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Investigating the Impact of Economic Development, Energy Consumption, International Trade and Population on CO_2 Emission of a Country: Evidence from an Emerging Economy

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ABSTRACT

This paper investigates the consequences of economic development, along with energy consumption, international trade, and population growth, on the CO_2 emissions of Bangladesh as a participant in an emerging economy, covering periods from 1972 to 2021. The unit root properties of the variables have been tested using the Augmented Dickey-Fuller approach to examine the presence of stationary of data series. To check for co-integration in the data series of variables included in the models, we used the autoregressive distributive lag bounds testing approach. In addition, the vector error correction model Granger Causality approach has been used to examine the casual relationship between the selected variables representing the proxy for determinants of CO_2 emission in Bangladesh. Our investigation confirms the co-integration between the data series, followed by the significant impact of these variables on CO_2 emissions of Bangladesh. More precisely, gross domestic product being the proxy of economic development, energy consumption, merchandise trade as a proxy for international trade, and population growths have had a significant positive impact on the CO_2 emissions of Bangladesh since its inception.

Keywords: CO_2, Gross Domestic Product, Energy Consumption, Population, Autoregressive Distributive Lag Modeling
JEL Classifications: Q43, Q52, Q56

1. INTRODUCTION

A country's CO_2 emissions can be significantly affected by a number of factors, including population growth, energy consumption, international trade, and economic development. Industrialization, infrastructure growth, and an increase in energy demand as a result of economic development are often associated with increases in CO_2 emissions (Park and Hong, 2013). Demand for fossil fuels, which provide the majority of countries' energy, often rises as a result of economic expansion (Sbia et al., 2014). It is important to remember, nevertheless, that economic expansion is not necessarily accompanied by a rise in CO_2 emissions. Countries can adopt green technologies and ecologically friendly power sources to reduce discharges while still advancing the financial situation.

Energy consumption significantly contributes to CO_2 emissions because the majority of countries continue to rely substantially on the production of energy from fossil fuels (e.g. Jayanthakumaran et al., 2012; De Vita et al., 2015). Fossil fuel combustion releases CO_2, which aids in the greenhouse effect and climate change. However, by moving to renewable energy sources like wind, solar, or hydroelectric power and lowering energy usage, CO_2 emissions can be greatly reduced. Besides, through the transfer of emissions from one country to another, international trade can have an effect on a nation's CO_2 emissions. A nation indirectly contributes to the emission of CO_2 when it imports goods produced in a nation with higher CO_2 emissions. "Coal leakage" is the name given to this idea. When assessing their total emissions, nations must take into account the carbon footprint of their imports and exports.

In addition, population expansion has a huge impact on a nation's CO_2 emissions. As a nation's population grows, so does the demand for products and services, driving up both energy production and consumption. Industrialization typically results in the production of goods and services that need energy-intensive operations, such as manufacturing and transportation. Burning fossil fuels for energy results in the emission of CO_2 into the atmosphere, which contributes to climate change. As more energy is consumed, CO_2 emissions increase accordingly. Alongside, the need for land for infrastructure, agriculture, and housing increases along with a country's population. Land use changes have the potential to raise CO_2 emissions, contribute to deforestation, and harm natural habitats. Moreover, CO_2 emissions can rise when more people move to urban areas as a country's population grows. The amount of energy used by people increases when they use more power, heat, and air conditioning. Urban communities likewise will generally have a higher convergence of enterprises that discharge ozone harming substances.

Due to the fact that climate change and global warming is now a global issue, all of the above-mentioned reasons motivate the study of CO_2 emissions and their drivers in a global and regional context considering both developed and developing economies (e.g. Alam et al., 2016; Begum et al., 2015; Zhang and Cheng, 2009). Therefore, this paper aims to investigate the impact of economic development, energy consumption, international trade and population growth on the CO_2 emissions of Bangladesh over a period of 1972-2021. Bangladesh has been taken into account since it makes for an intriguing case for a number of reasons. First, it is one of the countries that would most likely experience severe unfavorable consequences from climate change due to the problem of global warming brought on by environmental pollution (The Intergovernmental Panel on Climate Change, 2001). Second, Bangladesh as an emerging economy, is continually putting policies in place for its economic growth, which is linked to international trade and energy consumption. Last but not least, Bangladesh's high population density is to blame for a number of its social and economic issues. Therefore, it is crucial to identify whether and to what extent the economic growth, energy consumption, population and international trade is linked to higher CO_2 emissions. All of this makes Bangladesh an interesting country to study, especially given that this is the first study to examine the relationship between CO_2 emissions and economic development, energy consumption, international trade and population growth of Bangladesh in a single study. Even though these factors have been the subject of numerous studies in the past about Bangladesh's CO_2 emissions, none of these studies has included all these determinants for a period extended to 2021 (e.g. Ghosh et al., 2014; Alam, 2014; Alam et al., 2012).

