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Original Research

Impact Analysis of Chinese FDI and Green Innovations on Carbon Emissions in Pakistan: Utilizing the ARDL Bounds Testing Method

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Abstract

This study investigates the relationship between Chinese foreign direct investment (FDI) and CO2 emissions in Pakistan using data from 2003 to 2019. The Autoregressive Distributed Lag (ARDL) bound testing approach is employed to perform impact analysis. The findings reveal an adverse impact of Chinese FDI on carbon emissions, underscoring the conflict between FDI and environmental sustainability. Population growth exacerbates CO2 emissions, while economic growth surprisingly shows no significant relationship. In contrast, green innovation emerges as a critical driver of progress in Pakistan, promoting positive environmental outcomes. Despite China's green development initiatives, foreign direct investment in Pakistan continues to contribute to pollution and environmental hazards. The study recommends the adoption of carbon reduction technologies, the establishment of emission monitoring systems, the prioritizing of eco-friendly investments, the implementation of population control measures, the strengthening of environmental regulations, and the fostering of bilateral agreements to promote sustainability in Pakistan's development trajectory.

Keywords: CO_2 emissions, Chinese FDI, green innovation, ARDL, Pakistan

Introduction

The enduring partnership between China and Pakistan, which was formalized in the 1950s, has consistently exhibited a collaborative spirit in various regional and international arenas. Over the years, this alliance has not only endured but has also strengthened, with a continuous track record of accomplishments and ongoing development. The introduction of the One Belt One Road (OBOR) Initiative has brought significant alterations to the global stage, fundamentally impacting diplomacy, bilateral connections, as well as economic, trade, and legal reforms across East Asia, Eurasia, South Asia, and Africa. Through OBOR, China has made substantial global investments totaling $1.94 trillion, with a primary focus on energy, transportation, and infrastructure via outward foreign direct investment [1, 2]. These financial commitments are not merely intended to foster regional peace and prosperity but also to elevate living standards, reduce regional disparities and social inequalities, and enhance life expectancy and overall quality of life, both within Pakistan and among neighboring regions [3, 4]. In the context of Pakistan, Chinese companies have channeled 15 billion US dollars into sectors such

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as energy, infrastructure, telecommunications, mineral exploration, and banking, all geared towards bolstering Pakistan's economic prospects [5].

In any given economy, the factors that propel production include tangible capital, labor expenses, and the degree of technological advancement, all of which directly influence productivity. Nonetheless, emerging economies frequently confront a shortage of capital, impeding their ability to invest and consequently impeding economic expansion. Over the last twenty years, foreign direct investment (FDI) has emerged as a crucial means of addressing the capital deficiencies in developing economies [6]. FDI is acknowledged for its role in accelerating economic growth by enhancing productivity. Commencing in the mid-1990s, there has been a substantial uptick in FDI inflows from advanced to emerging economies. While FDI has undoubtedly propelled economic growth, it has also left an indelible imprint on the environment [7]. In the case of Pakistan, Chinese FDI has generated high expectations for the economy, yet it cannot escape the adverse environmental consequences. For instance, the construction of new power facilities, electrical grids, increased consumption of fossil fuels, the expansion of road networks, railway lines, extensive infrastructure projects, and industrial zones have contributed to a surge in heavy traffic [8]. This has, in turn, exerted a detrimental impact on air and water quality, agricultural practices, wildlife habitats, flora and fauna diversity, and the overall ecological balance in Pakistan and the broader region. Such unregulated progress has led to substantial damage to recreational areas and natural habitats on a worldwide basis. Essentially, there is frequently a balancing act between economic development and harm to the environment as nations aim for robust growth [9]. Increased production and urbanization serve as drivers of economic expansion, yet they also come with heightened carbon emissions and environmental deterioration. The connection between urbanization, heightened production, and carbon emissions is straightforward: an increase in production and urbanization invariably leads to heightened pollution levels [10]. This issue is particularly dynamic in emerging economies, where environmental degradation remains a substantial challenge. Elevated carbon emissions pose a significant threat to developing and emerging economies globally, as carbon dioxide emissions stand as a leading contributor to environmental pollution [11]. Therefore, there is an acute need for innovation within existing operations to attain maximal growth with minimal environmental costs.

