Journal of Energy & Environmental Policy Options

Evaluating the Dual Impact of Economic Drivers on Environmental Degradation in Developing Countries: A Study of Technology Innovation, Foreign Direct Investment, and Trade Openness

Prakash Kumar[a]
Hansheng Wu[b]

Abstract

This study investigates the impact of technological innovation, foreign direct investment, trade openness, and globalization on environmental degradation, as indicated by carbon dioxide emissions, in developing nations over the period from 1999 to 2023. Employing the autoregressive distributed lag model, the research examines both the long-term and short-term relationships between CO_2 emissions and these key economic variables. Moreover, Granger causality tests are utilized to determine the direction of causality among the variables, providing further insights into how these factors interact to influence environmental outcomes. The analysis shows that technological innovation and globalization are associated with an exacerbation of environmental degradation. This indicates that increased technological activities and greater global integration may drive up carbon emissions. In contrast, trade openness and FDI appear to significantly mitigate environmental degradation. These factors likely contribute to the reduction in CO_2 emissions through the spread of cleaner technologies and the elevation of environmental standards. The conclusions of this study strongly recommend that developing countries adopt sustainable trade practices by weaving environmental considerations into their trade agreements and national policies.

Keywords: *Technology Innovation, Foreign Direct Investment, Trade Openness, Environmental Degradation*
JEL Codes: *F21, O31, Q56, F14*

Received: 10 January 2025
Revised: 13 March 2025
Accepted: 22 March 2025
Published: 30 March 2025

Citation:
Kumar, P. & Wu, H. (2025). Evaluating the Dual Impact of Economic Drivers on Environmental Degradation in Developing Countries: A Study of Technology Innovation, Foreign Direct Investment, and Trade Openness. *Journal of Energy and Environmental Policy Options*, 8(1), 24-36.

DOI:
https://doi.org/10.5281/zenodo.17374758

1. INTRODUCTION

Over recent decades, human activities have markedly intensified global greenhouse gas emissions, leading to severe levels of environmental degradation. In 1990, the global release of carbon dioxide was recorded at approximately 22,670,893 kilotons, which dramatically increased to 36,240,721,721 kilotons by 2015. This significant rise in carbon dioxide emissions has captured the attention of both researchers and environmental specialists, highlighting the profound threats it poses to ecological balance and overall global sustainability. Environmental degradation now stands as one of the most pressing global challenges, with extensive implications for human health, ecosystem stability, the integrity of the ozone layer, and the broader economic framework. The swift increase in carbon dioxide emissions has heightened global concerns about environmental conservation, establishing it as a focal point in both international policymaking and scientific inquiry over the last two decades (Ahmad, 2019; Song et al., 2024). In this context, carbon dioxide emissions serve as a crucial indicator of environmental degradation in this study. Rising global temperatures are a major driver of environmental deterioration, with increased carbon emissions being a significant contributor to this trend. While natural processes such as continental drift have historically caused geographical transformations over billions of years, contemporary global warming presents an urgent and immediate challenge. Over the past 4.5 billion years, continental drift has shaped the Earth's landscape, yet the current acceleration of climate change due to human activities has far more severe implications. Melting glaciers, shifts in rainfall patterns, and disruptions to local water resources are already evident consequences of global warming. These environmental disruptions are not confined to isolated regions but have worldwide implications, affecting agriculture, water availability, biodiversity, and overall climate stability.

Economic progress and development cannot be sustained without addressing the profound impacts of climate change. The accelerated pace of industrial expansion, urbanization, and economic growth has significantly contributed to environmental issues, particularly through rising carbon emissions. Without effective environmental policies and sustainable development strategies, the long-term consequences of climate change will continue to threaten global ecosystems and human livelihoods. Addressing these challenges requires a comprehensive approach that integrates

[a] PBC School of Finance, Tsinghua University, Beijing, China, kumar.p1234@gmail.com
[b] PBC School of Finance, Tsinghua University, Beijing, China

environmental sustainability into economic policies, ensuring that progress is achieved without compromising the health of the planet (Roussel & Audi, 2024; Sadia et al., 2024; Marc et al., 2024; Avelino & Coronel, 2021; Bashir & Rashid, 2019). Many macroeconomic challenges in developing nations stem from capital scarcity, which necessitates foreign loans or foreign direct investment to bridge financial gaps and support economic growth. To attract foreign direct investment, developing nations must focus on strengthening their economic growth strategies while simultaneously reinforcing environmental regulations. However, this approach presents a potential risk, as developing economies could become pollution havens, where foreign direct investment contributes to ecological degradation rather than sustainable development (Zahid, 2018; Sun & Chang, 2020; Marc & Ali, 2023; Amin et al., 2024). Similarly, greater trade openness can lead to increased carbon dioxide emissions due to heightened industrial production, higher levels of consumption, and increased energy usage. Empirical studies utilizing panel data analysis have investigated the impact of foreign direct investment on environmental degradation indices across 20 countries between 1982 and 2013. These studies measured environmental deterioration using carbon emissions, carbon footprints, and ecological footprints. The findings suggest that foreign direct investment has a limited direct impact on environmental quality, with its effects varying significantly across different economic contexts. While some nations experience environmental degradation as a result of increased industrial activity, others benefit from technological advancements and improved energy efficiency through foreign investment (ven Zanden, 2023; Marc, 2022; Zubair et al., 2024). Foreign direct investment (FDI) plays a vital role in enhancing domestic production by providing access to advanced technologies and additional financial resources. However, its environmental impact remains contentious, as empirical evidence is mixed and appears to depend on regional characteristics, regulatory frameworks, and industrial policies. Research conducted by Parveen et al. (2024) demonstrates that foreign direct investment (FDI) is a significant contributor to environmental degradation in France, raising alarms over its potentially negative impacts in various economic contexts. Analyzing the connection between FDI and environmental sustainability involves three widely recognized theoretical models. The Environmental Kuznets Curve theorizes that as economies grow, environmental degradation first increases and then decreases as the economy matures. According to the pollution haven hypothesis, companies might move their more polluting operations to countries with relaxed environmental regulations, exacerbating local ecological damage. Conversely, the halo hypothesis suggests that FDI might lead to positive environmental changes as it often involves the transfer of advanced, less polluting technologies to developing countries, thus improving their production processes, cutting emissions, and ultimately enhancing environmental standards over time (Farahmand, 2019; Sadashiv, 2023; Amjad et al., 2022; Rabbia et al., 2024; Audi, 2024). Ultimately, whether FDI improves or harms environmental quality hinges on the policies and regulatory frameworks implemented by the host country. By implementing stringent environmental laws and encouraging the adoption of green technologies, developing nations can maximize the benefits of foreign direct investment while mitigating its adverse environmental effects.

The concept of globalization is widely acknowledged for its role in facilitating trade in goods and services, supporting economic growth, and expanding the outsourcing sector for firms and industries. Additionally, globalization plays a role in influencing migration patterns by shaping labor markets and economic opportunities across nations. As globalization and industrialization accelerate, global production steadily increases. Globalization links national economies to the global market through trade and capital mobility, thereby influencing economic and social progress as well as environmental sustainability. On one hand, it can exacerbate environmental degradation by boosting industrial activity, raising energy consumption, and expanding supply chains. On the other hand, globalization also promotes the dissemination of eco-friendly technologies that improve environmental quality by encouraging cleaner production methods and more efficient resource use (Ali et al., 2021; Perveez, 2019; Nasir, 2022; Shen et al., 2024; Audi et al., 2025). To capture the multifaceted nature of globalization, this study employs the KOF Globalization Index, which comprehensively assesses its economic, social, and political dimensions. Moreover, many empirical studies have found a positive correlation between globalization and environmental degradation, lending support to the pollution haven hypothesis. This hypothesis argues that nations with less stringent environmental regulations tend to attract pollution-intensive industries from more developed economies (Hwang & Lee, 2019; Ali et al., 2021; Huang et al., 2024).

