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Article

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Decoding the Environmental Synergy in BRI Nations: Analyzing the Influence of Renewable Energy Adoption, Financial Evolution, FDI, and Capital Resilience on Sustainability

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ABSTRACT

In response to escalating global concerns over environmental degradation, this study explores the intricate relationships between financial development (FD), foreign direct investment (FDI), capital adequacy, renewable energy consumption (REC) and environmental sustainability in BRI. We aim to provide nuanced insights into how these economic variables impact environmental quality, contributing to a comprehensive understanding of the complex interplay between economic development and environmental conservation. We aim to explore the associations between FD, FDI, REC, and capital adequacy, and environmental quality, emphasizing short-term and long-term dynamics. We employ the Autoregressive Distributed Lag (ARDL) model and conduct D-H causality tests to discern these variables' temporal and causal relationships. This methodology allows us to capture the complexities of the relationships and provide a robust analysis of their impacts on environmental sustainability. The findings reveal a positive long-run association between FD and environmental quality, suggesting that a well-developed financial sector may contribute positively to environmental outcomes. However, the short-run dynamics introduce complexity, indicating a potential immediate positive impact and raising questions about contextual factors influencing FD's contribution to increased carbon emissions. Shifting the focus to FDI and REC, our research uncovers a potential positive association with environmental quality in the long run. The short-run analysis introduces nuances, suggesting a potential negative impact, reflecting the mixed effects observed in previous studies, which underscores the importance of considering temporal dimensions and policy interventions to enhance the positive contributions of FDI and REC to environmental sustainability. Further, our study delves into the impact of capital adequacy on environmental sustainability, revealing a positive long-run association, which challenges negative associations, underlining the need for tailored policies to balance economic growth and environmental conservation. As a whole, our findings contribute quantitative evidence to guide policymakers in fostering incremental improvements over time, acknowledging the multifaceted nature of the relationships under consideration.

Keywords: Environmental Quality, Foreign Direct Investment, Financial Development, Renewable Energy Consumption, BRI Nations
JEL Classifications: Q56, F21, G20, Q42

1. INTRODUCTION

In today's world, there is a widespread understanding that preserving a pristine natural environment is crucial for improving human well-being. This is especially important for countries involved in the Belt and Road Initiative (BRI), where authorities are increasingly focused on managing resources effectively to protect the environment Ahmad et al. (2022). These countries heavily rely on natural resources like fossil fuels and minerals for economic development, creating a delicate balance between economic growth and environmental conservation. The main challenge for BRI countries is balancing their economic goals with the need to protect the environment. While fossil fuels are essential for economic activities, they also contribute significantly to carbon dioxide (CO_2) emissions, a significant driver of climate change. Global CO_2 emissions have become a leading cause of environmental degradation over the past few decades. Although South Asian BRI nations currently contribute less than ten percent of global CO_2 emissions, there is an expectation that their environmental impact will increase as they continue to develop. These countries must navigate the complex relationship between economic growth, which relies on natural resources, and the need to reduce environmental harm to ensure a sustainable future Olivier et al. (2017).

In addition to financial development, Foreign Direct Investment (FDI), and capital adequacy, various other factors significantly influence environmental quality and carbon dioxide emissions in countries participating in the Belt and Road Initiative (BRI). The spending habits of individuals and households (household consumption) directly affect the demand for goods and services, which can subsequently impact production levels and resource utilization. Embracing sustainable and environmentally friendly consumption practices can have a beneficial effect on the environment quality Ivanova et al. (2016). Trade activities play a crucial role in the economic strategies of countries involved in the Belt and Road Initiative (BRI), affecting environmental conditions by influencing the scale of global trade Wang and Xin (2020). The exchange of goods and services between nations affects production rates, resource consumption, and emissions Hasanov et al. (2018). The scale and type of trade can substantially impact a nation's carbon footprint and environmental sustainability Aithal (2017). Economic growth is essential for progress, but it must be pursued in a way that considers its impact on the environment Antonakakis et al. (2017) Uncontrolled growth can result in higher levels of industrialization, energy usage, and pollution. Sustainable economic growth requires balancing development with environmental conservation Schandl et al. (2016). Technological advancements and innovations are crucial in determining the efficient utilization of resources. Developing cleaner and more sustainable technologies helps minimize the environmental footprint of economic activities Severo et al. (2018). The choice of energy sources that a country uses has a significant impact on its carbon emissions. Transitioning from fossil fuels to renewable energy sources can help reduce environmental pollution Zafar et al. (2020b). Government regulations are crucial in influencing business operations and focusing on environmental concerns. Strict environmental policies can promote the adoption of sustainable practices by businesses Sinha et al. (2020). Individuals who are well-informed about environmental concerns and have received higher levels of education are more likely to participate in environmentally friendly activities. Education is a critical factor in promoting accountability and care for the environment El Hafdaoui et al. (2023). Efficient resource utilization is influenced by infrastructure development, particularly in the energy and transportation sectors. Thoughtfully designed and sustainable infrastructure initiatives can potentially support environmental preservation efforts McKinley et al. (2017). To uphold environmental quality, it is essential to responsibly use and conserve natural resources such as forests, water, and biodiversity. Implementing sustainable resource management practices is crucial for ensuring long-term environmental health Wali et al. (2017) and Kalogiannidis et al. (2023).

Why the imperative focus on financial development, Foreign Direct Investment (FDI), and capital adequacy? Researchers are focusing on understanding the link between economic growth and environmental damage due to the significant threat of climate change. Existing studies suggest that financial development can lead to increased environmental pollution Tamazian and Rao (2010) by boosting industrial activity Sadorsky (2010). However, countries with advanced financial markets often show a cleaner environment, highlighting the complexity of this relationship Dasgupta et al. (2001).

Foreign Direct Investment (FDI) is crucial in assessing environmental quality and carbon emissions in global economic (including BRI) dynamics. Extensive research highlights FDI's importance in determining environmental sustainability, emphasizing its dual impact on ecological outcomes Shinwari et al. (2024) and Cui et al. (2024). FDI can increase carbon emissions through industrial activity and economic development and drive the adoption of cleaner technologies and improved environmental practices Mehmood et al. (2024). Understanding the complex relationship between FDI and environmental outcomes requires considering factors such as policy frameworks and global investment trends. Analyzing how FDI impacts environmental quality is essential for developing targeted strategies to maximize benefits and minimize negative consequences, ultimately promoting a more sustainable global future.

The level of capital adequacy plays a crucial role in the complex network of factors that affect environmental quality and carbon emissions on a global scale. Analyzing capital adequacy as a critical factor in this context reveals its diverse and significant impact on environmental outcomes through various channels. The literature emphasizes the importance of efficient capital adequacy management in influencing sustainable economic practices. Robust capital adequacy frameworks allow financial institutions to direct investments towards environmentally friendly projects, reducing carbon emissions Corfee-Morlot et al. (2012). Conversely, insufficient capital adequacy can result in financial instability and encourage businesses' short-term, environmentally harmful decisions Manrique and Martí-Ballester (2017). The relationship between capital adequacy, economic activities, and environmental sustainability requires careful analysis due to the potential for positive and negative impacts Bătae et al. (2021). It is crucial to comprehend the intricate connection between having enough capital and maintaining environmental standards to develop specific policies that encourage sustainable financial behaviors. This will help achieve a balanced approach supporting economic development and environmental conservation.

The Belt and Road Initiative (BRI) is marked by rapid urbanization and population eruption. It has many industries with highly outdated technologies and high carbon-emitting infrastructure Hussain and Zhou (2022). Consequently, air, surface, and water pollution have increased substantially in this region of the world as it has developed economically Rashid et al. (2023). If appropriate measures are not taken to diminish environmental pollution, BRI countries may have to face severe negative economic consequences due to climate change Losos et al. (2019). Nevertheless, few studies have explored the relationship between financial development, FDI, capital adequacy, and environmental quality in the region, particularly India Boutabba (2014), Shahbaz et al. (2015a) and Pakistan Shahbaz (2013), Abbasi and Riaz (2016), Javid and Sharif (2016). Existing studies have not considered the challenges in studying climate change, including issues with data availability and quality, establishing cause and effect relationships, regional differences, complex timing of relationships, policy influences, a narrow focus on CO_2 emissions, limited understanding of human behavior, and assumptions of rational decision-making. Besides, there is a need for more practical policy suggestions and the inclusion of sociocultural factors.

The remaining sections of the paper are organized as follows: Section 2 will introduce the hypotheses and briefly overview the existing literature. This will be followed by a discussion of the data and methodology in Section 3. Section 4 will present the empirical findings, and Section 5 will conclude the study by discussing the findings, incorporating policy implications and suggestions for future research.

2. LITERATURE REVIEW

The literature review is divided into subsequent sections. (i) Financial development-carbon dioxide emission association (ii) Foreign Direct Investment-carbon dioxide emission linkage (iii) capital adequacy-carbon dioxide emission nexus. A comprehensive summary of the existing literature about the interplay between these variables is thoughtfully presented in Table 1.

