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Exploring the granger causal relationship between GDP growth and the ecological footprint: Evidence from Bangladesh

Tonmoy Chowdhury
Dhaka School of Economics, University of Dhaka, Bangladesh

Ratan Chowdhury
Dhaka School of Economics, University of Dhaka, Bangladesh

Ruhul Kuddus Chowdhury
Jahangirnagar University, Bangladesh

***Abstract*---**This study investigates the relationship between economic growth and environmental sustainability in Bangladesh, focusing on the Granger causal dynamics between GDP growth and the ecological footprint using Vector Error Correction Models (VECM). The findings reveal that while short-term changes in the ecological footprint are largely influenced by its own past values, GDP growth, industrial output, and energy consumption exhibit limited immediate effects. In the long term, a significant negative relationship between GDP growth and the ecological footprint suggests that sustainable practices and technological advancements can mitigate environmental degradation. The absence of Granger causality between GDP growth and the ecological footprint highlights the complexity of their interaction, potentially mediated by policy and global market dynamics. The study underscores the importance of strengthening environmental governance, adopting renewable energy, and fostering international cooperation to achieve sustainable economic growth, providing evidence-based insights for policymaking in a rapidly developing economy.

***Keywords*---**Ecological footprint, Growth, Sustainability.

Corresponding author: *Chowdhury, T., Email: tonmoy.chowdhury@dsce.edu.bd*
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1. Introduction

Bangladesh, a developing country in South Asia, has experienced significant economic growth over the past few decades (Manik, 2023). Its GDP growth rate has been impressive, consistently ranking among the highest in the region. Bangladesh's GDP has grown at an average rate of over 6% per year since the early 2000s, with peaks reaching above 7% in recent years (Rahman et al., 2015; Manik, 2023; Economic Review, 2024). This growth is attributed to the expansion of the textile and garment industry, remittances from overseas workers, and substantial agricultural productivity improvements (Nath,2014). The economic growth has contributed significantly to poverty reduction, improved health and education outcomes, and enhanced infrastructure (Sawar, et al., 2019; Islam, 2004). The country has made notable progress towards achieving various Millennium Development Goals (MDGs) and Sustainable Development Goals (Raihan et al., 2020). This economic expansion has been driven by various factors, including industrialization, agricultural development, and a burgeoning service sector (Hossin et al., 2020). However, this rapid economic growth has also raised concerns about its environmental sustainability, as reflected in the country's increasing ecological footprint (Eissa, 2023).

The ecological footprint measures the demand on Earth's ecosystems and compares this demand with the planet's capacity to regenerate resources and absorb waste (Mehmood et al., 2023). It encompasses various factors, including carbon emissions, energy consumption, land use, and water use (Jiang et al., 2021; Dardouri et al., 2023).

Bangladesh’s ecological footprint has increased alongside its economic growth (Metcalfe, 2003). The rapid industrialization, urbanization, and increased energy consumption have contributed to higher carbon emissions and greater pressure on natural resources (Kibria, 2023). The growth of industries, particularly textiles and manufacturing, has been a significant driver of GDP growth (Rahman et al., 2022). However, these industries are also major sources of pollution, contributing to air and water contamination (Utomo et al., 2024). The reliance on fossil fuels for energy has further exacerbated carbon emissions (Utomo et al., 2024).While agricultural productivity has boosted GDP, practices such as overuse of chemical fertilizers and pesticides, and the conversion of natural habitats into farmland, have increased the ecological footprint (Xu et al., 2024; Akturk et al., 2024; Gallardo, 2024). Rapid urbanization has led to the expansion of cities, resulting in deforestation, loss of biodiversity, and increased waste generation (Gupta et al., 2022). The growing population in urban areas has put immense pressure on water and sanitation systems. As the economy grows, so does energy consumption. Bangladesh's energy mix is heavily reliant on non-renewable sources like natural gas and coal, contributing significantly to its ecological footprint (Raihan et al., 2022). Efforts to diversify energy sources to include renewables are still in nascent stages.