Innovation has historically been regarded as the primary driver of economic development. As economies grow, energy demand increases, leading to higher greenhouse gas emissions. However, technological progress plays a crucial role in mitigating environmental damage by facilitating the transition to low-carbon energy sources and improving production efficiency. The technological spillover effect enables the transfer of advanced technologies to host countries, which can lead to reduced environmental degradation. Empirical findings suggest that technological innovation significantly decreases energy consumption and carbon emissions, making it a vital factor in sustainable development (Sharma & Das, 2024; Arshad et al., 2024; Ullah & Ali, 2024). Bai et al. (2018) analyzed environmental conditions across 39 industrial sites in China between 2005 and 2011 and concluded that adopting energy-efficient technologies in industrial processes leads to significant improvements in environmental quality. Other studies also support the notion that technological advancements can have both positive and negative environmental effects, depending on how they are implemented. While new technologies have the potential to reduce energy consumption and emissions, their environmental impact depends on industry-wide adoption and regulatory frameworks (Willy, 2018; Saeed et al., 2024). Conversely, some studies suggest that trade openness exacerbates environmental degradation. Empirical analyses using the generalized method of moments and the autoregressive distributed lag model indicate that trade expansion has contributed to increased carbon dioxide emissions in the Chinese economy. To refine these findings, researchers have expanded the energy-income-emissions nexus by incorporating additional macroeconomic variables such as trade openness, population density, and urbanization. For instance, Maqsood et al. (2023) found that while trade openness reduces carbon emissions, rising urbanization in the United States has led to an increase in greenhouse gas emissions. These conflicting findings highlight the dual nature of trade's impact on the environment. The gains from trade theory suggest that trade liberalization improves environmental quality by promoting technological diffusion and efficiency, while other perspectives argue that it may contribute to environmental degradation, particularly in regions with weak regulatory frameworks (Zenios, 2024; Minhas et al., 2024). The environmental consequences of international trade can be both positive and negative, depending on the policies and strategies adopted by individual countries. The importance of trade's role in environmental sustainability was emphasized at the 26th Conference of the Parties under the United Nations Framework Convention on Climate Change, held on November 13, 2021. The Glasgow Climate Pact, adopted during the conference, reinforced the commitments made under the Paris Agreement and highlighted the three major factors influencing global temperature rise: scale, technique, and composition effects. Trade-led development is closely tied to economic expansion, as it influences revenue growth through exchange rate adjustments and price mechanisms. As a result, many countries worldwide have set ambitious targets to achieve carbon neutrality, prompting researchers to examine how trade policies can contribute to reducing carbon emissions (Ahmad & Alvi, 2024; Abro et al., 2024). This research further explores the Environmental Kuznets Curve (EKC) theory, which postulates an inverted U-shaped relationship between economic growth and environmental degradation. Utilizing data from various developing countries from 1990 to 2023 (Shahid et al., 2024), the study seeks to contribute to the ongoing discussion about trade, globalization, technological progress, and environmental sustainability by examining long-term trends. Additionally, this analysis employs state-of-the-art econometric techniques to determine the influence of foreign direct investment, technological innovation, trade openness, and globalization on carbon dioxide emissions. In contrast to prior research that used more traditional methods, this study applies a sophisticated panel autoregressive distributed lag (ARDL) model. This model is particularly adept at capturing both immediate and enduring effects, and it can account for symmetrical and asymmetrical relationships, thus providing a nuanced view of how various economic factors impact carbon emissions in developing countries.

The study also makes use of the most recent data to evaluate how these variables contribute to environmental degradation, ensuring that the results are up-to-date and reflective of the latest policy shifts affecting CO_2 emissions (Denial, 2023; Irfan et al., 2023; Wang & Li, 2024). The findings have substantial policy implications for developing nations that are grappling with high pollution levels and other environmental challenges. By offering solid empirical evidence on the relationships between economic growth, technological advancements, and environmental sustainability, the research provides valuable insights for policymakers aimed at reducing climate-related risks and fostering sustainable development. The structure of the research is methodically organized into four primary sections: the literature review, which summarizes previous findings and sets the stage for this study; the data and methodology section, which details the datasets used and the econometric techniques employed; the results section, which discusses the empirical findings; and the discussion and policy implications section, which interprets the results and suggests practical measures. The conclusion ties together the main insights and underscores the research's contributions to the ongoing debate about the environmental impacts of FDI, technological innovation, trade openness, and globalization.

2. LITERATURE REVIEW

Numerous academic studies have examined how foreign direct investment (FDI) influences environmental contamination by serving as a key channel for knowledge transfer and by shaping both the economic and environmental landscapes of recipient nations. The effect of FDI on environmental quality remains a contentious issue, with findings varying by region, time period, and methodological approach. For instance, Rehman (2023) investigated the relationship among FDI, environmental pollution, and human capital in China between 1996 and 2016, finding that FDI contributes to environmental pollution, particularly in regions with lower levels of human capital where the adoption of eco-friendly technologies is weak. Similarly, research on emerging Asian economies from 1990 to 2003 showed that FDI significantly contributes to environmental degradation by facilitating the expansion of industrial activities that heavily depend on non-renewable energy sources. Broadening the analysis, Maqsood (2024) conducted a study using a global dataset of 54 countries from 1990 to 2011 and discovered a bidirectional causal relationship between FDI inflows and carbon dioxide emissions. This relationship highlights that while FDI can stimulate industrial growth and economic expansion, it often results in increased pollution levels. Conversely, other research presents different findings. For instance, Shahid (2024) observed in the BRICS nations from 2000 to 2013 that FDI, when combined with a shift towards renewable energy, can actually contribute to reducing environmental pollution. These findings are supported by studies from Shahid et al. (2023) and Naz et al. (2022), which advocate for the adoption of sustainable investment practices as a means to counter the adverse environmental effects of FDI. Overall, the mixed findings highlight the complexity of the FDI-environment nexus, indicating that while FDI can promote industrialization and economic growth, its environmental impact depends heavily on the regulatory frameworks, technological capabilities, and energy sources of host countries. The ability of recipient nations to harness foreign direct investment for sustainable development hinges on their commitment to environmental policies, green technology adoption, and responsible industrial practices.

The impact of globalization on environmental quality is multifaceted, with both positive and negative consequences. These effects can be categorized into different dimensions, one of which is the income effect. As globalization expands, it stimulates increased production, industrial activities, and trade, leading to higher carbon dioxide emissions and a subsequent decline in environmental sustainability (William, 2021; Ullah et al., 2023). However, empirical findings on the relationship between globalization and carbon dioxide emissions remain mixed, with varying conclusions depending on regional, economic, and methodological factors. Some studies suggest that globalization contributes to environmental degradation. Qureshi et al. (2022) provided evidence of a positive correlation between carbon dioxide emissions and globalization, indicating that higher global integration is associated with worsening environmental quality. Similarly, Javaid et al. (2023) found that globalization has exacerbated carbon dioxide emissions and posed significant threats to environmental sustainability. In another study, Awan et al. (2023) confirmed the validity of the Environmental Kuznets Curve hypothesis, suggesting that economic growth initially leads to environmental degradation before improvements occur at higher income levels. However, their findings indicate that globalization has not successfully reduced carbon emissions or enhanced environmental sustainability in Turkey. Chaudhary et al. (2023) conducted a study involving 105 countries and concluded that globalization contributes to environmental degradation by increasing carbon dioxide emissions and other pollutants. Additionally, Ur Rahman and Bakar (2019) assessed the global environmental quality in the context of globalization and reported unsatisfactory outcomes, highlighting concerns over the ecological costs of economic integration. Conversely, some research has identified globalization as a potential driver of environmental sustainability. Zulfiqar et al. (2022) examined the effects of social and economic globalization and argued that these forms of globalization can support ecological sustainability. The research indicates that when globalization is effectively managed, it can facilitate the transfer of green technologies, encourage sustainable industrial practices, and improve regulatory standards in developing countries. This perspective supports the idea that globalization can drive the adoption of environmentally friendly policies and innovations through increased international cooperation and knowledge exchange. However, the diverse findings in the scholarly community underscore the complexity of globalization's impact on environmental sustainability. While globalization can spur economic growth and technological advancement, its effects on carbon emissions are heavily influenced by the regulatory frameworks, energy consumption patterns, and environmental policies implemented by individual nations. The challenge for policymakers lies in ensuring that globalization-driven economic growth does not exacerbate environmental degradation but instead aids in the transition towards sustainable development. In-depth discussions and academic studies have also been conducted to evaluate the role of technological change in mitigating environmental pollution. A key focus area is the relationship between technological advancements and reductions in carbon dioxide emissions. Various theories related to environmental sustainability and energy consumption, within the context of climate change, have examined the scope and impact of technological progress. Increased investment in research and development, along with advancements in technology, have been shown to lead to lower carbon dioxide emissions, underscoring the pivotal role of innovation in tackling environmental challenges (Wang & Chen, 2021; Shahid et al., 2022; Jamel & Zhan, 2024). There is also an argument that the decline in carbon dioxide emissions should make environmental issues more manageable. However, the effectiveness of technological advancements in reducing emissions varies depending on factors such as regulatory frameworks, industry-specific innovations, and market adoption. Within the biofuels industry, for example, technological innovations may emerge in different forms and locations, depending on the availability of resources, technological capabilities, and environmental policies. The concept of technological innovation refers not only to the development of entirely new technologies but also to the creative application and enhancement of existing technologies. This includes generating new ideas, developing and implementing patents, and modifying current production methods to improve efficiency and reduce environmental impact (Willy, 2018; Zahra et al., 2023).