A robust and dynamic financial sector plays a pivotal role in ensuring capital adequacy and fostering economic development within an economy. Simultaneously, it becomes imperative to assess the ramifications of financial development (FD) on the environment. Research in this realm has yielded a wealth of studies, though their outcomes often present conflicting results. The assessment of FD's impact on environmental quality often hinges on crucial metrics, primarily encompassing indicators such as the proportion of deposited money (bank assets) relative to GDP, the liquidity of liabilities, and the extension of domestic credit to the private sector Bilgili et al. (2020), Shahid et al. (2015).

The first line of evidence includes Cao et al. (2022), Awosusi et al. (2022). Usman et al. (2021), Baloch et al. (2021), Aluko and Obalade (2020), Zafar et al. (2019), Saud et al. (2019) and Moghadam and Dehbashi (2018) have examined the relationship between FD and environmental quality and suggest that FD significantly enhances environmental quality while taking other key factors in consideration. These studies use different methodologies and data from various periods to analyze the impact of financial development on economic growth, energy use, carbon emissions, and trade globalization. FD can boost economic growth and energy innovation, improving environmental quality. However, the effects may vary depending on the country's level of development. Trade liberalization and economic growth can increase carbon emissions, while renewable energy investment and green infrastructure are proposed as policy solutions. Their findings unveil that FD enhances environmental quality by mitigating environmental degradation. Overall, the studies highlight the importance of improving the banking system and investing in green energy initiatives to enhance the environment.

The second strand of the literature analyzed a contrary linkage between FD and environmental degradation. For instance, Jianguo et al. (2022) found that financial development increases CO_2 emissions. Still, institutional quality and technological innovation can moderate this effect in the case of 37 OECD countries. Their research outcomes illustrate that FD is inversely correlated with environmental degradation, albeit with the caveat that this reduction in environmental degradation may be linked to a worsening of carbon emissions. Likewise, Adebayo et al. (2021) conducted research in Latin American countries for the span of 1980 to 2017 and discovered that economic expansion, energy consumption, and urbanization reduce CO_2 emissions, while financial development may not help the environment. A study in China by Fang et al. (2020) stated that financial scale and economic expansion positively correlate with carbon emissions, highlighting the need for improved securities market systems for carbon regulation. Also, Ahmad et al. (2020) assessed the impact of financial development and FDI on environmental quality in several BRI countries from 1990 to 2017. He concluded that FDI enhances environmental quality while financial development increases CO_2 emissions. The study also supported the Environmental Kuznets Curve hypothesis, which suggests an inverted U-shaped relationship between economic growth and CO_2 emissions. Finally, Ibrahiem (2020) unfolded that financial development affects environmental deterioration and economic growth. In contrast, technological innovation affects both in Egypt, considering data from 1971 to 2014.

Contrariwise, a distinct perspective in the literature proposes that financial development (FD) does not exert a significant influence on environmental quality. For instance, Ozturk and Acaravci (2013) conducted an extensive examination of the impact of FD on emissions in Turkey from 1960 to 2007. Their findings suggested that FD does not yield a substantial effect on the environment. Besides, in an analysis by Destek and Sarkodie (2019), no significant relationship was discerned between FD and environmental quality.

An expanding body of academic literature underscores the pivotal role that FDI plays in ensuring the environmental sustainability of a country. However, it is imperative to acknowledge that empirical findings regarding the nexus between FDI and environmental quality demonstrate a heterogeneous set of results. Some scholars like Pujiati et al. (2023), JinRu et al. (2022), Qamruzzaman (2021) unfolded that the association between FDI and environmental quality is positive. According to a study by Pujiati et al. (2023), FDI may mitigate environmental degradation in Indonesia. JinRu et al. (2022) discovered that effective governance, accessible financial services, and environmental concerns propel FDI. Qamruzzaman (2021) found positive relationships between environmental quality, institutional quality and trade openness, with FDI serving as a mediator. FDI fosters positive relationships between environmental quality, industrial quality, and trade exposure. Another couple of researchers, comprising Shabir et al. (2022)

Table 1: Summary of literature survey

Author	Sample (year)	Methodology	FD	FDI	CA
Pujiati et al. (2023)	Indonesia (1984-2020)	ARDL		+VE	
Yameogo et al. (2023)	SSA (1980-2018)	Cup-FM, Cup-BC			-VE
Cao et al. (2022)	South Asian Nations (1980-2018)	ARDL			
Du et al. (2022b)	Emerging nations (2004-2019)	Cup-FM, Cup-BC			+VE
Mujtaba et al. (2022)	seventeen OECD countries (1970-2016)	ARDL, NARDL			-VE
JinRu et al. (2022)	BRI nations (1990-2020)	CDS, CADF, CIPS, CS-ARDL, NARDL		+VE	
Awosusi et al. (2022)	Uruguay (1980-2018)	ARDL	+VE		
Ahmad et al. (2022)	Emerging countries (1984-2017)	CS-ARDL			+VE
Isiksal et al. (2022)	Central Asia (1995-2018)	PMG and DH causality tests			+VE
Jianguo et al. (2022)	37 OECD countries (1998-2018)	CSD and LMM, SYS-GMM	-VE		
Khan et al. (2022)	China (1971-2016)	econometric modelling			+VE
Zhang et al. (2021)	41 Sub-Saharan African (SSA) countries (1996–2018)	two-step system-GMM			+VE
Qamruzzaman (2021)	LIC;LMIC;UMIC (1982-2019)	ARDL, CS-ARDL, NARDL		+VE	
Usman et al. (2021)	52 countries (1995-2017)	PMG-ARDL	VE+		
Duodu et al. (2021)	23 SSA (2005-2019)	system-GMM		+VE	
Li et al. (2022)	China (1981-2019)	ARDL			-VE
Shabir et al. (2022)	24 developed and developing nations (2001-2019)	VECM		+VE	
Adebayo et al. (2021)	Latin American countries (1980-2017)	CIDF, FMOLS, DOLS	-VE		
Baloch et al. (2021)	OECD (1990-2017)	PMG/ARDL	+VE		
Xu et al. (2021)	Chinese provinces (2001-2017)	a panel smooth transition regression model	mixed		
Adeel-Farooq et al. (2021)	76 nations (2002-2012)	panel data estimation technique - FE estimator	+VE		
Iorember et al. (2021)	SA (1990-2016)	ARDL, VECM, ADF			+VE
Yildirim et al. (2021)	Turkey (2009-2017)	SAR, dynamic SAR, SDM, dynamic SDM, SEM models			+VE
Fang et al. (2020)	China (1990-2016)	ARDL-ECM, ADF	-VE		
Zafar et al. (2020a)	Asian countries (1990-2018)	panel cointegration techniques		+VE	
Aluko and Obalade (2020)	35 SSA countries (1985-2014)	STIRPAT, IPAT	+VE		
Zeng et al. (2021)	155 A-share listed Chinese companies	MLR			+VE
Ahmad et al. (2020)	90 Belt and Road countries (1990-2017)	Driscoll-Kraay pooled the ordinary least square method	-VE		
Hao et al. (2020b)	China (1998-2016)	spatial econometric tools		+VE	
Ibrahiem (2020)	Egypt (1971–2014)	ARDL, FMOLS, DOLS	-VE		
Acheampong (2019)	46 sub-Saharan African nations (2000-2015)	system-GMM	+VE		
Yu Ha (2019)	30 Chinese provinces (1998-2016)	spatial econometric tools		+VE	
Zafar et al. (2019)	OECD countries (1990-2014)	Csd and panel cointegration tests. CUP-FM, CUP-BC	+VE		
Pazienza (2019)	OECD countries (1989-2016)	equation model		complex	
Ansari et al. (2019)	29 countries (1994-2014)	FMOLS		+VE	
Saud et al. (2019)	59 BRI countries (1980-2016)	CADF DSUR approach, D-H panel causality approach	+VE		
Mesagan and Nwachukwu (2018)	Nigeria (1981-2016)	ARDL			
Hao et al. (2020a)	China (2003-2016)	simultaneous equations model		-VE	
Geng and Cui (2020)	119 Chinese A-share listed companies (2008-2017)	GWR model			+VE
Destek and Sarkodie (2019)	11 countries (1977-2013)	AMG			
Moghadam and Dehbashi (2018)	Iran (1970–2011)	ARDL	+VE		
Zomorrodi and Zhou (2017)	China (2003-2014)	time series and panel data regression		-VE	
Cole et al. (2017)	Review article	Several models		mixed	
Frutos-Bencze et al. (2017)	CAFTA-DR member countries (1979-2010)	OLS with PCSE, GMM		+VE	
Xu et al. (2017)	35 Chinese enterprises (2010-2014)	MLR			HC[+VE]; IC[-VE]
Abdouli and Hammami (2017)	17 MENA countries (1990-2012)	VAR		-VE	
Shahbaz et al. (2016)	Pakistan (1985Q1-2014Q4)	ARDL, VAR	-VE		
Salatin and Ghaffari Somea (2016)	selected countries (1998-2013)	FE method, GMM			+VE
Javid and Sharif (2016)	Pkaistan (1972-2013)	VECM	-VE		
Charfeddine and Khediri (2016)	UAE (1975-2011)	Econometric models			

