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Revisiting Renewable Energy and Foreign Direct Investment: Paradoxical Impacts on Ecological Footprint

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ABSTRACT

This research analyses the influence of foreign direct investment (FDI) and renewable energy usage on China's ecological footprint from 1990 to 2022, employing the Autoregressive Distributed Lag (ARDL) model. The findings indicate that, in the short-term, a 1% increase in renewable energy consumption raises the ecological footprint by 0.022 global hectares (gha) per capita. However, in the long-term, this increase is more pronounced, augmenting the footprint by 0.033 gha per capita. Moreover, foreign direct investment (FDI) exhibits a significant negative relationship with the ecological footprint in the short-term, indicating that such expenditures facilitate environmental enhancements. Nonetheless, over the long term, foreign direct investment does not exert a statistically significant influence on China's ecological footprint. These findings contest traditional assumptions about the environmental advantages of renewable energy and underscore the necessity for improved regulations that optimise renewable energy practices. The study's findings indicate the necessity of encouraging green foreign direct investment to maintain its immediate environmental advantages. Recommendations include diversifying energy sources, strengthening environmental regulations, and integrating technological innovation in FDI-driven sectors to foster long-term sustainability. The paper concludes with recommendations for further research, including sectoral analysis, comparative studies, and the examination of environmental policies in reducing the ecological footprint.

Keywords: Foreign Direct Investment, Renewable Energy Consumption, Ecological Footprint
JEL Classifications: P28, P33, Q57

1. INTRODUCTION

Current average annual growth and technological progress are highest in emerging economies such as China, India and Indonesia. Predictions of slowdowns in growth rates in these countries have proven minimal, while those in many developing countries have not increased as predicted (Zheng et al., 2023). Regional GDP trends indicate that global economic activity, particularly, in high-income economies in Asia (Guo et al., 2025; Yin et al., 2022). However, the downside is significant in some countries, as greenhouse gas emissions continue to rise (ESCAP, 2024; Mohamed et al., 2024). The countries and economies in the Asia-Pacific region are increasingly affected by climate-related disasters.

The situation in China is particularly concerning. The country's rapid economic growth has mainly been driven by substantial investments in infrastructure development and state support for heavy industrial activities powered by locally produced fossil fuels (Yin et al., 2022). Public authorities have prioritised achieving growth targets, often disregarding efficiency, particularly energy efficiency, in production units (Degbedji et al., 2024). This has resulted in the establishment of a governance system and organisation of production and energy systems that resist efforts to improve energy efficiency and reduce pollutant emissions. The weight of the state's political and industrial system, as well as the lack of coordination within a highly decentralised country, has significantly slowed down the real consideration of environmental issues.

Intensive industrialisation has taken precedence over the country's sustainability. This increase in factor productivity has made China highly attractive to Foreign Direct Investment (FDI). In 2006, China and India already had air pollutant concentrations higher than the interim maximum target set for 2010, and these are expected to rise further by 2060 (OECD, 2016). China, Indonesia, and India have the highest levels of NOx particulate matter, primarily from the transport and industry sectors. According to the State of Global Air 2020 report, deaths from to air pollution in China totalled 238,000 between 2010 and 2019.

The continued existence of conflicting industrialisation incentives, where economic performance takes precedence over environmental considerations, has increased the challenges of implementing sustainability policies (Zheng et al., 2023). In 2020, China's GDP exceeded 100 trillion-yuan, accounting for 17.3% of global GDP. However, this rapid growth relies on extensive investments, and the environmental performance score increased from 60.74 in 2018 to 37.3 in 2020, ranking 120th among 180 countries (Environmental Performance Index, 2020). China's total carbon emissions reached 9,899 million tons, accounting for 30.6% of global emissions, disproportionate to its population and GDP. Across the entire ecosystem —water, air, and soil —the warning lights are red in China (Yin et al., 2022).

Despite Chinese government's efforts to balance economic development and environmental improvement, the results remain negligible. Nevertheless, Asian countries in general, and China in particular, have made efforts to improve renewable energy capabilities and increase corporate sustainability reporting (ESCAP, 2024). The country's attractiveness has not diminished, but according to the Report on the State of the Ecology and Environment in China produced by the Ministry of Ecology and Environment, the concentration of nearly six pollutants from industrial and household activities decreased between 2019 and 2020.

