t and Y_t up to and including time (t). To ensure the presence and direction of long-run Granger causality between the variables, this study utilized the coefficient of error correction term (Granger, 1988).

4. RESULTS AND DISCUSSION

4.1. Unit Root Test Results

For any empirical investigation, variables must be stationary to avoid spurious results. All five variables of this study are subjected to Kapetanios, Shin and Snell unit root test (KSSUR), Phillips–Perron test (PP) and Augmented Dickey–Fuller (ADF) tests. For these tests, the null hypothesis of a unit root cannot be rejected if the test statistic is insignificant. The result is represented in Table 4.

By using AIC and SIC, it has been calculated how long the lag should be. (b) An intercept and a trend term are also included in all unit root testing. (c)The estimated coefficients have significant levels of ***, **, and *, denoting statistical significance at 1%, 5%, and 10%.

Based on the findings in Table 4, our research sample is a combination of the I(0) and I(1) series. All three tests produced results that were consistent with the findings regarding carbon dioxide emissions, GDP per capita, square of GDP per capita, renewable energy consumption, and industrialization are stationary at first difference or I(1); however, the findings regarding population is stationary at level or I(0). In the Table 5, unit root with structural breaks is provided.

4.2. Bound Cointegration Test Results

To examine the cointegration among the variables, this study proceeded to the ARDL bounds test approach, as the variables are integrated into different orders. The results are exhibited in Table 6.

The result indicates that the null hypotheses of no cointegration are rejected at the 1% level. So, there are unique co-integrating

Table 4: Unit root test

Variable	IPS Test		PP Test		ADF Test		Remark
	Level	1st Diff.	Level	1st Diff.	Level	1st Diff.	Stationary at I (1)
$lnCO_2$	−1.895	−6.658***	−1.491	−7.149***	−1.547	−6.993***	Stationary at I (1)
lnGDPPC	−6.658***	−11.531***	0.935	−6.154***	0.862	−7.733***	Stationary at I (1)
$lnGDPPC^2$	−1.248	−12.380***	1.834	−7.584***	1.654	−7.319***	Stationary at I (1)
lnPOP	−3.865***	9.258***	−3.485**	−5.675***	−4.491**	−5.244***	Stationary at I (0)
lnINDUS	−1.824	−8.512***	−0.7254	−6.919***	−0.845	−6.921***	Stationary at I (1)
lnREN	−2.246	−4.568	−1.025	−3.025	−0.632	−4.025***	Stationary at I (1)

Source: Authors' computations

Table 5: Unit root tests with structural breaks

Variables	ZA statistic	Year of Break	Decision
$lnCO_2$	5.642***	1995	Break Exists
lnGDPPC	6.645***	2010	
$lnGDPPC^2$	4.32*	2012	
lnPOP	−5.518***	1996	
lnINDUS	−2.162	2002	
lnREN	−4.65**	2008	

Source: Authors' computations

Table 6: Bound cointegration test

Test statistic	Value	K
F-Statistic	8.659	5
Critical value bounds		
Significance level	I (0)	I (1)
10%	3.28	4.26
5%	4.49	4.78
1%	5.85	6.28

Source: Authors' computations

Table 7: ARDL full test

Variables	ADJ	LR	SR
L.lnGDPpc		15.25***(3.096)	
L.lnGDPpcsq		−1.032***(0.227)	
L.lnPOP		2.210**(0.938)	
L.lnINDUS		−0.583 (0.430)	
L.lnREN		−1.133***(0.245)	
$L.lnCO_2$	−0.908*** (0.166)		
D.lnGDP			10.45 (16.31)
$D.lnGDP^2$			−0.779 (1.242)
D.lnPOP			13.58**(6.315)
D.lnINDUS			0.355 (0.399)
D.lnREN			−1.518***(0.195)
Constant			−62.36***(13.08)
Observations	29	29	29
R-squared		0.922	

Standard errors in parentheses *** $P<0.01$, **P<0.05, *P<0.1, The estimated coefficients have significant levels of ***, **, and *, denoting statistical significance at 1%, 5%, and 10%. Source: Authors' computations

Table 8: Granger causality test results

Null hypothesis	Wald Statistic	Decision
$lnCO_2$⇒lnGDPPC	9.658***	$lnCO_2$⇒lnGDPPC
lnGDPPC⇒$lnCO_2$	6.655***	
$lnCO_2$⇒lnPOP	0.958	$lnCO_2$ ⇒ lnPOP
lnPOP⇒$lnCO_2$	6.325***	
$lnCO_2$⇒lnREN	0.548	No causality
lnREN⇒$lnCO_2$	2.056	
$lnCO_2$⇒lnINDUS	8.654***	$lnCO_2$⇒lnINDUS
lnR&D⇒$lnCO_2$	7.657***	

