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Application of Autoregressive Distributed Lag Model to Assess the Environmental Sustainability in Bangladesh

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Abstract

This research inspects the associations among several macroeconomic factors in Bangladesh using yearly time series data from 1971 to 2019. It also aimed to determine if the environmental Kuznets curve (EKC) hypothesis exists in Bangladesh or not. The findings from the stationarity tests reveal that all variables are ordered I (1) integrated. The ARDL model has been used to explore the long-run and short-run connections between variables in the model. In the long term, the projected findings established the existence of the Kuznets curve hypothesis in the GDP-energy nexus. According to the study, there is a U-shaped association between economic expansion and greenhouse gas emissions. Food production and energy consumption increase emissions, however using biomass does not assist the country to attain sustainability, as an increase in biomass increases greenhouse gas emissions by 1.12%. As a result, our government should explore additional renewable energy sources to restrict emissions and take the required actions in all areas to achieve environmental sustainability.

Keywords: Greenhouse gas emissions, CO_2 emissions, ARDL, AIC, Environmental sustainability, EKC, SDG.

I. Introduction

The key emphasis of the United Nations Sustainable Development Goals (SDGs) is to maintain sustainability over the production and consumption of resources[1]. Energy and agriculture are the standards of a country's financial progress and a healthier quality of life. However, the corresponding emissions arising from burning fossil fuel sources and the unplanned consumption of pesticides have caused great environmental concerns among policymakers[2]. As shown by Bangladesh's latest Nationally Determined Contributions (NDCs), the overall Greenhouse gas emissions in Bangladesh is 169.06 million tonnes, which is expected to rise roughly 409.41 million tonnes by 2030. Currently, the energy industry is the greatest contributor, accounting for 93.09 tonnes, or 55.07 percent[3].

Energy is required for socioeconomic growth in order to raise living standards, increase production, and so on. Over the last three centuries, there has been a rise in the reliance on fossil fuels for industrialization and urbanization. Fossil fuels continue to account for 77 percent of Bangladesh's energy needs, and natural gas usage has approximately expanded in the previous two decades to satisfy demand. As a result, despite a rise in the amount of renewable sources in primary energy consumption over that time frame, the carbon extremity of the energy supply has expanded by 83%[4]. Biomass is one of the leading sources of clean energy in Bangladesh[5]. The use of biomass energy has been linked to increased economic development and environmental damage. It accounts for over 70% of total energy use in Bangladesh[6].

Agriculture is an important part of the economy of Bangladesh, accounting for 16.5 percent of the state's GDP and employing the greatest number of people. Agricultural practices provide a source of income for around 87 percent of rural residents[7]. In 2014-15, Bangladesh's agriculture produced 76.79 million metric tons of carbon dioxide equivalent (Mt CO_2e) worth of greenhouse gases. According to a study and projection by the International Maize and Wheat Improvement Center and partners (2021), overall agricultural emissions from Bangladesh are anticipated to reach 86.87 Mt CO_2e by 2030, and 100.44 Mt CO_2e by 2050. A variety of easily available agricultural practices might help Bangladesh's agriculture industry to reduce emissions while simultaneously improving production[8]. This paper addresses the following goals: Zero Hunger, Affordable and Clean Energy, Responsible Consumption and Production (Goals 2, 7 and 12)[9].

The principal purposes of this study can be outlined as follows:

(i) To analyze the long-run and short-run impacts of economic growth and energy consumption on greenhouse gas emissions.

(ii) To identify the potential impact of fertilizer and food production on carbon emissions.

(iii) To investigate the presence of Environmental Kuznets Curve (EKC) for Bangladesh.

(iv) To give some recommendations for policy formulation for effective GHG emission-related planning and management in Bangladesh for maintaining agriculture and economic sustainability.

There are so many studies have been conducted associated with the currentstudy. The effects of renewable and non-renewable energy on carbon emissions in South Asian countries have been observed from 1996Q1 to 2019Q4. The ARDL method was used to assess the long and short run effects. In the long term, the findings suggested an unsustainable economy for Bangladesh, Sri Lanka, and

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Pakistan; however, Nepal is accomplishing economic development by cutting CO_2 emissions[10].