In 2022, the overall annual average concentrations of the six pollutants and criteria in 339 prefecture-level cities and above across China met the requirements of China's ambient air quality standards. The annual average concentration of PM2.5 was 29 ug/m^3, reflecting a year-on-year decrease of 1 ug/m^3 (Zhang et al., 2023). On the other hand, in the three key regions, namely the Beijing-Tianjin-Hebei (BTH) and surrounding areas, the Yangtze River Delta (YRD), and the Fenwei Plain, the annual average concentration of PM2.5 did not see any improvement, but rather an increase of between 2% and 7%.

The concerning situation in the Chinese economy and highly industrialised countries has prompted significant reactions in the literature. Several empirical studies have evaluated the factors that can improve the ecological situation in industrialised countries, revealing three main areas of focus. First, studies have evaluated the effect of the digital economy on pollution (Awan et al., 2022; Li et al., 2021; Sahan et al., 2025; Wu et al., 2023; Zhang et al., 2023). Then, studies have assessed the effectiveness of green financing on the economy's sustainability (Liang and Yang, 2019; Zeraibi et al., 2023; Du and Wang, 2023; Zhou et al., 2023; Liu et al., 2023; Zhang and Zhu, 2022).

Finally, studies investigate the impact of the energy transition on enhancing ecology (Ahmadpour et al., 2021; Assi et al., 2021; Huang and Tian, 2023; Karasoy and Akçay, 2019; Koengkan et al., 2021; Saint Akadiri et al., 2019; Li et al., 2022; Zhang and Zhu, 2022). This study aligns with the third perspective and aims to address two gaps in the literature. The first gap is the consideration of the sustained appeal and ongoing industrialisation of the Chinese economy, which hinder effective mitigation of the trade-off between robust growth and environmental impact. We consider the allure of the Chinese economy.

The detrimental impact of Foreign Direct Investment (FDI) on the environment of economies has already been empirically established under the pollution haven hypothesis (Chiriluș and Costea, 2023; Kisswani and Zaitouni, 2023; Mahmood, 2023). However, the literature has overlooked the significance of the energy transition in this correlation. Balsalobre-Lorente et al. (2023) have demonstrated that renewable energy can alleviate CO_2 emissions in BRICS economies. Nevertheless, we focus specifically on the Chinese economy, which is the most appealing.

The second gap is the consideration of the ecological footprint, also known as the environmental footprint, which enables us to quantify the pressure exerted by economic activities on resources and ecosystems. In this context, drawing on various studies (Assi et al., 2021; Mohamed et al., 2024), we focus on renewable energy consumption rather than production (Balsalobre-Lorente et al., 2023).

This study aims to evaluate the impact of FDI and renewable energy consumption on the ecological footprint of the Chinese economy. To achieve this, we use an ARDL to capture the short- and long-term effects of renewable energy consumption on the relationship between attractiveness, industrialisation, and pollution. In the concluding section, we outline the structure of this article as follows. Section two reviews the literature, section three presents the methodology of the study, Section four presents and discusses the results, and Section five concludes and puts forward recommendations for public stakeholders. In line with the aim of evaluating the impact of foreign direct investment (FDI) and renewable energy consumption on China's ecological footprint, the study is guided by the following research questions:

Q1: What is the impact of renewable energy consumption on the ecological footprint in China in the short and long run?

This research question is essential for assessing whether China's shift to renewable energy sources is fulfilling its desired environmental objectives. Although renewable energy is generally perceived as mitigating environmental deterioration, the ecological footprint, an extensive metric surpassing carbon emissions, encompasses the whole environmental impact of energy usage, including land use, water utilisation, and biodiversity depletion.

Given that China's energy transition has necessitated extensive infrastructure development and the manufacturing of renewable technologies (such as solar panels and wind turbines), it is essential to evaluate whether the advantages of renewable energy surpass the environmental costs linked to their production and integration. Furthermore, assessing both the short- and long-term impacts enables the research to determine whether early investments and disturbances result in enduring environmental benefits or continue as ecological liabilities. This inquiry helps policymakers in determining whether the advancement of renewable energy is producing the anticipated sustainability benefits or whether there are unforeseen repercussions that require attention.

