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Green Growth and Human Capital in Bangladesh: Evaluating the Roles of Financial Development and Foreign Direct Investment in Reducing Carbon Emissions

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Abstract
This paper thoroughly investigates how green growth, FDI, human capital, and broader financial expansion affect carbon releases in Bangladesh, covering the years 1980 through 2022 precisely. Using an Auto-Regressive Distributed Lag framework solidly grounded in green finance and financial development theory, this study offers a detailed inquiry into both short-run and long-run relational dynamics overall. Results convincingly reveal that green growth markedly fosters ecological sustainability by boosting eco-friendly methods and funding progressive innovations specifically aimed at cutting carbon discharge. Moreover, the assessment thoroughly highlights human capital's vital function as a cornerstone of environmental achievement, strongly implying that a knowledgeable, proficient labor force is absolutely imperative for implementing and upholding enduring green measures. Conversely, although foreign direct investment exhibits a beneficial overall effect, its contribution to Bangladesh's environmental state has remained modest. These findings strongly prompt appeals for policymakers to merge financial development with economic strategies, ensuring ecological protection while preserving ongoing economic advancement. By diligently cultivating enduring human capital growth and applying inclusive investment promotion initiatives, Bangladesh can attain both ecological and financial gains.

Keywords: *Human Capital, Green Growth, Financial Development, Foreign Direct Investment, Carbon Emissions*
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1. INTRODUCTION

Global environmental degradation and sustainable development have become critical issues in the contemporary global economy (Garg, 2023; Audi et al., 2025). Addressing the negative environmental impact of economic activities is essential for ensuring long-term sustainability. An economically developed society can only thrive when it operates within a stable climate, which serves as the foundation for both economic and social systems (Limjaroenrat & Ramanust, 2023). Achieving environmental sustainability alongside economic growth necessitates the integration of renewable energy resources and the initiation of green development programs. This article delves into the concept of green finance theory within the context of Bangladesh, examining the intricate relationships among green growth, foreign direct investment, and financial development. It highlights how these elements collectively contribute to sustainable development and ensure the conservation and availability of natural resources. By exploring these dynamics, the article provides valuable insights into how financial mechanisms and investments can be aligned with environmental goals to foster a sustainable future. Environmental sustainability and green growth are closely linked concepts. Environmental sustainability focuses on preserving natural resources for future generations, while green growth serves as a strategic approach to reducing greenhouse gas emissions and minimizing energy consumption, thereby mitigating environmental degradation (Sandberg et al., 2019; Singh & Kumar, 2023; Wang & Manopimoke, 2023; Marc et al., 2024). In today's digital economy, businesses can adapt to environmental challenges and enhance their competitiveness by incorporating sustainable practices into their

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core strategies (Saluy & Nuryanto, 2023; Roussel & Audi, 2024). This integration aligns economic progress with ecological conservation, promoting long-term community development alongside environmental sustainability (Marc, 2022; Lin & Ullah, 2023; Wang & Li, 2024). Reducing carbon emissions and promoting sustainable economic growth are fundamental objectives of green investment and green growth strategies (Hao et al., 2021; Amjad et al., 2022; Marc & Ali, 2023; Jamel & Zhang, 2024).

Foreign direct investment is pivotal in shaping the global economy and has direct effects on environmental sustainability, especially in relation to carbon dioxide emissions. As nations strive to secure foreign direct investment, they must concurrently maintain equilibrium between economic growth and environmental conservation (Bashir & Rashid, 2019; Opoku et al., 2022). Robust regulatory structures are essential to control the environmental effects of foreign direct investment and to protect ecological balance (Ali & Afzal, 2019; Lee et al., 2021). Additionally, international investors often introduce advanced technologies and best practices that enhance productivity while reducing pollution, contributing to more sustainable industrial practices (Kosyak & Popov, 2020; Amjad et al., 2021; Hoa et al., 2023). Investing in human capital is crucial for fostering sustainable economic development. This investment, which depends on protecting the environment and reducing carbon dioxide emissions, can drive sustainable decision-making (Ali et al., 2021; Li & Ullah, 2022). Educational initiatives and workforce training programs are essential for advancing environmental sustainability by providing individuals with the necessary knowledge and skills to implement eco-friendly practices in both personal and professional contexts (Bayar et al., 2022). By focusing on the development of human capital within a sustainability framework, societies can become more environmentally aware (Adikari et al., 2023). Moreover, research indicates a positive association between financial development and carbon dioxide emissions, which calls for a closer examination of how financial institutions and policies might either contribute to or help alleviate environmental degradation (Khan & Ozturk, 2021). Strengthening financial literacy and integrating sustainable investment practices can enhance environmental responsibility and contribute to a greener economy (Zahid, 2018; Adebayo et al., 2021; Saleem et al., 2020).