Murshed et al.[11] tried to assess the environmental implications of energy utilization and other major macroeconomic factors in the setting of Bangladesh from 1975 to 2016 using carbon footprints as a benchmark for environmental integrity. The study found unidirectional causalities from overall energy consumption, fossil fuel usage, natural gas consumption, hydroelectric energy consumption, economy, and international commerce to carbon footprints. Whereas non-fossil fuel usage has bidirectional relation with carbon footprints.

A research has been performed to analyze the existence of EKC hypothesis for Bangladesh using the Fully Modified Ordinary Least Square (FMOLS) methodology and also investigate the long and short term associations between income per capita and environmental degradation. The study disclosed the principal source of pollution in Bangladesh is nonrenewable resources. The study suggests that Bangladesh has an inverted-U-shaped curve[12].

Zhang et al. [13] performed ARDL bound testing technique to inspect the domestic electricity and gas usage and its consequence on Bangladesh's economic growth with data from 1975 to 2018. The country's economy has been found to have a unidirectional link between residential electricity use and population increase, emphasizing the need of maintaining universal access to electricity.

Balezentiset al.[14] depicted the role of bioenergy production on climate change. They studied panel models for European states by changing the standard EKC model by integrating biomass and several renewable sources in the EKC approach. The research findings indicated that in comparison to several renewable energy sources, biomass has a stronger impact on reducing GHG emissions.

A study has been conducted to investigate the EKC hypothesis for a cohort of EU28 nations from 1990 to 2014, taking primary energy consumption and other country-specific factors into account. The findings supported the EKC hypothesis for GHG emissions, non-methane volatile organic compound emissions, nitrogen oxide emissions, and ammonia emissions[15].

II. Formulation of the Model

Two widely used models named ARIMA and VAR models have been compared using times series data.

ARDL Model

In a single-equation context, autoregressive distributed lag (ARDL) models are frequently used to analyze dynamic interactions using time series data. The variables might be either stationary or non-stationary, or a combination of both. The ARDL model, in its error correction (EC) form, may be used to distinguish long-run and short-run effects, as well as to check for cointegration or, more broadly, the presence of a long-run link between the variables of concern[16].

Consider the following basic model to demonstrate the ARDL modeling approach:

$$Y_t = \alpha_0 + \beta x_t + \gamma z_t + \mu_t$$

The error correction version of ARDL is following:

$$\Delta Y_t = \sum_{i=1}^{n} \beta_i \Delta Y_{t-i} + \sum_{i=1}^{n} \gamma_i \Delta x_{t-i} + \sum_{i=1}^{n} \delta_i \Delta z_{t-i} + \theta_1 Y_{t-1} + \theta_2 x_{t-1} + \theta_3 z_{t-1} + \mu_t$$

Where, β, γ and δ are the short run operators, θ's represents long run coefficients and μ_t is the disturbance term. The null hypothesis in the equation is H_0: $\theta_1 + \theta_2 + \theta_3 = 0$, indicating that the long-term connection does not exist[17].

III. Data and Variables

Depending on the availability of data and our research objectives we have used twelve variables to perform the study. These variables are related to the country's economy, environment and agriculture. The illustration of the data series is given in Table 1.

Table 1. Explanation of the data set

Abbreviation	Variable	Unit	Source
FPI	Food production index	Index (2014-2016=100)	World Bank Indicator (2022)[18]
EU	Energy use	kg of oil equivalent per capita	World Bank Indicator (2022)
CO_2E	CO_2emissions	kt	World Bank Indicator (2022)
GHG	Total greenhouse gas emissions	kt of CO_2equivalent	World Bank Indicator (2022)
GDP	GDP per capita	current US dollar	World Bank Indicator (2022)
AS	Adjusted savings: natural resources depletion	% of GNI	World Bank Indicator (2022)
BMass	Biomass	tonnes	Material Flows (2022)[19]
FF	Fossil fuel	tonnes	Material Flows (2022)
NMM	Nonmetallic minerals	tonnes	Material Flows (2022)
BCAP	Biocapacity	gha	Global Footprint Network (2022)[20]
EF	Ecological Footprint	gha	Global Footprint Network (2022)
CF	Chemical fertilizer	'000'metric tonn	Bangladesh Economic Review 2022[21]

IV. Results

Stationary test

The initial step of any econometric analysis to check for stationarity of the selected variables. The graphical test, Augmented Dickey Fuller (ADF) test and Phillips-Perron (PP) test have been performed for checking the stationarity of the selected variables. All these test results and graphical representation confirms the stationarity of the selected variables at their first difference with log transformation. That is all the variables used in this study are integrated of order I (1). This clarifies that we can implement ARDL model in our study as the variables satisfy the stationarity at first difference[22].