RQ2: How does foreign direct investment influence the ecological footprint in China over time?

This focuses on the dual function of foreign direct investment in economic development and environmental sustainability. Foreign Direct Investment (FDI) can introduce capital, technology, and managerial expertise that promote sustainable development; however, it may also enable the transfer of polluting industries from nations with stringent regulations to those with more permissive environmental standards, a phenomenon referred to as the "Pollution Haven Hypothesis."

China, a premier target for foreign direct investment, particularly in heavy industries and manufacturing, warrants examination of the impact of these investments on environmental deterioration or enhancement.

The ecological footprint facilitates a comprehensive assessment of the impact of foreign direct investment beyond mere carbon emissions. By examining both short- and long-term effects, the study can determine whether initial environmental benefits from cleaner technologies introduced by FDI are sustained, or whether the benefits diminish over time as industrial scale intensifies.

2. LITERATURE REVIEW

The global community's intensified efforts to address climate change and foster sustainable development have made understanding the complex factors influencing environmental sustainability a primary concern in academic and policy discussions. The literature indicates that attaining green economic growth and environmental preservation relies not only on technological innovations or the adoption of clean energy but also on the robustness of institutions, financial systems, regulatory frameworks, and socio-economic structures.

Many studies have investigated how regulatory quality, foreign direct investment, renewable energy, urbanisation, and industrialisation shape ecological outcomes in both developed and emerging economies, particularly in Africa and Asia.

This literature review is organised into two subject areas. The initial section consolidates research highlighting the influence of institutions, financial development, and policy mechanisms on the facilitation or obstruction of sustainable outcomes. It emphasises the influence of governance, financial instruments, and environmental rules on sustainable transitions.

The second portion examines sectoral, technological, and structural issues, including commerce, industrial activities, urban expansion, and digital innovation, that directly impact environmental sustainability. This review organises the studies to offer a thorough understanding of existing knowledge, reveals consistent patterns, and underscores deficiencies for future study on green development strategies.

2.1. Institutional, Financial and Policy Drivers of Environmental and Green Economic Outcomes

In recent years, growing attention has been directed toward the influence of institutions, financial systems, and public policy in steering sustainable development and green economic growth. An expanding body of research highlights the critical roles of institutional quality, foreign direct investment (FDI), fiscal policies, and regulatory frameworks in advancing—or hindering—environmental progress. These studies offer a nuanced view of how governance, financial instruments, and global economic integration shape ecological outcomes, particularly in the Global South.

Jayawardana et al. (2025) systematic analysis examines economic and social sustainability in prefabricated buildings, emphasising the need of policy integration, lifecycle costing, and stakeholder engagement, which are essential for institutional and policy-driven sustainability transitions. The study's emphasis on lifecycle economic performance aligns with our discourse in the assessment regarding governance, fiscal instruments, and strategic sectoral prioritisation for sustainability.

Degbedji et al. (2024) offer a compelling empirical analysis on how institutional frameworks influence green economic outcomes in West Africa. Drawing on panel data from eight WAEMU countries over two decades, the study employs a robust methodology to highlight the role of regulatory quality and institutional integrity in fostering renewable energy adoption and eco-efficiency. This finding aligns with broader debates around the institutional preconditions required for effective environmental governance.

The work by Ahmadpour et al. (2021) takes a complementary approach by examining the welfare implications of renewable energy through a welfare surplus model. The authors argue that while increasing the share of renewables contributes to social welfare, it is essential that energy policies do not impose excessive burdens on either producers or consumers. This balance between affordability and sustainability reflects a key concern in environmental economics: how to internalise the externalities of energy consumption without triggering unintended socio-economic consequences.

Assi et al. (2021) further investigate the multifaceted role of financial development, demonstrating that its impact on environmental quality is ambiguous. Financial institutions can facilitate green technologies and investments in renewable energy; yet, they may also intensify environmental degradation if funding is allocated to pollution-intensive companies. Their research highlights that the quality of financial intermediation and the surrounding regulatory framework are vital in shaping environmental outcomes. Consumption of clean energy and technical breakthroughs are key mitigators of environmental pollution, providing avenues for sustainable growth when integrated with prudent financial planning.