The estimated coefficients have significant levels of ***, **, and *, denoting statistical significance at 1%, 5%, and 10%. The AIC has determined the optimal lag period

relationships among the variables in the model. In this study, the long-run forcing variables are GDP, GDP2, renewable energy consumption, industrialization and population, and they move first when a standard stochastic shock hits the system. The implication of the above finding is that: CO_2 emission follows changes in these indicators.

4.3. ARDL and ECM Results

In this study, we used a log-level autoregressive distributed lag (ARDL) error correction representation approach to analyze the long-run relationships and short-run dynamics after the establishment of cointegration. The result is represented in Table 7.

This table reveals that the error correction term (adjustment, the first lag of CO_2 emission) is statistically significant and negative (−0.908). A significant and negative error correction term describes the rate at which variables return to equilibrium. So, a comparatively high adjustment coefficient directs a quicker adjustment procedure (in absolute terms). This study's findings indicate that over 90% of the disequilibrium caused by shocks in the previous year is restored to the long-run equilibrium in the current year.

Table 7 shows that lnGDP and its quadratic form $lnGDP^2$ have a significant positive and a negative impact on $lnCO_2$. It means that the long-run relationship between lnGDP and $lnCO_2$ is not linear, confirming the EKC theory's existence. Furthermore, CO_2 emission is negatively influenced by lnREN (−1.133), lnINDUS (−0.583) and positively by population (2.21). On the other hand, in the short-run, lnGDPPC and its quadratic form $lnGDP^2$ have an insignificant negative and a positive impact on $lnCO_2$. It means that though the short-run relationship between lnGDP and $lnCO_2$ is not linear, the existence of the EKC theory is not confirmed. In the long run, renewable energy consumption and population exhibit the same impact on $lnCO_2$ emission in the short run. The results also showed that Industrialization has an insignificant positive impact on $lnCO_2$ emission.

4.4. Granger Causality Test Results

The results of the Pairwise Granger causality test from a single equation are presented in Table 8. At a significance threshold of 1%, the null hypothesis that CO_2 emissions do not Granger cause GDPPC is rejected. Conversely, the null hypothesis that GDPPC does not affect CO^2 emissions through Granger causation is similarly rejected at the same level of significance. Thus, a bidirectional causal relationship exists between CO_2 emissions and per capita GDP in Bangladesh over a short period. Aside from the unidirectional relationship between population and CO_2 emission, population Granger significantly causes CO_2 emission.

Last but not least, the Granger causality test reveals that there is also a bidirectional relationship between CO_2 emission and Industrialization, and the relationship is significant at a 1% level of significance. Therefore, the coefficient of the error correction component is significant at a significance level of 1 percent. Thus, there is a long-term causal relationship between GDP and CO_2 emission, as well as Industrialization and CO_2 emission.

4.5. Diagnostic Tests Results

The goodness of fit of the ARDL-error correction model is the last addressed issue. For this purpose, a series of diagnostic and stability tests were carried out at Table 9.

The diagnostic tests examine serial correlation, homoscedasticity, heteroscedasticity, normality and model specification. The result in Table 9 indicates no challenges of misspecification, heteroscedasticity, higher-order autocorrelation or normality in the model. This clarifies that the results from this investigation are robust and reliable for making inferences. Also, the plot of the CUSUMSQ shows that the model is stable as the graph lies within the 5% significance level boundaries (Figure 1).

5. DISCUSSION

The GDP has positive impact on CO_2 emission, on the other hand, GDP^2 has negative impact on CO_2 emission. So, the more income rise it will be beneficial for environment in Bangladesh. However, important is the government's policy, which will adopt an appropriate strategy for environmental protection and CO_2 emissions. For example, in Poland the government is interested in political interests and environmental protection comes second, an example of this is the policy related to coal mines. (Zimon and Zimon, 2020; Zimon and Salehi, 2023; Sadowska, 2016; Zimon et al., 2023).