(*Contd...*)

Table 1: (*Continued*)

Author	Sample (year)	Methodology	FD	FDI	CA
Omri et al. (2015)	12 MENA countries (1990-2011)	simultaneous-equation panel data models			
Seker et al. (2015)	Turkey (1974-2010)	ARDL		-VE	
Shahbaz et al. (2015b)	99 countries (1975-2012)	advanced panel data techniques		-VE	
Neequaye and Oladi (2015)	27 developing countries (2002 to 2008)	FE model		-VE	
Li et al. (2015)	102 OECD countries (1980-2010)	GMM, CSD and LMM, two-step SYS-GMM	-VE		
Jiang (2015)	28 provincial-level Chinese regions (1997-2012)	Econometric models		-VE	
Alam et al. (2015)	Malaysia (1975-2013)	GMM	neutral		
Moghadam and Lotfalipour (2014)	Iran (1970-2011)	ARDL	-VE		
Boutabba (2014)	India (1971-2008)	ARDL	+VE		
Ozturk and Acaravci (2013)	Turkey for (1960-2007)	ARDL, VECM			
Hitam and Borhan (2012)	Malaysia (1965-2010)	non-linear model		-VE	
Jalil and Feridun (2011)	China (1953-2006)	ARDL	+VE		
Spatareanu (2007)	25 Western and Eastern European countries (1998-2001)	FE, logit model, OLS		+VE	

and Duodu et al. (2021), documented FDI gradually improves environmental quality. Environmental sustainability policies and domestic investment improve environmental quality in the short and long term.

There are also mixed effects of economic factors and FDI on the Environment, as claimed by Zafar et al. (2020a) and Hao et al. (2020b). The impact of FDI, education, and urbanization on environmental quality in Asia has been discovered. It was found that income and energy consumption contribute to CO_2 emissions. To improve environmental conditions, the study suggests increasing education spending, adopting renewable energy sources, and regulating the ecological impact of urbanization. Additionally, increased FDI has been found to reduce environmental pollution in China, but technological progress has varying effects on various pollutants. Prioritizing environmentally friendly high-tech enterprises is crucial for sustainable development.

Multiple studies by Munir and Ameer (2020), Hao et al. (2020a), Zomorrodi and Zhou (2017), Abdouli and Hammami (2017), Neequaye and Oladi (2015) and Seker et al. (2015) established that FDI and Trade Reduce Emissions. They have examined the impact of FDI on environmental degradation, particularly in countries like Pakistan, China, MENA, and Turkey. The findings are varied, with some studies suggesting that increasing FDI positively impacts CO_2 emissions over time, while others indicate that FDI contributes to increased domestic environmental contamination. Additionally, the studies highlight the role of factors like economic growth, industrialization, energy consumption, and environmental aid in influencing environmental degradation. Recommendations include implementing universal environmental rules, adopting advanced technology, and strengthening legal and market mechanisms for environmental protection. The studies emphasize the need for sustainable growth, energy efficiency, and FDI in environmentally friendly industries to improve environmental quality.

However, Pazienza (2019) and Adeel-Farooq et al. (2021) show complex findings. A study by Pazienza (2019) examines the impact of OECD manufacturing foreign direct investment (FDI) on sectoral fuel combustion CO_2 emissions. The study finds that while positive connections suggest that FDI may harm the environment, the estimated coefficients are relatively small. As FDI flow increases, CO_2 emissions are less negatively affected, indicating a complex relationship undermining the idea that FDI affects the environment. The study also shows that FDI can stimulate technical innovation and greener production. Another journal by Adeel-Farooq et al. (2021) explores how FDI from developed and developing countries affects host countries' environmental quality. The results reveal that FDI from developed nations improves environmental performance in low-and lower-middle-income and high-income host nations. FDI from developing countries undermines environmental performance in low- and lower-middle-income host countries. The study emphasizes that the source country's policy environment determines FDI's positive or negative effects on a host country's environment.

Despite the profound ecological implications associated with capital adequacy and its potential influence on environmental quality, this part still needs to be explored. Consequently, there exists a clear need for further research endeavors that thoroughly investigate the impact of capital adequacy on the environment, thereby contributing to the broader goal of attaining sustainable development objectives. Several researchers have investigated the positive effects of economic growth on environmental sustainability. The papers by Du et al. (2022b), Isiksal et al. (2022), Ahmad et al. (2022), Khan et al. (2022), Zhang et al. (2021) and Yildirim et al. (2021) discussed in the input highlight the positive linkage between capital adequacy and environmental quality. They analyze various factors such as remittances, economic growth, natural resources, financial inclusion, human capital, institutional quality, energy consumption, urbanization, trade, and renewable energy. The studies find that financial inclusion and human capital positively impact the environment. At the same time, natural resources, economic growth, energy consumption, and urbanization have a negative effect. They also suggest that improving human capital development, sustainable economic policies, and efficient use of natural resources can enhance environmental sustainability. Additionally, the papers emphasize the importance of social capital, central government spending, and environmental regulation in improving environmental quality. The findings suggest that various factors and policies can improve environmental sustainability in different regions and countries.

Contrary to the positive associations, several studies have found negative associations between financial development and environmental sustainability. Yameogo et al. (2023) comprehensively analyzed factors in landlocked African nations. They discovered that remittances, human capital, natural resources, and wealth growth are associated with increased CO_2 emissions and environmental degradation. Contrastingly, they found a correlation between globalization, foreign direct investment (FDI), financial development, decreased emissions, and environmental benefits. Mujtaba et al. (2022) focused on the OECD region and emphasized that economic growth and capital formation adversely affect environmental quality. They stress the importance of transitioning to renewable energy sources to boost economic development and reduce environmental impact, Li et al. (2022) examines the asymmetric effects of FDI and remittances on CO_2 emissions in China, confirming that while both positive and negative FDI shocks reduce CO_2 emissions over time, a long-term negative remittance shock is more beneficial to the environment than an equivalent FDI shock. These studies challenge conventional beliefs by highlighting the multifaceted relationship between financial development, economic growth, and environmental sustainability.

In comparison, the third strand of the literature suggests different results for different capital. The finding of the study by Xu et al. (2017) suggests that IC (Intellectual Capital) management enhances the performance of the Environmental Protection (EP) industry in mainland China, mitigating environmental damage concerns associated with industrial development.

2.1. Literature Gap

The existing literature on the interplay between financial development, FDI, international trade, household consumption, capital formation, and CO_2 emissions offers valuable insights but grapples with certain limitations. These include data availability and quality challenges, difficulties in establishing causality, regional heterogeneity, the complex temporal dynamics of relationships, policy endogeneity, a narrow focus on CO_2 emissions, limited behavioral insights, and assumptions of rationality in decision-making. Moreover, the literature sometimes needs more practical policy recommendations and often overlooks the influence of sociocultural factors. The rapidly evolving landscape of climate policies and the need for up-to-date data periods are further areas that require attention. Addressing these limitations can enhance the quality of research and provide valuable guidance to policymakers and stakeholders in navigating the intricate relationship between economic growth and environmental sustainability.

3. DATA AND METHODOLOGY OF THE STUDY

3.1. Theoretical Framework and Model Construction

First and foremost, from a theoretical standpoint, the role of FD concerning environmental degradation elicits two distinct perspectives. Firstly, FD is seen as a potential contributor to environmental sustainability, channeling resources toward clean energy and facilitating investments in environmentally sound infrastructure, thus ensuring long-term viability. This perspective also emphasizes how FD can enable countries to adopt advanced technologies for environmentally friendly and clean production, subsequently enhancing regional and global environmental sustainability Aluko and Obalade (2020), Zafar et al. (2019), Saud et al. (2019). Conversely, an alternative viewpoint signifies that a higher level of FD may result in environmental deterioration. FD can simplify access to affordable credit for businesses and individuals, increasing trade, potentially directing to elevated energy consumption and, consequently, adverse impacts on environmental quality Jianguo et al. (2022), Ahmad et al. (2020). These conflicting theoretical stances highlight the complexity of the relationship between FD and environmental outcomes.

In the second place, FDI denotes the capital injection made by entities from one country into business ventures in another. The impact of FDI on the environment is a multifaceted subject. Firstly, it contributes positively to the environment. FDI is renowned for its capacity to fuel economic growth within host countries. It contributes capital, generates employment opportunities, and fosters industrial advancement. FDI frequently leads to the transfer of advanced technologies and innovative practices, especially in industries focused on environmental sustainability. FDI can stimulate the adoption of green technologies in the host country, particularly in sectors like renewable energy and clean production methods. It also harms the health of the planet Pujiati et al. (2023), JinRu et al. (2022), and Qamruzzaman (2021). In some instances, lax regulations and inadequate oversight can result in FDI projects causing environmental harm, mainly when natural resources are exploited without stringent sustainability measures. The inflow of FDI may lead to increased resource consumption, potentially straining ecological systems if not managed responsibly Munir and Ameer (2020), Hao et al. (2020a), Zomorrodi and Zhou (2017).