Burke (2020) offers a normative perspective by emphasizing the ethical dimension of energy transitions. His review argues for prioritising energy efficiency and sufficiency, particularly for marginalised communities most vulnerable to the effects of climate change. The argument here goes beyond economics to highlight issues of energy justice and the equitable distribution of the burdens and benefits of environmental policies. These concerns are echoed in Byaro et al. (2022), who focus on the Tanzanian context. Their study finds that while trade, industrialisation, and urbanisation have driven economic growth, they also pose serious environmental challenges. Without adequate institutional checks, these processes can lead to irreversible environmental degradation.

The literature on FDI provides further evidence of the institutional dependencies of environmental outcomes. Chiriluș and Costea (2023) empirically validate the Pollution Haven Hypothesis in Romania, showing that weak environmental regulations attract environmentally damaging FDI. Similarly, Chowdhury et al. (2021), using panel quantile regression, demonstrate that FDI, despite its role in stimulating economic growth, often leads to increased ecological footprints in countries with lax regulations. These studies highlight the paradox of globalisation: while it facilitates capital flows and technology transfer, it also enables environmental arbitrage, where firms relocate pollution-intensive operations to jurisdictions with weaker oversight.

Yin et al. (2022) explore the potential of green fiscal policies as counter-cyclical tools during crises, such as the COVID-19 pandemic. The study finds that well-designed green fiscal interventions can stabilize volatile energy markets and enhance energy efficiency even under adverse macroeconomic conditions. This evidence supports the broader argument that policy instruments need not only to be environmentally sound but also economically stabilizing and socially inclusive.

The role of green investment is further advanced in the work of Zeraibi et al. (2023), who argue that greenfield investments aligned with renewable energy transitions can significantly enhance environmental quality and financial inclusion. Interestingly, the study shows that the impact of economic density is uncertain; it can improve or degrade environmental quality depending on the nature of the industrial activities promoted. This insight reinforces the importance of strategic sectoral prioritization in national development plans. Institutional mechanisms such as government procurement policies are also shown to have a positive environmental impact.

Zhang et al. (2022) analyze Green Public Procurement (GPP) programs and find that firms involved in these schemes are more likely to adopt cleaner technologies and reduce their emissions. These findings highlight how market-based instruments can complement command-and-control policies in achieving sustainability goals. Sahan et al. (2025) pivot the discussion to the organizational level, demonstrating the role of Green Human Resource Management (GHRM) in embedding environmental consciousness within firms. Through practices such as training, green performance appraisals, and eco-friendly workplace policies, GHRM fosters a culture of sustainability that supports broader environmental objectives.

Two additional studies further illustrate the institutional and financial dynamics shaping environmental outcomes in Africa. Osabohien et al. (2025) examine the nexus between renewable energy, carbon footprints, and economic growth using data across African countries. Their results reveal that while renewable energy consumption contributes positively to environmental sustainability, the depletion of natural resources and inefficient economic structures remain significant challenges. Luan et al. (2025), employing a system GMM approach, find that clean energy adoption, when supported by industrialisation and strong macroeconomic policies, significantly enhances sustainable development. These studies provide empirical support for the idea that institutional synergy, among energy, industry, and policy, is key to achieving green economic transformation.

Other important contributions include the works of Roy (2024), Sabir and Gorus (2019), Onifade et al. (2021), and Leal and Marques (2021), which all stress that globalization, if left unchecked, exacerbates environmental degradation. However, these studies are also optimistic, emphasizing the conditional nature of globalization's effects, highlighting that environmental benefits can be realized through regulation, green finance, and technological advancement.

2.2. Sector-Specific, Technological and Structural Drivers of Environmental Sustainability

While institutions and policies lay the groundwork for environmental governance, much of the practical realization of sustainability goals occurs at the sectoral and technological levels. This section of the literature review focuses on the empirical and theoretical contributions that examine how renewable energy technologies, economic structure, urbanisation, industrialization, and trade patterns affect environmental quality.