This study will place its primary focus on Pakistan's environmental situation, given its status as one of the top ten most affected countries according to the 2017 Climate Risk Index. Pakistan ranks seventh among the nations with high carbon emissions, signaling a concerning climate situation in the country. This presents significant challenges to Pakistan's food production and energy security. Additionally, air pollution has become a major health concern, contributing to the increased prevalence of diseases like heart disease, stroke, and lung cancer, as highlighted by Rahman et al. [12]. Notably, air pollution has adverse effects on the intellectual and physical development of the youth in Pakistan. According to the World Bank's 2019 report, air pollution is responsible for the annual deaths of 7 million people worldwide. The recent IPCC report in 2022 underscores the potential for global emissions reduction, with the possibility of controlling 4% of CO2 emissions and 10% of greenhouse gas emissions [13]. Simultaneously, China is making substantial investments, totaling $1.49 trillion, under OBOR. Despite China's notable progress in enacting relevant legislation, such as the comprehensive revision of the Environmental Protection Act in 2015 and the implementation of the Environmental Protection Tax Act since 2018 [14], Pakistan still grapples with significant challenges in addressing its environmental issues and remains categorized as one of the world's most environmentally vulnerable nations. In light of this current scenario, it becomes imperative for Pakistan to prioritize not only its developmental endeavors but also the rigorous enforcement of both domestic and international environmental laws. In this endeavor, China can assume a reciprocal role in assisting Pakistan in achieving its objectives, thereby contributing to the enhancement of the regional environment. China has already made commitments to construct a green Belt and Road Initiative (BRI) aligned with the Sustainable Development Goals (SDGs) for 2030 and the Paris Agreement. The Chinese government professes its readiness for a "green shift," entailing the transformation or phasing out of polluting industries, a reduction in emission levels per GDP, and the restoration of degraded ecosystems. However, it is essential to explore whether this commitment holds true in the context of Pakistan. The collective findings of this study will furnish invaluable insights for policymakers, empowering them to craft suitable initiatives and policies geared toward environmental preservation and pollution mitigation.

The existing body of research has extensively explored the complex interplay between CO2 emissions and a variety of factors, including economic advancement, energy consumption, electricity usage, forest and agricultural productivity, air quality, institutional quality, environmental conditions, temperature sensitivity, climate fluctuations, reductions in human capital, nonrenewable energy sources, fiscal and monetary policies, urbanization, and healthcare expenditures [15-23]. However, there is a noticeable research gap when it comes to understanding the impact of Chinese foreign direct investment (CFDI) on CO2 emissions, particularly within the context of Pakistan. While prior theoretical studies have shed light on the influences of the China Pakistan Economic Corridor (CPEC) on Pakistan's economy [24, 25], and have examined this phenomenon, there is a scarcity of empirical investigations that delve into the role of Chinese FDI and its consequences for promoting green innovation in the environmental sector. This study aims to bridge this research gap by investigating the intricate connection between economic advancements, CO2 emissions, and

Chinese FDI within the context of Pakistan. By employing the autoregressive-distributed lag (ARDL) technique, which is renowned for its robustness in generating results while accounting for weaknesses in statistical power and sample size, this research endeavor seeks to offer a comprehensive understanding of this relationship. The significance of this study lies in its potential to provide valuable insights for policymakers. It can help shape effective energy policies and foster sustainable resource growth in Pakistan, ultimately contributing to the global effort to mitigate climate change and promote green innovation in emerging economies like Pakistan through strategic partnerships with China.

The study is organized as follows: Section two provides a concise overview of the theoretical foundation, incorporating it with supplementary concepts. Sections three and four outline the research methodology, present the findings, and engage in a discussion. Finally, in the fifth section, we present the study's conclusions and potential policy recommendations.

Literature Review

This paper presents a comprehensive synthesis of relevant literature, addressing the research objective from multiple angles. These facets encompass (i) investigations into the impact of FDI on economic growth, analyses of the consequences of FDI on environment. (ii) Inquiries into the effects of green innovation on economic growth. (iii) Examination of the impacts of green innovation on the environment. Regarding the connection between FDI and economic growth, previous research has shown that FDI can bring about positive changes in the host country's economy through various mechanisms. However, this is contingent upon the presence of accommodating host-country regulations and a sufficient initial level of development [26]. FDI serves as a channel for the transfer of innovative technologies and expertise to the host nation. It also fosters competition in the local market, leading to improvements in the quality of products and services. Moreover, it contributes to the development of human capital by enhancing the skills of the workforce and disseminating technical, managerial, and marketing knowledge. FDI also integrates the host economy into the global economic landscape by aligning regulatory and legal frameworks. Moreover, it stimulates domestic firms to adopt international business standards and elevate their management practices [27, 28]. In a study spanning the years 1980 to 2011 and employing the Generalized Method of Moment (GMM) methodology, Sghaier and Abida [29] focused on four North African countries: Morocco, Algeria, Tunisia, and Egypt. Their research uncovered a robust positive correlation between FDI and economic growth, corroborating similar findings in studies conducted by Alfaro et al. [30] and Choong [31]. These investigations highlighted the importance of developing the local financial system as a prerequisite for unlocking FDI's potential as a driver of economic growth. Notably, Nistor [32] and Asongu [33] also discerned significant effects of FDI inflows on economic growth in developing nations. While Nistor [32] observed a positive impact, Asongu [33] contended that the effect was negative, particularly for BRICS and MINT countries. Additionally, a study by Simionescu [34] showcased a substantial and positive correlation between FDI and GDP growth in emerging economies.