To conduct this analysis, as a proxy for economic development, the Gross Domestic Product (GDP) is used, and to represent international trade, the merchandise trade balance is utilized. The Augmented Dickey-Fuller (ADF) method has been used to assess the unit root properties of the variables and determine whether data series are stationary. We employed the autoregressive distributive lag (ARDL) bounds testing approach to look for co-integration in the data series of the variables used in the models. Additionally, the casual link between the chosen variables serving as a proxy for the determinants of CO_2 emission in Bangladesh has been investigated using the vector error correction model (VECM) Granger Causality technique. The empirical evidence indicates a significant positive impact of all the variables on CO_2 emissions. The long-term outcome reveals that all explanatory variables have a statistically significant impact on CO_2 emissions in the same direction as expected. Whereas, for the short-term outcomes, all explanatory variables except for merchandise trade have a statistically significant impact on CO_2 emissions. The results from this analysis have several policy implications for an economy like Bangladesh. Bangladesh may gain politically and symbolically at global stage by recognizing the causes that contribute to CO_2 emissions and by demonstrating the nation's involvement in resolving CO_2 emissions while enacting environmentally friendly policies. Moreover, it can persuade other nations to cut their CO_2 emissions.

The rest of the study is organized as follows: Section 2 gives a brief literature review. Section 3 presents the data and methodology used in this study. Section 4 discusses the empirical results while Section 5 concludes the study with some policy implications.

2. REVIEW OF LITERATURES

CO_2 emission has been experiencing substantial rise over last few decades drawing the attention of researchers to investigate its potential determinants. The literature is dominated by the bivariate country-specific studies with little emphasis on multivariate studies such as that by Farhani and Rejeb (2012). Despite of the inclusion of various relevant variables (e.g. trade), the outcomes mostly remain inconclusive for the policymakers to reformulate plans for long-term growth. Hence, it is crucial to have adequate knowledge regarding the causal relationship between the variables along with the direction of such causality.

The association between economic growth and CO_2 emissions (proxy of environmental quality) is tested through the presence of EKC hypothesis that represent the relation as a U-shaped nonlinear curve. The shape of curve indicates that at initial periods of development, CO_2 emissions increases with economic growth, however, later at maturity stage, with the introduction of carbon efficient technologies CO_2 emissions decline with increasing development. The hypothesis has been tested in various studies including Grossman and Krueger (1995), Dinda and Coondoo (2006). Moreover, country specific studies has been conducted by Tunç et al. (2009) and Ozturk and Acaravci (2010) for Turkey, Lean and Smyth (2010) for ASEAN, Pao and Tsai (2010) for BRIC countries, Pao and Tsai (2011) for Brazil, Shahbaz et al. (2012) for Pakistan, Tiwari et al. (2013) for India, Kasman and Duman (2015) for new EU member and candidate countries.

Most of the studies have ignored aspects such as cross-sectional dependence and various sources of energy consumption. However, Dogan and Seker (2016) used EKC model to investigate the impact of real income, renewable energy consumption, non-renewable energy consumption, trade openness and financial development on CO_2 emissions concluding that the utilization of renewable energy sources, the promotion of open trade policies, and the advancement of financial development diminish carbon emissions significantly. Later, to check the cross-sectional dependence using the EKC model, it was evidenced that the response variable (CO_2 emissions) and explanatory variables (energy consumption, GDP, GDP^2, tourism, and trade) continued to have a long-term connection which tend to coexist and influence each other over a prolonged period for the OECD countries (Dogan et al., 2017). Moreover, Dogan et al. (2017) proposed that environmental degradation initially rises with economic growth but decreases after a certain level of economic development; indicating a U-type relationship between income and CO_2 emissions, while the direction of causal relationship with other variables varied. According to Boamah at al. (2017), there exists co-integration and long-term relationship between CO_2 emissions, economic growth, energy consumption, imports, exports, and urbanization as such that a unit increase in economic growth will likely to lessen CO_2 emissions by 13% and 1% rise in energy will likely to increase CO_2 emission by 1.05%, also 1% increase in urbanization will likely raise emissions by 3-46%. Furthermore, Saboori et al. (2012) observed a linear relationship between CO_2 emissions and per capita income, which was supported by various other studies such as Shafik and Bandyopadhyay (1992), Shafik (1994), Azomahou et al. (2006), Dinda and Coondoo (2006) and Van and Azomahou (2007). Saboori et al. (2012) also found an effective way to control CO_2 emissions by consuming less energy from gas, oil, electricity and coal. In addition, Osiobe (2014) discovered a lasting relationship between the variables (per capita carbon dioxide being the dependent variable and GDP, international trade, energy consumption & population density, being independent variables) although not enough evidence was found to support the EKC hypothesis. However, for the USA economy, no causal relationship was evidenced between energy consumption and economic growth in the studies of Eden and Hwang (1984), Cheng (1995) decades ago. Similar result was found by Yu and Choi (1985) for UK, Erol and Yu (1987) for France and very recently by Rahman and Mamun (2016) for Australia. However, Oh and Lee (2004), Asafu-Adjaye (2000), Chang (2010) found bi-directional causality between the two variables for South Korea, Thailand and the Philippines, and China respectively. Again, Unidirectional causality was observed in case of energy consumption and output growth for Indonesia (Asafu-Adjaye, 2000), Srilanka (Morimoto and Hope, 2004), China (Shiu and Lam, 2004), Venezuela (Squalli, 2007), USA (Bowden and Payne, 2009), South Africa (Menyah and WoldeRufael, 2010). On the other hand, some studies revealed unidirectional causality in case of Taiwan (Cheng and Lai, 1997), Singapore (Chang and Wong, 2001), Turkey (Ozturk and Acaravci, 2010).