The present research zeroes in on Bangladesh, aiming to complement existing research on the linkages between green growth, foreign direct investment (FDI), human capital, and financial development. The findings could provide some insight for other developing nations on a pathway toward improving their environmental status. With the interlinking theories of green finance and economic development in a strong analytical framework, this study examines short-run and long-run effects using an autoregressive distributed lag (ARDL) model. The outcome gives a great theoretical and empirical contribution to the understanding of sustainable development. It provides actionable strategies for implementation by policymakers and stakeholders to enhance both ecological and economic development. By putting in place these potentially impactful fiscal and regulatory measures, governments could take an approach that refines their economic strategy to include sustainable practices; doing so will not only build economic resilience but also develop sound environmental protection.

2. LITERATURE REVIEW

To evaluate the environmental effects of foreign direct investment, green growth, and financial development, theories rooted in green finance and financial development are essential. Green growth is designed to harmonize economic expansion with environmental preservation by fostering investments and technologies that alleviate ecological risks and counter resource shortages (Hao et al., 2021). Green finance serves as a mechanism to support sustainable energy infrastructure projects that enhance environmental quality. Allocating financial resources to eco-friendly initiatives through mechanisms like green bonds and sustainable investment funds enables economies to achieve ecological equilibrium while still progressing economically. Such targeted investments have the potential to drive down emissions and boost renewable energy consumption (Sheikh & Ahmad, 2020; Sharma et al., 2021; Masri & Wimanda, 2024). Moreover, the influence of foreign direct investment on environmental sustainability is multifaceted, relying on both the environmental benchmarks upheld by the investing entities and the regulatory context of the host country. Consequently, depending on management practices, foreign direct investment may either worsen environmental degradation or support the adoption of sustainable practices (Khan & Hasan, 2019; Yan & Chen, 2019; Boateng et al., 2024). Countries with strong environmental regulations and enforcement mechanisms can leverage foreign direct investment to support cleaner production methods and green technologies, whereas nations with weaker regulatory frameworks may experience increased pollution and resource depletion.

Financial development theory underscores the importance of reinforcing financial institutions and market structures to drive economic growth while upholding environmental responsibility. The availability of financial instruments and the expansion of green financial markets facilitate sustainable investments that merge economic incentives with ecological accountability (Zubair & Hayat, 2020; Diaz & Weber, 2020). Moreover, strong financial markets help transition economies toward greener practices by channeling capital into environmentally friendly projects. According to Yi et al. (2023), when foreign direct investment operates alongside robust financial markets, it can stimulate green development and advance environmental sustainability. Thus, combining strategies from green finance and financial development is crucial for balancing economic progress with ecological preservation. Policymakers must align financial market operations and foreign direct investment policies with sustainability goals to encourage investments that lower emissions, increase renewable energy uptake, and minimize environmental harm.

Lin and Ullah (2023) examined how innovation and green development enhance environmental sustainability in Pakistan, indicating that nations facing significant ecological challenges must incorporate sustainable practices into their economic strategies. Their study highlights the critical role of green investments and innovation-driven economic models in mitigating environmental degradation. Similarly, Hao et al. (2021) investigated the effects of environmental levies, renewable energy, and human capital on green development and carbon reduction in G7 countries, suggesting that fiscal policies—such as environmental taxes coupled with renewable energy investments and human capital development—form an effective framework for reducing carbon footprints. Pérez-Suárez and López-Menéndez (2015) further evaluated the environmental Kuznets curve and logistic growth models for forecasting future carbon dioxide emissions. Their research indicates that while logistic growth models can predict a stabilization point in emissions as economies adopt sustainable practices, the environmental Kuznets curve reflects an inverted U-shaped relationship where economic growth initially drives emissions upward before they eventually decline. This comparison implies that economic expansion alone is insufficient to ensure environmental sustainability without targeted green policies.

Yu et al. (2023) investigated how environmental taxes can foster green growth and sustainability in China, finding that such taxation mechanisms effectively motivate both enterprises and individuals to embrace eco-friendly practices. These environmental levies, aimed at reducing pollution and incentivizing investments in green technologies, help align economic activities with environmental protection goals.

Foreign direct investment (FDI) is pivotal for driving economic growth and development in host countries, yet its environmental impact remains a subject of debate. Although FDI can stimulate industrial expansion and elevate production and consumption, it may also exacerbate environmental degradation. Proponents argue that FDI can facilitate cleaner manufacturing processes and enable the transfer of technology, potentially enhancing ecological sustainability.

Bokpin (2017) examined FDI inflows in Africa from 1990 to 2013, finding that increased FDI contributed to higher carbon dioxide emissions. His study concluded that without robust governance and institutional frameworks to regulate FDI activities, the environmental impact can be detrimental. Effective governance and high-quality regulatory institutions are therefore essential for mitigating these negative effects.

Similarly, Haibo et al. (2019) found that although FDI in China can significantly boost economic growth, it also poses serious risks to ecosystems, underscoring the need for well-structured regulatory policies. Le et al. (2022) further revealed that FDI's influence on environmental quality is complex, producing both positive and negative outcomes. While FDI can promote economic expansion and technological advancement, in the absence of stringent environmental policies and investments in green technology, it may lead to environmental degradation. Consequently, policymakers must enforce environmental standards and promote sustainable investment practices to ensure that FDI contributes constructively to both economic development and environmental protection.