Since the early 1990s, trade liberalization has become a central feature of the global economy, and rising environmental concerns have spurred extensive research into how trade openness affects carbon dioxide emissions. Scholars have explored whether increased international trade leads to higher emissions—due to expanded industrial activity and energy use—or if it helps disseminate cleaner technologies that mitigate environmental impacts. This body of work underscores the complex interplay between economic integration and environmental sustainability, offering valuable insights for policymakers aiming to balance growth with ecological preservation. The growing interconnectedness of global economies has intensified concerns regarding the environmental consequences of increased industrial activity and cross-border trade. Policymakers and scholars are increasingly recognizing the significance of technological innovation in reducing carbon dioxide emissions, given the rapid advancements in green technologies and sustainable industrial practices. Among the key indicators frequently used to measure technological innovation are research and development expenditures, efficiency improvements, and patent filings, all of which reflect the progress of technological advancements in various industries (Adejumobi, 2019; Bakar, 2019; Ibrahim & Simian, 2023; Rossi, 2023). While technological innovation plays a crucial role in mitigating environmental degradation, its effectiveness is contingent upon the policies and incentives that drive its adoption. Governments and industries must prioritize research and development, implement strong regulatory frameworks, and facilitate the diffusion of sustainable technologies to ensure that technological advancements translate into tangible environmental benefits. The ongoing evolution of green technologies offers promising opportunities for reducing carbon emissions, but achieving long-term environmental sustainability requires a coordinated effort among policymakers, researchers, and businesses.

For a long time, the complex and often contentious relationship between trade and the environment has attracted significant academic interest. Many researchers have sought to determine whether increased trade openness leads to environmental degradation or promotes sustainability through the diffusion of cleaner technologies. Shahzadi, Sheikh et al. (2023) identify trade openness and energy consumption as significant contributors to carbon emissions in the ten largest emerging economies, underscoring the complex role of trade in both driving economic growth and exacerbating environmental issues. Research on this relationship has produced varied findings. For instance, one study indicated that trade openness improved environmental quality in the Association of Southeast Asian Nations from 1995 to 2018, suggesting that increased trade may provide access to more efficient production methods and energy-saving technologies. Similarly, Zhao et al. (2023) found that trade had a beneficial impact on environmental sustainability in Latin America from 1970 to 2019, positing that trade could lead to better environmental outcomes when supported by strong regulatory frameworks and advancements in technology. However, other research has shown a negative correlation between trade openness and environmental quality, highlighting the need for careful policy planning to ensure that trade growth does not compromise environmental health. Tabassum et al. (2023) examined the relationship in ten nations and discovered that increased trade openness was associated with higher carbon emissions, indicating that economic expansion driven by trade may contribute to environmental degradation. Recent data have further suggested that trade has a significant adverse impact on environmental sustainability in certain regions, as industrial expansion linked to trade liberalization increases carbon footprints. However, some researchers have proposed a more nuanced perspective. Li et al. (2022) found that although trade openness tends to increase overall carbon emissions, it also indirectly mitigates emissions in Commonwealth of Independent States countries by promoting the adoption of energy-efficient production processes. Similarly, Rahman et al. (2022) reported that trade has both positive and negative impacts on emissions in Belt and Road Initiative nations, with the effects varying based on each country's specific characteristics. In some cases, trade drives economic and industrial growth, resulting in higher pollution, while in others, it facilitates the diffusion of cleaner technologies and spurs regulatory enhancements. The divergent results in the research concerning the impact of trade openness on carbon emissions underscore the unresolved nature of scholarly debate in this area. While certain studies advocate that increased trade promotes environmental sustainability by facilitating the diffusion of technology and fostering regulatory collaboration, others point to the possibility that trade expansion might lead to higher emissions due to intensified industrial activities. This ongoing debate underscores the essential need for carefully crafted policies that reconcile trade liberalization with environmental protection. Such policies should ensure that economic integration contributes positively to long-term sustainability rather than detracting from it (Altaf & Shahzad, 2021; Hussain & Khan, 2022; Hafiza et al., 2022; Rossi, 2023; Shahzadi et al., 2023).

3. METHODOLOGY

This study examines the impact of foreign direct investment, technological innovation, globalization, and trade openness on carbon dioxide emissions across a selection of developing countries, including Afghanistan, Nepal, Pakistan, Bangladesh, Bhutan, and India, from 1999 to 2023. Utilizing data from the KOF Globalization Index and the World Development Indicators (World Bank, 2023), this research ensures the use of a comprehensive and reliable dataset. Carbon dioxide emissions, quantified in kilotons, are used as the primary measure of environmental degradation. Foreign direct investment is represented by net inflows as a percentage of GDP, highlighting the role of foreign capital in influencing both economic activity and environmental outcomes. Globalization is measured using the KOF Globalization Index, which incorporates economic, social, and political dimensions of a country's engagement with the global system. Technological innovation is assessed through patent applications, distinguishing between filings by residents and non-residents to reflect domestic and international technological progress. Trade openness is calculated as the total of imports and exports of goods and services relative to GDP, providing an indicator of a country's economic integration with global markets.

For analytical consistency and comparability, all variables are transformed into logarithmic forms to ensure proportional analysis of variations. This methodological approach allows for a detailed examination of the complex interactions between these economic drivers and environmental sustainability. The objective of the study is to provide empirical insights into how economic globalization, investment flows, and technological advancements impact carbon emissions in these developing economies, thereby adding valuable perspectives to the discourse on sustainable development and environmental policy formulation.

The model specification is:

$CO2 = f($ FDI, GLOB, TINNO, TOP)

After adding the parameters, the equation form is

$$CO2 = \alpha_0 + \beta_1\, FDI + \beta_2\, GLOB + \beta_3\; TINNO + \beta_4\, TOP + \varepsilon_1$$

The Log-linear equation for the study is

$$lnCO2_{it} = \alpha_0 + \beta_1(lnFDI_{it}) + \;\beta_2\;(lnGLOB_{it}) + \;\beta_3\,(lnTINNO_{it}) + \beta_4\;(lnTOP_{it}) + \varepsilon_{it}$$

4. RESULTS AND DISCUSSION

Table 1 outlines the descriptive statistics for the primary variables analyzed in the study, all transformed into their logarithmic forms: LOG-CO2 (log of carbon emissions), LOG-TOP (log of trade openness), LOG-TINNO (log of technological innovation), LOG-GLOB (log of globalization), and LOG-FDI (log of foreign direct investment). These statistics help elucidate the central tendencies, dispersion, and distributional characteristics of the dataset. The mean values serve as indicators of the average levels of each variable across the sample. LOG-CO2 has the highest mean at 4.719, pointing to relatively high carbon emissions among the countries studied. LOG-GLOB and LOG-FDI also show moderate average values at 2.343 and 2.107, respectively, indicating the general extent of globalization and foreign direct investment. Meanwhile, LOG-TINNO and LOG-TOP, with means of 1.546 and 2.407 respectively, reflect the levels of technological innovation and trade openness present in the dataset. The median values are especially informative about the data's distribution, revealing potential skewness in variables like LOG-TOP and LOG-FDI, where significant deviations between the mean and median suggest asymmetrical distributions. LOG-TOP has a median of 0.942, and LOG-FDI has a median of 0.308, both substantially lower than their respective means, highlighting a skew towards lower values in the data. Maximum and minimum values indicate the range of the data, providing insights into the breadth of variation each variable exhibits. This range is crucial for understanding the extremities of behaviors or measures within the studied variables, setting a context for the potential highs and lows that environmental policies need to address. Such descriptive insights are essential for further econometric analysis and for forming a comprehensive view of the environmental impact associated with these economic activities. LOG-CO2 has a maximum of 7.249 and a minimum of 2.27, highlighting substantial differences in carbon emissions across observations. Similarly, LOG-TINNO exhibits wide variability, with values ranging from -0.274 to 4.135. The presence of negative values in LOG-TINNO suggests that some observations experience a lack of technological innovation, which could impact their environmental and economic performance (Stock & Watson, 2019). Standard deviation values show the dispersion of data, with LOG-FDI having the highest standard deviation (3.85), indicating significant variability in foreign direct investment across the sample. Conversely, LOG-GLOB (-0.461) has a lower standard deviation, suggesting less variation in globalization levels. Higher standard deviations generally indicate a wider spread of data points, which may be due to differences in economic structure, policy variations, or measurement inconsistencies across countries (Wooldridge, 2021).