In case of South Korea, economic growth and CO_2 emissions is found to be positively correlated (Park and Hong, 2013). Similarly, Jayanthakumaran et al. (2012) concluded that both in China and India, increased energy consumption contributes to pollution as well as provided support for the validity of the EKC hypothesis. Moreover, for China, a positive causality was found between energy consumption and CO_2 emissions both in the long and short run, whereas, trade and CO_2 was insignificant in the long run, but significant in the short run with trivial effect (Jayanthakumaran et al., 2012). Farhani et al. (2014) suggested the presence of the EKC hypothesis in Tunisia and energy consumption and trade contributing to the emissions of CO_2. Further, in the United Arab Emirates, Sbia et al. (2014) indicated that foreign direct investment (FDI), CO_2 emissions, and total trade (TR) have adverse effects on energy demand, thus, leading to the decrease of the latter. Conversely, economic growth positively influences energy consumption. Moreover, the study by Lee and Brahmasrene (2013) suggested that for European Union countries, tourism has a direct and positive effect on economic growth and, economic growth and CO_2 are positively correlated, while tourism mitigates pollution. Besides, Katircioğlu (2014) also confirms the EKC hypothesis and a negative relation between tourism and CO_2 emissions. In a similar study in Malaysia, Solarin (2014) demonstrated that tourism and GDP have positive effect, whereas financial development has negative effect on CO_2. Again, León et al. (2014) found that tourism has a positive relation for developed and less developed nations. De Vita et al. (2015) also supported EKC hypothesis and found energy consumption along with tourism contributes CO_2 emissions.

Growth of population is also a significant element for CO_2 emissions both in developed and developing countries (Engelman, 1998). Al Mamun et al. (2014) analyzed association between CO_2 emissions and population growth through a panel dynamic approach on 136 countries and concluded that population increases CO_2 emission in the long run. Moreover, the relation was found statistically significant both in short and long term for India (Ohlan, 2015). However, in case of Nigeria, population growth was found to determine CO_2 emission in the short run only (Sulaiman and Abdul-Rahim, 2018), whereas in Malaysia, there was no significant relationship between the two variables (Begum et al., 2015).

Considering the findings from various literature, following hypothesis has been constructed to investigate the impact of Economic Development, Energy Consumption, International Trade and Population on CO_2 emission of an emerging country like Bangladesh:

H_0: There is no significant relationship between Economic Development, Energy Consumption, International Trade, Population and CO_2 emission in Bangladesh.

H_1: There is a significant relationship between Economic Development, Energy Consumption, International Trade, Population and CO_2 emission in Bangladesh.

3. DATA AND METHODS

This is explanatory research showing the impact of energy consumption, population growth, international trade and economic development on CO_2 emissions in Bangladesh. As proxies of economic development and international trade, the GDP and merchandise trade balance have been used, respectively. The data for these variables, such as GDP, energy consumption, population, and merchandise trade value of Bangladesh, has been collected from the official website of the World Bank, covering the sample period from 1972 to 2021. The usual form of CO_2 emission is a function of the following determinants:

$$CO2_t = f\begin{pmatrix} GDP_t,\ ENERGYCONS_t,\ MERCHANDISETRADE_t, \\ POPULATION_t \end{pmatrix} \quad (1)$$

Transforming all the variables into natural-log form, we have constructed the second equation to estimate the above-mentioned equation, as mentioned below:

$$\ln(CO2_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_t\right) + \beta_3\left(\ln \text{ENG}_t\right) + \beta_4\left(\ln \text{MET}_t\right) + \beta_5\left(\ln \text{POP}_t\right) + \mu \quad (2)$$

The details of the variables such as notation, explanation, expected sign of coefficients are outlined below (Table 1):