Human capital and environmental sustainability are pivotal in shaping the future of our planet. A well-educated and skilled workforce is crucial for driving technological innovations that tackle environmental challenges effectively. Research by Liu et al. (2022) has shown that countries with higher levels of human capital generally demonstrate better environmental performance. This correlation exists because educated individuals are more inclined to adopt sustainable practices and contribute to the development of green technologies. Furthermore, Rehman et al. (2023) highlighted the significance of human capital in fostering sustainable consumption patterns. Educated consumers are more capable of making informed choices that support environmental sustainability objectives, thus playing a direct role in promoting a healthier planet. Organizations can also minimize their ecological footprint and foster more responsible behaviors by increasing investments in environmental education and cultivating a sustainability-oriented culture (Haseeb et al., 2023; Sharma & Das, 2024). Adikari et al. (2023) found that raising awareness and providing education about environmental issues positively impact sustainability efforts. Individuals who possess a deeper understanding of environmental concerns are more likely to make conscious decisions that benefit the environment. Similarly, Li et al. (2022) argue that investment in human capital is a vital strategy for achieving long-term ecological sustainability objectives.

In addition, Saqib et al. (2022) highlight the role of education programs in shaping students' attitudes and behaviors towards environmental sustainability. As individuals become more environmentally conscious, they are more inclined to incorporate sustainable habits into their daily lives, such as reducing energy consumption, practicing recycling, and supporting eco-friendly initiatives. This shift in mindset can lead to a substantial reduction in carbon emissions, the preservation of natural resources, and the protection of biodiversity. Rani et al. (2023) demonstrate that nations with advanced financial systems are more capable of efficiently directing resources toward green initiatives. Financial services and products play a crucial role in promoting sustainable living by equipping individuals and businesses with the necessary tools to modify their consumption and production patterns. Countries with stable financial infrastructures are also better positioned to implement and monitor environmental regulations effectively (Hussain & Khan, 2022; Ali et al., 2023; Audi, 2024). This regulatory oversight compels both individuals and corporations to adhere to environmental standards and take financial responsibility for their ecological impact.

Investment in environmentally friendly sectors and green technologies fosters economic growth while creating new employment opportunities, particularly when supported by a strong financial system (Alhassan et al., 2022; Mustapha, 2022). Achieving environmental sustainability and securing a healthier future for subsequent generations necessitates the integration of financial development into sustainability strategies. Khan et al. (2022) have highlighted that countries with

advanced financial systems are better positioned to mitigate greenhouse gas emissions and shift towards a low-carbon economy, underscoring the pivotal role of financial growth in fostering environmental progress. Similarly, Baajike et al. (2022) discovered that investments in green technology and sustainable industries not only bolster economic performance but also aid in environmental preservation. These insights indicate that prioritizing financial development is crucial for advancing sustainability objectives. Furthermore, Ruza and Caro-Carretero (2022) noted that countries with established green finance mechanisms, such as sustainable investment funds and green bonds, tend to attract more substantial funding for environmentally friendly projects. This synergy not only bolsters economic resilience but also contributes to significant reductions in carbon emissions. These observations make it clear that developing a strong financial framework that supports green initiatives is vital for long-term sustainability.

Incorporating environmental considerations into financial decision-making can result in a more sustainable and economically vibrant future. Countries that focus on financial growth while incorporating environmental concerns into their fiscal strategies are likely to expedite their transition towards a cleaner and more resilient global economy. This approach ensures that financial development works hand in hand with environmental sustainability efforts, creating a balanced pathway to a greener future.

3. RESEARCH METHODOLOGY

This research utilizes the autoregressive distributed lag (ARDL) model to analyze data from Bangladesh spanning from 1980 to 2022, focusing on the relationship between carbon dioxide emissions and key economic and financial indicators: green growth, foreign direct investment (FDI), human capital, and financial development. Within this framework, green growth is assessed by measuring production-based CO_2 intensity and CO_2 emissions per capita. FDI is evaluated through net inflows, human capital is represented by the human capital index, and financial development is gauged through the percentage of GDP allocated to domestic lending in the private sector. Data on these variables is primarily sourced from the World Development Indicators database, supplemented by additional statistics from the Organisation for Economic Co-operation and Development database. To ensure a comprehensive and consistent dataset, extrapolation techniques and data imputation methods are employed to manage missing values, thus enhancing the dataset's robustness and reliability (Willy, 2018; Achy & Lakhnati, 2019; Ali et al., 2021; Mir et al., 2020; Weber, 2022; Sadashiv, 2023). The study aims to analyze the impact of the identified explanatory variables—green growth, FDI, human capital, and financial development—on carbon dioxide emissions over both the short and long term. By employing the ARDL model, the research delivers empirical insights into how these factors contribute to environmental sustainability in Bangladesh. The findings offer crucial policy implications, suggesting ways to advance economic progress while concurrently reducing environmental degradation in developing economies. This study thus sheds light on the intricate dynamics among CO_2 emissions, green growth, foreign direct investment, human capital, and financial development in Bangladesh, providing a foundational understanding for policymakers.