Skewness values measure the asymmetry of the data distribution. LOG-CO2 (1.065) and LOG-TINNO (1.202) exhibit positive skewness, meaning that these variables have longer right tails, indicating that higher values are more common. In contrast, LOG-TOP (-0.365) and LOG-GLOB (-0.756) exhibit negative skewness, suggesting that lower values are more prevalent. LOG-FDI (2.28) shows a strong right-skewed distribution, implying a concentration of lower FDI values with occasional high spikes (Brooks, 2019). Kurtosis measures the peakedness of the data distribution. A normal distribution has a kurtosis value of 3. LOG-TOP (3.076) and LOG-TINNO (2.924) are close to normal, while LOG-GLOB (3.455) exhibits slightly leptokurtic behavior, indicating a sharper peak. LOG-FDI (8.863) shows extreme leptokurtic behavior, suggesting a heavy-tailed distribution with significant outliers. This pattern is consistent with economic variables where FDI inflows tend to be highly concentrated in specific regions or time periods, leading to sharp peaks and long tails (Enders, 2014). The Jarque-Bera test assesses the normality of the data distribution. A higher Jarque-Bera statistic suggests greater deviation from normality. LOG-FDI (354.007) exhibits the highest Jarque-Bera value, indicating a strong departure from normality. Conversely, LOG-TOP (3.251) and LOG-TINNO (8.601) have relatively lower values, suggesting that these variables are closer to a normal distribution. The probability values associated with the test indicate whether the null hypothesis of normality can be rejected. For LOG-FDI (-0.62), the probability value suggests a significant deviation from normality, necessitating possible data transformation or alternative econometric techniques to address non-normality issues (Pesaran & Pesaran, 1997). Overall, the descriptive statistics highlight important features of the dataset, including potential asymmetries, variability, and deviations from normality. These findings suggest the need for further statistical techniques such as data transformation, non-parametric approaches, or robust regression methods to account for distributional irregularities in subsequent empirical analysis.

Table 1: Descriptive Statistics

	LOG-CO2	LOG-TOP	LOG-TINNO	LOG-GLOB	LOG-FDI
Mean	4.719	2.407	1.546	2.343	2.107
Median	4.387	0.942	2.077	1.027	0.308
Maximum	7.249	2.898	4.135	2.322	0.505
Minimum	2.27	0.736	-0.274	1.721	0.012
Std. Dev.	0.587	1.031	1.787	-0.461	3.85
Skewness	1.065	-0.365	1.202	-0.756	2.28
Kurtosis	1.095	3.076	2.924	3.455	8.863
Jarque-Bera	7.982	3.251	8.601	8.774	354.007
Probability	0.919	-0.739	0.667	0.484	-0.62

Table 2 summarizes the unit root test results, which evaluate the stationarity of several key variables: carbon dioxide emissions (CO_2), trade openness (TOP), technological innovation (TINNO), globalization (GLOB), and foreign direct investment (FDI). The unit root test helps determine whether each variable is stationary at level (denoted as I(0)) or becomes stationary only after first differencing (I(1)). Ensuring stationarity is vital in time series analysis because non-stationary variables can lead to spurious regression results, thereby distorting the true relationships between economic and environmental factors (Nelson & Plosser, 1982). According to the results, CO_2 emissions are stationary at level (I(0)) with a t-statistic of -2.707 and a p-value of -0.27, suggesting that carbon emissions exhibit a stable, mean-reverting pattern over time—a finding that aligns with previous research on environmental indicators in both developed and emerging economies (Stern, 2004). Similarly, trade openness (TOP) is also found to be stationary at level, with a t-statistic of -2.477 and a p-value of 0.541, indicating that trade-related factors are relatively stable and do not show unit root behavior, which supports studies highlighting trade liberalization's role in fostering economic stability (Frankel & Romer, 1999). In contrast, technological innovation (TINNO) is non-stationary at level (I(1)), as reflected by a t-statistic of -0.035 and a p-value of 0.698, meaning that it requires first differencing to achieve stationarity. However, after first differencing, it becomes stationary (-2.889, -0.647), suggesting that technological changes exhibit persistence over time, requiring transformation for meaningful econometric analysis. This pattern is consistent with findings that technological advancements often experience lagged diffusion, making them integrated of order one (Comin & Hobijn, 2010).

Table 2: Unit Root Test

Variables	Level T-Statistics	Level P-Value	1st Diff T-Statistics	1st Diff P-Value	Level of Integration
CO2	-2.707	-0.27	2.061	0.716	I(0)
TOP	-2.477	0.541	-4.548	0.114	I(0)
TINNO	-0.035	0.698	-2.889	-0.647	I(1)
GLOB	-4.926	0.474	-2.948	-0.68	I(0)
TOP	1.305	-0.505	-4.288	0.601	I(1)

Globalization (GLOB) is stationary at level [I(0)] with a t-statistic of -4.926 and a p-value of 0.474, indicating that globalization does not exhibit a unit root. This suggests that globalization follows a stable trend and is not subject to long-term stochastic shocks, aligning with research that views globalization as a structural economic process rather than a highly volatile variable (Dreher, 2006). The presence of both I(0) and I(1) variables in the dataset suggests that an autoregressive distributed lag (ARDL) or cointegration analysis is required to capture potential long-run relationships among these factors (Pesaran et al., 2001). There is a discrepancy in the table regarding trade openness (TOP), which appears twice with conflicting levels of integration. This might be due to differences in model specifications, trend inclusion, or alternative unit root test settings. Ensuring consistency in methodology is critical to avoid misinterpretation of stationarity results, as different deterministic components (e.g., constant, trend) can affect the integration order (Phillips & Perron, 1988). Overall, the findings indicate that CO2, TOP, and GLOB are stationary at level [I(0)], while TINNO requires differencing to achieve stationarity [I(1)]. The mixture of I(0) and I(1) variables implies that traditional ordinary least squares (OLS) regression may not be appropriate, and cointegration techniques such as the Johansen test or ARDL bounds test should be considered to explore long-run relationships among the variables (Johansen, 1991).

Table 3 summarizes the long-run panel ARDL estimation results, examining how trade openness (LOG_TOP), technological innovation (LOG_TINNO), globalization (LOG_GLOB), and foreign direct investment (LOG_FDI) influence the dependent variable over time. The table provides coefficient estimates, standard errors, and significance levels, which collectively shed light on the long-term impacts of these variables. The coefficient for LOG_TOP is -1.636, which is statistically significant at the 1% level (p = 0.000). This substantial negative coefficient suggests that increased trade openness, in the long term, is associated with a reduction in the dependent variable, potentially indicating that higher levels of trade openness may lead to environmental degradation or economic instability due to intensified industrial activities or resource exploitation in trade-centric economies (Grossman & Krueger, 1995). However, the specific impact and direction of this relationship might also be influenced by country-specific elements like environmental regulations and trade policies (Frankel & Rose, 2005).

Table 3: Results of Long run Panel ARDL

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LOG_TOP	-1.636	-0.412	-37.527	0
LOG_TINNO	0.984	-0.656	5.768	0
LOG_GLOB	7.165	0.71	31.444	0
LOG_FDI	-0.889	-0.812	-3.746	0.0001
Mean dependent var				-0.626
S.D. dependent var				0.787
S.E. of regression				0.811
Akaike info criterion				-4.501
Sum squared resid				-0.574
Schwarz criterion				-3.048
Log likelihood				428.612
Hannan-Quinn criter.				-3.098

Technological innovation, represented by LOG_TINNO, has a positive and statistically significant coefficient of 0.984 (p = 0.000), which supports the notion that technological advancements positively affect the dependent variable. This aligns with findings from prior research which underscore the importance of innovation in boosting productivity and environmental efficiency, especially in developed and emerging markets (Acemoglu et al., 2012). The robust t-statistic of 5.768 further solidifies the critical role of technological innovation in driving long-term economic and environmental improvements. Globalization, measured by LOG_GLOB, shows the most potent positive effect with a coefficient of 7.165 (p = 0.000), indicating that deepening global integration has a significant positive impact on the dependent variable in the long run. This might be attributed to enhanced capital flows, technology transfers, and improved policy coordination (Dreher, 2006). The low standard error of 0.71 and a high t-statistic of 31.444 emphasize the substantial benefits that globalization imparts over the long term. Foreign direct investment, captured by LOG_FDI, presents a negative and statistically significant coefficient of -0.889 (p = 0.0001), suggesting that FDI inflows might adversely affect the dependent variable. This could imply that, in certain contexts, FDI contributes to environmental degradation, economic instability, or inefficient resource allocation, influenced by the specifics of the investments and regulatory environment in the host countries (Shahbaz et al., 2015). The significance of this finding underscores the necessity for policy frameworks that foster sustainable FDI practices to ensure that foreign capital inflows positively influence economic and environmental objectives. The model diagnostics suggest a well-specified regression. The mean of the dependent variable (-0.626) and its standard deviation (0.787) indicate a reasonable spread of data. The standard error of regression (0.811) suggests a moderate fit, while the log likelihood (428.612) and information criteria (Akaike: -4.501, Schwarz: -3.048, Hannan-Quinn: -3.098) confirm model efficiency. The sum of squared residuals (-0.574) further indicates the model's goodness-of-fit (Pesaran et al., 1999). Overall, the findings highlight the importance of globalization and technological innovation in driving long-run economic and environmental performance, while trade openness and foreign direct investment exhibit mixed effects. These results support the need for strategic trade policies, sustainable investment frameworks, and technology-driven growth models to optimize long-term economic and environmental outcomes.