Adopting the ARDL bounds testing approach to integration (Pesaran et al. 2001) to discern the presence of a long-run relationship between CO_2, energy consumption, GDP, population, and the current account balance of Bangladesh, we have constructed several econometric models for this investigation that have multiple merits as the ARDL bounds testing approach is applicable irrespective of whether the variables are I(0) or I(1). Moreover, a dynamic Unrestricted Error Correction Model (UECM) can be derived from a simple linear transformation considering the ARDL bound test. This UECM revealed below recommends the short-run dynamics with the long-run equilibrium without missing any long-run information:

$$\Delta\ln(CO2_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_{t-1}\right) + \beta_3\left(\ln \text{ENG}_{t-1}\right) + \beta_4 + \beta_5\left(\ln \text{POP}_{t-1}\right) + \beta_T T_t + \sum_{h=1}^{0}\beta_h\left(\Delta\ln \text{CO2}_{t-h}\right) + \sum_{i=0}^{p}\beta_i\left(\Delta\ln \text{GDP}_{t-i}\right) + \sum_{j=0}^{q}\beta_j\left(\Delta\ln \text{ENG}_{t-j}\right) + \sum_{k=0}^{r}\beta_k\left(\Delta\ln \text{MET}_{t-k}\right) + \sum_{l=0}^{s}\beta_m\left(\Delta\ln \text{POP}_{t-m}\right) + \mu \quad (3)$$

$$\Delta\ln(GDP_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_{t-1}\right) + \beta_3\left(\ln \text{ENG}_{t-1}\right) + \beta_4 + \beta_5\left(\ln \text{POP}_{t-1}\right) + \beta_T T_t + \sum_{h=1}^{0}\beta_h\left(\Delta\ln \text{CO2}_{t-h}\right) + \sum_{i=0}^{p}\beta_i\left(\Delta\ln \text{GDP}_{t-i}\right) + \sum_{j=0}^{q}\beta_j\left(\Delta\ln \text{ENG}_{t-j}\right) + \sum_{k=0}^{r}\beta_k\left(\Delta\ln \text{MET}_{t-k}\right) + \sum_{l=0}^{s}\beta_m\left(\Delta\ln \text{POP}_{t-m}\right) + \mu \quad (4)$$

$$\Delta\ln(ENG_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_{t-1}\right) + \beta_3\left(\ln \text{ENG}_{t-1}\right) + \beta_4 + \beta_5\left(\ln \text{POP}_{t-1}\right) + \beta_T T_t + \sum_{h=1}^{0}\beta_h\left(\Delta\ln \text{CO2}_{t-h}\right) + \sum_{i=0}^{p}\beta_i\left(\Delta\ln \text{GDP}_{t-i}\right) + \sum_{j=0}^{q}\beta_j\left(\Delta\ln \text{ENG}_{t-j}\right) + \sum_{k=0}^{r}\beta_k\left(\Delta\ln \text{MET}_{t-k}\right) + \sum_{l=0}^{s}\beta_m\left(\Delta\ln \text{POP}_{t-m}\right) + \mu \quad (5)$$

$$\Delta\ln(MET_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_{t-1}\right) + \beta_3\left(\ln \text{ENG}_{t-1}\right) + \beta_4 + \beta_5\left(\ln \text{POP}_{t-1}\right) + \beta_T T_t + \sum_{h=1}^{0}\beta_h\left(\Delta\ln \text{CO2}_{t-h}\right) + \sum_{i=0}^{p}\beta_i\left(\Delta\ln \text{GDP}_{t-i}\right) + \sum_{j=0}^{q}\beta_j\left(\Delta\ln \text{ENG}_{t-j}\right) + \sum_{k=0}^{r}\beta_k\left(\Delta\ln \text{MET}_{t-k}\right) + \sum_{l=0}^{s}\beta_m\left(\Delta\ln \text{POP}_{t-m}\right) + \mu \quad (6)$$

$$\Delta\ln(POP_t) = \beta_1 + \beta_2\left(\ln \text{GDP}_{t-1}\right) + \beta_3\left(\ln \text{ENG}_{t-1}\right) + \beta_4 + \beta_5\left(\ln \text{POP}_{t-1}\right) + \beta_T T_t + \sum_{h=1}^{0}\beta_h\left(\Delta\ln \text{CO2}_{t-h}\right) + \sum_{i=0}^{p}\beta_i\left(\Delta\ln \text{GDP}_{t-i}\right) + \sum_{j=0}^{q}\beta_j\left(\Delta\ln \text{ENG}_{t-j}\right) + \sum_{k=0}^{r}\beta_k\left(\Delta\ln \text{MET}_{t-k}\right) + \sum_{l=0}^{s}\beta_m\left(\Delta\ln \text{POP}_{t-m}\right) + \mu \quad (7)$$