In the realm of environmental impact, Wang et al. [35] have put forth the notion that foreign direct investment (FDI) can potentially yield adverse effects on the environmental quality of the host country. In contrast, He et al. [36] present an opposing viewpoint, asserting that FDI, particularly when it involves advanced technology, has the potential to disseminate cleaner and more environmentally friendly production technologies within the host country. They argue that this diffusion can lead to the implementation of improved environmental protection measures and a reduction in CO2 emissions. Consequently, the environmental consequences of FDI remain uncertain. Keho [37] conducted a study focused on West African countries and argued that the effects of FDI on CO2 emissions is contingent upon the level of trade in the country of investment. For instance, in Burkina Faso, Gambia, and Nigeria, where trade openness is higher, the positive effect of FDI on emission reduction becomes more evident. However, in Benin, Ghana, Mali, Niger, Sierra Leone, Senegal, and Togo the long-term influence of FDI on CO2 emissions is statistically insignificant. Analyzing the association between Trade, FDI, and industrial emissions within the context of the Central American Free Trade Agreement (CAFTA-DR) for the period 1979 to 2010, Frutos-Bencze et al. [38] discovered that Trade and FDI had an adverse effect on pollutant emissions selected, included carbon dioxide, ultimately leading to increased emissions. It's worth noting that Demena and Afesorgbor [39] highlighted variations in indicators, sample sizes, and research methodologies employed by scholars when assessing the environmental consequences of FDI and trade, which have resulted in divergent conclusions. Meanwhile, He et al. [36] employed the Bootstrap ARDL method to investigate the connection between trade, FDI, and CO2 emissions in BRICS. Their findings underscored the context-specific nature of these relationships, which vary across different situations and countries.

In the context of innovation, research suggests that increased trade openness and economic activities tend to be associated with higher energy consumption. Conversely, technological innovations have been shown to enhance energy efficiency, thereby contributing to the mitigation of CO2 emissions [40]. Furthermore, studies have demonstrated that investments in innovation have resulted in reduced CO2 emissions in various countries and regions worldwide. Fernández et al. [41] established a reciprocal relationship between CO2 emissions and innovations. According to the literature, green innovation promotes sustainable growth, positively impacting productivity in the medium to long term [42], and plays a pivotal role in advancing sustainable development. These studies advocate for the promotion of green innovation as a vital means to effectively address environmental challenges.

Numerous researchers have undertaken a comprehensive exploration of the intricate connection among innovation and growth, offering diverse insights across various countries and regions. Kotabe [43] shed light on a positive association among innovation and economic growth in the United Kingdom, Germany, Japan, and the United States. Crosby [44] extended this perspective by analyzing the connection among patents and economic growth, demonstrating the significant contributions of innovation activities to Australia's economic expansion. Ulku [45], utilizing the generalized method of moments, lent support to the innovation-based growth model, emphasizing that advancements in the research sector promote sustainable economic development. Broadening the scope, Bernier and Plouffe [46] corroborated the positive effect of innovation in the financial sector on the economy, analyzing data from twenty-three countries. Hasan and Tucci [47], who examined fifty-eight economies, concurred with these findings, observing that economies with higher patent counts tend to experience more robust economic growth. In contrast, Kacprzyk and Doryn [48] reported a minimal impact of innovation on the EU-15 and EU-13 countries economic growth.

Within the realm of environmental studies, researchers advocate for the promotion of local innovation and investments in research and development (R&D) as potent tools for mitigating carbon emissions. Studies consistently unveil a negative association among patent numbers and carbon emissions, underscoring the role of patent authorizations in enhancing environmental quality. Additionally, Salman et al. [49] delved into ASEAN countries, shedding light on the pivotal role of energy-efficient technological innovations in mitigating carbon emissions. In the context of green technology innovation, Du et al. [50] conducted a comprehensive study spanning 76 countries, stratified as either high-income or low-income nations. Their findings delineated a nuanced relationship: for low-income countries, green technology innovation displayed a minimal impact on carbon emissions, whereas the influence was substantial for highly developed nations. Töbelmann and Wendler [51] scrutinized 27 European Union countries between 1992 and 2014, affirming that an upswing in environmental patent applications correlated with a decrease in carbon emissions. These findings resonate with other researchers, including Hordofa et al. [52] and Xin et al. [53], who have similarly underscored the interplay between green technology innovation and carbon emissions. They advocate for heightened investments in R&D by organizations and government institutions, emphasizing the importance of integrating innovative and environmentally-friendly technologies to ameliorate environmental quality, enhance human well-being, and safeguard health.