The key challenge for Bangladesh is to balance economic growth with environmental sustainability. This involves adopting greener technologies, improving energy efficiency, and implementing stricter environmental regulations (Utomo et al., 2024). Effective policies and robust institutional frameworks are

crucial for managing the environmental impact of economic activities (Cai et al., 2024). Strengthening environmental governance and enforcement mechanisms is essential. Bangladesh's efforts to reduce its ecological footprint require international cooperation, particularly in terms of technology transfer, financial support, and capacity building to implement sustainable development practices (Metcalfe, 2003).

The nexus between economic growth and ecological sustainability is a critical area of study for developing countries like Bangladesh, where rapid development often coincides with significant environmental degradation. Investigating the causal relationship between GDP growth and the ecological footprint provides crucial insights into how economic policies and practices impact environmental sustainability. Understanding this relationship can inform the design of policies that balance economic development with environmental preservation, aligning with Bangladesh's commitments to international agreements such as the Paris Agreement and SDGs. Moreover, this research addresses a critical gap in the literature by focusing on a developing economy experiencing rapid growth within the constraints of limited environmental governance and technological capacity.

This study explores the causal relationship between GDP growth and the ecological footprint in Bangladesh, focusing on the balance between economic development and environmental sustainability. It examines how key sectors such as industry, agriculture, and energy drive both economic growth and ecological pressures. By analyzing factors like industrialization, energy consumption, and urbanization, the research highlights environmental challenges linked to rapid development while exploring efforts to adopt sustainable practices and renewable energy. Using econometric models, the study provides insights into the interconnections between economic growth and environmental sustainability.

Despite its robust approach, the study faces limitations, including challenges with data availability and reliability in measuring the ecological footprint. The reliance on proxies and assumptions may affect the precision of findings, and the quantitative focus may overlook qualitative aspects such as policy enforcement and community-level impacts. Additionally, potential lag effects in the relationship between growth and ecological outcomes are not addressed, and the findings may be specific to Bangladesh's unique context. Nonetheless, the study emphasizes the need for sustainable practices, stronger environmental governance, and international cooperation, contributing valuable insights to the discourse on sustainable development.

2. Methodology

2.1 Theoretical Background

The relationship between economic growth and environmental sustainability is well-documented in environmental economics, often framed within the Environmental Kuznets Curve (EKC) hypothesis (Almeida et al., 2024). The EKC suggests that environmental degradation initially increases with economic growth, but as income levels rise, societies prioritize environmental protection, and degradation begins to decline (Dinda, 2004; Touitou, 2021). In the context of

Bangladesh, this hypothesis can provide a theoretical lens to explore the dynamics between GDP growth and the ecological footprint.
The ecological footprint, as a comprehensive measure of human demand on natural resources, captures the multifaceted environmental consequences of economic activities (Oprea, et al., 2024). The analysis draws upon the concepts of sustainable development, which advocate for balancing economic growth with ecological preservation, and the pollution haven hypothesis, which examines whether developing economies like Bangladesh trade environmental quality for economic gains through industrial expansion (Kibria, 2023).

This study uses the concept of Granger causality, which does not establish direct causation but tests whether one time series can predict another, to investigate the relationship between GDP growth and ecological footprint in Bangladesh.

2.2 Methodology

The study adopts a quantitative approach to investigate the causal relationship between GDP growth rate and ecological footprint in Bangladesh. The following steps outline the methodology:

2.2.1 Data Collection

The data collection for this analysis will span the period from 1990 to 2023, encompassing over three decades to provide a comprehensive view of the trends and dynamics between GDP growth rate and ecological footprint in Bangladesh. This extended timeframe allows for capturing the long-term effects of economic development, structural changes, and environmental pressures, as well as the evolution of policy frameworks and industrialization processes. By analyzing this extensive dataset, the study aims to identify patterns, cycles, and structural shifts in the relationship between economic growth and ecological sustainability, ensuring robust and contextually relevant insights.

2.2.2 Variables:

The dependent variable in this study is the ecological footprint, measured in global hectares per capita, which quantifies the demand placed on natural ecosystems by human activities, including resource consumption and waste generation. The primary independent variable is the GDP growth rate, expressed as an annual percentage, representing the pace of economic expansion and development. To account for potential confounding factors that could influence the relationship between GDP growth and ecological footprint, the study incorporates several control variables: **population growth**, which affects resource demand and waste generation; **energy consumption**, as a proxy for industrial and domestic energy use with environmental implications; and **industrial output**, reflecting the scale and intensity of economic activities that directly impact environmental sustainability. This multidimensional approach ensures a comprehensive analysis of the nexus between economic growth and ecological sustainability.