Table 9: Diagnostic tests results

Statistics test	Statistics	P-value
Breusch-Godfrey LM test for autocorrelation	Chi-square=0.423	0.685
White test for homoscedasticity	Chi-square=32.248	0.486
Breusch-Pagan/Cook-Weisberg test for heteroskedasticity	Chi-square=0.356	0.5214
J B normality test	Chi-square=2.821	0.3652
LM test for autoregressive conditional heteroskedasticity (ARCH)	Chi-square=0.026	0.6842
Ramsey RESET test	F (4, 36)=2.365	0.5714
Adjusted R^2	0.427	

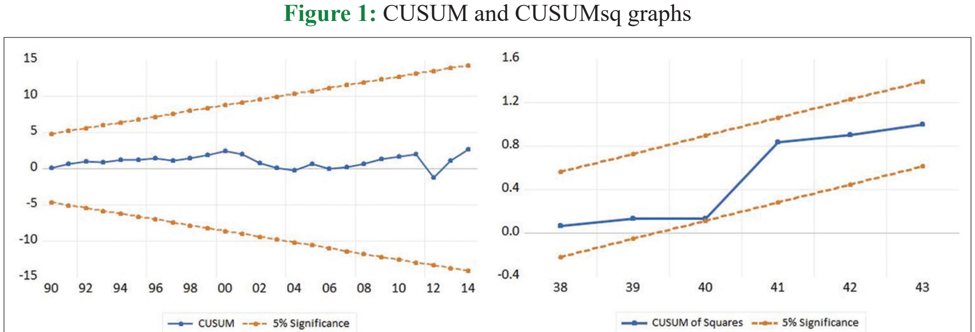
The estimated coefficients have significant levels of ***, **, and *, denoting statistical significance at 1%, 5%, and 10%. The AIC has selected the optimal lag duration

Consequently, EKC exists in Bangladesh. According to the Environmental Kuznets Curve (EKC), as Bangladesh's per capita GDP rises, the country's environmental impact will also rise at first, but then fall as the population grows richer. The EKC hypothesis postulates that developing nations put more emphasis on expanding their economies than on protecting their natural resources at first, but that as their middle classes increase, they shift their focus to environmental protection. Findings from studies pointing to an EKC indicate that progress in both economic development and environmental protection are possible, at least within specified bounds (Voumik and Sultana, 2022). The similar EKC hypothesis exists in South-Eastern Europe (Abul and Satrovic, 2022), in Kenya (Al-Mulali et al., 2016), and in China (Mahmood et al., 2023).

The impact of population is also detrimental for environment. Numerous environmental issues arise when populations rise. Simila results findings by Rehman et al. (2022), Baloch et al. (2020), and Ali et al. (2019). One is that there will be a greater demand for essentials like food and water, which may result in their overuse and eventual exhaustion as populations rise. More people also mean more garbage, which can increase pollution and environmental degradation. In addition, it strains essential infrastructure like housing and transportation, which can hasten the spread of cities and the loss of natural areas. More population also means more carbon emissions, which has a higher overall influence on the climate (Begum et al., 2015).

The impact of renewable energy is beneficial and significant for environment. Simila results findings by Sultana et al. (2023), Raihan et al. (2023), Panwar et al. (2011), and Chien (2022). Renewable energy sources, such as solar, wind, and hydropower, can reduce CO_2 emissions by decreasing the demand for fossil fuels. Electricity generation from the combustion of fossil fuels like coal and natural gas is a significant contributor to greenhouse gas emissions. As opposed to conventional power plants, the generation of electricity from renewable sources does

Figure 1: CUSUM and CUSUMsq graphs



not result in any pollution. CO_2 emissions can be reduced further by using renewable energy to power vehicles rather than their traditional fossil fuel counterparts. By using renewable energy to power electric vehicles, for instance, we may drastically cut transportation-related CO_2 emissions (Voumik and Mimi, 2023; Pattak et al., 2023; Voumik and Mimi, 2023; Zimon et al., 2023). On the other hand, industrialization has negative impact on CO_2 emission in the short run.