Lee and Min [54] ventured into the intricate dynamics of green research and development (R&D), financial development, and carbon dioxide equivalent (CO2) emissions in Japan's manufacturing industry. Their outcomes pointed to a salient link: augmented firm-level R&D investments led to diminished CO2 emissions, while green innovation yielded positive financial impacts. Utilizing the GMM estimation on the data consists of 14 developing countries over the period of 2007-2016, Alam et al. [55] identified a significant and positive impact of climate change on the innovation performance of SMEs. Álvarez-Herránz et al. [56] confirmed the crucial role of energy-centric innovation in decreasing GHG emissions, focusing their analysis on OECD member countries. However, Shahbaz et al. [57] reported a counterintuitive finding, noting a negative relationship between energy innovation and CO2e emissions. They attributed this phenomenon to the opposing influences of FDI and financial development, which had a mitigating effect on CO2e emissions. Long et al. [58] highlighted eco-friendly innovation of Korean owned enterprises in China, revealing that innovation led by production reduces toxic gas emissions; emphasizing the dual benefits for the environment and economic performance.

In addition to the aforementioned studies, it's worth noting that the well-documented opposite connection among innovation and pollution transcends various regions and countries. This phenomenon has been observed in diverse settings, including China, US, and EU [41], specific Chinese provinces [8], as well as among OECD countries [59]. Moreover, the examination of this relationship extends to the BRICS countries [60], with a specific focus on the United States [61]. Particular significance lies in exploring this relationship within major greenhouse gas-emitting regions. A comprehensive understanding of the Chinese FDI effect on CO2 emissions holds critical importance, as it furnishes valuable insights for policymakers striving to enhance strategies for carbon emission management [62-64]. Furthermore, within the Pakistani context, several studies have been undertaken [65-67], all of which have indicated that foreign direct investment has a significant impact on emissions. However, the specific influence of Chinese FDI on the environment remains relatively unexplored. Therefore, this research aims to investigate this phenomenon, with a particular focus on Pakistan. Qadri et al. [65] revealed that Pakistan has the potential to control its carbon emissions and work towards a sustainable environment by emphasizing carbon-free projects. Their findings suggest that policymakers should exercise control over foreign investments that contribute to carbon emissions and redirect funds towards renewable energy initiatives to effectively mitigate carbon emissions. Hence, conducting this study is of utmost importance.

The overall research framework is built upon existing literature, utilizing various databases such as Web of Science and Science Direct to conduct a comprehensive literature search. Different combinations of keywords relevant to the subject matter are employed, with a specific focus on selecting journals pertinent to the study's scope. Furthermore, the websites of these selected journals are thoroughly examined to access a wide array of papers relevant to the current research topic.

Methods

Data and Model

In this research, our primary focus is on Pakistan. To gather our data, we compiled a time series dataset with an annual frequency, spanning the years from 2003 to 2019. We sourced economic indicators from the World Bank's database, while data regarding CO2 emissions came from British Petroleum's website. Information regarding Chinese foreign direct investment flows was collected from China's annual statistical bulletin [68]. To facilitate the application of the ARDL method, we transformed our data from an annual to a quarterly format using the quadratic match sum method. The central aim of this study is to delve into the interplay between Chinese FDI, green technology innovation, and environmental factors within Pakistan. To accomplish this objective, we have employed a model rooted in the neoclassical growth theory and the IPAT environmental model, as expressed in Equation 1:

$$I = P * A * T \qquad Eq\ (1)$$

The equation posits that the "effects on ecosystems (I) result from the combination of the population size (P), affluence (A), and technology (T) of the specific human population under consideration." The primary model is expanded into an additional version referred to as the stochastic model (STIRPAT). This version is commonly recognized as the Stochastic Impacts via Regression on Population, Affluence, and Technology, as instituted by Dietz and Rosa [69]. Utilizing the STIRPAT model, the study formulates the following Equation 2 for further analysis:

$$CO2_{it} = f(CFDI_{it}, GI_{it}, GDP_{it}, Pop_{it}, v_{it}) \qquad Eq\ (2)$$

Where, CO2 is a function of Chinese foreign direct investment, green innovation population, GDP, and population respectively. The model goal is to address the CFDI and green innovation on CO2 emission by taking into consideration other factors (population, income) in the model.

The study employed a comprehensive array of statistical steps, including descriptive statistics, unit root tests, lag length determination, bound tests, ARDL analysis for both long-run and short-run relationships, and CUSUM analysis, to thoroughly offer the complex relationship between Chinese Foreign Direct Investment and CO2 emissions in Pakistan. The use of descriptive statistics lays the foundation for a clear and concise presentation of the data, aiding in the initial understanding of the variables involved. Unit root tests and lag length determination are crucial steps to assess the stationarity of time series data and determine the appropriate lag order for subsequent analyses. The bound test, based on the ARDL approach, allows for the assessment of long-run and short-run relationships between FDI and CO2 emissions, offering a robust and nuanced perspective on their interactions. Finally, the CUSUM analysis helps in monitoring the stability of the estimated relationships over time, adding a dynamic dimension to the investigation. The judicious selection and application of these methodologies reflect a well-thought-out research design, enhancing the reliability and credibility of the study's conclusions.