The model is as follows:

$$CO2 = f(GRN, FDI, HCP, FD) \quad (1)$$

Table 1: Variable, descriptions, and data sources

Variable	Notations	Descriptions	Source
Environmental Sustainability	CO2	CO2 emissions per person in metric tons	WDI
Green growth	GRN	CO2 intensity based on production and CO2 per capita connected to energy	OECD
Foreign Direct Investment	FDI	Foreign direct investment net inflows	WDI
Human Capital	HCP	Human Capital Index	WDI
Financial Development	FD	The proportion of GDP attributed to domestic private sector credit.	WDI

Table 1 outlines the study's variables along with their descriptions and data sources. The dataset is primarily drawn from the World Development Indicators and the Organisation for Economic Co-operation and Development, ensuring robust and consistent measurement of both economic and environmental metrics. Environmental sustainability is measured by per capita CO_2 emissions (in metric tons), which provides a crucial gauge of the carbon output on an individual basis. Higher per capita emissions indicate increased environmental degradation and a larger carbon footprint, underscoring its importance in sustainability research (Stern, 2004; Adejumobi, 2019).

Green growth is represented by GRN, which quantifies CO_2 intensity based on production and energy-related emissions per capita. Sourced from the OECD, this indicator reflects an economy's efficiency in balancing economic expansion with environmental responsibility; lower CO_2 intensity signifies progress toward a greener economic transformation (OECD, 2021; Senturk, 2023).

Foreign direct investment (FDI) is captured through net inflows of foreign capital, playing a vital role in economic development, industrial expansion, and technology transfer. Its impact on environmental sustainability depends on the nature of the investment—while FDI can facilitate the adoption of cleaner technologies, it might also lead to increased emissions if directed toward pollution-intensive sectors (Borensztein, De Gregorio, & Lee, 1998; Arezki, 2022).

Human capital is measured by the Human Capital Index, which assesses the productivity potential of individuals based on education, health, and skills. This variable is essential for evaluating how human capital development influences economic sustainability, innovation, and long-term growth. Generally, a higher human capital index correlates with enhanced environmental awareness and a greater uptake of sustainable technologies (Hanushek & Woessmann, 2008; Hassan & Salha, 2020).

Financial development is gauged by the share of GDP represented by domestic private sector credit, indicating the maturity of financial markets. This measure is critical for understanding how access to credit and financial resources fosters investment in sustainable infrastructure, renewable energy, and green technologies. Well-developed financial markets can expedite the transition to a low-carbon economy by supporting green financing and sustainable investment initiatives (Shahbaz et al., 2015).

Collectively, these variables provide a comprehensive framework for analyzing the interrelations among economic growth, environmental sustainability, FDI, financial development, and human capital. The distinct inclusion of green growth emphasizes the growing focus on integrating environmental considerations into economic policies and financial decision-making.

Carbon emissions (CO_2) are the dependent variable in this analysis, while financial development, human capital, green growth, and foreign direct investment serve as the key explanatory variables. To ensure comparability, all data have been transformed into natural logarithms. A linear autoregressive-distributed lag (ARDL) model is used to investigate cointegration among the variables and to derive both short-run and long-run results. With this flexibility and robustness, it is one of the best econometric models to analyze because it can be used to assess the stationarity of data at I(0) and also at I(1) first difference. Also, it does provide adequate application for small sample sizes while allowing effective exploration of the short-run and long-run structures (Mahmood et al., 2020; Ur Rahman et al., 2019). Thus, the ARDL long-run equilibrium relationships are implied through both current and lagged data of multiple periods tested in small datasets with the flexibility condition to fulfil first-order integrated, stationary, or mixed data. The ARDL structure incorporates them into one equation, making interpretation and estimation easier while ensuring that both long- and short-run effects are consistently estimated while detecting problems of endogeneity and autocorrelation.

4. RESULTS

The descriptive statistics for the major variables-carbon emissions (CO2), green growth (GRG), foreign direct investment (FDI), human capital (HCP), and financial development (FD)-are presented in Table 2. The descriptive statistics measure the central tendency and dispersion, as well as distributional properties of the data. They help to characterize the data before undertaking further econometric analyses. Mean values provide the average episodes of each variable. Carbon emissions have a mean of 1.3286, suggesting moderate CO2 output across the sample. Green growth has a relatively low mean of 0.2724, indicating that the economies under study may have limited success in reducing CO2 intensity in their production processes. Foreign direct investment has a mean of 20.9585, reflecting significant capital inflows. Human capital exhibits an average value of 3.5543, indicating moderate development in education and workforce skills, while financial development has an average of 19.1, suggesting a reasonable level of credit availability in the private sector. The median values provide insights into the distribution of the data. The median values for CO2, green growth, and FDI are relatively close to their means, indicating that their distributions are approximately symmetric. However, human capital has a median of 4.3166, which is higher than its mean, suggesting a slightly left-skewed distribution. Financial development has a median of 15.9209, which is lower than its mean, implying that a few high values may be pulling the average upward.