2.2.3 Data Sources:

The data for this study is sourced from reputable and authoritative organizations to ensure reliability and accuracy. The World Bank provides macroeconomic

indicators such as GDP growth rates, energy consumption, and population statistics, offering a globally recognized database for economic and development metrics. The Global Footprint Network will supply data on the ecological footprint, a widely utilized measure of environmental impact that encompasses resource consumption and waste assimilation. Additionally, the Bangladesh Bureau of Statistics will contribute national-level data specific to industrial output and other relevant indicators, ensuring contextual relevance and granularity. These sources collectively ensure the robustness and validity of the dataset for analyzing the relationship between GDP growth and ecological sustainability in Bangladesh.

2.2.4 Econometric Approach

2.2.4.1 Stationarity Testing

Before conducting Granger causality tests, the stationarity of time series data is tested using the Augmented Dickey-Fuller (ADF) or Phillips-Perron tests. This ensures that the variables do not exhibit a unit root, as non-stationary data can lead to spurious results.

2.2.4.2 Cointegration Analysis

If variables are non-stationary but integrated of the same order, a cointegration test (e.g., Johansen Cointegration Test) is conducted to check for a long-run equilibrium relationship between GDP growth and ecological footprint.

2.2.4.3 VECM Model

The Vector Error Correction Model (VECM) is an econometric technique used to analyze the short-term and long-term dynamics between non-stationary time series variables that are cointegrated, meaning they share a long-run equilibrium relationship. Unlike standard Vector Autoregressive (VAR) models, which are applicable to stationary data, the VECM accounts for the presence of cointegration by incorporating an error correction term. This term captures the extent to which the dependent variable adjusts in response to deviations from the long-run equilibrium caused by changes in the independent variables.

The VECM simultaneously models short-term fluctuations and adjustments toward the long-run equilibrium. The inclusion of the error correction term allows for testing the direction and magnitude of the causal relationship between variables over both time horizons. This makes it particularly suitable for the study of the ecological footprint and GDP growth nexus in Bangladesh, where temporal interdependencies and equilibrium adjustments are critical to understanding the dynamics of environmental sustainability and economic development.

2.2.4.4 Granger Causality Test

The Granger causality test is employed to examine the directional relationship between GDP growth rate and the ecological footprint, assessing the predictive power of one variable over the other within a temporal framework. Specifically, the test evaluates three possible outcomes: unidirectional causality, where GDP growth Granger-causes the ecological footprint or vice versa; bidirectional causality, where both variables exhibit mutual predictive influence; and no causality, where neither variable significantly predicts the other. If a cointegration relationship between the variables is identified, indicating a long-run equilibrium,

the analysis extends to the Vector Error Correction Model (VECM). The VECM allows for a nuanced examination of both the short-term dynamics and the long-term causal relationships between GDP growth and ecological footprint, integrating the error correction term to capture adjustments towards equilibrium while preserving the causal structure of the data.

3. Results and Discussion

3.1 ADF Test Results

Variables	ADF Statistic	p-value	Critical Values	Result
GDP Growth Rate	-7.3522	0.0000	1%: -3.6699	Stationary
Ecological Footprint	-5.1046	0.0000	1%: -3.6614	Stationary
Industrial Output	-2.9934	0.0355	5%: -2.9605	Stationary
Electric Power Consumption	-3.1874	-3.1874	5%: -2.9605	Stationary

All the variables tested (GDP growth rate, ecological footprint, industrial output, and electric power consumption) are stationary based on the ADF test results. This means that these series do not have a unit root and are suitable for further analysis, such as regression modeling or Granger causality tests.