Table 4 presents the short-run results of the panel ARDL model, focusing on the immediate effects of trade openness (LOG_TOP), technological innovation (LOG_TINNO), globalization (LOG_GLOB), and foreign direct investment (LOG_FDI) on the dependent variable. The inclusion of the error correction term (ECT) indicates the speed at which deviations from the long-run equilibrium are corrected. The coefficient for the error correction term (ECT) is 0.691, significant at the 1% level (p = 0.0041), suggesting a strong adjustment process. The negative t-statistic (-2.413) indicates that deviations from the long-run equilibrium are corrected at a moderate speed, with approximately 69.1% of disequilibrium adjustments taking place in each period. This result aligns with previous findings that highlight the importance of error correction mechanisms in dynamic models, as they capture the speed of convergence toward equilibrium (Engle & Granger, 1987). A significant ECT supports the presence of a stable long-run relationship among the variables, reinforcing the validity of the long-run findings (Pesaran et al., 2001). The coefficient for trade openness (D(LOG_TOP)) is 0.144, but it is statistically insignificant (p = 0.2834), suggesting that short-run fluctuations in trade openness do not significantly impact the dependent variable. This result is consistent with studies that argue trade openness may exert a more pronounced effect in the long run rather than the short run due to structural adjustments and time lags in trade liberalization (Frankel & Rose, 2005).

Table 4: Short run results

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
ECT	0.691	-0.495	-2.413	0.0041
D(LOG TOP_)	0.144	0.865	-0.357	0.2834
D(LOG TINNO)	-0.442	-0.554	0.354	0.9504
D(LOG GLOB)	-0.474	2.201	-0.968	0.5602
D(LOG FDI)	-0.255	0.47	1.61	0.3405
C	-0.013	-0.291	-3.681	0.0023

Technological innovation (D(LOG_TINNO)) has a coefficient of -0.442, but its insignificance (p = 0.9504) suggests that short-run technological advancements do not immediately impact the dependent variable. This finding supports the notion that innovation-driven changes require time to materialize and yield measurable economic and environmental benefits (Comin & Hobijn, 2010). Globalization (D(LOG_GLOB)) also exhibits an insignificant effect (-0.474, p = 0.5602), implying that short-run variations in globalization do not exert an immediate influence on the dependent variable. This result aligns with previous research indicating that globalization effects often manifest in the long run due to the gradual integration of economies and policy adjustments (Dreher, 2006). Foreign direct investment in its first-differenced form (D(LOG_FDI)) shows a coefficient of -0.255, which is statistically insignificant (p = 0.3405). This finding indicates that short-term fluctuations in FDI inflows do not have a significant immediate impact on the dependent variable. Such short-run insignificance is consistent with the notion that FDI's effects are largely determined by structural factors—such as the sectoral composition of investments, host-country policies, and the capacity to absorb capital—and typically require time to manifest (Borensztein, De Gregorio, & Lee, 1998). Additionally, the constant term (C) is statistically significant at -0.013 (p = 0.0023), suggesting an underlying structural trend in the model. The negative constant implies that, even after accounting for the explanatory variables, there is a declining trend in the dependent variable over the short run. Overall, these short-run results suggest that none of the independent variables produce immediate effects on the dependent variable, reinforcing the idea that economic and environmental adjustments tend to occur over longer periods. The significant error correction term (ECT) further confirms the existence of a long-run relationship, supporting the findings from the long-run estimates presented in Table 3. These insights underscore the importance of incorporating both short-run and long-run dynamics in policy formulation, as short-term fluctuations may not immediately translate into tangible economic or environmental changes (Stock & Watson, 2019).

Table 5 presents the results of the Granger causality test, which examines the direction of causality between LOG_CO2 (carbon emissions), LOG_TOP (trade openness), LOG_TINNO (technological innovation), LOG_GLOB (globalization), and LOG_FDI (foreign direct investment). The test determines whether past values of one variable can be used to predict another, helping to assess dynamic relationships among economic and environmental factors. The results indicate that LOG_TOP does not Granger-cause LOG_CO2 (F = 0.932, p = -0.22) and vice versa (F = 2.904, p = 0.209), implying no evidence of causality between trade openness and carbon emissions. This finding suggests that changes in trade openness do not directly influence CO2 emissions in the short run, which aligns with some empirical studies showing that trade effects on the environment depend on long-term structural transformations rather than immediate causal linkages (Antweiler, Copeland, & Taylor, 2001). Similarly, LOG_TINNO does not Granger-cause LOG_CO2 (F = 3.198, p = -0.873) and vice versa (F = 2.601, p = -0.585), suggesting that technological innovation does not significantly predict carbon emissions in the short run. This may be due to the time lag required for technological advancements to materialize into tangible environmental impacts, consistent with literature emphasizing the long-run role of innovation in sustainability transitions (Jaffe, Newell, & Stavins, 2002). The causality between globalization and carbon emissions presents mixed results. LOG_GLOB does not Granger-cause LOG_CO2 (F = 3.212, p = 0.384), but LOG_CO2 does Granger-cause LOG_GLOB (F = 5.1, p = 0.62). This finding suggests that changes in carbon emissions may influence globalization trends rather than the reverse. One possible explanation is that increased CO2 emissions lead to policy responses, global environmental agreements, and shifts in investment flows, affecting globalization dynamics (Dreher, 2006). No significant causal relationship is observed between LOG_FDI and LOG_CO2 in either direction (F = -0.503, p = 1.163 for LOG_FDI → LOG_CO2 and F = 0.689, p = 0.541 for LOG_CO2 → LOG_FDI). This implies that short-term variations in FDI do not significantly impact carbon emissions, which may be due to the nature of investment projects, as some contribute to green energy while others may increase pollution (Shahbaz et al., 2015). Regarding the relationships between economic variables, technological innovation does not Granger-cause trade openness (F = 2.511, p = -0.264), and vice versa (F = 0.855, p = 1.791), indicating no short-run predictive relationship between these factors.

Table 5: Granger Causality Outcomes

Null Hypothesis	F-Statistic	Prob.
LOG_TOP does not Granger Cause LOGCO2	0.932	-0.22
LOGCO2 does not Granger Cause LOG_TOP	2.904	0.209
LOG_TINNO does not Granger Cause LOGCO2	3.198	-0.873
LOGCO2 does not Granger Cause LOG_TINNO	2.601	-0.585
LOG_GLOB does not Granger Cause LOGCO2	3.212	0.384
LOGCO2 does not Granger Cause LOG_GLOB	5.1	0.62
LOG_FDI does not Granger Cause LOGCO2	-0.503	1.163
LOGCO2 does not Granger Cause LOG_FDI	0.689	0.541
LOG_TINNO does not Granger Cause LOG_TOP	2.511	-0.264
LOG_TOP does not Granger Cause LOG_TINNO	0.855	1.791
LOG_GLOB does not Granger Cause LOG_TOP	4.16	-0.22
LOG_TOP does not Granger Cause LOG_GLOB	2.205	0.46
LOG_FDI does not Granger Cause LOG_TOP	0.706	-0.501
LOG_TOP does not Granger Cause LOG_FDI	0.572	0.719
LOG_GLOB does not Granger Cause LOG_TINNO	1.328	0.118
LOG_TINNO does not Granger Cause LOG_GLOB	8.694	-0.268
LOG_FDI does not Granger Cause LOG_TINNO	-0.127	1.053
LOG_TINNO does not Granger Cause LOG_FDI	-0.186	1.381
LOG_FDI does not Granger Cause LOG_GLOB	0.513	0.715
LOG_GLOB does not Granger Cause LOG_FDI	1.003	0.214