Empirical Results

Descriptive Statistics

The Table 1 below presents the descriptive statistics of the sampled country. The results reveal that the maximum and minimum values of CO2 emissions are approximately 210,958 and 98,607, respectively, with a standard deviation of 26,781. China's investment in Pakistan has a mean value of 9.028 and a standard deviation of approximately 0.7340. The range of investment values varies from a maximum of 9.7575 to a minimum of 7.4390. Green innovation, on the other hand, has a mean value of 2.8373, ranging from 0.004321 to 3.240302, with a standard deviation of 0.74486. In terms of GDP, the mean value is approximately 3.00. The GDP values range from a minimum of 2.93 to a maximum of 3.08, indicating a relatively narrow range. The standard deviation is 0.04, suggesting low variability. Population data also provide insights, but the specific details are not mentioned in the provided information. Regarding the skewness of the variables, CO2 emissions and GDP exhibit positive skewness indicating a longer right tail. On the other hand, CFDI (Chinese foreign direct investment), GI (green innovation), and POP (population) variables

Table 1. Descriptive statistics.

Variable	Mean	Max.	Min.	Std. Dev.	Skewness	Kurtosis
CO2	149189.4	210958.1	98607.81	26781.96	0.727114	3.104006
CFDI	9.028108	9.757511	7.439017	0.734087	-1.0838	2.851812
GI	2.837314	3.240302	0.004321	0.744864	-3.48797	13.51153
GDP	3.00466	3.0784	2.927556	0.038161	0.029806	2.805317
Pop	19.01342	19.17311	18.84656	0.101051	-0.05576	1.797426

Source: Author's estimations

are negatively skewed, indicating a longer left tail. Each variable has its own statistical measures capturing information about its central tendency, spread, skewness, and kurtosis. Furthermore, the Jarque-Bera statistic and its corresponding probability provide information about the normality assumption for each variable. However, no details about the specific values of the Jarque-Bera statistic or the probability are provided in the given information. Overall, these descriptive statistics provide a comprehensive understanding of the characteristics and distributions of the variables under investigation.

Unit Root Tests

Ensuring the stability of variables is a vital aspect of empirical analysis, aimed at preventing misleading findings and facilitating the formulation of sound policy recommendations. In our study, we utilized two commonly employed unit root tests, namely the Im, Pesaran, and Shin (IPS) test and the Phillips and Perron (PP) test. These tests serve the purpose of evaluating whether our variables are stationary, with stationary variables characterized by consistent means and variances, while non-stationary ones exhibit trends or variations in means and variances over time. The outcomes of our unit root tests, conducted using the IPS method, are presented in Table 2. These results provide insights into the stationarity characteristics of our variables, revealing that all variables, except for GDP, exhibit stationarity properties. In particular, most variables demonstrate stationarity when analyzed at the first difference. To further validate these stationarity findings, we performed the PP unit root test, the results of which are also presented in Table 2. These results affirm that the majority of our variables are stationary when assessed at the first difference. Notably, CFDI and GI stand out as variables that exhibit stationarity both at the level and at the first difference, with the first difference showing greater statistical significance. In light of these robust stationarity findings, we can confidently conclude that most of our variables exhibit stationarity. This observation underscores the appropriateness of employing the autoregressive-distributed lag bounds testing approach for our subsequent analytical endeavors.

Lag Length Selection Criteria

Following the unit root tests, the next critical step involves determining the most suitable number of lags using various VAR selection criteria. The choice of an appropriate lag order is crucial for investigating the presence of cointegration among our variables of interest. In Table 3, we present the VAR lag selection criteria we have employed, which encompass the likelihood ratio (LR), final prediction error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SC), and Hannan-Quinn Information Criterion (HQ). Upon analyzing the results presented in Table 3, a consistent pattern emerges. All of the selected criteria, namely LR, FPE, AIC, SC, and HQ, unanimously point to the selection of four lags as the optimal choice. As a result, for the empirical analysis within the current multivariate model, this study incorporates a total of four lags to effectively capture the dynamic relationships among the variables.

ARDL Bounds Test

In this study, we utilized an autoregressive distributed lag (ARDL) bounds test approach to explore the presence of co-integration, indicating long-term relationships among the variables of interest. The outcomes of this

Table 2. Unit root test results.

Variable	**Im, Pesaran, and Shin**		**Phillips-Perron (PP)**	
	At level	**At first difference**	**At level**	**At first difference**
CO2	0.3516	-2.68868*	-1.026	-3.823***
CFDI	-2.042	-8.296***	-2.609*	-8.449***
GI	-3.142**	-6.426***	-3.372***	-7.746***
GDP	0.5871	-1.6673	-0.663	-9.212***
Pop	-1.396	-4.874***	-1.396	-4.874***

*Note: *, **, *** indicate null hypothesis rejected at 10%, 5%, and 1% significance level respectively.*

Table 3. Selection criteria for optimal lags.