Sun et al. (2023) examine the physical and geomechanical properties of coalbed methane reservoirs across different coal ranks and pressure conditions. Their study aligns with the review's focus on technological and structural dynamics, particularly in energy sectors where resource extraction and infrastructure design influence environmental outcomes. This supports the argument that sustainability necessitates consideration of the technological foundations of energy production.

Awan et al. (2022) present a critical view of the interaction between urbanisation and technological advancement. Their study reveals that while technological innovation has considerable potential to reduce emissions, particularly in the transport sector, its environmental benefits can be nullified by uncontrolled urban expansion. This tension between growth and sustainability highlights the need for integrated urban and technological planning to maximize environmental gains. Azam et al. (2022) extend this line of inquiry by evaluating the impact of trade openness and urbanisation on carbon emissions. Using econometric models, they find that both factors contribute to environmental degradation, while the effect of industrialization depends largely on the technological capabilities of the sector.

The role of technological advancement is further investigated by Balsalobre-Lorente et al. (2023), who emphasize the synergy between economic complexity and renewable energy adoption. Their study finds that countries investing in Industry 4.0 technologies, such as automation, digitalisation, and artificial intelligence, are better positioned to reduce carbon emissions and improve industrial efficiency. The case of BRICS countries is particularly illustrative, as these emerging economies balance the dual challenge of expanding industrial capacity while adhering to global climate commitments.

Li et al. (2022) examine the nonlinear relationships among renewable energy consumption, pollution, and economic growth. Their findings suggest that renewable energy may initially exert a drag on economic growth due to transition costs and infrastructure deficits. However, over time, it significantly reduces emissions and supports long-term economic resilience. This nuanced perspective challenges the simplistic dichotomy of growth versus sustainability, showing instead that both can be harmonized through strategic planning and long-term investment.

Karasoy et al. (2019) also investigate the dual effects of energy and trade on the environment. While they confirm that renewable energy consumption contributes to pollution reduction, they caution that trade liberalization often exacerbates pollution through intensified industrial activity. This underscores the importance of coupling liberalization with environmental safeguards and cleaner production standards. Chen et al. (2021) explore the industrial context of environmental degradation in China. Their study demonstrates that China's heavy reliance on coal and other non-renewable energy sources has led to significant environmental harm.

Pata (2018) adds another geographical context to the discussion by analysing the environmental impact of urbanization and industrialization in Turkey. The study finds a direct correlation between these factors and increased carbon emissions. Nonetheless, it also suggests that adverse effects can be mitigated through policy interventions such as greener urban planning and the adoption of sustainable industrial technologies. This finding aligns with the broader literature on the Environmental Kuznets Curve (EKC), which posits that environmental degradation initially rises with economic growth but eventually declines with increased income and environmental awareness.

Saint Akadiri et al. (2019) provide cross-national evidence from the European Union, demonstrating that renewable energy consumption is associated with reduced carbon emissions and enhanced economic sustainability. However, their findings also indicate that the impact of renewables varies significantly across countries depending on their energy policies, industrial base, and institutional capacity. This variability supports the need for context-specific policy design rather than one-size-fits-all solutions.

The digital economy's impact on emissions is addressed by Li et al. (2021), who show that digital technologies can have opposing effects on environmental outcomes. On one hand, digitalization facilitates remote work, smart energy grids, and efficient logistics, all of which reduce emissions. On the other, the energy-intensive nature of data centres and server infrastructure may contribute significantly to emissions unless powered by clean energy. This duality necessitates a balanced approach to digital transformation that emphasizes sustainability at every layer.

Zeraibi et al. (2023) revisit the idea of economic complexity by examining the role of greenfield investments in renewable sectors. Their findings suggest that these investments can significantly improve environmental quality when targeted at clean energy industries. However, when directed toward traditional manufacturing or extractive industries, they may exacerbate resource depletion and pollution. This bifurcation stresses the importance of investment direction and sectoral focus. Sahan et al. (2025) and Zhang et al. (2022) highlight the importance of organizational and procurement strategies in fostering environmental stewardship. While Sahan et al. demonstrate how human resource practices can inculcate green values within firms, Zhang et al. show that government procurement can be a powerful lever to promote environmentally responsible behaviour in the private sector.