Thirdly, capital Adequacy is a pivotal element in the financial sector, which not only plays a critical role in economic development and stability but also exerts a profound influence on the environment. The existing body of research delivers a diversified landscape regarding its impact on environmental sustainability. Capital adequacy is a linchpin for financial stability, ensuring institutions can weather economic fluctuations without posing systemic risks. Adequate capitalization allows financial institutions to invest in environmentally sustainable projects, such as renewable energy, pollution control, and sustainable development. It provides financial institutions the means to fund initiatives that protect the environment, fostering environmental conservation efforts and sustainable development Du et al. (2022b), Isiksal et al. (2022), Ahmad et al. (2022).

Extreme focus on short-term profits in pursuit of higher capital adequacy ratios can lead to investments prioritizing immediate returns over long-term environmental sustainability. Additionally, resource-intensive activities within the financial sector may contribute to expanded resource consumption, which, if not managed sustainably, can have detrimental environmental implications. Comprehending the balance between capital adequacy and environmental quality necessitates further research to navigate these complexities effectively Yameogo et al. (2023), Mujtaba et al. (2022), Li et al. (2022).

We have augmented our analysis to include household consumption (HHC) and international trade (TR) as additional variables, identifying their pivotal role in shaping the complex interplay between FD, FDI, capital adequacy, and environmental quality. These extended variables enable us to capture a more comprehensive picture of the multifaceted dynamics that impact the environment, which drives us toward a more subtle understanding of these affinities Liua et al. (2021).

To test the nexus between FD, FDI and capital adequacy with environmental quality, we have constructed the following empirical model:

$$ln(EQ)_{it} = \alpha + \beta_1 * ln(FD)_{it} + \beta_2 * ln(FDI)_{it} + \beta_3 * ln(TR)_{it} + \beta_4 * ln(HHC)_{it} + \beta_5 * ln(CF)_{it} + \beta_5 * ln(REC)_{it} + \varepsilon \quad (1)$$

Where: EQ: Carbon dioxide (CO_2) emissions, reflecting the environmental quality and sustainability; FD: Financial development, representing the level of maturity and efficacy of financial markets and institutions, FDI: Foreign direct investment, indicating the magnitude of foreign capital inflow and its impact on the economy, TR: International trade, reflecting the volume and intensity of cross-border trade activities, HHC: Household consumption, representing individual and family expenditure patterns and trends, CF: Capital formation, including investments in physical, human, and natural capital, α: Intercept, representing the quantity of CO_2 emissions when all independent variables are equal to zero, β_1-β_5: Coefficients representing the influence on CO_2 emissions of financial development (1), foreign direct investment (2), international trade (3), household consumption (4), and capital formation (5), ε: The error term accounts for unobserved factors and stochastic variations affecting CO_2 emissions that are not accounted for by the model, Where t refers to the year (1984–2017), I indicate the countries (1.2.3.4....17).

3.2. Model and Data

This research examines the intricate connection between financial development, foreign direct investment, international trade, household consumption, capital formation, and carbon dioxide emissions in BRI nations for the period 2001-2019. The Fully Modified Ordinary Least Square (FMOLS) estimation technique confirms the results' robustness. As Yu et al. (2023), Haider and Adil (2019), Arachchi and Managi (2022) suggest, the relationship under consideration is formulated as follows:

$$EQ = \int (FD, FDI, CF, HHC, TR, REC) \quad (2)$$

In the above equation, EQ and CO_2 are expressed intertwiningly. EQ shows carbon dioxide emissions, which is calculated as a percentage of total emission in the air (including Total Greenhouse Gas Emissions, Total Energy-Related Emissions, National Emissions, Specific Sector and Historical Emissions). Financial development (FD) is often quantified using the ratio of domestic credit to the private sector to GDP, reflecting the depth of financial services concerning economic output. Foreign direct investment (net inflows) is abbreviated as FDI. It is expressed as a proportion of GDP. Household consumption, denoted by HHC, measured as a percentage of GDP, assesses the proportion of a country's economic activity driven by personal spending, reflecting consumer behavior's role in the overall economy. Trade, TR quantified as a percentage of GDP, gauges the significance of international commerce in a nation's economic output, highlighting the role of trade in the country's economy.

The study dissected the dynamic association between FD, FDI, capital adequacy, household consumption, and environmental quality in BRI nations for the period 2001-2019. Environmental quality is a proxy for carbon dioxide emission, sourced from world development indications.

3.3. Estimation Strategy

The subsequent sections provide a detailed discussion of each of these steps.

3.3.1. Cross-sectional dependence (CSD) test

Cross-sectional dependence (CD) is a prevailing concern in panel time series analysis, often originating from unobserved shocks that can introduce bias into the results. To address this challenge, we employ the approach developed by Pesaran (2004). The test equation is formulated as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \right) \quad (3)$$

where $\hat{\rho}_{ij}^2$ Indicate the pair-wise correlation residual sample estimate, and T and N are for cross-sections N and time.

3.3.2. Slope homogeneity tests

Once we have assessed the cross-sectional correlation, it becomes imperative to investigate slope homogeneity, as variations can exist across countries concerning demographics, economics, and socio-economic structures. To address this aspect, we apply the slope homogeneity test proposed by Pesaran and Yamagata (2008). The test equations are presented below:

$$\tilde{\Delta}_{SH} = (N)^{\frac{1}{2}} (2K)^{-\frac{1}{2}} \left(\frac{1}{N} \tilde{S} - k \right) \quad (4)$$

$$\tilde{\Delta}_{ASH} = (N)^{\frac{1}{2}} \left(2k \left(\frac{T-k-1}{T+1} \right) \right)^{-\frac{1}{2}} \left(\frac{1}{N} \tilde{S} - k \right) \quad (5)$$

$\tilde{\Delta}_{SH}$ and $\tilde{\Delta}_{ASH}$ Shows the delta tilde and delta tilde adjusted, respectively.

3.3.3. Unit root test

Once we have established the presence of cross-sectional dependence (CD) and heterogeneity in slope parameters, it's crucial to assess the integrating properties of variables employing second-generation unit root tests. In this context, we use the cross-sectional augmented Dickey-Fuller (CADF) and Pesaran's

I'm Pesaran-Shin (CIPS) unit tests Pesaran (2007). These unit root tests are notably well-suited for heterogeneous panel data and have demonstrated superior performance and consistency compared to first-generation unit root tests.

$$\Delta CA_{it} = \varphi_i + \varphi_i Z_{i,t-1} + \varphi_i \overline{CA}_{t-1} + \sum_{l=0}^{\rho} \varphi_{ij} \Delta C\overline{A}_{t-1} + \sum_{l=0}^{\rho} \varphi_{ij} \Delta CAi_{,t-1} + \mu_{it} \quad (6)$$

Where $\overline{CA}_{t-1}$ *and* $\Delta C\overline{A}_{t-1}$ are the cross-section averages.

The CIPS is computed like the IPS statistic in Im et al. (2003), as follows:

$$CIPS(N,T) = \frac{1}{N}\sum_{i=1}^{N} t_i \ (N,T) \quad (7)$$

$t_i\,(N,T)$ denotes the value of β_i. The inclusion of yt in the unit root equation renders the test statistic inconsistent with ADF statistics. Therefore, Pesaran offers the critical values.

3.3.4. Cointegration test

Following the stationarity diagnostics, the subsequent step involves identifying the long-run cointegration relationship among the underlying variables. To accomplish this, we operate the ECM panel cointegration test introduced by Westerlund (2007). This test delivers robust results even in the presence of heterogeneous slopes and cross-sectional dependence. The Westerlund test is outlined as follows:

$$\alpha_i(L)\Delta y_{it} = \delta_{1i} + \delta_{2i}t + \alpha_i\left(y_{it-1} - \beta'_i x_{it-1} + \lambda_i(L)' v_{it}\right) + e_{it} \quad (8)$$

In Eq. (10) α_i represent the cointegration vector between y and x, and β_i Is an error correction coefficient. Empirically tests can be determined as:

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\alpha'_i}{SE(\alpha'_i)} \quad (9)$$

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{T\alpha'_i}{\alpha'_i(1)} \quad (10)$$

$$P_t = \frac{\alpha'}{SE(\alpha')} \quad (11)$$

$$\alpha' = \frac{P_a}{T} \quad (12)$$

where, $\alpha' = \frac{P_a}{T}$ Denotes the proportion of the error to be corrected annually for the short-term disequilibrium.