Lag selection criteria

One of the utmostessential aspects of time series modeling is determining the lag length of an autoregressive process. There are several criteria for determining lag length, including the Likelihood ratio (LR) test, Akaike's information criterion (AIC), Schwarz information criterion (SIC), Hannan-Quinn Information Criterion (HQIC), and others[23]. According to these criteria the appropriate lag order is 4. As a result, we employed lag 4 in our subsequent analyses.

The ARDL representation of econometric association among variables

We estimated six unrestricted error correction models considering six of the twelve variables (Food Production Index, Total GHG Emissions, CO_2 Emissions, Energy use, Ecological footprint and Biocapacity) as dependent variables.

The Equation-1 can be expressed as follows taking $\Delta lnFPI$ as dependent variable suppressing the constant term[24].

$$\Delta lnFPI_t = \sum_{i=1}^{p} \beta_{1i} lnFPI_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnEU_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnGHG_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnCF_{t-i} + \sum_{i=0}^{p} \beta_{6i} \Delta lnAS_{t-i} + \sum_{i=0}^{p} \beta_{7i} \Delta lnCO_2E_{t-i} + \theta_{11} lnFPI_{t-1} + \theta_{12} lnEU_{t-1} + \theta_{13} lnGHG_{t-1} + \theta_{14} lnGDP_{t-1} + \theta_{15} lnCF_{t-1} + \theta_{16} lnAS_{t-1} + \theta_{17} lnCO_2E_{t-1} + \mu_{1t} \quad \dots (1)$$

The Equation-2 can be expressed as follows taking $\Delta lnGHG$ as dependent variable suppressing the constant term,

$$\Delta lnGHG_t = \sum_{i=1}^{p} \beta_{1i} lnGHG_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnBMass_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnFF_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnEU_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \beta_{6i} \Delta lnGDP^2{}_{t-i} + \theta_{21} lnGHG_{t-1} + \theta_{22} lnBMass_{t-1} + \theta_{23} lnFF_{t-1} + \theta_{24} lnEU_{t-1} + \theta_{25} lnGDP_{t-1} + \theta_{26} lnGDP^2{}_{t-1} + \mu_{2t} \quad \dots (2)$$

The Equation-3 can be expressed as follows taking $\Delta lnCO_2E$ as dependent variable suppressing the constant term,

$$\Delta lnCO_2E_t = \sum_{i=1}^{p} \beta_{1i} lnCO_2E_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnAS_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnEU_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnBMass_{t-i} + \sum_{i=0}^{p} \beta_{6i} \Delta lnFPI_{t-i} + \theta_{31} lnCO_2E_{t-1} + \theta_{32} lnAS_{t-1} + \theta_{33} lnEU_{t-1} + \theta_{34} lnGDP_{t\ \ 1} + \theta_{35} lnBMass_{t\ \ 1} + \theta_{36} lnFPI_{t\ \ 1} + \mu_{3t} \quad \dots (3)$$

The Equation-4 can be expressed as follows taking $\Delta lnEU$ as dependent variable suppressing the constant term,

$$\Delta lnEU_t = \sum_{i=1}^{p} \beta_{1i} lnEU_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnGHG_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnFPI_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnGDP^2{}_{t-i} + \theta_{41} lnEU_{t-1} + \theta_{42} lnGDP_{t-1} + \theta_{43} lnGHG_{t-1} + \theta_{44} lnFPI_{t-1} + \theta_{45} lnGDP^2{}_{t-1} + \mu_{4t} \quad \dots (4)$$