3. METHODOLOGY

This section outlines the empirical strategy of the article in three parts – the theoretical model, the data and sources, and the estimation method.

3.1. Theoretical Model, Data and Variables

The recurrence and worsening of environmental problems in economies have led researchers to establish the IPAT model. This basic equation, as designed by Ehrlich and Holdren (1972), determines sustainability outputs based on three major causal factors: population, wealth, and technology. The model aims to understand the influence of changes in population, wealth, and technology on their environmental impact. The dynamics of research on factors that decrease ecological degradation have led to the establishment of equation 1 (Holdren, 2018) as follow:

$$I + \Delta I = (P + \Delta P) \times (A + \Delta A) \times (T + \Delta T) \quad (1)$$

Where I is the environmental impact and its variation from one period to another. The variables P, A, and T represent respectively the population, affluence or economic attractiveness, and technology. In the specific case of China, the model is only representative. Moreover, the three factors are not independent in accordance with the hypothesis of Commoner et al. (1971), which suggests that the factors contributing to the environmental impact are multiplicative rather than additive. Previous empirical work has provided evidence for the use of the IPAT model to determine the causes of carbon dioxide emissions and ecological degradation (Burke, 2020; Chen et al., 2021; Onifade et al., 2021). In the case study, we have the equation 2 as:

$$EF_{it} = f(REC_{it}, FDI_{it}, GDPPC_{it}, INDUS_{it}, ICT_{it}, URBAN_{it}) \quad (2)$$

Where EF refers to the ecological footprint of country i in year t; REC is the renewable energy consumption, FDI denotes the foreign direct investments, GDPPC is the per capita gross domestic product, INDUS represents the industrialisation level, and ICT and URBAN represent respectively the level of economic digitalisation and the share of urban population.

The data used for the function of equation 2 mainly come from the Asian Bank and public organizations of China. The data for the period 1990–2022. The temporal itinerary is justified to consider the period of intensive growth of the country at the beginning of the 21st century. The explained variable is the ecological footprint (EF). The data was sourced from the World Development Indicators (WDI). The variables of interest are renewable energy consumption (UA and AFREC) and foreign direct investment (FDI). The control variables are the total greenhouse emissions (TGE), the GDP per capita (GDPPC), the level of industrialization (INDUS), the telecommunication technology (Onifade et al. 2021), and the urbanization (Urbany et al., 1989). The control variables are consistent with empirical assessments in the literature on the case of industrialized countries (Karasoy and Akçay, 2019; Li et al., 2022; Chiriluș and Costea, 2023; Balsalobre-Lorente et al., 2023; Chen et al., 2021).

3.2. Estimation Method

Experimenting with non-cross-sectional data related to a single country is essential for industrialized economies to understand the dynamics of a phenomenon. In the particular case of these economies, unlike developing economies, the trends of economic indicators may not be synchronous and may remain relatively constant in the short term.

The advantage of this method is twofold. First, it is suited to mixed integration orders with I(0) and I(1), but the second integration order, i.e. I(2), should not be present for any series, because we work with a single economy (Pesaran et al., 2001). This particularity is specific to autoregressive and instrumental estimations because it allows for the limitation of endogeneity defects when some variables are constant in the time series. The inclusion of an appropriate lag results in the elimination of existing serial correlation as well as endogeneity of the variables. Another advantage of using the ARDL method is that we can estimate the short-run and long-run effectiveness of the rectifiers for the variable of interest (Assi et al., 2021; Kisswani and Zaitouni, 2023).

The application of VECM requires that all variables in the model be integrated of order one [I(1)] and that a long-run cointegration relationship exists among them. However, our stationarity diagnostics using the Augmented Dickey-Fuller (ADF) test reveal that the dataset includes variables with mixed orders of integration; some variables are non-stationary at the level and do not become stationary even after first differencing (i.e., they are not I(1)). For example, GDP per capita (GDPPC), ICT penetration, and renewable energy consumption (REC) do not satisfy the I(1) condition.