3.3.5. Short-run and long-run analysis

Economists have applied various econometric techniques for the empirical analysis of panel data. However, the first-generation cointegration estimation techniques, such as Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS), and others, may yield biased results when confronted with cross-sectional dependence and heterogeneity in panel data. The Cross-Sectional Autoregressive Distributed Lags (CS-ARDL) model, as proposed by Chudik and Pesaran (2015), is not only robust against cross-sectional dependency and heterogeneity but also adept at handling non-stationarity and endogeneity issues. Consequently, this study employs the CS-ARDL method to examine the short-run and long-run relationships between FD, human capital, institutional quality, economic growth, energy consumption, and EF. The test equation for CS-ARDL is formulated as follows:

$$\Delta EF_{i,t} = \varphi_i + \sum_{j=1}^{\rho} \varphi_{it} \Delta EF_{i,t-j} + \sum_{j=0}^{\rho} \varphi'_{ij}\, AEV_{i,t-j} + \sum_{j=0}^{\rho} \varphi'_{it}\, \overline{Z}_{t-j} + \varepsilon_{i,t} \quad (13)$$

The cross-sectional averages are denoted as $\overline{Z}_t = \left(\Delta\overline{EF}_t, A\overline{E}V'_t\right)'$ and AEV represents the set of explanatory variables.

3.3.6. Robustness test (AMG)

The findings obtained through the CS-ARDL approach are further validated using the Augmented Mean Group (AMG) method. The AMG test is particularly robust as it addresses cross-sectional dependence, heterogeneity, and endogeneity issues more effectively than conventional methods Eberhardt (2012).

3.3.7. D-H causality test

While the outcomes obtained from the AMG and CS-ARDL estimators provide valuable insights, they do not establish causal relationships between the variables, which are vital for policy recommendations. To address this, the study employs the contemporary second-generation Dumitrescu and Hurlin (2012) test. The model is presented as follows:

$$z_{i,t} = \alpha_i + \sum_{j=1}^{p} \beta_i^j z_{i,t-j} + \sum_{j=1}^{p} \gamma_i^j T_{i,t-j} \quad (14)$$

where, β_i^j represents the parameters of autoregressive and lag length denoted by j.

4. ESTIMATION AND INTERPRETATION

4.1. Cross-sectional Dependency

The cross-sectional dependence (CD) test conducted using equation (5) in Table 2 confirms the presence of significant CD in the panel data, with the null hypothesis rejected at the 1% significance level. This indicates a high level of interdependence among countries, suggesting that shocks in one emerging country can affect other regions and nations.

In Table 3, the slope homogeneity test results show that all three models exhibit heterogeneous slopes, as evidenced by delta ($\tilde{\Delta}$) and adjusted delta ($\tilde{\Delta}_{adjusted}$) values.

Table 4 presents the unit root test results, indicating that both financial development (FD) and institutional quality exhibit unit root problems at the level. However, differencing these variables once renders them stationary.

Table 2: Cross-sectional dependency

Variables	CF	CO_2	FDI	FD	HHC	TR	REC
Breusch-Pagan LM	174.249***	295.455***	420.059***	398.13***	193.688***	360.194***	251.52***
Pesaran scaled LM	23.56***	39.138***	37.148***	24.121***	35.231***	38.706***	37.68***
Bias-corrected scaled LM	175.634***	192.797***	203.372***	120.873***	104.707***	171.87***	126.924***
Pesaran CD	53.29***	46.43***	5.923***	44.82***	12.022***	50.159***	45.026***

Table 3: Results of the slope of the homogeneity test

	CF	CO_2	FDI	FD	HHC	TR	REC
Δ	48.242***	60.676***	17.281***	44.183***	55.905***	81.318***	75.215***
Adj.Δ	103.326***	91.959***	78.855***	64.032***	60.458***	85.766***	97.625***

Table 4: Panel unit root test

Variables	CADF test statistic for constant		CIPS test statistic for constant		CADF test statistic for constant and trend		CIPS test statistic for constant and trend	
	Level	First difference	Level	First difference	Level	First difference	Level	First difference
CO_2	−2.572	−6.877***	−1.148	−7.246***	−2.726	−5.784***	−2.855	−5.774***
FDI	−1.244	−3.151***	−1.479	−6.95***	−2.562	−5.84***	−1.6	−3.387***
FD	−2.199	−2.757***	−2.04	−7.294***	−1.317	−5.299***	−1.534	−3.259***
TR	−1.614	−2.399***	−2.435	−2.769***	−1.634	−4.353***	−1.852	−6.688***
HHC	−2.512	−2.294***	−2.153	−5.792***	−1.56	−4.349***	−1.757	−3.323***
CA	−1.561	−4.765***	−2.435	−4.884***	−2.354	−3.768***	−2.662	−4.102***
REC	−1.444	−6.014***	−1.893	−2.394***	1.1459	−5.7047***	−2.276	−4.779***

P<0.01, 0.05, 0.10 indicate ***, ** and *, respectively

The study implemented panel cointegration tests following wester, kao, and Pedroni in documenting the long-run association between EQ, FDI, FD and CA. Table 5 exhibited the result of the panel cointegration test and referring to the test statistics, it is found statistically significant. The study revealed long-run association in the empirical nexus.

4.2. Base Line Estimation

Trade (TR), with a substantial positive coefficient (0.2617) and a high t-statistic (6.3545), is statistically significant, suggesting that its influence on emissions is not likely due to random chance. A 10% increase in trade is associated with a roughly 2.617% increase in carbon dioxide emissions. This positive relationship may stem from the transportation and energy-intensive nature of traded goods, contributing to heightened emissions Liu et al. (2020). Conversely, Household Consumption (HHC) showcases a meaningful negative impact (Coefficient: −0.4940), indicating that higher household consumption is linked to decreased carbon dioxide emissions: a 10% increase in household consumption leads to a roughly 4.940% decrease in carbon dioxide emissions. This inverse relationship may be attributed to consumer preferences for cleaner, more energy-efficient products, reducing the overall carbon footprint Bülbül et al. (2020); (Qamruzzaman, 2023a; Lin and Qamruzzaman, 2023).

FDI demonstrates a positive influence (Coefficient: 0.0172), implying that increased foreign investment corresponds to higher emissions. For FDI, a 10% increase corresponds to an approximately 1.720% increase in carbon dioxide emissions. This positive association might be due to the potential for foreign investors to engage in industries with less stringent environmental regulations or employ energy-intensive processes Du et al. (2022a). Meanwhile, the smaller coefficients and lower statistical significance for FD and CF suggest a less pronounced impact. A 10% increase in these variables might lead to minor carbon dioxide emission changes. However, the specific impact would require a more nuanced investigation. These more invalid links reflect the indirect nature of financial and corporate factors in influencing emissions, as various contextual and industry-specific factors likely mediate their impact Soundarrajan and Vivek (2016) and Liu et al. (2023) (Table 6).

4.3. Results of Short-run and Long-run Assessment: CS-ARDL and PGM Estimation

A one-unit increase in financial development is associated with a 7.19% increase in the dependent variable in the long run. This suggests that over time, improvements in financial development led to a proportional rise in carbon emissions. The positive impact aligns with expectations, indicating that a more developed financial sector contributes positively to the overall economic activity and, consequently, to the variable under consideration Han et al. (2022). However, in the short run, a one-unit increase in FD (D(FD)) leads to a 10.49% increase in carbon emission. The short-run dynamics reflect a more immediate response to changes in financial development, emphasizing the prompt influence of financial sector improvements on the variable of interest Zhou et al. (2019).

The negative coefficient of −0.065607 implies a 6.56% decrease in carbon emission for a one-unit increase in FDI in the long run. This suggests that, over time, higher levels of foreign direct investment are associated with a proportional reduction in the variable under consideration. The negative impact may indicate potential environmental concerns related to particular industries attracting foreign investment Balcilar et al. (2023). In the short run, a one-unit increase in FDI (D(FDI)) results in a 2.60% decrease in the dependent variable. The short-run response highlights the

Table 5: Panel cointegration test

Model	FDI--->EQ	FD--->EQ	CA--->EQ	TR--->EQ	HHC--->EQ
Gt	−14.666***	−12.069***	−12.323***	−6.726***	−8.533***
Ga	−14.057***	−11.632***	−7.418***	−9.123***	−15.113***
Pt	−14.39***	−7.297***	−12.601***	−14.324***	−11.523***
Pa	−10.284***	−9.65***	−11.797***	−13.941***	−7.798***
KRCPT					
MDF	18.588***	6.041***	19.91***	16.668***	0.668***
DF	19.58***	−7.437***	−6.468***	3.955***	−5.837***
ADF	13.813***	22.932***	7.694***	13.101***	−4.535***
UMDF	−8.124***	3.585***	11.666***	18.373***	10.669***
UDF	22.806***	−6.832***	−8.064***	9.484***	5.18***
PCT					
MDF	−1.233***	7.738***	−8.248***	2.238***	3.381***
PP	11.648***	12.229***	10.225***	−2.886***	14.046***
ADF	14.212***	10.458***	9.391***	13.756***	12.577***

Table 6: Base line estimation

Variables	OLS			RE			FE		
	Coeff.	SE	t-statistic	Coeff.	SE	t-statistic	Coeff.	SE	t-statistic
FD	0.2598	0.0229	11.336	0.0903	0.0142	6.3171	−0.0157	0.0152	−1.0292
FDI	−0.0005	0.0273	−0.0191	0.0325	0.0077	4.1846	0.0172	0.0073	2.3321
CF	−0.5169	0.0839	−6.1615	0.0853	0.0268	3.1754	−0.0175	0.0260	−0.6713
TR	1.0357	0.0860	12.041	0.1780	0.0438	4.0562	0.2617	0.0411	6.3545
HHC	−2.2719	0.1348	−16.845	−0.4393	0.0708	−6.2053	−0.4940	0.0651	−7.5883
REC	−0.1438	0.035	−4.1085	−0.1011	0.0459	−2.2026	−0.1091	0.0301	−3.6245
C	5.2540	0.8300	6.3295	−0.3653	0.3946	−0.9257	0.0342	0.3426	0.0999

more immediate and direct impact of changes in foreign direct investment on the variable, showcasing the swifter adjustments in the short-term Ren et al. (2022). The negative coefficient of −0.111219 implies an 11.12% decrease in carbon emission for a one-unit increase in cash flow in the long run. Over time, this suggests that higher levels of capital formation are associated with a proportional reduction in the variable under consideration. This negative impact may raise questions about the environmental sustainability of certain cash flow activities Ullah et al. (2023). In the short run, a one-unit increase in CF (D(CF)) leads to a 40.34% decrease in carbon emission. The short-run dynamics accentuate the immediate influence of changes in capital formation on the variable, underlining the rapid adjustments within a shorter timeframe Fragkos et al. (2017).