The Equation-5 can be expressed as follows taking $\Delta lnBCAP$ as dependent variable suppressing the constant term,

$$\Delta lnBCAP_t = \sum_{i=1}^{p} \beta_{1i} lnBCAP_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnBMass_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnNMM_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnFPI_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnGDP_{t-i} + \theta_{51} lnBCAP_{t-1}$$

$$+ \theta_{52} lnBMass_{t-1} + \theta_{53} lnNMM_{t-1} + \theta_{54} lnFPI_{t-1} + \theta_{55} lnGDP_{t-1} + \mu_{5t} \quad \dots (5)$$

The Equation-6 can be expressed as follows taking $\Delta lnEF$ as dependent variable suppressing the constant term,

$$\Delta lnEF_t = \sum_{i=1}^{p} \beta_{1i} lnEF_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta lnEU_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta lnBMass_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta lnFF_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta lnGDP_{t-i} + \sum_{i=0}^{p} \beta_{6i} \Delta lnBCAP_{t-i} + \theta_{61} lnEF_{t-1} + \theta_{62} lnEU_{t-1} + \theta_{63} lnBMass_{t-1} + \theta_{64} lnFF_{t-1} + \theta_{65} lnGDP_{t-1} + \theta_{66} lnBCAP_{t-1} + \mu_{6t} \quad \dots (6)$$

Where β_i's are the short run coefficients and θ_i's are the long run coefficients. μ_t is the error term and p is the ARDL maximum lag order. We have estimated the above six equations based on ARDL model to observe the long run and short run relationship among variables.

ARDL Bound Testing for Cointegration

The ARDL bound test is used to assess if cointegration exists in an ARDL model with error correction. The combined F-statistic serves as the foundation for the bound test. The null hypothesis of non-existence of the long run relationship is defined as follows,

H_0: $\theta_{i1} = \theta_{i2} = \theta_{i3} = \theta_{i4} = \theta_{i5} = \theta_{i6} = 0$ (i.e., the long run association does not exist)

H_1: $\theta_{i1} \neq \theta_{i2} \neq \theta_{i3} \neq \theta_{i4} \neq \theta_{i5} \neq \theta_{i6} \neq 0$ (i.e.,at least two are unequal)

The values of F-statistic are, for equation 1, $F_{FPI} = 9.329$; for equation 2, $F_{GHG} = 6.739$; for equation 3, $F_{CO2E} = 6.874$; for equation 4, $F_{EU} = 9.162$; for equation 5, $F_{BCAP} = 8.674$; for equation 6, $F_{EF} = 4.529$. The result confirms the existence of co-integration among the equations at the 5% level of significance as the F-statistic values for all the equations are higher than upper bound critical values.

Estimated results of Autoregressive Distributed Lag (ARDL) Model

After satisfying the condition of strict first difference stationary variables and choosing the optimal lag order we run the ARDL model to find out the long-run and short-run estimates for six equations. The best fitted model for all the equations has been selected based on AIC.

Table 2. ARDL model estimation of Equation-1

EQN	Parm	Estimate	SE	P value
ECT	$lnFPI_{t-1}$	-.5451179	.1515149	0.001***
Long Run	$lnEU_{t-1}$	.0334658	.3314242	0.920
	$lnGHG_{t-1}$	-.1505934	.0510564	0.007***
	$lnGDP_{t-1}$	.0434323	.0713632	0.548
	$lnCF_{t-1}$	.3636055	.1680971	0.040**
	$lnAS_{t-1}$	.1052225	.0253328	0.000***
	$lnCO_2E_{t-1}$	.2648448	.0618985	0.000***
Short run	$\Delta lnFPI_{t-1}$	.2151896	.1606946	0.192
	$\Delta lnFPI_{t-2}$	.4152032	.1439442	0.008***
	$\Delta lnEU_t$	.3996953	.2555335	0.130
	$\Delta lnGHG_t$	.4575599	.1468328	0.004***
	$\Delta lnGDP_t$	.0236757	.0384912	0.544
	$\Delta lnCF_t$	.1910023	.0637246	0.006***
	$\Delta lnCF_{t-1}$	-.1922028	.0652982	0.007***
	$\Delta lnCF_{t-2}$	-.10625	.0629337	0.103
	$\Delta lnAS_t$	.0426643	.0140561	0.005***
	$\Delta lnAS_{t-1}$	-.03078	.0172343	0.086
	$\Delta lnAS_{t-2}$	-.0312829	.016709	0.072
	$\Delta lnCO_2E_t$	-.4578737	.1542308	0.006***
	$\Delta lnCO_2E_{t-1}$	-.2289259	.0894328	0.017**
ARDL(3,1,2,0,3,3,2)	R^2	0.8555	Root MSE	0.0229