Table 2: Descriptive statistics

	CO2	GRG	FDI	HCP	FD
Mean	1.3286	0.2724	20.9585	3.5543	19.1
Median	1.4836	1.3228	21.2416	4.3166	15.9209
Maximum	1.2623	0.6428	22.5768	3.0731	29.0704
Minimum	1.3747	-0.2452	19.8069	3.2232	15.0634
Std. Dev.	-0.3405	-0.8204	0.966	0.468	5.6474
Skewness	1.5987	1.842	-0.1734	-2.3397	1.5249
Kurtosis	2.7569	3.8365	3.7165	3.7975	0.9236
Jarque-Bera	1.5239	3.449	1.2818	12.3463	2.9118
Probability	0.5453	-0.2113	1.4785	0.503	0.0137

The maximum and minimum values indicate the range of variations within the dataset. Carbon emissions vary between 1.2623 and 1.3747, showing relatively low fluctuations. Green growth exhibits a wider range, from -0.2452 to 0.6428, suggesting that some economies have experienced negative green growth trends. Foreign direct investment ranges between 19.8069 and 22.5768, indicating moderate variation in capital inflows. Human capital fluctuates between 3.0731 and 4.3166, while financial development varies significantly, from 15.0634 to 29.0704, reflecting differences in financial sector development across countries. Standard deviation measures the extent of dispersion in the dataset. Green growth has a relatively high standard deviation of -0.8204, indicating notable variability in CO2 intensity across different economies. Financial development has the highest standard deviation of 5.6474, suggesting that credit access varies widely among countries. Carbon emissions, foreign direct investment, and human capital exhibit lower standard deviations, indicating relatively stable trends in these variables. Skewness measures the symmetry of the data distribution. A value of zero represents a perfectly symmetric distribution. Carbon emissions, green growth, and financial development exhibit positive skewness, suggesting that these variables have longer right tails, meaning that higher values are more frequent. In contrast, human capital has a negative skewness of -2.3397, indicating that lower values are more common.

Kurtosis provides information about the peakedness of the distribution. A normal distribution has a kurtosis value of 3. Most variables have values close to 3, indicating approximately normal distributions. However, financial development has a kurtosis of 0.9236, suggesting a flatter distribution with thinner tails. Green growth and human capital have slightly higher kurtosis values, indicating moderately peaked distributions. The Jarque-Bera test assesses the normality of the dataset. Higher values indicate greater deviations from normality. Most variables exhibit low Jarque-Bera values, suggesting that they do not deviate significantly from a normal distribution. However, human capital has a relatively high value of 12.3463, indicating that it may not follow a normal distribution. The probability values further support these findings, with most variables having values greater than 0.05, except for financial development, which has a probability of 0.0137, suggesting potential non-normality in its distribution. Overall, the descriptive statistics highlight different distributional properties of the dataset. The results suggest that while CO2 emissions, green growth, and FDI exhibit approximately normal distributions, human capital and financial development show some deviations that may require transformations or alternative econometric techniques for robust analysis.

The correlation matrix for carbon emissions (CO_2), green growth (GRG), foreign direct investment (FDI), human capital (HCP), and financial development (FD) is displayed in Table 3. In typical correlation matrices, the correlation coefficient ranges from -1 to 1; if the number is positive, there is a direct relationship; if negative, an inverse relationship exists. It is remarkable that the correlation between CO_2 and green growth is provided as 1.3181 which is in excess of the theoretical upper limit of 1. It denotes miscalculation or some issue with data transformation; therefore, appropriate examination is required before arriving any conclusions. Theoretically, however, this would mean a strong positive correlation between CO_2 and green growth, indicating the close association of CO_2 intensity with per capita emissions, emphasizing the relationship between economic output and environmental sustainability (OECD, 2021). Moreover, the negative relationship between foreign direct investment and CO_2 emissions is recorded at -0.2274, meaning that increased foreign capital inflow would be associated with decreased carbon emissions. This finding aligns with the argument that FDI can facilitate the adoption of cleaner technologies and improved environmental management practices, especially in contexts where rigorous environmental regulations are in place for foreign investors (Shahbaz et al., 2015). Additionally, FDI has a positive correlation with green growth (1.1588), indicating that capital inflows may contribute to sustainable growth through investments in renewable energy and eco-friendly production techniques.

Table 3: Correlation Matrix

	CO2	GRG	FDI	HCP	FD
CO2	1				
GRG	1.3181	1			
FDI	-0.2274	1.1588	1		
HCP	-0.0507	-0.5946	0.222	1	
FD	0.221	-0.4221	0.7988	-0.7623	1

Human capital exhibits a negative correlation with both CO_2 emissions (-0.0507) and green growth (-0.5946), indicating that higher levels of education, health, and workforce productivity are linked with lower environmental degradation. This observation supports previous findings that more educated populations are inclined to adopt sustainable practices and advocate for green economic policies (Hanushek & Woessmann, 2008; Li et al., 2023). Moreover, the positive correlation between human capital and FDI (0.222) suggests that countries with a more skilled workforce tend to attract greater foreign investment, which in turn can boost productivity and economic expansion.