The positive coefficient of 0.556231 indicates a substantial 55.62% increase in carbon emission for a one-unit increase in trade in the long run. Over time, higher levels of trade are associated with a proportional rise in the variable under consideration. This positive impact aligns with the expectation that increased trade activities may contribute to higher economic output and, consequently, higher emissions Ganapati and Wong (2023). In the short run, a one-unit increase in TR (D(TR)) results in a 53.81% increase in carbon emission. The short-run response underscores the immediate influence of changes in trade on the variable, emphasizing the swift adjustments in economic activities associated with trade Li et al. (2021). The negative coefficient of −2.177159 signifies a significant 217.72% decrease in carbon emission for a one-unit increase in household consumption in the long run. Over time, higher household consumption levels are associated with a substantial proportional reduction in the variable under consideration. This negative impact suggests that environmentally conscious consumption patterns may reduce emissions Mustaffa and Kudus (2022). In the short run, a one-unit increase in HHC leads to a 15.49% decrease in carbon emission. The short-run dynamics emphasize the more immediate and direct impact of changes in household consumption on the variable, showcasing the rapid adjustments in the short-term Sugsaisakon and Kittipongvises (2021) (Table 7).

The present study has extended the empirical estimation with the implementation of DSUR, CUP-FM AND CUP-BC to ensure the robustness of empirical estimation, especially for the long-eon assessment. Table 8 displayed the results of the robustness assessment and veiled the similar line of connection to EQ, Table 9 displayed the causality test results and exposed both unidirectional and bidirectional connections among research variables. For the feedback hypothesis, the study revealed a bidirectional causal association running between FDI and EQ, FD and EQ, TR and EQ, and HHC and EQ. Moreover, the undirected effects run from capital adequacy to environmental quality.

4.4. Country-wise Assessment

For foreign direct investment to environmental quality (Table 10), the study documented Positive significant associations in countries like Lebanon, Estonia, Indonesia, South Africa, Nepal, Belarus, Tajikistan, Slovakia, Jordan, Thailand, Macedonia, Armenia, Moldova, Panama, China, Cambodia, Bangladesh, and Mongolia. Furthermore, the bolstering effect of FDI on CO_2 control has revealed that the negative significant associations in countries like Oman, Ethiopia, Pakistan, Brunei Darussalam, Poland, Israel, Kuwait, Saudi Arabia, Kazakhstan, Slovenia, Albania, Georgia, Bahrain, Qatar, Hungary, Colombia, Kyrgyz Republic, Bulgaria, Azerbaijan, Romania, Iran, Philippines, UAE, Turkey,

Table 7: CS ARDL-PMG

	CS-ARDL			PMG		
	Coefficient	t-stat	SE	Coefficient	t-stat	SE
LONG RUN						
FD	0.0719	0.0632	1.1368	0.0775	0.009	8.6111
FDI	−0.0656	0.0422	−1.5539	0.1387	0.0055	25.2181
CF	−0.1112	0.1326	−0.8381	0.1289	0.0052	24.7884
TR	0.5562	0.1054	5.2728	0.1136	0.0035	32.4571
HHC	−0.1671	0.0023	−72.6521	0.0287	0.0025	11.48
REC	−−0.1438	0.035	−4.1085	−0.1011	0.0459	−2.2026
short−run						
FD	0.1048	0.0263	3.9742	0.0581	0.0048	12.1041
FDI	−0.0259	0.0248	−1.0453	0.1044	0.0108	9.6666
CF	−0.4033	0.0780	−5.170	0.1173	0.0025	46.92
TR	0.5381	0.1001	5.3755	0.0435	0.0035	12.4285
HHC	−0.1548	0.1862	−0.8315	0.0599	0.0046	13.0217
REC	−0.09202	0.0302	−3.0470	−0.0835	0.041	−2.0385
COINTEQ01	−0.471	0.0007	−61.973	0.1027	0.0095	10.8105
CD test		0.031747			0.027107	
Wooldridge Test for auto		0.814654			0.119228	
Normality test		0.352218			0.28627	
Remsey RESET test		0.228911			0.99054	

Table 8: Results of robustness assessment

	DSUR			CUP-FM			CUP-BC		
	Coff.	t-stat	SE	Coff.	t-stat	SE	Coff.	t-stat	SE
FD	0.0927	0.0023	40.3043	0.1144	0.0093	12.301	0.1584	0.0056	28.2857
FDI	−0.0636	0.0052	−12.2307	−0.115	0.0052	−22.1153	−0.0854	0.0097	−8.8041
CF	−0.0718	0.0102	−7.0392	−0.0951	0.0101	−9.4158	−0.1508	0.0103	−14.6407
TR	0.0258	0.0025	10.32	0.099	0.0019	52.1052	0.1057	0.0093	11.3655
HHC	−0.088	0.0078	−11.282	−0.1099	0.0094	−11.6914	−0.1402	0.0056	−25.0357
REC	−0.1176	0.0384	−3.0625	−0.1563	0.0268	−5.832	−0.1182	0.0327	−3.6146
c	6.2345	0.859	7.2578	4.6509	0.6151	7.5612	6.9211	0.2123	32.6005
CD test		0.024547			0.0257			0.03068	
Wooldridge Test for autoco		0.158021			0.6006			0.638712	
Normality test		0.017341			0.9480			0.214613	
Remsey RESET test		0.831755			0.9181			0.192105	

Table 9: Results of DH causality test

	CO_2	FD	FDI	CF	TR	HHC	REC
CO_2		(3.442)**	1.5409	1.8629	(3.9787)**	1.8044	(4.4399)**
		(3.6279)	(1.6241)	(1.9635)	(4.1935)	(1.9019)	(4.6797)
FD	1.8682		(4.0531)**	(2.7991)*	(5.1965)***	(2.7003)*	1.4505
	(1.9691)		(4.272)	(2.9503)	(5.4772)	(2.8461)	(1.5289)
FDI	(4.3368)**	1.8108		(3.5876)**	(3.1944)**	(5.8076)***	1.7088
	(4.571)	(1.9086)		(3.7814)	(3.3669)	(6.1212)	(1.801)
CF	(4.2114)**	(2.1052)*	(2.6057)*		(5.0223)***	(3.0956)**	(2.8767)**
	(4.4388)	(2.2188)	(2.7464)		(5.2935)	(3.2628)	(3.032)
TR	(5.7502)***	1.679	(2.3931)*	(5.3166)***		(3.9383)**	1.1349
	(6.0607)	(1.7697)	(2.5224)	(5.6037)		(4.151)	(1.1962)
HHC	1.0393	(5.1349)***	(5.1381)***	1.7258	(6.0765)***		(3.2773)**
	(1.0954)	(5.4122)	(5.4156)	(1.819)	(6.4046)		(3.4543)
REC	(3.0626)**	(4.0563)**	1.6386	1.0053	(5.8799)***	(2.5409)*	
	(3.228)	(4.2753)	(1.7271)	(1.0596)	(6.1974)	(2.6781)	

Yemen Republic, Iraq, Croatia, Korea Republic, Czech Republic, Morocco, Vietnam, and New Zealand. The study found a group of nations have experienced adverse effects on environmental quality due to trade liberalization in countries like Lebanon, Ukraine, Belarus, Saudi Arabia, India, Kazakhstan, Thailand, Vietnam, New Zealand, and Singapore. Furthermore, the neutral effects can be detected in countries like Oman, Pakistan, Brunei Darussalam, Poland, Israel, Myanmar, Hungary, Iran, UAE, Turkey, and Yemen Republic.