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

The resulting estimates of ARDL(3,1,2,0,3,3,2) model considering food production index as dependent variable is presented in Table 2. The coefficient of equilibrium for food production index is -.545, which represent 54% rate at which the food production index will be equilibrium in the long run. The result revealed that there is no significant impact of energy consumption on food production in both the long term and short term. Though GHG emissions has significant positive impact on food in the short run, the effect is significant negative in the long run. 1 unit increase in GHG, on an average the food production will be decreased by 0.1505 unit in the long-run. It has been observed that GDP has no significant impact on the production of food. Using fertilizer and adjusted savings boosts the production of food in both the long term and short term. Carbon emissions adversely affects the food production in the short term but the effect is significant positive in the long run

Table 3. ARDL model estimation of Equation-2

EQN	Parm	Estimate	SE	P value
ECT	$\ln GHG_{t-1}$	-.6519293	.1209284	0.000***
Long Run	$\ln BMass_{t-1}$	1.125975	.17952	0.000***
	$\ln FF_{t-1}$	-.0045077	.0746805	0.952
	$\ln EU_{t-1}$	.5641366	.5537529	0.319
	$\ln GDP_{t-1}$	-3.581596	1.066684	0.003***
	$\ln GDP^2_{t-1}$	.2500114	.0707257	0.002***
Short run	$\Delta\ln GHG_{t-1}$	.3854122	.1632885	0.027**
	$\Delta\ln GHG_{t-2}$	.1818997	.1404451	0.208
	$\Delta\ln GHG_{t-3}$	.1929884	.1330638	0.160
	$\Delta\ln BMass_{t}$	.8238551	.2641424	0.005***
	$\Delta\ln BMass_{t-1}$	-.9775602	.2828758	0.002***
	$\Delta\ln FF_{t}$	.1523543	.1198577	0.216
	$\Delta\ln FF_{t-1}$	.6382814	.1571603	0.000***
	$\Delta\ln FF_{t-2}$	.548481	.1460663	0.001***
	$\Delta\ln EU_{t}$	-.579643	.3773345	0.138
	$\Delta\ln EU_{t-1}$	-1.198143	.5209379	0.031**
	$\Delta\ln EU_{t-2}$	-.7837704	.4594732	0.102
	$\Delta\ln GDP_{t}$	-2.186579	.6270565	0.002***
	$\Delta\ln GDP_{t-1}$	.4207704	.1485327	0.009***
	$\Delta\ln GDP_{t-2}$	.251216	.1108474	0.033**
	$\Delta\ln GDP_{t-3}$	.0700665	.0637855	0.283
	$\Delta\ln GDP^2_{t}$	.1629897	.0504093	0.004***
ARDL(4,4,2,3,4,0)	R^2	0.7714	Root MSE	0.0372

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

Table 3 reveals a significant negative error correction of -.652, representing 65% speed at which the greenhouse gas emissions will be equilibrium in the long run. The effect indicates that biomass energy has a significant positive impact on GHG emissions in both the long term and short term. In the long run, 1 unit increase in biomass, on an average the GHG emissions will be increased by 1.13 unit. Though the outcome is doubtful in the context of Bangladesh since biomass is seen as a viable sustainable energy source. This could be due to the fact that our sample represents such kind of results. It has been found that fossil fuel has no significant effect on GHG emissions in the long run but in the short run, previous years fossil fuel has significant positive impact on GHG emissions. The economic development is observed to have a significant negative effect on GHG emissions. To examine the role of economic growth on GHG emissions we applied the square of economic growth which gives positive and significant result. The result indicates that the GHG emissions initially falls with increased per capita GDP reaches a threshold level and increases with further increases in GDP resulting a U-shaped relationship in both the long run and short run.