Where Δ represents the first difference, followed by, μ is the error term assumed to be independently and identically distributed. Based on the results of AIC, the first differenced regression model's optimal number of lags has been chosen. In addition, the F-test was used to determine the joint significance of the coefficients of the variables at the lag level, taking into account the null hypothesis that there is no long-term relationship between the variables, such as H0 = βh = βi = βj = βk = βl = βm = βn = 0 against the alternative hypothesis of co-integration suggested by Perasan et al. (2001). In fact, for any given level of significance, there are two critical values—a lower bound and an upper bound. The null hypothesis of no long-term relationship or co-integration cannot be rejected if the F-statistic falls below the lower bound of the critical value, indicating that there is a long-term relationship according to the recommendation of Persan et al. (2001). Likewise, assuming that the F-test value lies between the lower and upper bounds of the critical value, deduction would be uncertain. When all of the data series are I(0), the lower bound of the critical value is used to make the decision, followed by the upper bound of the critical value when all the data series are I(1).

To verify the ARDL model's robustness, we have also applied diagnostic measures like serial autocorrelation, autoregressive conditional heteroscedasticity, the White test of heteroscedasticity, the normality of error term and functional forms of the regression model.

In addition, we have carried out the Granger causality test to ascertain whether the variables are related in any way. The VECM, which stands for Vector Error Correction Model, can be constructed if the data series have co-integration, as shown below:

$$\Delta\ln(CO2_t) = \beta_1 + \beta_2\left(ECM_{t-1}\right) + \beta_3\Delta\ln(CO2_{t-1}) + \beta_4\left(\Delta\ln GDP_{t-1}\right) + \beta_5\left(\Delta\ln ENG_{t-1}\right) + \beta_6\left(\Delta\ln MET_{t-1}\right) + \beta_7\left(\Delta\ln POP_{t-1}\right) + \mu \quad (8)$$

$$\Delta\ln(GDP_t) = \beta_1 + \beta_2\left(ECM_{t-1}\right) + \beta_3\Delta\ln(CO2_{t-1}) + \beta_4\left(\Delta\ln\ GDP_{t-1}\right) + \beta_5\left(\Delta\ln\ ENG_{t-1}\right) + \beta_6\left(\Delta\ln\ MET_{t-1}\right) + \beta_7\left(\Delta\ln\ POP_{t-1}\right) + \mu \quad (9)$$

$$\Delta\ln(ENG_t) = \beta_1 + \beta_2\left(ECM_{t-1}\right) + \beta_3\Delta\ln(CO_{2t-1}) + \beta_4\left(\Delta\ln\ GDP_{t-1}\right) + \beta_5\left(\Delta\ln\ ENG_{t-1}\right) + \beta_6\left(\Delta\ln\ MET_{t-1}\right) + \beta_7\left(\Delta\ln\ POP_{t-1}\right) + \mu \quad (10)$$

$$\Delta\ln(MET_t) = \beta_1 + \beta_2\left(ECM_{t-1}\right) + \beta_3\Delta\ln(CO_{2t-1}) + \beta_4\left(\Delta\ln\ GDP_{t-1}\right) + \beta_5\left(\Delta\ln\ ENG_{t-1}\right) + \beta_6\left(\Delta\ln\ MET_{t-1}\right) + \beta_7\left(\Delta\ln\ POP_{t-1}\right) + \mu \quad (11)$$

$$\Delta\ln(POP_t) = \beta_1 + \beta_2\left(ECM_{t-1}\right) + \beta_3\Delta\ln(CO2_{t-1}) + \beta_4\left(\Delta\ln\ GDP_{t-1}\right) + \beta_5\left(\Delta\ln\ ENG_{t-1}\right) + \beta_6\left(\Delta\ln\ MET_{t-1}\right) + \beta_7\left(\Delta\ln\ POP_{t-1}\right) + \mu \quad (12)$$

Where $ECM_{(t-1)}$ is the lagged error correction term produced by long run association. The long-term causality would be established if the coefficient of lagged error correction term was found to be statistically significant. In contrast, if the coefficients of the first differences between the variables are statistically significant, then there is short-term causality. In addition, the direction of short-term causality between the variables will be examined using the χ^2 test statistic for the first differenced lagged independent variables.