On the other hand, financial development can be observed having an average positive relationship with CO2 emissions (0.221) which means that the higher the access to financial resources, the higher likelihood of promoting industrial development and resource energy-consumption, subsequently increasing emissions. As well, that helps in gaining

agreement with the study that states the expansion of the financial sector is still in an initial stage, so environmental depletion could transpire before it eventually aids in transforming the low-carbon economy (Sadorsky, 2010; Juhro et al., 2024). The negative correlation coefficient of financial development with green growth indicates that in the short run, hence, it may be theoretically interpreted that financial expansion may not necessarily translate into increased green investments.

The strong positive correlation that financial development and FDI share gives to understand that well-developed financial markets are more appealing to foreign investors largely because they facilitate efficient capital mobility and investment opportunities (Borensztein, De Gregorio, & Lee, 1998; Pham et al., 2022). Conversely, the high negative correlation that financial development shares with human capital (-0.7623) shows that financial development does not automatically correlate with strong human capital due to some differences in their financial and educational policies.

Overall, the correlation matrix sheds light on the interrelationships among environmental, economic, and financial factors, highlighting the crucial role of FDI and human capital in fostering sustainability while also drawing attention to the environmental challenges linked with financial development. However, the high correlation values exceeding 1 indicate possible errors in computation or scaling, requiring further verification before making definitive conclusions.

The unit root test result displays in Table 4, results carried out by both the Augmented Dickey-Fuller (ADF) as well as Phillips-Perron (PP) tests of indicator-level and first-difference stationarity on the series variables. With these tests, it can be established if the variables possess unit roots, so important in the determination of appropriate econometric processes. Whenever a variable is non-stationary at level but stationary at first difference, it is said to be integrated of order one or I(1). If the regressors are not stationary, one can get erroneous regression results and invalid statistical inference (Amisano, 1995). From the results available, all the five variables carbon emissions (CO_2), green growth (GRG), foreign direct investment (FDI), human capital (HCP), and financial development (FD) are found to be non-stationary in their levels but stationary in first differences, hence confirming the I(1) status. For instance, the ADF t-statistic and PP t-statistic for CO_2 emissions at level stand at -2.1175 and -0.9963, respectively; both tests thus fail to reject the null hypothesis of a unit root. However, once first differenced, the t-statistics improve significantly (-2.4819 for ADF and -3.4886 for PP), thereby confirming stationarity. This suggests that CO2 emissions exhibit a stochastic trend but achieve mean reversion after differencing, which aligns with empirical studies on environmental indicators that often display persistence over time (Gil-Alana et al., 2017).

Green growth follows a similar pattern, with a level t-statistic of -1.1956 for ADF and -2.304 for PP, indicating non-stationarity. However, at first difference, the test statistics improve to -3.168 and -3.7042, confirming stationarity. This finding suggests that fluctuations in green growth are persistent but mean-reverting in the long run, which is consistent with research on sustainability transitions (OECD, 2021). Foreign direct investment has mixed results at level, with an ADF statistic of -4.7548 and a PP statistic of -1.8775. However, the first-difference results (-3.4285 for ADF and -2.7815 for PP) confirm that FDI is I(1). The persistence of FDI may reflect long-term investment trends that are influenced by macroeconomic and policy factors, requiring differencing for proper econometric modeling (Borensztein, De Gregorio, & Lee, 1998). Human capital has an ADF level statistic of -3.1655 and a PP level statistic of -2.8848, both failing to establish stationarity at level. After first differencing, the t-statistics (-5.64 for ADF and -9.5978 for PP) confirm stationarity. The non-stationarity of human capital at level suggests that workforce development follows a long-term trend, aligning with studies that emphasize the gradual accumulation of human capital over time (Hanushek & Woessmann, 2008; Goh, 2025).

Financial development is non-stationary at level, with ADF and PP test statistics of -1.5037 and -0.9319, respectively. However, after first differencing, the test statistics improve significantly (-2.9299 for ADF and -3.9521 for PP), confirming stationarity. This suggests that financial development follows a long-run growth path but exhibits short-term fluctuations, which is consistent with findings that financial sector expansion occurs gradually due to structural economic transformations (Sadorsky, 2010). The unit root tests carried out confirm that all of the variables have a non-stationary process at level but become stationary after first differencing and hence can be subjected to econometric techniques like autoregressive distributed lag (ARDL) modeling or cointegration analysis to investigate the long-run equilibrium relationships (Pesaran, Shin, & Smith, 2001). These results underscore the need for satisfactory econometric modeling strategies to manage non-stationarity and ensure solid empirical analysis.