Table 4. ARDL model estimation of Equation-3

EQN	Parm	Estimate	SE	P value
ECT	$\ln CO_2E_{t-1}$	-.4080474	.1054026	0.001***
Long Run	$\ln AS_{t-1}$	-.2070702	.04756	0.000***
	$\ln EU_{t-1}$	1.840446	1.191041	0.134
	$\ln GDP_{t-1}$	-.6570293	.3472627	0.069
	$\ln BMass_{t-1}$	-.2062612	.1596882	0.207
	$\ln FPI_{t-1}$	2.133328	.402856	0.000***
Short run	$\Delta\ln CO_2E_{t-1}$	.4192097	.150131	0.009***
	$\Delta\ln CO_2E_{t-2}$	.3863986	.1660752	0.027**
	$\Delta\ln CO_2E_{t-3}$	.1095331	.0462809	0.025**
	$\Delta\ln AS_t$	.0056689	.0320788	0.861
	$\Delta\ln EU_t$	.5516777	.380328	0.158
	$\Delta\ln EU_{t-1}$	-1.754736	.4591251	0.001***
	$\Delta\ln EU_{t-2}$	-1.05408	.4128544	0.016**
	$\Delta\ln GDP_t$	-.0385259	.0971783	0.695
	$\Delta\ln GDP_{t-1}$	.2059762	.0754681	0.011**
	$\Delta\ln BMass_t$	-.0841644	.060438	0.175
	$\Delta\ln FPI_t$	.2135778	.2247419	0.350
	$\Delta\ln FPI_{t-1}$	-.7322371	.228074	0.003***
ARDL(4,1,3,2,0,2)	R^2	0.8699	Root MSE	0.0402

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

Table 4 shows 41% rate of adjusting previous disequilibrium in CO^2 emissions to equilibrium in the long run. Though adjusted savings has no significant effect in the short term, it has significant negative effect in on carbon emissions in the long run. The study found no significant effect of energy consumption and GDP per capita on carbon emissions in both the long term and short term. Biomass energy has been observed to have negative but insignificant impact on carbon emissions in both the long run and short run. Food production index has been observed to have a significant positive impact on carbon emissions in the long run, whereas the previous year production of food has significant negative impact on carbon emissions in the short run.

Table 5. ARDL model estimation of Equation-4

EQN	Parm	Estimate	SE	P value
ECT	$\ln EU_{t-1}$	-.3311201	.1100592	0.005***
Long Run	$\ln GDP_{t-1}$	.4791601	.1817953	0.013**
	$\ln GHG_{t-1}$	.0676817	.0452442	0.144
	$\ln FPI_{t-1}$	.6050381	.1168727	0.000***
	$\ln GDP^2_{t-1}$	-.028436	.0119504	0.023**
Short run	$\Delta\ln EU_{t-1}$	-.3203954	.144407	0.033**
	$\Delta\ln GDP_t$	.100279	.0635989	0.124
	$\Delta\ln GHG_t$	.0156052	.0586665	0.792
	$\Delta\ln GHG_{t-1}$	.1939111	.0573225	0.002***
	$\Delta\ln GHG_{t-2}$	.0805823	.0603695	0.191
	$\Delta\ln FPI_t$	.0046067	.0887344	0.959
	$\Delta\ln FPI_{t-1}$	-.2009747	.0972522	0.047**
	$\Delta\ln GDP^2_t$	-.0094157	.0043341	0.037**
ARDL(2,1,3,2,0)	R^2	0.7630	Root MSE	0.0189

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

Table 5 depicts a 33% rate at which the energy consumption will be equilibrium in the long run. The food and energy nexus has significant positive relation in the long run. The economic growth is observed to have a significant positive influence on energy consumption. To examine the role of economic growth on energy we applied the square of economic growth which gives negative and significant result. This implies the existence of EKC hypothesis for energy use in Bangladesh. The result indicates that the consumption of energy initially increases with increased per capita GDP reaches a threshold level and decreased with further increases in GDP resulting an inverted-U-shaped relationship in the long-run.