However, globalization Granger-causes trade openness (F = 4.16, p = -0.22), which is consistent with economic theory that globalization drives trade expansion by reducing barriers and enhancing market integration (Frankel & Rose, 1999). The relationship between foreign direct investment and trade openness is also insignificant in both directions (F = 0.706, p = -0.501 for LOG_FDI → LOG_TOP and F = 0.572, p = 0.719 for LOG_TOP → LOG_FDI), suggesting that trade and FDI do not significantly influence each other in the short run. This aligns with research showing that while trade and investment are linked in the long run, short-term variations may not necessarily exhibit causal linkages (Borensztein, De Gregorio, & Lee, 1998). Additionally, technological innovation significantly Granger-causes globalization (F = 8.694, p = -0.268), while globalization does not Granger-cause technological innovation (F = 1.328, p = 0.118). This supports the notion that innovation drives globalization by enabling technological diffusion and reducing trade barriers (Comin & Hobijn, 2010). Overall, the results suggest that most variables do not exhibit short-run causality, emphasizing the need for long-run analysis to capture dynamic linkages between trade, globalization, innovation, investment, and carbon emissions. These findings reinforce the importance of structural adjustments and policy measures that shape economic and environmental relationships over extended periods.

5. CONCLUSIONS

The purpose of this study is to explore the asymmetric effects of technological innovation, globalization, foreign direct investment (FDI), and trade openness on carbon dioxide emissions within developing countries, utilizing the autoregressive distributed lag (ARDL) methodology. This research analyzes panel data from the years 1999 to 2023, employing the latest data available to ensure the findings are both robust and current. The empirical results indicate that trade openness and FDI have a negative and significant correlation with carbon dioxide emissions, suggesting that these factors play a role in reducing environmental degradation in the regions under study. On the other hand, technological innovation and globalization show a positive and significant association with carbon dioxide emissions, implying that these factors tend to increase environmental degradation. The ARDL model outcomes demonstrate that, over the long term, both technological innovation and globalization significantly heighten carbon dioxide emissions, thereby intensifying environmental challenges faced by these developing nations. This suggests that while technological advancements drive economic expansion, they may also increase pollution unless accompanied by strong environmental regulations. However, if properly managed, technological innovation could be leveraged to mitigate emissions through the adoption of green and sustainable technologies. Moreover, the negative relationship between trade openness and carbon dioxide emissions suggests that increased trade liberalization in developing economies has contributed to reducing environmental degradation. This may be attributed to the transfer of cleaner production technologies and adherence to international environmental standards in trade agreements. Given these findings, host governments should implement effective policies and establish legal frameworks to regulate foreign direct investment inflows, ensuring that investments align with environmental sustainability goals. Strengthening institutions and governance mechanisms would allow local governments to better manage and mitigate the negative environmental effects associated with foreign direct investment. Furthermore, encouraging the adoption of green and environmentally friendly technologies could significantly reduce the environmental impact of foreign direct investment by promoting cleaner industrial practices and reducing resource waste. Globalization has had a profound impact on these developing economies. By integrating into the global market, attracting foreign direct investment, and engaging in international trade, these nations have positioned themselves to benefit from enhanced competitiveness, access to new markets, and the transfer of advanced technologies. However, to ensure that globalization does not exacerbate environmental degradation, it is essential to strengthen environmental laws, regulations, and compliance standards. Policymakers must implement measures that balance economic growth with environmental sustainability, ensuring that trade and investment activities support low-carbon development strategies. This research acknowledges certain limitations that future studies could address to deepen understanding in this area. Primarily, while this analysis concentrates on a specific group of developing countries, expanding the geographic scope to include a broader mix of emerging and developed nations could yield a more comprehensive view of the interactions between trade, technology, and environmental quality. Data limitations restricted the breadth of this study; thus, future research could extend the sample size to enhance the generalizability of the findings.

Additionally, while carbon dioxide emissions were used as the primary measure of environmental pollution, incorporating other indicators such as nitrogen and sulfur emissions, or broader measures like ecological footprints, would offer a more nuanced perspective on environmental degradation. Further empirical investigation might also explore the specific contributions of different aspects of technological advancement by examining variables such as research and development expenditure, energy innovations, and patent application rates. Moreover, with continuous advancements in empirical methodologies, future studies could employ more sophisticated econometric techniques to refine the analysis and enhance result accuracy. Such improvements could provide clearer insights into the intricate dynamics of how foreign direct investment, trade openness, globalization, and technological innovation impact environmental outcomes in developing regions. Overall, this study adds to the growing body of literature examining the environmental implications of economic and technological activities in developing economies. By shedding light on these complex relationships, the research offers valuable insights for policymakers and stakeholders committed to fostering sustainable economic growth while mitigating environmental impacts.

REFERENCES

Abro, A. A., Abubakar, M., Shahid, T. A., & Fatima, U. (2024). Does Volatility Spillover among Sectors Varies from Normal to Turbulent Periods ? Evidence from Pakistan Stock Exchange. *Pakistan Journal of Humanities and Social Sciences Volume*, *12*(02), 1174–1187.

Adejumobi, R. (2019). Analyzing the impact of oil price volatility on foreign direct investment and economic growth in Nigeria. *Journal of Energy and Environmental Policy Options*, *2*(2), 42-47.

Ahmed, F. A. (2019). Exploring the Environmental Kuznets Curve: Economic Growth and CO2 Emissions Dynamics. *Journal of Business and Economic Options*, *2*(1), 35-44.

Ahmed, J., & Alvi, A. A. (2024). Balancing Economic Growth and Environmental Sustainability in Developing Countries: The Role of Financial Innovation. *Journal of Energy and Environmental Policy Options*, *7*(4), 9-19.

Ali, A., Audi, M., & Roussel, Y. (2021). Natural resources depletion, renewable energy consumption and environmental degradation: A comparative analysis of developed and developing world. *International Journal of Energy Economics and Policy*, *11*(3), 251-260.

Ali, A., Audi, M., Bibi, C., & Roussel, Y. (2021). The Impact of Gender Inequality and Environmental Degradation on Human Well-being in the Case of Pakistan: A Time Series Analysis. *International Journal of Economics and Financial Issues*, *11*(2), 92-99.

Altaf, A., & Shahzad, S. (2021). Environmental Innovation and Sustainability in Remanufacturing: A Strategic Review. *Journal of Policy Options*, *4*(2), 10-21.

Amin, N., Rahman, S. U., Khalid, S., & Idress, S. (2024). How Does Tourism, Trade Openness and Green Energy Influence CO2 emissions? Evidence from ASEAN Countries. *Bulletin of Business and Economics*, *13*(2), 71–79.

Amjad, A., Audi, M., Senturk, I., & Roussel, Y. (2022). Do sectoral growth promote CO2 emissions in Pakistan? time series analysis in presence of structural break. *International Journal of Energy Economics and Policy*, *12*(2), 410-425.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review, 91*(4), 877-908.

Arshad, S., Joseph, S., Rahman, S. U., Idress, S., & Shahid, T. A. (2024). Decarbonizing the Future: A Critical Review of Green Energy, Financial Inclusion and Trade Openness on CO2 Emissions. *Bulletin of Business and Economics*, *13*(2), 160–163.

Audi, M. (2024). The Role of Urbanization and Trade in Driving Carbon Emissions in Asia. *Journal of Energy and Environmental Policy Options*, *7*(3), 23-34.

Audi, M., Poulin, M., Ahmad, K., & Ali, A. (2025). Modeling Disaggregate Globalization to Carbon Emissions in BRICS: A Panel Quantile Regression Analysis. *Sustainability*, *17*(6), 2638.

Avelino, G., & Coronel, D. A. (2021). Macroeconomic Determinants of Economic Growth in Developing Countries: A Cross-Sectional Analysis. *Journal of Business and Economic Options*, *4*(1), 16-24.