Due to this violation of the VECM's assumptions, employing such a model would result in misleading or inconsistent estimates. In contrast, the Autoregressive Distributed Lag (ARDL) approach adopted in this study is more appropriate for the current dataset. ARDL models are well-suited for cases where variables are a mix of I(0) and I(1). They enable robust estimation of both short-run and long-run dynamics without requiring all variables to be I(1) or pre-testing for cointegration in a system of equations. We employed the ARDL approach to ensure methodological soundness and robustness of our results, given the characteristics of the available data. The ARDL model is shown in equation (3)

$$\begin{aligned}\Delta \ln EF_t = {} & \alpha_0 + \sum_{i=1}^{p}\alpha_1 \Delta \ln REC_{t-i} + \sum_{i=1}^{p}\alpha_2 \Delta \ln FDI_{t-i} + \sum_{i=1}^{p}\alpha_3 \Delta \ln TGE_{t-i} \\ & + \sum_{i=1}^{p}\alpha_4 \Delta \ln GDPPC_{t-i} + \sum_{i=1}^{p}\alpha_5 \Delta \ln INDUS_{t-i} + \sum_{i=1}^{p}\alpha_6 \Delta \ln ICT_{t-i} \\ & + \sum_{i=1}^{p}\alpha_7 \Delta \ln URBAN_{t-i} + \gamma_1 \ln REC_{t-1} + \gamma_2 \ln FDI_{t-1} + \gamma_3 \ln TGE_{t-1} \\ & + \gamma_4 \ln GDPPC_{t-1} + \gamma_5 \ln INDUS_{t-1} + \gamma_6 \ln ICT_{t-1} + \gamma_7 \ln URBAN_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

In equation 3, α_1, α_2, α_3, α_4 to α_7 indicate the short-term impact of the explanatory variables. Similarly, γ_1 to γ_7 show the long-term effect of the variables. The ARDL bounds testing method requires many steps to obtain information about the short-term and long-term dynamics. First, a multicollinearity test is used to establish that there is no multicollinearity between our different variables. The results are presented in Table 1. Then, to ensure that our variables are stationary, we perform a test whose results are presented in Table 2. Finally, we perform the Optimal Lag Length Selection tests and the Model Bounds Test which are presented in Tables 3 and 4 respectively.

4. RESULTS

4.1. Summary of Descriptive Statistics

The following Table 5 summarises the descriptive statistics of the variables included in this estimation. Table 5 confirms that all variables follow a normal distribution, as indicated by the skewness and kurtosis values, and validated by the Jarque-Bera test. The outcomes show that the mean of ecological footprint, renewable

Table 1: Correlation matrix

	EF	REC	FDI	TGE	GDPPC	INDUS	ICT	URBAN
EF	1							
REC	−0.961	1.000						
FDI	−0.408	0.270	1.000					
TGE	0.997	−0.947	−0.441	1.000				
GDPPC	0.960	−0.860	−0.532	0.973	1.000			
INDUS	−0.428	0.225	0.868	−0.477	−0.632	1.000		
ICT	0.952	−0.841	−0.571	0.967	0.991	−0.657	1.000	
URBAN	0.983	−0.927	−0.438	0.984	0.980	−0.500	0.956	1.000

Source: Authors' computation

Table 2: Stationary test

Variables	ADF	Remark
EF	4.777*** [0.000]	I (0)
REC	−3.491*** [0.002]	I (0)
FDI	−2.616*** [0.015]	I (1)
TGE	5.482*** [0.000]	I (0)
GDPPC	14.588*** [0.000]	I (0)
INDUS	−3.172*** [0.004]	I (1)
ICT	7.352*** [0.000]	I (0)
URBAN	27.674*** [0.000]	I (0)

Source: Authors computation

energy consumption, foreign direct investment, total greenhouse gas emission, GDP per capita, industrialization, internet users and urbanization are 2.421 gha per person, 21.176% of total final energy consumption, 3.238% of GDP, 7689561 kt of CO_2 equivalent, 6980.188$, 44.287% of GDP, 21.604% of population and 43.024% of total population, respectively. Likewise, the maximum and minimum values of ecological footprint, renewable energy consumption, foreign direct investment, total greenhouse gas emission, GDP per capita, industrialization, internet users and urbanization are 3.534, 33.910, 5.987, 12942868, 16296.610, 47.557, 70.053, 61.428 and 1.347, 11.340, 0.884, 3238859, 1423.896, 37.843, 0.000, 26.442, respectively.