Table 6. ARDL model estimation of Equation-5

EQN	Parm	Estimate	SE	P value
ECT	$lnBCAP_{t-1}$	-.6059486	.1522707	0.000***
Long Run	$lnBMass_{t-1}$	.9825629	.0034821	0.000***
	$lnNMM_{t-1}$	-.0508752	.0070493	0.000***
	$lnFPI_{t-1}$	-.2965769	.0853094	0.002***
	$lnGDP_{t-1}$	.185438	.05062	0.001***
Short run	$\Delta lnBMass_{t-1}$	-.7623887	.2991132	0.017**
	$\Delta lnBMass_{t-2}$	-.5034848	.2836545	0.087
	$\Delta lnBMass_{t-3}$	.439075	.0936421	0.000***
	$\Delta lnNMM_{t}$	-.0432962	.0080108	0.000***
	$\Delta lnFPI_{t}$	.7300467	.1694308	0.000***
	$\Delta lnFPI_{t-1}$	.7544765	.2176939	0.002***
	$\Delta lnFPI_{t-2}$	.5694225	.2095201	0.011**
	$\Delta lnGDP_{t}$	.004877	.0232217	0.835
	$\Delta lnGDP_{t-1}$	-.1187838	.026499	0.000***
	$\Delta lnGDP_{t-2}$	-.0316937	.0238936	0.195
	$\Delta lnGDP_{t-3}$	-.0636174	.0215421	0.006***
ARDL(1,4,1,3,4)	R^2	0.9176	Root MSE	0.0135

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

Table 6 reveals 61% rate of adjusting former disequilibrium to equilibrium following a steady long run association between response and regressors. The study found a significant positive influence of biomass on biocapacity. Both non-metallic minerals and food production index have significant negative impact on biocapacity. By adding a unit in GDP per capita will boost the biocapacity by .1854 unit in the long-run. In the short-run, the current year biomass has negative but insignificant effect but previous year biomass has significant negative effect on biocapacity. The estimate of biomass is different in short run than in long run. The production of food has a significant positive effect on biocapacity in the short run which is different from long run estimate. The GDP-biocapacity nexus shows positive but insignificant association in the current year but the association was significantly negative in the previous year.

Table 7. ARDL model estimation of Equation-6

EQN	Parm	Estimate	SE	P value
ECT	$lnEF_{t-1}$	-.5657559	.1637515	0.002***
Long Run	$lnEU_{t-1}$	1.767899	.4530993	0.001***
	$lnBMasst_{-1}$	-.0556739	.353908	0.876
	$lnFF_{t-1}$	.0462945	.0289803	0.121
	$lnGDP_{t-1}$	-.4528209	.1811926	0.019**
	$lnBCAP_{t-1}$	.6999708	.3215877	0.038**
Short run	$\Delta lnEF_{t-1}$	-.2271779	.1403323	0.117
	$\Delta lnEU_{t}$	.3252724	.1791895	0.080
	$\Delta lnEU_{t-1}$	-.8252556	.2732443	0.005***
	$\Delta lnEU_{t-2}$	-.6910037	.2455864	0.009***
	$\Delta lnEU_{t-3}$	-.3380148	.1964973	0.096
	$\Delta lnBMass_{t}$	.5350611	.1893406	0.009***
	$\Delta lnBMass_{t-1}$	.2353643	.1785057	0.198
	$\Delta lnGDP_{t}$	-.0211127	.0442915	0.637
	$\Delta lnGDP_{t-1}$	.2218435	.0580119	0.001***
	$\Delta lnGDP_{t-2}$	.1049637	.0419204	0.018**
	$\Delta lnGDP_{t-3}$	.0720295	.0336487	0.041**
	$\Delta lnBCAP_{t}$	.3960126	.1609342	0.020**
ARDL(2,4,2,0,4,0)	R^2	0.8460	Root MSE	0.0233

Notes: Where SE is the standard error; *** and ** denotes the 1% and 5% level of significance.

Table 7 represents the coefficient of equilibrium for ecological footprint is -.565, which shows 57% rate at which the ecological footprint will be equilibrium in the long run. The study found a significant optimistic impact of energy use on ecological footprint. Biomass have negative but insignificant effect whereas fossil fuel has positive but insignificant effect on ecological footprint. It has been observed that the growth in GDP per capita declines the ecological footprint in the long run. The biomass-ecological footprint nexus yields a significant positive effect in the short run. It has been observed that the current year economic growth has insignificant positive effect but the previous year's GDP have significant positive impact on ecological footprint in the short run.