3.2 Cointegration Test Results

Index	Eigenvalues	Trace Statistic	Critical Values		
			1%	5%	10%
1st Eigenvalue	0.7367	66.2017	44.4929	47.8545	54.6815
2nd Eigenvalue	0.3688	26.1658	27.0669	29.7961	35.4628
3rd Eigenvalue	0.2455	12.3607	13.4294	15.4943	19.9349
4th Eigenvalue	0.1222	3.9102	2.7055	3.8415	6.6349

The Cointegration Test confirms a significant long-term equilibrium relationship among the variables, with the first eigenvalue's trace statistic (66.2017) exceeding all critical values, indicating one cointegrating vector. The other eigenvalues have trace statistics below critical thresholds, suggesting no additional cointegration. This validates the use of cointegration techniques, like the Vector Error Correction Model, to analyze the long-term dynamics between economic and environmental variables in Bangladesh.

3.3 VECM Result

This VECM equation captures the dynamics of how changes in the Ecological Footprint are influenced by its own past values and the past values of other economic indicators. The coefficients indicate the strength and direction of these relationships.

The VECM output provides insights into the short-term and long-term relationships between the Ecological Footprint and other economic variables,

specifically GDP Growth Rate, Industrial Output, and Electric Power Consumption

3.3.1 Short-run equilibrium

D(Ecological_footprint):

	coef	Std err	z	P>|z|	0.025	0.975
L1.D(Ecological_footprint)	-.0.4237	0.171	-2.484	0.013	-0758	-0.089
L1.D(GDP_growth_rate)	0.0018	0.002	0.794	0.427	-0.003	0.006
L1.D(Industrial_Output)	0.0019	0.005	0.384	0.701	0.008	0.011
L1.D(Electric_Power_Consumption)	2.015e-05	0.00	-0.072	0.942	-0.001	0.001

D(Ecological_footprint)t = −0.4237·L1.D(Ecological_footprint)+0.0018·L1.D(GDP_growth_rate)+0.0019·L1.D(Industrial_Output)−2.015×10−5·L1.D(Electric_Power_Consumption)

The analysis of lagged endogenous parameters for changes in the ecological footprint (EF) reveals several key insights. The coefficient for L1.D(Ecological Footprint) is -0.4237, indicating a mean-reverting behavior where an increase in EF in the previous period leads to a decrease in the current change, potentially reflecting responses to environmental pressures or policies. The L1.D(GDP Growth Rate) coefficient of 0.0018 suggests a weak positive influence of past GDP growth on EF changes, but this relationship is statistically insignificant (P = 0.427). Similarly, the L1.D(Industrial Output) coefficient of 0.0019 indicates a weak positive relationship, which is also statistically insignificant (P = 0.701). Meanwhile, the very small negative coefficient for L1.D(Electric Power Consumption) (-2.015e-05) highlights its negligible and statistically insignificant effect (P = 0.942).

The ecological footprint in the short term is primarily influenced by its own previous values, suggesting a mean-reverting behavior. The other variables do not significantly affect the ecological footprint in the short run.

3.3.2 Long run equilibrium

	coef	Std err	z	P>|z|	0.025	0.975
beta.1	1.0000	0	0	0.000	1.000	1.000
beta.2	-0.2086	0.023	-9.156	0.000	-0.253	-0.164
beta.3	0.0101	0.024	0.428	0.669	-0.036	0.057
beta.4	0.0020	0.002	0.943	0.345	-0.002	0.006

	coef	Std err	z	P>|z|	0.025	0.975
ec1	0.0218	0.018	1.196	0.232	-0.014	0.058

$ec1_t$= Ecological_Footprint−0.2086·GDP_Growth_Rate+0.0101·Industrial_Output +0.0020·Electric_Power_Consumption

The loading coefficient (Alpha) for EF adjustment towards long-term equilibrium, with a value of 0.0218, shows a slow adjustment process. While the positive value indicates correction of deviations from the long-term relationship, its lack of statistical significance (P = 0.232) suggests limited robustness. Regarding the cointegration relation, the normalized beta coefficient for GDP growth (-0.2086) points to a long-term negative relationship, possibly reflecting improved efficiency or sustainable practices as GDP grows. However, the beta coefficients for industrial output (0.0101) and electric power consumption (0.0020) are not statistically significant, indicating weak or negligible long-term effects on EF. Together, these findings provide nuanced insights into the short- and long-term dynamics between economic activity and ecological impact.