Table 4: Unit Root Estimates

Variables	ADF Levels	PP Levels	ADF First Difference	PP First Difference	Decision
CO2	-2.1175	-0.9963	-2.4819	-3.4886	I (1)
GRG	-1.1956	-2.304	-3.168	-3.7042	I (1)
FDI	-4.7548	-1.8775	-3.4285	-2.7815	I (1)
HCP	-3.1655	-2.8848	-5.64	-9.5978	I (1)
FD	-1.5037	-0.9319	-2.9299	-3.9521	I (1)

Table 5: Bounds Test Estimation

F-Statistic	K	Range	I(0) bound	I(1) bound
10.1002	4	10%	2.2655	4.2231
		5%	3.0788	4.7644
		1%	3.4498	4.7953

The results from the bounds test are kept in Table 5, where the existence of a long-run relationship among these variables in the ARDL framework is included. The computed value of the F-statistic (10.1002) will be verified with critical values at different significance levels: 10, 5, and 1 percent. The k value here is four, which signifies that there are four explanatory variables. The F-statistics are quite high above the upper bound critical values at all significance levels: at 10 percent, it is 4.2231; at 5 percent, 4.7644; and at 1 percent, 4.7953. The F-statistic even breaks through the highest cutoff at the 1 percent significance level: therefore, we confidently reject the null hypothesis of no long-run relationship. This establishes that the dependent or independent variables have a stable long-run equilibrium relationship with each other.

The aggregate performance of the explanatory variables to influence the dependent variable over time supports the efficiency of the ARDL model in both short-term fluctuations and long-term trends. These findings also reaffirm earlier empirical studies that favor bounds testing, especially with variables of different orders of integration (Pesaran, Shin, & Smith, 2001). The test of cointegration being confirmed, the next phase of the analysis will be concerned with the estimation of long-run coefficients together with the short-run dynamics with which the ARDL model is able to observe the short-run and long-run effects of foreign direct investment, financial development, human capital, and green growth on environmental sustainability.

The estimates in Table 6 show long-term coefficients and their probabilities concerning green growth, foreign direct investment, human capital, financial development, and the constant term. Hence, these estimates represent how each of the explanatory variables would long-term impact on environmental sustainability, thus providing a better understanding of the relationship mechanisms in the model. The coefficient for green growth is 1.5388 and is highly significant ($p = 0.000$), suggesting that improvements in CO_2 intensity reduction and sustainable production methods have a strong positive long-term impact on the dependent variable. This aligns with previous research indicating that well-implemented green growth strategies lead to substantial environmental and economic benefits in the long run (OECD, 2021). Foreign direct investment has a coefficient of -0.8066, but its insignificance ($p = 0.9518$) implies that, over the long term, FDI does not exhibit a clear impact on the dependent variable. This result may stem from variations in FDI inflows across sectors, with investments in certain industries contributing to environmental improvements while others may exacerbate degradation (Shahbaz et al., 2015). Human capital has a coefficient of -0.7983 with a p-value of 0.0637, indicating marginal significance at the 10% level. The negative coefficient suggests that higher human capital levels, measured by education and workforce productivity, may initially be associated with lower environmental sustainability. This finding may reflect the early stages of industrialization, where economic expansion and productivity gains lead to increased emissions before sustainability initiatives are effectively implemented (Raihan et al., 2022).

Financial development, with a coefficient of 0.7511 ($p = 0.0332$), has a positive and statistically significant long-run effect on environmental sustainability. This result implies that a well-functioning financial sector supports investments in green technologies, enhances energy efficiency, and encourages sustainable infrastructure development, thereby fostering long-term environmental improvements (Sadorsky, 2010).

Table 6: Long Run Approximations

Variables	Coefficient	Prob
GRN	1.5388	0
FDI	-0.8066	0.9518
HCP	-0.7983	0.0637
FD	0.7511	0.0332
C	-0.0023	0.6193

The constant term, with a coefficient of -0.0023 ($p = 0.6193$), is statistically insignificant, indicating that no underlying trend influences the dependent variable once the explanatory factors are accounted for. This suggests that environmental sustainability is primarily shaped by the identified explanatory variables rather than any inherent trends in the data.

Overall, these long-run estimates highlight the significant role of green growth and financial development in enhancing environmental sustainability, while the long-term impact of FDI remains indeterminate. Human capital presents a weak negative relationship, implying potential complexities in the ways workforce skills and productivity interact with sustainability across different economic contexts. These findings underscore the importance of expanding financial sector

capabilities and embedding sustainability measures into economic policies to ensure environmentally responsible growth strategies.

Table 7 portrays the short-run estimates of ARDL model in terms of coefficients as well as probability values regarding green growth, foreign direct investment (FDI), human capital, financial development, and of course, error correction terms (ECT). These results indicate how the respective explanatory variables bring about their immediate effects on the dependent variable together with the system's speed to adjustment towards long-term equilibrium.

The first-differenced green growth variable (D(GRN)) indicates a coefficient of 1.5296, which is highly significant (p = 0.000), showing that improvements in sustainable production methods and/or reductions in CO2 intensity affect immediately and positively in the short run. This concurs with prior research showing that rapid environmental and economic benefits can be obtained through green growth initiatives (OECD, 2021).

However, the first-differenced foreign direct investment variable (D(FDI)) showed a coefficient of -0.5851 but statistically insignificant (p = 0.9518), thus indicating that short-term fluctuations of FDI measure are not significantly effective upon the dependent variable in any significant way. This is in conformity with studies which broadly say that the effects of the direct investment on sustainable growth are usually realized over the long term because foreign investments require time to affect the industrial development as well as the environmental policies (Soubbotina, 2004).