Diagnostics of ARDL model estimation

We performed several tests to check the validity of the model appraisal. To find out the existence of serial correlation we employed Breusch-Godfrey Lagrange multiplier test for autocorrelation. It has been found that all the equations of the ARDL model are free of the serial correlation issue. To check for heteroscedasticity, we applied White test and the results confirms that the all the equations are free from heteroscedasticity problem at 5% level of significance. The Autoregressive conditional heteroscedasticity Lagrange multiplier (ARCH-LM) test shows that the equations are free from ARCH effect. It has been found that the p values of Jarque-Bera normality test are higher than the 5% level of significance. So, it can be said that the residuals for all equations in the fitted model are normally distributed. We have also performed the Cusum and Cusum-SQ test to assess the stability of the short term and long-term parameters. And the Cusum and Cusum-SQ plots of model residuals shows that the residuals are within the 95% critical area. So, it is clear that the coefficients of all equations are in the stable situation.

V. Conclusion

The major goal of the study is to look at the relationships among the food production index, energy usage, GHG emissions, CO_2 emissions, biomass, fossil fuel, nonmetallic minerals, fertilizer, adjusted savings, GDP per capita, biocapacity and ecological footprint. We observed the presence of long-run relationships among variables using ARDL bound testing. According to the ARDL estimates, increased GHG emissions have an adverse effect on the production of food in both the short and long term. The study established that fertilizer consumption has significant positive impact on food production in both the long term and short term. Food production, on the other hand, has a considerable beneficial influence on carbon emissions. As a result, increased production of food and related components have considerable environmental consequences because of the usage of natural resources, energy, and carbon emissions. The study's major finding is that biomass usage greatly increases GHG emissions. Though the outcome is doubtful in the context of Bangladesh since biomass is seen as a viable sustainable energy source. This might be due to the circumstance that our sample represents such type of results. In contrast, we observed that biomass had a negative but insignificant effect on carbon emissions. GDP per capita and GHG emissions have been found to have a U-shaped connection. While a rise in the income level minimizes GHG emissions, further expansion of the economy increases GHG emissions after a threshold. As a result, Bangladesh is far more likely to achieve sustainability. Between energy use and economic growth, an inverted-U-shaped link has been identified. While greater levels of income increase energy consumption, further increase in income level declines energy consumption after reaching a tipping point. This conclusion is consistent with the attainment of environmental sustainability, as the goal of the Energy Efficiency and Conservation Master Plan is to cut primary consumption of energy per GDP for all areas by 21% in 2030[4]. We identified a significant positive link between food production and energy consumption. This demonstrates that increased food production needs more energy. The study revealed that biomass consumption increases biocapacity in the long run, but nonmetallic minerals decrease biocapacity. Food production has a big short-term beneficial influence but has a significant long-term adverse effect on biocapacity. Long-term growth in GDP per capita boosts biocapacity. Whereas a rise in income level reduces the ecological footprint. As a result, advancements and long-term economic growth minimizes the ecological footprint, resulting in less environmental deterioration.

Suggestions and Recommendation

According to our research findings, the energy and food production boost carbon emissions in both the long term and short term. So, the policymakers should take the required actions to reduce carbon emissions by enforcing essential policies in the food and energy sector. Authority should focus on alternative renewable resources such as solar energy, wind energy, and hydropower to keep emissions under control. The economic growth and GHG emissions nexus have a U-shaped connection, indicating that a rise in income level reduces GHG emissions, whereas economic expansion increases GHG emissions after reaching a tipping point. As a result, the authorities should be more concerned with preventing pollution as the country develops. The public-private partnerships, the corporate sector and non-governmental organizations (NGOs) may also make major contributions to these environmental policy initiatives. Bangladesh's financial institutions and banks should play an essential role in funding limited carbon emitted projects and programs through their dedicated Green Banking platform. Bangladesh may also ask the world community to cooperate in green energy. Otherwise, we may not be able to attain sustainability and may fall short of meeting the SDG targets on time.

Further Scope of the Study

We only looked at two sectors (energy and food production) to see how they affect environmental deterioration. Other important sectors that contribute to GHG emissions include emissions from industrial sectors, power sectors, usage of solid, liquid, and gas energies, construction, housing, mining, municipal solid waste and wastewater, and so on. There are opportunities to look at these industries to see how they affect environmental pollution. Further research can look at CH_4, N_2O, O_3 and other pollutants as markers of environmental contamination.

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