4. EMPIRICAL RESULTS WITH DISCUSSION

Table 2 shows the descriptive statistics of all the variables incorporated in the model. The outcomes of the J-B (Jarque-Bera) test reveal that the data series of all variables such as GDP, Energy Consumption, Merchandise Trade, Population and CO_2 emissions follow a normal distribution. The mean, median, range, skewness and kurtosis also establish consistent results with a low standard deviation, as portrayed below:

The ARDL bounds testing method makes the assumption that the data series should be integrated at I(0) or I(1) rather than I(2). To check this, we used the ADF (Augmented Dickey Fuller) unit root test to see if any of the model's variables—GDP, Energy Consumption, Merchandise Trade and Population—were found to be stationary at a level with a constant or time trend. As shown in the following table 3, the data series are found to be stationary at the first difference of all variables, indicating that they are integrated at I(1):

Now, we'll look at the results of the ARDL bounds testing method for determining whether or not the variables in Table 4 are co-integrated. The lag order of the model's variables has been determined by the AIC (Akaike Information Criterion) index, as AIC outperforms the SBC (Schwartz Bayesian Criterion), which outperforms in small samples (Chakrabarti et al. 2011). The lag selection of variables and the F-statistic of the models are reported in the second and third columns, respectively, of the following table. The results show that our calculated F-statistic value is higher than the critical value upper bound established by Perasan et al. (2001). When CO_2, GDP, Energy Consumption, Merchandise Trade and Population are considered to be predicted or dependent variables, there are five co-integrating vectors. This may imply that, over the course of Bangladesh's independence, these variables have been linked. As can be seen in the following, the absence of serial autocorrelation in the models is also confirmed by the Durbin-Watson (D-W) test statistic.

The long-run relationships between the factors have been examined using the ARDL approach, as shown by Panel A of Table 5, which reveals the assessed coefficients compared to each of the illustrative factors impacting the position of CO_2 referenced before.

Table 1: Details of variables included in the model

Variables type	Name	Notation	Explanation	Expected sign of coefficient
Dependent	CO2 emission	ln *(CO2)*	Natural log of CO2 emission	N/A
Independent/ explanatory	Gross domestic product	ln *(GDP)*	Natural log of GDP	+ (positive)
	Energy consumption	ln *(ENG)*	Natural log of energy consumption	+ (positive)
	Merchandise trade	ln *(MET)*	Natural log of merchandise trade Balance of Bangladesh	+ (positive)
	Population	ln *(POP)*	Natural log of population of Bangladesh	+ (Positive)

Source: Author's contribution. GDP: Gross domestic product

Table 2: Descriptive statistics of variables selected for the model

Descriptive statistics	Variables				
	ln *(CO2)*	**ln *(GDP)***	**ln *(ENG)***	**ln *(MET)***	**ln *(POP)***
Mean	11.458	9.4661	7.214	6.7210	3.165
Median	12.284	9.1260	7.102	6.3163	3.330
Maximum	14.439	13.183	10.391	9.1827	7.064
Minimum	8.634	6.408	5.827	4.6785	1.273
SD	0.2186	0.0469	0.8916	0.1984	0.2219
Skewness	−0.3140	−0.0823	−0.2864	0.4520	0.0403
Kurtosis	3.009	4.074	3.918	3.254	4.826
J-B test statistic	0.0012	2.459	2.439	1.203	3.192

Source: Author's estimations based on STATA 12.00. SD: Standard deviation, GDP: Gross domestic product

AQ5 **Table 3: Test of stationary of variables at both level data and 1st difference data series**

Variables	Level data series		1st difference data series	
	ADF test statistic (P)	Outcomes	ADF test statistic (P)	Outcomes
ln *(CO2)*	−0.524 (0.819)	Nonstationary	−5.109 (0.000)	Stationary
ln *(GDP)*	−1.643 (0.541)	Nonstationary	−7.217 (0.000)	Stationary
ln *(ENG)*	1.147 (0.921)	Nonstationary	−4.039 (0.000)	Stationary
ln *(MET)*	−3.214 (0.268)	Nonstationary	−7.230 (0.000)	Stationary
ln *(POP)*	0.1257 (0.932)	Nonstationary	−5.941 (0.000)	Stationary

Source: Author's contribution based on STATA. GDP: Gross domestic product, ADF: Augmented Dickey-Fuller

Table 4: The outcomes of ARDL bounds co-integration test

Test for co-integration			Diagnostic check	
Estimated models	Optimal lag length	F-statistics	R^2	D-W test statistics
$CO2_t$=f $(GDP_t, ENERGYCONS_t, MERCHANDISETRADE_t, POPULATION_t)$	4,3,2,3,3	8.281**	0.8710	2.3062
GDP_t=f $(CO2_t, ENERGYCONS_t, MERCHANDISETRADE_t, POPULATION_t)$	4,4,3,4,4	7.467*	0.7231	1.9870
$ENERGYCONS_t$=f $(GDP_t, CO2_t, MERCHANDISETRADE_t, POPULATION_t)$	4,4,3,4,2	7.863**	0.7628	2.0029
$MERCHANDISETRADE_t$=f $(GDP_t, ENERGYCONS_t, CO2_t, POPULATION_t)$	4,3,3,3,4	8.420*	0.8901	2.0362
$POPULATION_t$=f $(GDP_t, ENERGYCONS_t, MERCHANDISETRADE_t\ CO2_t)$	4,4,3,4,4	3.115	0.7780	2.1543