The positive effect of CA on CO_2 has been exposed in countries like Lebanon, Estonia, Indonesia, Ukraine, Nepal, Belarus, Tajikistan, Slovakia, Israel, Saudi Arabia, India, Kazakhstan, Slovenia, Albania, Georgia, Jordan, Myanmar, Hungary, Malaysia,

Table 10: Results of country-wise assessment: DOLS

	FDI	FD	CA	TR	HHC	REC
Lebanon	0.269***	0.034***	0.069*	0.157***	0.172***	−0.07***
Oman	−0.125*	−0.159**	0.039*	−0.109**	0.054**	0.12*
Estonia	0.018**	−0.037	0.023*	−0.118**	0.136**	−0.071***
Indonesia	−0.029*	0.275	0.018**	0.057	0.142**	0.109***
Ukraine	0.022**	0.188	0.211	0.267**	0.273**	0.189*
South Africa	0.148**	0.15	−0.01	0.201**	0.045	−0.245***
Nepal	0.094**	0.171	0.151	0.263*	−0.059***	0.044**
Ethiopia	−0.198	−0.053**	−0.125*	0.087	−0.007	−0.053
Pakistan	−0.272***	−0.105**	−0.109**	0.04	0.031***	−−0.032***
Belarus	0.087***	0.168***	0.23**	0.204	0.253	−0.149*
Tajikistan	0.143***	0.261**	−0.051**	−0.019**	−0.045***	−0.144***
Slovak Rep.	0.092**	0.091**	−0.032**	0.187***	0.161***	0.136***
Brunei Daru−	−0.251***	−0.151**	−0.12	−0.045	−0.073*	0.019*
Poland	−0.253***	−0.154**	0.022*	0.018***	−0.029*	−0.083
Israel	−0.222**	0.228**	0.209***	0.193***	0.043	−0.173***
Kuwait	0.139***	−0.028**	0.133***	−0.04	0.134	−0.022
Saudi Arabia	0.269**	0.268**	−0.069***	0.027*	0.266***	0.081***
India	0.222***	0.168***	0.112**	0.255***	0.071**	−0.044**
Kazakhstan	0.274***	0.024*	0.097	−0.098*	0.219*	−0.041
Slovenia	0.032***	0.131**	0.166***	−0.062	0.178*	0.003*
Albania	−0.219***	0.101***	0.167***	−0.11*	0.178*	0.018
Georgia	−0.162*	−0.108***	0.113*	0.012**	0.229*	−0.243***
Bahrain	−0.236***	0.085***	−0.014***	0.188**	0.177*	−0.015**
Jordan	0.005***	0.009***	0.176***	0.24***	0.268***	−0.134***
Qatar	−0.06***	0.079**	−0.113***	0.251***	0.099***	−0.191***
Myanmar	0.018	−0.159**	−0.041***	−0.052	−0.007*	−0.182***
Hungary	0.003	0.132***	−0.074***	−0.003	0.142***	−0.107***
Malaysia	0.031***	0.167***	−0.066***	0.06	0.215*	0.256
Colombia	0.056***	0.231	−0.118*	0.134***	−0.065	0.078***
Thailand	0.225***	0.079	0.136***	0.077*	0.227	−0.024
Macedonia	0.193***	−0.087**	0.24***	−0.163	−0.064	0.132***
Armenia	0.07***	−0.148***	0.056*	0.235***	0.093	−0.092
Moldova	0.252***	−0.083**	0.001	0.093***	−0.066***	−0.012***
Egypt	0.109***	−0.083	0.036*	−0.103**	0.245*	−0.152***
Panama	0.188***	0.177***	0.243**	0.021***	0.267	−0.231
China	0.16***	0.032	0.18***	0.053***	0.11***	−0.137
Cambodia	0.235*	0.199***	−0.022***	0.181***	0.07	0.191
Kyrgyz Rep.	0.148***	0.239	0.25**	0.155***	0.14***	−0.123***
Bangladesh	0.22***	−0.007	0.151	−0.115***	−0.004	−0.113***
Mongolia	−0.034**	−0.001	0.176	−0.075	0.269***	−0.015***
Bulgaria	−0.035**	0.002***	0.233	0.182***	0.141*	−0.017***
Azerbaijan	−0.015	0.264*	0.045	−0.127***	−0.075***	−0.182***
Sri Lanka	0.183	0.073***	−0.066	0.064*	0.158***	−0.109***
Romania	−0.144*	−0.084***	−0.066**	0.112***	−0.042	−0.272***
Iran	−0.224***	−0.016*	0.215**	0.161***	0.137***	−0.168**
Philippines	0.164*	−0.138	0.116***	0.101***	−0.071	0.061
UAE	−0.188***	−0.007	−0.003***	−0.016	0.238	0.013
Turkey	−0.008***	0.132**	0.244	0.014*	0.274***	−0.037***
Yemen Rep.	−0.016***	0.23*	0.061**	0.001*	−0.057***	0.138***
Iraq	0.088***	0.235***	−0.125*	0.222**	0.142***	−0.003**
Croatia	−0.051**	0.274	0.252***	0.175**	0.273*	−0.181***
Singapore	0.258***	−0.138***	−0.082***	0.093	0.219***	−0.195***
Korea Rep.	0.078*	−0.129***	0.163	0.219***	0.197	−0.031***
Russia	0.166***	−0.165***	0.175*	0.045*	0.185*	0.170***
Czech Rep.	−0.025*	−0.131*	−0.079***	0.204	−0.061***	−0.108*
Morocco	0.252***	−0.111***	−0.003**	−0.021	0.261**	−0.054***
Vietnam	0.192***	−0.087	−0.008	0.034	0.202	−0.152*
New Zealand	0.259**	0.124***	−0.06*	0.258***	0.071***	−0.217***

Thailand, Armenia, Moldova, Panama, China, Cambodia, Kyrgyz Republic, Bangladesh, Mongolia, Bulgaria, Azerbaijan, Sri Lanka, Iran, UAE, Turkey, Iraq, Croatia, Korea Republic, Russia, Czech Republic, Morocco, and New Zealand. On the other hand, the beneficial effects of CA in controlling CO_2 can be found in countries like Oman, Ethiopia, Pakistan, Brunei Darussalam, Poland, Kuwait, Qatar, and the Yemen Republic.

The destructive role of trade openness on environmental degradation has been exposed in countries like Lebanon, Estonia, Indonesia, Ukraine, South Africa, Nepal, Belarus, Tajikistan, Slovakia, Poland, Israel, Kuwait, Saudi Arabia, India, Kazakhstan, Slovenia, Albania, Georgia, Bahrain, Jordan, Myanmar, Hungary, Malaysia, Colombia, Thailand, Macedonia, Armenia, Moldova, Panama, China, Cambodia, Kyrgyz Republic, Bangladesh, Mongolia, Bulgaria, Azerbaijan, Sri Lanka, Romania, Iran, Philippines, UAE, Turkey, Yemen Republic, Iraq, Croatia, Singapore, Korea Republic, Russia, Czech Republic, Morocco, Vietnam, and New Zealand. On the other hand, trade openness fosters environmental quality in different countries like Oman, Ethiopia, Pakistan, Brunei Darussalam, Myanmar, Hungary, and Bulgaria.

Referring to HHC effects on environmental degradation, the study documented HHC aggravated the environmental degradation through CO_2 emission that is positive linkage in BRI nations like Lebanon, Oman, Estonia, Indonesia, Ukraine, South Africa, Nepal, Belarus, Tajikistan, Slovakia, Israel, Kuwait, Saudi Arabia, India, Kazakhstan, Slovenia, Albania, Jordan, Qatar, Hungary, Malaysia, Thailand, Armenia, Moldova, Egypt, Panama, China, Cambodia, Kyrgyz Republic, Bangladesh, Mongolia, Bulgaria, Azerbaijan, Sri Lanka, Romania, Iran, UAE, Turkey, Yemen Republic, Iraq, Croatia, Singapore, Korea Republic, Russia, Czech Republic, Morocco, Vietnam, and New Zealand. The beneficial effects are documented in countries like Ethiopia, Pakistan, Brunei, Darussalam, Poland, Myanmar, Colombia, and the Philippines.

5. DISCUSSION

Our study has generated valuable insights into the relationship between financial development (FD) and carbon dioxide (CO_2) emissions, as our regression analysis results outlined. In our analysis, the coefficient for FD in the long-run equation is 0.071920 with a t-statistic of 1.136846, suggesting a positive association with environmental quality. In the short-run equation, the coefficient for the first lag of FD (D(FD)) is 0.104898 with a t-statistic of 3.974272, reinforcing the positive short-term impact on environmental quality. Aligned with studies such as Cao et al. (2022), Awosusi et al. (2022). Usman et al. (2021), our findings support the notion that FD contributes positively to environmental quality. These studies, like ours, emphasize the potential of a robust financial sector to enhance environmental outcomes. Our research's positive correlation between FD and environmental quality resonates with their conclusions, implying that financial development can catalyze positive environmental change. In contrast to Jianguo et al. (2022), Ahmad et al. (2020), who propose a contrary linkage between FD and CO_2 emissions, our results indicate a potential positive short-term impact of FD on the environment. This divergence emphasizes the complexity of the relationship, and further investigation into contextual factors is warranted (Qamruzzaman, 2024). Our findings suggest that, in distinctive contexts, FD may contribute to increased carbon emissions in the short run, necessitating a nuanced understanding of the dynamics at play. Our results align with studies by Ozturk and Acaravci (2013) and Destek and Sarkodie (2019), suggesting that FD may not significantly influence environmental quality. The positive long-run impact in our study, coupled with the short-run positive effect, indicates that the influence of FD may not be immediate and could take time to materialize. The partial alignment suggests that, in specific circumstances, the expansion of the financial sector may not be an immediate, decisive factor in shaping environmental outcomes.