Lag	**LogL**	**LR**	**FPE**	**AIC**	**SC**	**HQ**
0	297.6125	NA	4.00e-11	-9.75375	-9.579221	-9.685482
1	653.0701	639.8237	6.60e-16	-20.769	-19.72183	-20.3594
2	671.8512	30.67580	8.26e-16	-20.56171	-18.64189	-19.81076
3	689.3988	25.73640	1.11e-15	-20.31329	-17.52083	-19.22101
4	1077.880	505.0256*	6.62e-21*	-32.42933*	-28.76423*	-30.99571*

*Note: At the 5% level, * indicates the lag order selection criterion* bounds test, as detailed in Table 4, clearly reject the null hypothesis of no co-integration at a significance level of 1%. This rejection is evident from the F-test statistic surpassing the critical values. Consequently, we can confidently assert that the variables considered in our model indeed exhibit specific co-integrating relationships. Furthermore, when we examine the co-integration equation results in Table 4, we find that both the lower-bound value (LBV) with an integration order of I(0) and the upper-bound value (UBV) with an integration order of I(1) are significant at various levels: 1%, 5%, and 10%. These significant findings provide robust evidence of the existence of long-term relationships among the variables under scrutiny.

Table 4. ARDL lag bounds test.

	Value	I(0)	I(1)
F-statistic	6.110		
10%		2.2	3.09
5%		2.56	3.49
2.5%		2.88	3.87
1%		3.29	4.37

ARDL Long-Run Results

The results obtained from the ARDL bounds test as shown in Table 5. confirm the presence of long-term cointegration among CO2 emissions, Chinese foreign direct investment (CFDI), green innovation (GI), population (POP), and GDP. Subsequently, we have employed the ARDL model to examine both the long-term and short-term coefficients for each of these variables. As anticipated, foreign direct investment has emerged as a significant environmental concern on a global scale. This concern stems from the practice of developed countries relocating their polluting industries to developing nations to evade stricter environmental regulations within their own borders. This strategy allows them to maintain their operations in regions where such activities are still permitted.

In our study, we have uncovered a substantial positive correlation between Chinese foreign direct investment and CO2 emissions in developing nations, such as Pakistan. This relationship is attributed to the country's strong emphasis on economic growth and financial innovation, often at the expense of environmental preservation. Several intertwined factors contribute to this connection: the prioritization of rapid economic development, the proliferation of production facilities, and the expansion of the financial sector. These factors indirectly promote resource allocation and reduce financing costs, stimulating economic growth but also intensifying energy consumption and pollutant emissions. Additionally, investments in infrastructure and transportation, crucial for trade and economic advancement, further contribute to heightened emissions. This is exacerbated by potentially less stringent environmental regulations in developing countries. In the case of Pakistan, this dynamic results in a surge of industrialization driven by foreign investment, leading to increased CO2 emissions and environmental challenges. This situation necessitates a delicate balance between economic prosperity and sustainability in policy considerations. Furthermore, foreign projects and firms in developing countries tend to produce more carbon emissions when they begin their projects, which is particularly harmful to Pakistan, given its already vulnerable climate conditions. These findings are consistent with previous studies that have highlighted the contribution of FDI to environmental degradation [65, 67].

To address these challenges, many nations, including China, are now focusing on green economic development [70, 71]. China, as a growing global economy through its Belt and Road Initiative (BRI), promotes economic growth through FDI but also has adverse effects on the environment, contributing to emissions in the Pakistani economy. However, the Chinese government is now committed to incorporating renewable technologies as part of green innovations. In current study, it is found that green innovation mitigates the adverse environmental impact. Green innovation exhibits a significant negative effect on CO2 emissions at the 1% significance level, indicating its potential to enhance environmental quality. This discovery aligns with studies conducted by Hung et al. [72] and Jiang et al. [73], which conclude that innovation plays a pivotal role in reducing CO2 emissions, albeit with some uncertainties. Green innovation helps alleviate the environmental impact by introducing novel ideas, behaviors, products, and processes [74-78]. Furthermore, renewable energy has the potential to reduce carbon emissions from the environment, as indicated by studies conducted by Hao et al. [79] and Zakari et al. [80]. There is a prevailing belief that when foreign investment flows into developing countries primarily for profitable motives, environmental considerations tend to be overlooked. Consequently, foreign direct investment can contribute to an initial increase in CO2 emissions, aligning with the concept of the early stages of the environmental Kuznets curve, where technological advancements may not effectively mitigate these emissions. However, as observed in the research conducted by Khan et al. [66], governments often shift their focus toward environmental concerns over time. This transition involves an emphasis on adopting green technologies, ultimately leading to a reduction in carbon emissions.

Interestingly, we have noted that GDP does not exert a significant influence on CO2 emissions in the context of Pakistan, contrary to conventional expectations. While GDP is typically regarded as a primary driver of escalating CO2 emissions, the presence of green innovation and the adoption of renewable energy in quality improvement endeavors in previous research may offer a rationale for these distinct findings [81-85]. The recent study by Xie et al. [86] also revealed that a 1% increase in economic growth leads to an increase in carbon emissions. Furthermore, the population exerts an adverse impact on

Table 5. ARDL long-run bounds test.