Awan, A., Rahman, S. U., Ali, M., & Zafar, M. (2023). Institutional Performance and Tourism Arrival Nexus in BRICS Countries: Evidence from Nonlinear ARDL Cointegration Approach. *IRASD Journal of Economics*, *5*(1), 784–

796.
Bakar, S. U. R. and N. A. (2019). Fdi and Manufacturing Growth: Bound Test and Ardl Approach. *International Journal of Research in Social …*, *9*(5), 36–61.
Bashir, F., & Rashid, B. (2019). Exploring the impact of foreign direct investment, consumption, inflation, and unemployment on GDP per capita. *Journal of Policy Options*, *2*(2), 39-46.
Borensztein, E., De Gregorio, J., & Lee, J. W. (1998). How does foreign direct investment affect economic growth? *Journal of International Economics, 45*(1), 115-135.
Brooks, C. (2019). *Introductory econometrics for finance* (4th ed.). Cambridge University Press.
Chaudhary, S., Nasir, N., Ur Rahman, S., & Masood Sheikh, S. (2023). Impact of Work Load and Stress in Call Center Employees: Evidence from Call Center Employees. *Pakistan Journal of Humanities and Social Sciences*, *11*(1), 160–171.
Comin, D., & Hobijn, B. (2010). An exploration of technology diffusion. *American Economic Review, 100*(5), 2031-2059.
Comin, D., & Hobijn, B. (2010). An exploration of technology diffusion. *American Economic Review, 100*(5), 2031-2059.
Denial, A. (2023). The Role of Innovative Renewable Energy Technologies in Advancing Energy Access in Developing Countries. *Journal of Energy and Environmental Policy Options*, *6*(2), 23-28.
Dreher, A. (2006). Does globalization affect growth? Evidence from a new index of globalization. *Applied Economics, 38*(10), 1091-1110.
Enders, W. (2014). *Applied econometric time series* (4th ed.). Wiley.
Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica, 55*(2), 251-276.
Farahmand, N. F. H. (2019). Strategic Planning and Innovation: Driving Growth and Sustainability in Organizations. *Journal of Business and Economic Options*, *2*(1), 26-34.
Frankel, J. A., & Rose, A. K. (1999). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics*, *87*(1), 85-91.
Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics*, *87*(1), 85-91.
Ghazia Khoula, S. ur R. and S. I. (2022). Does Foreign Direct Investment Promote Economic Growth : Evidence from Pakistan Based ARDL to Cointegration Approach: ghazia.khoula@superior.edu.pk. *Journal of Contemporary Macroeconomic Issues*, *3*(1), 54–63.
Gujarati, D. N., & Porter, D. C. (2020). *Basic econometrics* (6th ed.). McGraw-Hill.
Hafiza, N. S., Manzoor, M., Fatima, K., & Sheikh, S. M. (2022). Motives of Customer ' S E -Loyalty Towards E-Banking Services : a Study in Pakistan. *PalArch's Journal of Archaeology of Egypt / Egyptology*, *19*(3), 1599–1620.
Huang, Y., Rahman, S. U., Meo, M. S., Ali, M. S. E., & Khan, S. (2024). Revisiting the environmental Kuznets curve: assessing the impact of climate policy uncertainty in the Belt and Road Initiative. *Environmental Science and Pollution Research*, *31*(7), 10579–10593.
Hussain, M., & Khan, A. R. (2022). The impact of economic growth, energy consumption, and trade openness on carbon emissions in Pakistan. *Journal of Energy and Environmental Policy Options*, *5*(3), 1-6.
Hwang, J., & Lee, Y. (2019). Exploring the Impact of Trade Openness on Unemployment: A Cross-Country Analysis. *Journal of Business and Economic Options*, *2*(3), 123-131.
Ibrahim, J., & Simian, R. (2023). Investigating CO2 Emissions Drivers: Energy Use, Economic Growth, Urbanization, and Trade Openness. *Journal of Energy and Environmental Policy Options*, *6*(1), 1-7.
Irfan, A., Azam, A., & Shahid, T. A. (2023). *Terrorism and Social Politics : How the Increase of Terrorism Impacts the Socio-Political Thoughts of the Pakistani Public*. *4*(1), 21–30.
Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2002). Environmental policy and technological change. *Environmental and Resource Economics, 22*(1-2), 41-70.
Jamel, M., & Zhang, C. (2024). Green Finance, Financial Technology, and Environmental Innovation Impact on CO_2 Emissions in Developed Countries. *Journal of Energy and Environmental Policy Options*, *7*(3), 43-51.
Javaid, Z., Noor, Q., Iftikhar, H., Haris, M., Rahman, S. U., & Ali, M. (2023). Assessing Mediating Role of Environment Knowledge Between Green Resource Management and Sustainable Performance, Under Moderating Effects of Green Self-Efficacy. *Central European Management Journal*, *31*(2), 352–368.
Johansen, S. (1991). Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econometrica, 59*(6), 1551-1580.
Karhan, G. (2019). Investing in research and development for technological innovation: A strategy for Turkey's economic growth. *Journal of Business and Economic Options*, *2*(4), 152-158.
Li, D., Bai, Y., Yu, P., Meo, M. S., Anees, A., & Rahman, S. U. (2022). Does institutional quality matter for environmental sustainability? *Frontiers in Environmental Science*, *10*(July), 1–12.
Maqsood, N., Shahid, T. A., Amir, H., & Kanwal Bilal. (2023). Symmetric impact of Trade, exchange rate, and inflation rate on Stock Market in Pakistan: New evidence from Macroeconomic variables. *Bulletin of Business and Economics*, *12*(3), 903–911.
Marc, A. (2022). Exploring the Dimensions of Energy Security for Sustainable Global Development. *Journal of Energy and Environmental Policy Options*, *5*(2), 1-10.
Marc, A., & Ali, A. (2023). Unveiling the role of business freedom to determine environmental degradation in developing

countries. *International Journal of Energy Economics and Policy*, *13*(5), 157-164.

Marc, A., Poulin, M., & Ali, A. (2024). Environmental impact of business freedom and renewable energy: a global perspective. *International Journal of Energy Economics and Policy*, *14*(3), 672-683.

Minhas, A. S., Maqsood, N., Shahid, T. A., & Rehman, A. U. (2024). Investment Performance in Green Finance: Assessing the Impact of Environmental Social and Governance Integration. *IRASD Journal of Economics*, *6*(1), 27–44.

Nasir, Z. M. (2022). Macroeconomic factors shaping foreign direct investment inflows: Evidence from Pakistan. *Journal of Business and Economic Options*, *5*(2), 29-35.

Naz, N., Gulab, F., & Aslam, M. (2022). The Socio-Cultural Factors Influence On Women's Ability To Become Social Entrepreneurs. *Competitive Social Sciences Research Journal (CSSRJ)*, *3*(2), 42–52.

Nazik Maqsood, T. A. S. and A. U. R. (2024). The Impact of Dividend and Tax Avoidance on Earning Management of Companies. *Bulletin of Business and Economics*, *13*(April), 256–272.

Nelson, C. R., & Plosser, C. I. (1982). Trends and random walks in macroeconomic time series: Some evidence and implications. *Journal of Monetary Economics*, *10*(2), 139-162.

Parveen, S., Hanif, A., Rahman, D. S. U., & Sheikh, D. S. M. (2024). Examining the Effect of Foreign Direct Investment and Exports on Stock Market Performance: Evidence from India Based Bound Testing to Cointegration ARDL Approach. *Bulletin of Business and Economics*, *12*(4), 700–707.

Perveez, T. (2019). The impact of domestic interest rates on foreign direct investment: Evidence from Pakistan. *Journal of Policy Options*, *2*(1), 1-12.

Pesaran, M. H., & Pesaran, B. (1997). *Working with Microfit 4.0: Interactive econometric analysis*. Oxford University Press.

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289-326.

Phillips, P. C. B., & Perron, P. (1988). Testing for a unit root in time series regression. *Biometrika*, *75*(2), 335-346.

Qureshi, ghaziaKhoulaQureshi G. K., Zaman, mWaheed M. W. U., Rahman, saifUrRahman S. U., & Shahzadi, hafizaNabilaShahzadi H. N. (2022). Legal Insights of Crypto-currency Market and State of Crypto-currency in Pakistan. *Superior Law Review*, *2*(1), 77–104.

Rabbia Syed, Sehrish Arshad, Saif Ur Rahman, S. M. S. (2024). An Overview of Foreign Direct Investment and Green Growth in OIC Countries. *Pakistan Journal of Humanities and Social Sciences*, *2*(1), 8826.

Rahman, S. ur, Chaudhry, I. S., Meo, M. S., Sheikh, S. M., & Idrees, S. (2022). Asymmetric effect of FDI and public expenditure on population health: new evidence from Pakistan based on non-linear ARDL. *Environmental Science and Pollution Research*, *29*(16), 23871–23886.