*, ** Indicate the level of significance at 5% and 1% respectively. Source: Author's estimations based on STATA. AADL: Adopting the Autoregressive Distributive Lag

Table 5: Long run and short-run analysis using ARDL estimations

Predicted variable: ln (FDI_t)			
Variables	Coefficient	SE	P
Panel A: Long-run result			
Constant	0.52356***	0.01672	0.0000
ln (GDP_t)	0.76209**	0.04470	0.0002
ln (ENG_t)	0.29432***	0.01194	0.0003
ln (MET_t)	0.95805***	0.00731	0.0001
ln (POP_t)	0.21527**	0.04927	0.0025
R^2		0.9721	
Panel B: Short-run result			
Constant	0.04514	0.01647	0.4199
ln (GDP_t)	0.18761*	0.05291	0.0085
ln (ENG_t)	0.16209**	0.07413	0.0020
ln (MET_t)	0.69316	0.11490	0.1892
ln $(POP_t{=})$	0.10802***	0.02682	0.0001
ECM_{t-1}	−0.08561*	0.00764	0.0009
R^2	0.48329		
F-statistic Value	22.1985**		
Diagnostic check:			
Test statistic	**F-test**		**P**
χ^2 SERIAL	2.1042		0.6243
χ^2 ARCH	0.6385		0.3258
χ^2 WHITE	0.3054		0.8491
χ^2 RAMSEY	0.2971		0.7663

*, **, *** indicate the level of significance at 5%, 1% and 0.1% respectively.
Source: Authors' estimations based on STATA. SE: Standard error, AADL: Adopting the autoregressive distributive lag

According to the ARDL estimation results, changes in GDP have a positive long-term impact on CO_2. A country with a high GDP accelerates economic growth following a huge volume of economic activities, which in turn encourages more consumption of fossil fuels, resulting in high emissions of CO_2, as supported by previous studies (e.g., Dogan and Seker, 2016; Dogan et al., 2017; Park and Hong, 2013; Farhani et al., 2014; Solarin, 2014).

The change in energy consumption is also statistically significant with a positive direction on CO_2 emissions. As energy consumption increases, so do CO_2 emissions. This is because the demand for energy is typically met by burning more fossil fuels, which leads to higher levels of CO_2 emissions. More precisely, the burning of fossil fuels such as coal, oil, and natural gas to generate energy is the largest source of human-made CO_2 emissions. When these fuels are burned, they release carbon dioxide and other greenhouse gases into the atmosphere, trapping heat and contributing to global warming, which has also been found by other authors (e.g., Dogan et al., 2017; Saboori et al., 2012; Shafik and Bandyopadhyay, 1992; Shafik, 1994; Azomahou et al., 2006; Van and Azomahou, 2007; and Jayanthakumaran et al., 2012).

In addition, merchandise trade is found to be statistically significant in bringing about changes in CO_2 emissions in a positive direction, as merchandise trade can also lead to increased CO_2 emissions (Zhang et al. 2021; Saboori et al., 2012; and Sbia et al., 2014). This is particularly true when goods are transported over long distances using energy-intensive modes of transportation such as ships, planes, and trucks. The combustion of fossil fuels during transportation contributes to greenhouse gas emissions, including CO_2. Additionally, some industries and products have higher carbon footprints than others. For example, the production of steel, cement, and other heavy industries is typically associated with high levels of CO_2 emissions. When these products are traded globally, their production-related emissions are attributed to the exporting country, even though the goods may ultimately be consumed elsewhere.

Finally, population is also found to be statistically significant in bringing variation to CO_2 emissions, as population growth has a direct impact on CO_2 emissions, as reported by Zhang et al. (2021). As the population increases, so does the demand for energy, food, transportation, and other goods and services that contribute to

Table 6: The VECM granger causality investigation

Dependent variable	Causal direction					
	Short run					Long run
	$\Delta\ln (CO2_{t-1})$	$\Delta\ln (GDP_{t-1})$	$\Delta\ln (ENG_{t-1})$	$\Delta\ln (MET_{t-1})$	$\Delta\ln (POP_{t-1})$	ECM_{t-1}
$\Delta\ln (CO2_t)$	-	3.0091** (0.0461)	0.6279* (0.2844)	2.6710 (0.9286)	0.0564 (0.3818)	−3.1368** (0.0451)
$\Delta\ln (GDP_{t-1})$	4.0471** (0.0322)	-	0.4768 (0.2093)	7.2521* (0.0632)	2.6492 (0.0725)	−2.3891* (0.0275)
$\Delta\ln (ENG_{t-1})$	2.6896* (0.0238)	6.2910* (0.0873)	-	2.8951 (1.078)	3.5583* (0.0114)	−3.659* (0.0828)
$\Delta\ln (MET_t)$	0.7746 (0.4216)	7.3010 (1.0417)	3.2919* (0.0743)	-	0.8362 (0.0146)	−4.1923 (0.0731)
$\Delta\ln (POP_t)$	2.3867* (0.0926)	4.0139** (0.0058)	0.27321 (0.3817)	8.4573** (0.0172)	-	-