Variable	Coefficient	Std. Error	t-test	P-value
C	-3517118	915436.1	-3.842014	0.000***
CO2(-1)	-0.188982	0.038346	-4.928376	0.000***
POP(-1)	174875.9	49742.88	3.515597	0.001***
GDP	14572.01	41444.36	0.351604	0.727
GI(-1)	159.9919	243.5848	0.656822	0.515
CFDI(-1)	-5285.109	1190.611	-4.438987	0.000***
D(CO2(-1))	0.36741	0.103384	3.553841	0.001***
D(POP)	10393622	3035593	0.00000	0.000***
D(POP(-1))	10245548	2987836	0.00000	0.000***
D(POP(-2))	10258567	2989891	0.00000	0.000***
D(POP(-3))	10274739	2991814	0.00000	0.000***
D(GI)	-784.7828	295.6959	-2.65402	0.011***
D(CFDI)	-1040.888	1309.219	-0.795045	0.431
D(CFDI(-1))	2867.849	1504.008	1.906805	0.063*
D(CFDI(-2))	2790.725	1462.289	1.908463	0.063*
D(CFDI(-3))	2340.135	1441.722	1.623153	0.112

Note: *, and *** are significant at 10% and 1% respectively.

Table 6. ARDL short-run error correction regression test.

Variable	Coefficient	Std. Error	t-test	P-value
D(CO2(-1))	0.36741	0.085551	4.294619	0.000***
D(POP)	10393358	1624542	0.00000	0.000***
D(POP(-1))	10245288	1598728	0.00000	0.000***
D(POP(-2))	10258307	1601454	0.00000	0.000***
D(POP(-3))	10274479	1603874	0.00000	0.000***
D(GI)	-784.7837	251.7103	-3.117805	0.003***
D(CFDI)	-1040.881	1161.901	-0.895843	0.375
D(CFDI(-1))	2867.806	1266.166	2.264953	0.029**
D(CFDI(-2))	2790.68	1234.761	2.260097	0.029**
D(CFDI(-3))	2340.09	1217.64	1.921825	0.061*
CointEq(-1)*	-0.188981	0.029576	-6.389756	0.000***
R-squared	0.759			
Adjusted R-squared	0.710			
S.E. of regression	1103.27			
Log likelihood	-499.423			
Durbin-Watson stat	2.157			

*Note: Note: *, **, and *** significant at 10%, 5%, and 1% respectively.*

the environment. Many cities in Pakistan grapple with overpopulation, contributing to a range of environmental challenges. Individuals often engage in environmentally harmful practices unknowingly, perceiving them as commonplace. Consequently, they inadvertently contribute to pollution and environmental degradation. The high population necessitates increased production, consumption, and economic activities, all of which are directly linked to CO2 emissions.

ARDL Short-Run Results

The short-term estimates extracted from the ARDL model, as outlined in Table 6, provide us with valuable additional insights. Notably, we observe that the error correction term (ECM(-1)) within the specified conditional error (CE) model is not only negative but also statistically significant at the 1% level of significance. This indicates a robust adjustment rate in response to any shocks within the model. Essentially, any temporary disruptions in the system tend to converge towards a long-term equilibrium at a pace of 18%. This finding aligns with the research conducted by Ahmed and Zeshan [87], which stressed that a highly significant error correction term is compelling evidence of the presence of a stable long-term relationship.

Goodness of Fit and Stability of the Model

To ensure the reliability of our model and to mitigate potential issues arising from parameter instability, we have integrated two critical tests into our study: the Cumulative Sum of Recursive Residuals (CUSUM) and the Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ). These tests are employed to assess the stability of both our long-term and short-term parameter estimates derived from the model. Fig. 1 provides a visual representation of the outcomes of our stability tests. As depicted in Fig. 1, the CUSUM and CUSUMSQ plots display fluctuations that consistently remain within the critical boundary region. This observation signifies that all the models we have employed are stable and accurate, as indicated by the black line remaining within the red bandwidth. This stability is of paramount importance for ensuring the reliability of our estimated parameters and further enhances the suitability of our model for policy analysis. It is noteworthy that the utilization of CUSUM and CUSUMSQ tests for evaluating model stability and goodness of fit is well-established in the existing literature. Several prior researchers, including Xiao and Phillips [88], Ploberger and Krämer [89], Lee et al. [90], Afzal et al. [91], Huang et al. [92], Westerlund [93], Seker et al. [94], and Rehman et al. [95], have incorporated these tests into their studies. Their collective body of work underscores the utility of these tests in assessing model reliability and appropriateness for analysis.