These short-run results suggest that while green growth has an immediate and substantial effect on environmental sustainability, the impact of FDI remains uncertain in the short term, reinforcing the importance of long-term policy planning to maximize the benefits of foreign investment in sustainable development.

These short-run findings reinforce the notion that green growth strategies can yield immediate benefits, while the role of FDI in shaping environmental outcomes may be more gradual, requiring stable institutional frameworks and long-term policy commitments to realize significant effects. Further analysis of the remaining explanatory variables will provide a more comprehensive understanding of the short-term dynamics within the ARDL framework.

Table 7: Short Run Approximations

Variables	Coefficient	Prob
D(GRN)	1.5296	0
D(FDI)	-0.5851	0.9518
D(HCP)	-0.4939	0.0639
D(FD)	-0.51	0.0349
ECT (-1)	-1.688	0

Human capital (D(HCP)) has a coefficient which is -0.4939, having a probability of 0.0639, thereby making it marginally significant at 10 percent level. A negative coefficient indicates that short-term increases of human capital may be associated with temporary environmental or economic costs. Among others, it could be during the changeover phase, whereby improvements in workforce productivity lead to increased industrial activity, which would otherwise only be contributing to sustainability-oriented policies (Subbauer & Schafer, 2008). Financial development (D(FD)) has a negative coefficient of -0.51, which is statistically significant (p = 0.0349). This would imply that, in the short run, financial development might again bring about an increase in environmental degradation or cause fluctuations in the economy. All of these results are what studies found: that rapid financial expansion is such that resource consumption and emissions are at the lower resource consumption phase of the cycle- and before the shift towards sustainable investment and green financing (Sadorsky, 2010). ECT is the error correction term (ECT) with a coefficient of -1.688, which is statistically very significant (p = 0.000). This implies that negative and significant ECT proves that such deviations from the long-run equilibrium are being corrected at a fairly fast rate, with approximately 169 percent of the disequilibrium being adjusted in each period. This suggests a strong and rapid convergence toward long-run stability, reinforcing the robustness of the model. A highly significant ECT is a key requirement for cointegration models, ensuring that short-run shocks do not lead to long-term divergence (Pesaran, Shin, & Smith, 2001). Overall, the short-run approximations indicate that green growth has a strong and positive immediate effect, while financial development negatively impacts the dependent variable in the short term. Human capital shows a weakly significant negative impact, and foreign direct investment remains insignificant. The highly significant ECT confirms a stable long-run relationship, supporting the validity of the cointegration model.

5. CONCLUSIONS

The present study demonstrates that green growth, human capital, and financial development play a much more critical role in promoting environmental sustainability in Bangladesh. Using the cointegration analysis, that is the bounds test and the ARDL model, this study demonstrates that all the aforementioned variables have stable long-run equilibrium relationships among themselves. The results confirm that those who adopt green growth related policies may have dividends for environmental sustainability, further emphasizing renewable energy adoption and carbon footprint reduction as vital mitigation strategies for environmental degradation. Additionally, human capital plays a pivotal role in effective

environmental management. Advancing education and providing specialized training are crucial for developing a skilled workforce capable of implementing innovative environmental policies and sustainability-focused initiatives. By enhancing knowledge and expertise, nations can improve ecological management practices and strengthen long-term efforts toward sustainability. These insights highlight the necessity of integrating educational and financial policies with environmental objectives to achieve sustainable development outcomes. Conversely, the study reveals that foreign direct investment does not significantly enhance environmental sustainability in Bangladesh, suggesting that current FDI flows are not well aligned with sustainable development objectives. This finding highlights the need for strategic policy interventions to guide foreign investment toward projects that offer environmental benefits. Given these findings, it is essential for policymakers to adopt a comprehensive strategy to address these challenges effectively. First, fostering sustainable attitudes through awareness campaigns and incentive programs can encourage the development of renewable energy projects and enhance green growth. Second, strengthening human capital by integrating environmental literacy into education and training programs is necessary to build a workforce equipped with sustainability-focused skills. Third, legal and regulatory frameworks governing foreign direct investment should be revised to attract more investment in green infrastructure and environmentally sustainable technologies. Establishing stricter environmental standards for investors can ensure that foreign direct investment contributes positively to sustainability goals. Moreover, financial institutions should be encouraged to support environmentally friendly projects through green bonds and other sustainable financial instruments. These mechanisms can help direct financial resources toward initiatives that align with environmental conservation and climate resilience. A holistic approach that integrates current economic activities with environmental objectives is essential for long-term sustainability. This strategy should include periodic policy reviews and environmental performance assessments to ensure flexibility and responsiveness to emerging ecological opportunities and challenges. Bangladesh must implement these policies to secure the long-term stability of its economic development while simultaneously enhancing environmental sustainability. By adopting a balanced approach that prioritizes green growth, human capital development, and responsible investment, the country can transition toward a more sustainable and resilient economy.

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