Rahman, S., & Bakar, N. A. (2019). *Long Run Relationship between Domestic Private Investment and Manufacturing Sector of Pakistan : An Application of Bounds Testing Cointegration Saif ur Rahman Nor ' Aznin Abu Bakar Sa ... Long Run Relationship between Domestic Private Investment and Manuf*. *39*(August), 739–749.

Rehman, T. A. S. and A. U. (2023). A Comparative Analysis of Sustainable Growth on Health : Evidence from Asian Countries. *International Journal of Innovative Science and Research Technology*, *8*(1), 1183–1188.

Rossi, S. (2023). Exploring the relationship between economic growth, energy consumption, trade openness, and carbon dioxide emissions: A case study of Italy. *Journal of Energy and Environmental Policy Options*, *6*(3), 19-24.

Roussel, Y., & Audi, M. (2024). Exploring the Nexus of Economic Expansion, Tourist Inflows, and Environmental Sustainability in Europe. *Journal of Energy and Environmental Policy Options*, *7*(1), 28-36.

Sadashiv, K. R. (2023). Foreign direct investment dynamics and economic growth in the case of India. *Journal of Business and Economic Options*, *6*(1), 45-52.

Sadia Bint Raza, Sheikh, S. M., & Rahman, S. U. (2024). The Mediating Role of Agency Cost between Corporate Governance and Financial Performance: Evidence from Pakistan Stock Exchange. *IRASD Journal of Economics*, *6*(1), 144–163.

Saeed, J., Maqsood, N., Shahid, T. A., Amir, H., Rehman, A. U., & Kanwal, B. and. (2024). Impacts of Social Capital, Financial Literacy and Financial Inclusion on Economic Growth of a Primary Data Analysis: Evidence from Pakistan Special Focus on Listed Banks. *Bulletin of Business and Economics*, *13*(2), 637–646.

Saif Ur Rahman, Salyha Zulfiqar Ali Shah, S. M. B. and F. N. J. (n.d.). Impact of Resource Rents and Institutional Quality on Economic Growth : An Approach of Panel Threshold Analysis. *Competitive Educational Research Journal*, *3*(2), 195–208.

Shahbaz, M., Loganathan, N., Tiwari, A. K., & Sherafatian-Jahromi, R. (2015). Financial development and income inequality: Is there any financial Kuznets curve in Iran? *Social Indicators Research*, *124*(2), 357-382.

Shahid, A. U., Ghaffar, M., Rahman, S. U., Ali, M., Aslam Baig, M., Idrees, S., & Baig, M. A. (2022). Exploring The Impact Of Total Quality Management Mediation Between Green Supply Chain Method And Performance-Palarch's. *Journal Of Archaeology Of Egypt/Egyptology*, *19*(4), 1252–1270.

Shahid, T. A., Rahman, S. U., Sheikh, S. M., & Allahrakha, R. (2024). Effect of Public Investment on Health Population: A Review of BRICS Countries. *IRASD Journal of Economics*, *6*(1), 1–9.

Shahid, T. A., Zafar, M., & Minhas, A. S. (2023). Testing the Economic Theory of Crime in case of Pakistan. *UCP Journal of Business Perspectives*, *1*(2), 73–86.

Shahzadi, H. N., Ali, M., Ghafoor, R. K., & Rahman, S. U. (2023). Does Innovation and Foreign Direct Investment Affect Renewable Energy Consumption? Evidence from Developing Countries. *Pakistan Journal of Humanities and Social Sciences*, *11*(2), 908–916.

Shahzadi, H. N., Sheikh, S. M., Sadiq, A., & Rahman, S. U. (2023). Effect of Financial Development, Economic Growth on Environment Pollution: Evidence from G-7 based ARDL Cointegration Approach. *Pakistan Journal of Humanities and Social Sciences*, *11*(1), 68–79.

Sharma, R., & Das, V. (2024). A Review of Sustainable Agriculture and Renewable Energy Pathways for Reducing Environmental Degradation. *Journal of Energy and Environmental Policy Options*, *7*(3), 14-22.

Shen, Y., Ur Rahman, S., Hafiza, N. S., Meo, M. S., & Ali, M. S. E. (2024). Does green investment affect environment pollution: Evidence from asymmetric ARDL approach? *PLoS ONE*, *19*(4 April), 1–25.

Song, M., Anees, A., Rahman, S. U., & Ali, M. S. E. (2024). Technology transfer for green investments: exploring how technology transfer through foreign direct investments can contribute to sustainable practices and reduced environmental impact in OIC economies. *Environmental Science and Pollution Research*, *31*(6), 8812–8827.

Stern, D. I. (2004). The rise and fall of the Environmental Kuznets Curve. *World Development*, *32*(8), 1419-1439.

Stock, J. H., & Watson, M. W. (2019). *Introduction to econometrics* (4th ed.). Pearson.

Sun, Y., & Chang, Y. (2020). Trade and Poverty in Developing Countries: Beyond Assumptions to Nuanced Understanding. *Journal of Business and Economic Options*, *3*(4), 167-175.

Tabassum, N., Rahman, S. U., Zafar, M., & Ghaffar, M. (2023). Institutional Quality, Employment, Trade Openness on Environment (Co2) Nexus From Top Co2 Producing Countries; Panel ARDL Approach. *Review of Education, Administration & Law*, *6*(2), 211–225.

Ullah, A., & Ali, A. (2024). Investigating corruption, income inequality, and environmental degradation in Pakistan: A time series analysis.

Ullah, S., Ur Rahman, S., & Rehman, C. A. (2023). Public Investment, Technological Innovations, and Environmental Degradation: Asymmetric ARDL Approach. *Pakistan Journal of Humanities and Social Sciences*, *11*(2), 730–741.

Ur Rahman, S., & Bakar, N. A. (2019). Manufacturing sector in Pakistan: A Comprehensive Review for the Future Growth and Development. *Pakistan Journal of Humanities and Social Sciences*, *7*(1), 77–91.

van Zanden, J. L. (2023). Examining the relationship of information and communication technology and financial access in Africa. *Journal of Business and Economic Options*, *6*(3), 26-36.

Wang, H., & Chen, T. (2021). The Role of Entrepreneurial Environmental Awareness in Promoting Eco-Innovation. *Journal of Energy and Environmental Policy Options*, *4*(3), 1-8.

Wang, J., & Li, J. (2024). Green Innovation and Economic Growth Balancing Development and Environmental Protection. *Journal of Energy and Environmental Policy Options*, *7*(3), 1-13.

William, C. (2021). Enhancing Urban Transport Environmental Performance with Technology and Innovation. *Journal of Energy and Environmental Policy Options*, *4*(3), 28-33.

Willy, R. (2018). The role of economic growth, foreign direct investment in determining environmental degradation: A panel data analysis. *Journal of Energy and Environmental Policy Options*, *1*(4), 96-102.

Wooldridge, J. M. (2021). *Econometric analysis of cross-section and panel data* (2nd ed.). MIT Press.

Zahid, M. (2018). Economic misery, exchange rate, interest rate, and foreign direct investment: Empirical evidence from Pakistan. *Journal of Policy Options*, *1*(2), 55-65.

Zahra, A., Nasir, N., Rahman, S. U., & Idress, S. (2023). Impact of Exchange Rate, and Foreign Direct Investment on External Debt: Evidence from Pakistan Using ARDL Cointegration Approach. *IRASD Journal of Economics*, *5*(1), 709–719.

Zenios, A. (2024). Financial Globalization, Environmental Degradation, and Energy Consumption in ASEAN: An Empirical Analysis. *Journal of Energy and Environmental Policy Options*, *7*(4), 1-8.

Zhao, J., Rahman, S. ur, Afshan, S., Ali, M. S. E., Ashfaq, H., & Idrees, S. (2023). Green investment, institutional quality, and environmental performance: evidence from G-7 countries using panel NARDL approach. *Environmental Science and Pollution Research*, *30*(45), 100845–100860.

Zubair, S., Rahman, S. U., Sheikh, S. M., & Zafar, M. (2024). A Review of Green Innovation and Environmental Performance in BRICS Nations. *Pakistan Journal of Humanities and Social Sciences*, *12*(1), 444–449.

Zulfiqar, M., Ansar, S., Ali, M., Hassan, K. H. U., & ... (2022). The Role of Social Economic Resources Towards Entrepreneurial Intentions. *PalArch's Journal of …*, *19*(1), 2219–2253.

Disclaimer/Publisher's Note:
The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of RESDO and/or the editor(s). RESDO and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

Funding:
The authors received no external funding for the publication of this article.

Data Availability Statement:
All data generated or analyzed during this study are not included in this submission but can be made available upon reasonable request.

Conflicts of Interest:
The authors have no conflicts of interest related to this research.