Conclusions and Policy Implications

The main goal of this research was to assess how Chinese FDI, green innovation, population, and income have influenced CO2 emissions over a period from 2003 to 2019. To examine both the short-term and long-term connections among these factors, we utilized the autoregressive distributed lag bounds testing approach. The study's results reveal that Chinese FDI has had an adverse impact on CO2 emissions, underscoring a negative correlation between FDI and environmental sustainability. Furthermore, population growth was found to exert an adverse impact on CO2 emissions. Notably, economic growth did not exhibit a significant relationship with CO2 emissions. On the other hand, green innovation emerged as a significant driver of progress in Pakistan, while also promoting positive environmental outcomes. Despite China's endeavors to address environmental degradation and promote a green and low-carbon development system, the Chinese FDI in Pakistan continues to lag behind, contributing to air pollution and environmental hazards. Therefore, it is crucial for Pakistan to implement appropriate policies that foster sustainable development without compromising the environment.

Based on the results, following the previous studies [1-7], it is recommended that governments, particularly in developing countries, establish comprehensive lists of smart carbon reduction technology proposals and industry-level carbon emission monitoring platforms. These platforms can facilitate real-time monitoring of emissions from high-energy-consuming enterprises, providing valuable data for technology popularization and policy formulation. In the context of Pakistan, careful consideration should be given to foreign direct investment, prioritizing environmentally friendly investments while discouraging pollution-intensive FDI. Implementing population control measures and environmental education programs are also essential to address the environmental stresses associated with population growth.

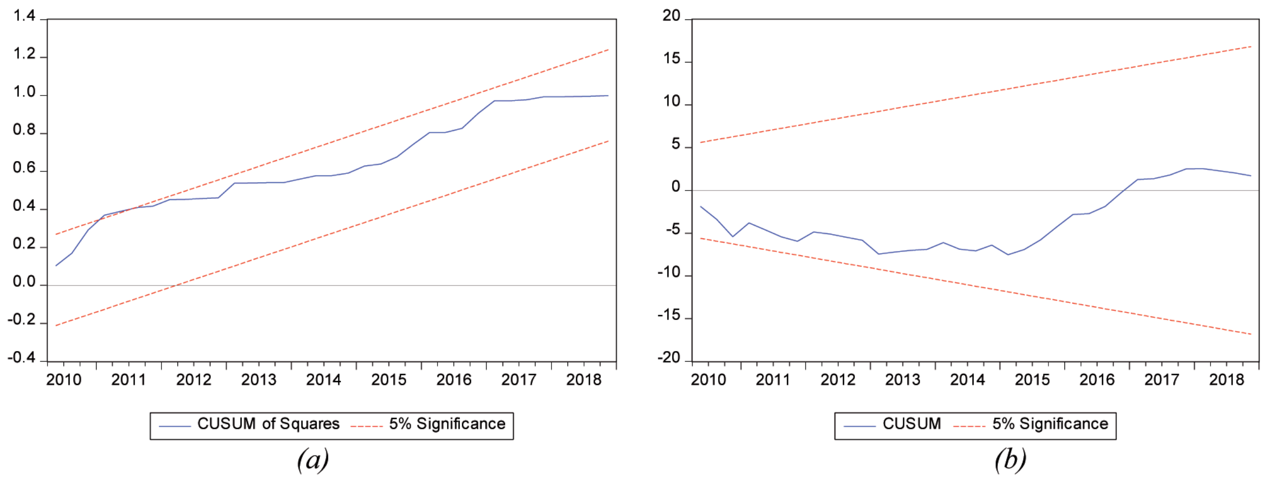

Fig. 1(a)(b). Plot of the CUSUM (cumulative sum) of recursive residuals and CUSUMSQ (cumulative sum of squares) of recursive residuals.

It is crucial to acknowledge and address the limitations of this study, as they can provide valuable guidance for future research in the field of environmental sustainability. This study primarily focused on a limited set of macroeconomic indicators and did not account for numerous other determinants that could potentially impact environmental sustainability. These unexplored factors include but are not limited to resource availability, labor market dynamics, capital investment, industrialization, globalization, institutional factors, resource rent, and the effectiveness of environmental governance. To ensure a more comprehensive and nuanced understanding of the complex relationship between economic development, foreign direct investment, green innovation, and environmental degradation, future research endeavors should incorporate these often-overlooked variables into their analyses. Considering these factors will enable researchers to offer a more holistic perspective on the subject.

Furthermore, an avenue for improvement lies in exploring alternative proxies for environmental degradation beyond the sole reliance on CO2 emissions. Different indicators, such as water quality, deforestation rates, or biodiversity loss, may provide a more comprehensive and robust assessment of the environmental impact of economic activities and technological innovations. By addressing these limitations and considering a broader spectrum of factors and environmental proxies, future investigations can contribute to a more nuanced and accurate understanding of the intricate interplay between economic growth, foreign investments, innovation, and environmental sustainability.

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Conflict of Interest

The authors declare no conflict of interest.

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