Furthermore, our findings also support the Environmental Kuznets Curve hypothesis, as evidenced by the positive association between FD and environmental quality in the short run. This aligns with Ahmad et al. (2022), who proposes an inverted U-shaped relationship between economic growth (including FD) and CO_2 emissions. The positive short-term impact of FD on environmental quality in our research indicates that there may be a critical threshold beyond which the positive impact diminishes. Considering studies focused on specific regions, our research does not explicitly provide geographical specificity(Qamruzzaman, 2023b). Nevertheless, policy implications can be drawn from our findings. The positive association between FD and environmental quality suggests that investing in a robust financial sector can contribute positively to environmental outcomes. This aligns with proposed policy solutions in the literature, such as trade liberalization, renewable energy investment, and green infrastructure. Similarly, in our analysis, the coefficient for FDI in the long-run equation is 0.065607 with a t-statistic of 1.553935, suggesting a potential positive association with environmental quality. In the short-run equation, the coefficient for the first lag of FDI (D(FDI)) is −0.025953 with a t-statistic of −1.045350, indicating a potential negative short-term impact on environmental quality. The mixed effects of FDI, education, and urbanization on environmental quality further underscore the complexities of these relationships.

Studies such as Pujiati et al. (2023), JinRu et al. (2022), Qamruzzaman (2021) assert a positive association between FDI and environmental quality. Suppose our results indicate a potential positive correlation between FDI and environmental quality. In that case, it aligns with the positive impacts suggested by these studies. The value added by our findings lies in providing quantitative evidence to support the positive relationship between FDI and environmental sustainability. Shabir et al. (2022) and Duodu et al. (2021) document that FDI gradually improves environmental quality. Our research may align with this perspective if our findings suggest a gradual positive impact of FDI on environmental conditions. The added value reinforces the idea that FDI when accompanied by environmental sustainability policies and domestic investment, can contribute to an incremental improvement in environmental quality over time (Yin and Qamruzzaman, 2024). Studies by Zafar et al. (2020a) and Hao et al. (2020b) highlight mixed effects of economic factors and FDI on the environment. If our results indicate a complex relationship between FDI and CO_2 emissions, it aligns with the findings of these studies. The value-added lies in our ability to quantify and contribute empirical evidence to the nuanced understanding of how economic factors interact with FDI to shape environmental outcomes (Qamruzzaman et al., 2023). Multiple studies, including by Munir and Ameer (2020), Hao et al. (2020a), Zomorrodi and Zhou (2017), Abdouli and Hammami (2017), Neequaye and Oladi (2015) and Seker et al. (2015), establish that FDI and trade reduce emissions. If our research corroborates this reduction in emissions due to FDI, it aligns with the collective findings of these studies. The value added here is in providing quantitative evidence supporting the argument that FDI and trade can positively reduce environmental emissions. Studies by Pazienza (2019) and Adeel-Farooq et al. (2021) present complex findings regarding the impact of FDI on CO_2 emissions. Suppose our results reveal a nuanced relationship, including potential small coefficients and effects that vary based on source country policies. In that case, it aligns with the intricate nature of FDI's impact on the environment suggested by these studies. The value added is in contributing empirical evidence to support the idea that various contextual factors influence the impact of FDI on environmental quality.

In alignment with studies by Du et al. (2022b), Isiksal et al. (2022), Ahmad et al. (2022), Khan et al. (2022), Zhang et al. (2021), (Qamruzzaman and Kler, 2023) and Yildirim et al. (2021), our research indicates a positive linkage between capital adequacy and environmental quality. The coefficient for capital adequacy in the long-run equation is 0.071920 with a t-statistic of 1.136846, suggesting a potential positive impact on environmental sustainability. Our findings resonate with the literature, emphasizing that effective capital adequacy management positively contributes to environmental quality. The shared emphasis on human capital development, sustainable economic policies, and efficient use of natural resources aligns with our potential recommendations for enhancing environmental sustainability. Contrary to the positive associations, our study does not align with the negative associations between financial development and environmental sustainability presented by studies like Yameogo et al., (Serfraz et al., 2023); Mujtaba et al. (2022). The literature suggests adverse economic growth and capital formation effects on environmental quality, challenging conventional beliefs. Our research indicates a potential positive impact of capital adequacy, challenging the notion of a negative association with environmental sustainability. This contrast highlights the complexity of the relationship between financial development and environmental outcomes, suggesting that the impact may vary based on specific factors. Our study aligns with the literature exploring asymmetric effects and multifaceted relationships, mainly as presented by Li et al. (2022). The nuanced findings of our research may reveal intricate and asymmetric effects of capital adequacy on environmental outcomes. This complexity underscores the need for tailored and context-specific policies to balance economic development and environmental conservation harmoniously. The study by Xu et al. (2017) introduces a unique perspective by examining the role of Intellectual Capital (IC) management in enhancing the performance of the Environmental Protection (EP) industry. While our study primarily focuses on financial capital adequacy, the literature on intellectual capital introduces an additional dimension to the discussion. If our research indicates that effective intellectual capital management positively influences environmental outcomes, it adds another layer to the multifaceted relationship between capital adequacy and environmental sustainability (Yan et al., 2023).

6. CONCLUSION

In the culmination of our research exploring the intricate dynamics between financial development (FD), foreign direct investment (FDI), capital adequacy, and environmental sustainability, we uncover nuanced insights that enrich the ongoing discourse in this critical nexus. Our regression analysis reveals a positive association between FD and environmental quality, signified by a long-run coefficient and a t-statistic. This aligns with studies emphasizing the potential positive impact of a robust financial sector on environmental outcomes. The short-run coefficient further reinforces this positivity, suggesting an immediate positive impact.

However, our results diverge from perspectives challenging the notion of a contrary linkage between FD and CO_2 emissions. This discrepancy underscores the complexity of the relationship, emphasizing the need for context-specific analyses and further exploration of the underlying factors shaping environmental dynamics. Our findings suggest that, in specific contexts, FD may contribute to increased carbon emissions in the short run, necessitating a nuanced understanding of the dynamics at play. Shifting focus to FDI, our research indicates a potential positive association with environmental quality, supported by a long-run coefficient. The short-run coefficient introduces a nuanced dimension with a potential negative impact. This complexity aligns with the mixed effects observed in studies, reflecting the intricate relationship between economic factors and FDI in shaping environmental outcomes.

Our study resonates with the positive associations highlighted by previous research. It adds quantitative evidence to support the argument that FDI can positively contribute to environmental sustainability. The gradual improvement in environmental quality associated with FDI, as documented, adds a temporal dimension to the discussion. Our results contribute to the nuanced understanding of the FDI-environmental quality relationship, providing empirical evidence to support the notion that FDI, accompanied by environmental sustainability policies and domestic investment, can contribute to incremental improvement over time.

Moreover, our research underlines the value of examining the impact of capital adequacy on environmental sustainability. The long-run coefficient for capital adequacy indicates a potential positive impact. This aligns with research suggesting a positive linkage between capital adequacy and environmental quality. Our findings challenge negative associations, highlighting the need for tailored policies to balance economic growth and environmental conservation. In the broader context, our results align with the Environmental Kuznets Curve hypothesis, particularly in the short run. The positive association between FD and environmental quality indicates a potential critical threshold beyond which the positive impact diminishes. This adds depth to the ongoing discussions surrounding this hypothesis. While our research does not explicitly provide geographical specificity, it offers valuable policy implications. The positive associations with FD, FDI, and capital adequacy suggest that investing in a robust financial sector and attracting foreign investments can contribute positively to environmental outcomes. The nuanced findings underscore the need for tailored policies considering the diverse impacts of these economic factors, reflecting the multifaceted nature of the relationships under consideration.

6.1. Policy Suggestion

A comprehensive approach integrating financial development (FD), foreign direct investment (FDI), and capital adequacy is essential to foster a positive impact on environmental quality. Firstly, governments should facilitate financial institutions to embrace green financing initiatives, directing investments toward eco-friendly projects and renewable energy. Simultaneously, strategic promotion of FDI in environmentally responsible sectors through incentives and vital regulatory frameworks can attract foreign investments that align with sustainability goals. Lastly, policymakers must converge capital adequacy essentials with sustainable development objectives, motivating financial entities to allocate capital towards initiatives that actively contribute to environmental conservation. By synergizing these policy measures, governments can harness the collective influence of FD, FDI, and capital adequacy to strengthen environmental quality.

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