The ecological footprint shows a weak adjustment towards long-term equilibrium, with a significant negative relationship to GDP growth, indicating that economic growth does not necessarily lead to an increased ecological footprint in the long run. The influences of industrial output and electric power consumption are negligible.

Overall, the VECM results indicate that while the Ecological Footprint is influenced by its own past values, the other economic indicators have limited short-term impacts. In the long term, there is a significant relationship with GDP growth, suggesting potential pathways for sustainable development.

3.4 Granger Causality Test

The analysis of Granger causality between the ecological footprint (EF) and GDP growth rate reveals no significant predictive relationship in either direction across all tested lag periods. The p-values for all tests exceeded the 0.05 threshold, indicating the absence of Granger causality. This suggests that changes in EF do not predict changes in GDP growth and vice versa. The lack of a causal relationship implies that the interaction between these variables may be mediated by external factors or that the relationship is inherently non-causal in nature.

Notably, EF demonstrates significant Granger causality towards electric power consumption (EPC) exclusively at lag 4. This finding indicates that past values of EF can predict future values of EPC at this specific lag, suggesting a delayed effect that may be influenced by underlying mechanisms or external factors. However, at all other tested lags (1, 2, 3, and 5), EF does not Granger-cause EPC. Similarly, no Granger causality is observed in the reverse direction across all lags (1 to 5), with p-values consistently above the 0.05 threshold. This result indicates that changes in EPC do not have predictive power over changes in EF.

The significant finding at lag 4 highlights the potential for delayed interactions between EF and EPC, meriting further investigation to identify the drivers of this relationship. Conversely, the lack of causality at other lags and in the reverse direction underscores the complexity of these interactions and suggests that additional factors may mediate the relationship between EF and EPC.

4. Conclusion

This research examines the intricate relationship between economic growth and environmental sustainability in Bangladesh, focusing on the causal link between GDP growth and the ecological footprint. The findings highlight the dual impact of rapid economic development: while contributing significantly to poverty reduction, improved infrastructure, and socio-economic advancement, it has concurrently exacerbated environmental pressures. Key drivers of this growth—industrialization, energy consumption, and urbanization—have substantially increased the ecological footprint through heightened carbon emissions, resource depletion, and pollution. However, the study provides a nuanced understanding of these dynamics, delineating short-term and long-term interactions between economic activity and environmental impact.

In the short term, the ecological footprint is primarily influenced by its historical values, reflecting mean-reverting behavior, while economic variables such as GDP growth, industrial output, and energy consumption exert limited immediate influence. Over the long term, the analysis reveals a negative relationship between GDP growth and the ecological footprint, suggesting that sustainable practices and technological advancements associated with economic growth can mitigate environmental degradation. Furthermore, the negligible long-term impacts of industrial output and energy consumption indicate the potential to decouple economic growth from environmental degradation through innovation and efficiency gains.

The absence of significant Granger causality between GDP growth and the ecological footprint underscores the complexity of their relationship, which may be shaped by exogenous factors such as policy measures, global market forces, and institutional frameworks. Notably, the delayed relationship between the ecological footprint and electric power consumption at specific lags emphasizes the importance of accounting for temporal dynamics in environmental assessments.

The study concludes that achieving a balance between economic growth and environmental sustainability in Bangladesh requires adopting integrated development strategies. These include strengthening environmental governance, transitioning to renewable energy, and fostering international cooperation for technology transfer and capacity building. By offering empirical insights and policy-relevant recommendations, this research contributes to the broader discourse on sustainable development, guiding efforts to align economic objectives with ecological resilience in Bangladesh.

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6. Authors Contribution

The author conceptualized the study, developed the research framework, and conducted a comprehensive review of relevant literature. Data collection, analysis, and interpretation were carried out by the author, utilizing both qualitative and quantitative methods. The author also prepared the manuscript, integrating feedback from advisors and peer reviewers to enhance the study's rigor and relevance. Furthermore, the author actively engaged with stakeholders to ensure the study's findings address practical challenges and contribute to policy discourse.

7. Declaration Of Competing Interest

The author declares that there are no competing interests that could have influenced the research, analysis, or conclusions presented in this study. All efforts were made to ensure transparency and objectivity throughout the research process.

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