6. CONCLUSION, POLICY IMPLICATIONS, LIMITATIONS AND FUTURE RESEARCHES

The purpose of this study is to investigate whether or not EKC exists in the economy of Bangladesh. For this purpose, the STIRPAT model in the EKC framework was utilized from 1971 to 2020. This empirical research work adapted the ARDL F-bound test. This method is used to investigate the cointegration relationship among the factors that interest the researcher and the short-run and long-run impacts of those variables, respectively. In the empirical analysis, the technique demonstrates that variables about the STIRPAT model (population, wealth, and technology) exhibit a long-run equilibrium relationship during the sampled time for the case of Bangladesh. This study also applied the pairwise Granger Causality technique to assess the short-run and long-run causality direction. The result of the F-bound test concluded that there are unique co-integrating relationships among the variables in the long-run. The investigation obtained the existence of EKC in Bangladesh. Apart from that, in the case of Bangladesh, affluence variable GDP per capita and population influence CO_2 emission positively, which is also statistically significant for both the short-run and long-run. The technology variable, renewable energy consumption, affects CO_2 emission negatively in both the short-run and long-run with statistical significance. The findings also showed that industrialization negatively influences CO_2 emission in the long run but positively affects CO_2 in the short run. But the coefficients of industrialization are insignificant in both cases. In this study, CO_2 emission exhibits a unidirectional relationship with the population and a bidirectional relationship with GDP per capita and industrialization. There is no causality between CO_2 emission and renewable energy consumption. No study is beyond criticism or limitation. We could not include some variables (e.g., Urbanization, deforestation, electricity consumption, globalization, democracy, and etc.) that may affect CO_2 emission. Bangladesh was chosen for this research based only on the fact that GDP per capita development and environmental degradation are increasing in tandem. From a similar standpoint, the results in other developing nations are variable. The research also has missing data. Conducting a study that uses data collected over a longer period of time to better capture the long-term relationship between industrialization, population, energy consumption, and CO_2 emissions in Bangladesh. In light of this, we request additional research that considers other pertinent variables besides the most recent data covering the more prominent regions. Future research should adopt the nonparametric estimation technique to contribute to appropriate policy guidelines. Future research will compare the results with other developing countries, to see the generalizability of the findings.

The presence of a statistically significant EKC relationship in both the long run and short run in Bangladesh proves that the country has the potential to move towards sustainable development. That is, the current level of economic activity can be pursued to achieve economic growth without causing much harm to the environment under the present management system. However, the results of pairwise Granger causality tests suggest that the growth in per capita income in Bangladesh is not environmentally benign. Because of the causal connection between per capita income and carbon emission, the government of Bangladesh's policies to boost economic growth and reduce environmental degradation need to be maintained. It will help to diminish challenges regarding sustainable development. The lion's share of the economic activities of Bangladesh depends on fossil-based energy sources such as coal and natural gas. The country must find a path to shift the production base from these CO_2 emitters to green and renewable energy sources. The study's findings indicate that Industrialization is a significant problem that must be addressed while implementing sustainability strategies. It is necessary to modify and optimize the industrial structure to preserve economic development through cleaner manufacturing while reducing CO_2 emissions. The government of Bangladesh should ensure that hazardous industries with a history of threatening public health undertake strict pollution control measures. International investors must also comply with limitations and restrictions to adopt greener manufacturing and industrialization practices. Energy production and usage must be sustainable for green Industrialization to develop, focusing on using renewable energy sources. Additionally, the authority may use administrative measures to support the reformation of large and high-emissions businesses while supporting industrial diversification to promote zero- and low-emissions sectors. Environmentally friendly practices must be made mandatory for all industry employees, and outdated, more damaging technologies must be completely phased out to allow for a more hygienic manufacturing system. Additionally, the authorities may give funds to buy equipment to control emissions. Politicians may impose environmental fees on industries that reject eco-friendly technologies. Additionally, modern technology must be developed by both public and commercial R&D organizations to lower emissions and promote the utilization of recycled industrial effluents as fuel.

While this study contributes valuable insights, it is not without limitations. Firstly, the research period from 1992 to 2021 may not capture short-term fluctuations or recent developments that could impact the relationships under investigation. Additionally, the analysis relies on the assumption of linearity in the relationships, potentially overlooking nonlinear and asymmetric dynamics that could influence the outcomes. The study's scope also omits potential regional variations within Bangladesh, which might affect the generalizability of findings. Future research should address these limitations by incorporating a more recent dataset, exploring nonlinear relationships, and considering regional disparities. Furthermore, the study primarily focuses on CO_2 emissions and renewable energy, overlooking other pollutants and alternative green energies and technologies. Future research endeavors could extend the analysis to encompass a broader environmental impact spectrum and assess the effectiveness of diverse sustainable technologies. Lastly, an in-depth examination of the specific policy measures and governance structures that facilitate or hinder the suggested sustainable practices could provide nuanced insights for policymakers aiming to navigate the complex interplay between industrialization, economic growth, and environmental conservation.

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