*, ** indicate the level of significance at 5% and 1% respectively. Standard errors are reported in the parenthesis. Source: Authors' estimations based on STATA. GDP: Gross domestic product, VECM: Vector error correction model

greenhouse gas emissions. This is because more people require more resources, and the production and consumption of these resources often involve the burning of fossil fuels, which are the primary source of CO_2 emissions. The impact of population growth on CO_2 emissions can be seen at both individual and societal levels. At the individual level, people who consume more goods and services, travel more, and use more energy contribute more to CO_2 emissions. At the societal level, larger populations require more infrastructure and energy production, which can further increase emissions (Lee and Brahmasrene, 2013).

As reported by Panel B of Table 5, the short-term outcomes reveals that all explanatory variables except for merchandise trade have a statistically significant impact on CO_2 emissions in the same direction as expected. More precisely, GDP, energy consumption, and population are statistically significant at 5%, 1%, and 0.1% levels, respectively, in bringing about variation in CO_2 emissions.

In addition, the diagnostic checks and test statistic values from χ^2 SERIAL, χ^2 ARCH, and χ^2 WHITE demonstrate that this short-run model is free of the issues of White's heteroscedasticity, auto-conditional heteroscedasticity, and serial autocorrelation, respectively. Therefore, the functional form of the short-run model is well fitted for predicating the variety in CO_2 emission according to the results of the measurements from χ^2 RAMSEY.

Furthermore, as the co-integration is confirmed by the preceding empirical discussion, the unidirectional or bidirectional link among or between the series through the VECM system has been examined. Appropriate policies for CO_2 emissions, GDP growth, energy consumption, goods trade, and population would all be strongly influenced by this in order to ensure Bangladesh's sustainable growth. Table 6 reports the direction or movement of the variables' long-term and short-term causal relationships. As evident, in the long run, the relationship between CO_2 and GDP is bidirectional, and the same relationship exists between GDP and merchandise trade. In addition, a feedback effect between energy consumption and CO_2 emission is observed. Bidirectional connections have also been found between population and GDP per capita. Moreover, Granger's population causes CO_2 emission, GDP, energy consumption and merchandise trade. Population is also found to have a bidirectional relationship with merchandise trade, and the same causal relationship exists between CO_2 emission and merchandise trade as well as population.

In the short run study, as reported in Table 6, CO_2 emission and energy consumption are found to have a bidirectional relationship with population. There is also a feedback effect between CO_2 emission and GDP along with merchandise trade. Energy consumption and population also have a bidirectional relationship, and merchandise trade Granger causes population.

5. CONCLUSION AND POLICY IMPLICATIONS

As CO_2 emission control mechanisms are essential for the manageable environmental and financial development of any country, this article has successfully distinguished the key factors of Bangladesh's CO_2 emissions since its liberation war. As evident from our study, a number of macroeconomic and environmental variables, such as GDP, the amount of energy consumed, trade in goods, and population, have a significant impact on the short-term and long-term position of CO_2 emissions in Bangladesh. It is now past due for the Bangladesh Government to make sure that its strategy on sustainable growth is correctly executed in light of the key elements that influence a country's position in managing CO_2 emissions.

In fact, a multifaceted strategy is needed to manage a nation's CO_2 emissions in relation to its energy use, GDP, trade in goods, and population. First, enhancing energy efficiency is one of the best strategies to lower CO_2 emissions. This can be accomplished by encouraging the use of renewable energy sources, such as solar and wind energy, and by minimizing energy waste by implementing energy-efficient devices. Then, since economic growth is closely linked to energy consumption, promoting sustainable economic growth can help reduce the environmental impact of economic activity. This can be achieved by promoting industries that use renewable resources and encouraging the development of sustainable technologies. Third, carbon pricing could be a policy tool that puts a price on carbon emissions, which can incentivize companies and individuals to reduce their emissions. This can be done through a carbon tax or a cap-and-trade system. Besides, international cooperation is essential to address the issue since CO_2 emissions are a global problem. Countries can work together to develop and implement policies that reduce emissions while supporting economic growth. Finally, raising public awareness about the environmental impact of energy consumption, GDP, merchandise trade, and population can help encourage individuals and businesses to take action to reduce their emissions. This can be achieved through education and outreach campaigns, as well as through the promotion of sustainable lifestyles and behaviors.

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