In addition to descriptive statistics, this study examines the relationships between the dependent variable and each independent variable (Table 1). The results reveal a strong association between ecological footprint and several factors, including renewable energy consumption, total greenhouse gas emissions, GDP per capita, internet usage, and urbanization. In contrast, the links between ecological footprint and both foreign direct investment and industrialization appear weak. Specifically, the correlation between ecological footprint and renewable energy consumption is strongly negative (−0.961), suggesting that increases in renewable energy consumption are associated with reductions in ecological footprint, and vice versa. On the other hand, ecological footprint shows strong positive correlations with total greenhouse gas emissions (0.997), GDP per capita (0.960), internet users (0.952), and urbanization (0.983), indicating that increases in these variables tend to raise the ecological footprint. Lastly, foreign direct investment (−0.408) and industrialization (−0.428) exhibit weak negative correlations with ecological footprint, suggesting that they are associated with slight reductions in environmental pressure.

4.2. Econometric Results

The Dicker Fuller Augmented (ADF) unit root tests are applied to capture the order of integrations of all the estimated variable and exhibit the results in Table 2. The outcomes of the ADF unit root test reveal that the variables such as ecological footprint, renewable energy consumption, total greenhouse gas emissions, GDP per capita, internet users and urbanization are stationary at level while foreign direct investment and industrialization are stationary after the first difference is taken.

The ARDL bounds test approach was employed to investigate the long-term relationship between the ecological footprint, renewable energy consumption, foreign direct investment, total greenhouse gas emissions, GDP per capita, industrialization, internet users, and urbanization in China, using annual data from 1990 to 2022. The initial step in the ARDL bounds test involved determining the optimal lag order for the variables in the model (Table 3). To achieve this, we applied the sequential modified LR test statistic, final prediction error (FPE), Akaike information criterion (AIC), Schwartz information criterion (SC), and Hannan-Quinn information criterion (HQ), all of which indicated that a lag order of 2 was appropriate. Table 4 presents the cointegration results for the two models, which indicate cointegration, as the F-statistic (28.759) exceeds the critical values for both the lower and upper bounds.

Table 6 reports the long run as well as the short run coefficients of the ARDL model analysing the relationship foreign direct investment, renewable energy consumption and ecological footprint. The error correction term is significant and negative, suggesting that the system corrects for previous period shocks and disequilibrium with an annual speed of adjustment of around 197.4 %. Empirical results indicate that renewable energy consumption increases ecological footprint both in short and long run. The results suggest that, in the short and long run, a rise of renewable energy consumption by 1% of total final energy consumption increases ecological footprint by 0,033 gha per person in the long run and 0.022 gha per person in the short run. However, foreign direct investment decreases ecological footprint both in long and short run but the outcomes of long run are insignificant.

Table 3: Optimal Lag length selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−853.261	NA	8.63E+15	59.39732	59.77451	59.51545
1	−515.319	466.1274	63785907	40.50475	43.89941	41.56791
2	−399.276	96.03511*	5857094*	36.91561*	43.32776*	38.92382*

Source: Authors' computation

Table 4: ARDL Bound test

Test statistic	Value	Significant (%)	I (0)	I (1)
F-statistic	28.759	10	1.92	2.89
k	7	5	2.17	3.21
		2.50	2.43	3.51
		1	2.73	3.9

Source: Authors' computation

Regarding the control variables, the outcomes showed that all of them positively influence ecological footprint in the long run, except for GDP per capita, which decreases ecological footprint. Indeed, a rise of total greenhouse gas emissions by one kt of CO_2 equivalent increases ecological footprint by 5.30E-07 gha per person. Similarly, a rise of (1) industrialization by one percentage of GDP, (2) internet users by one percentage of population, and (3) urbanization by one percentage of total population, increases ecological footprint by 0.022, 0.009, and 0.049 gha per person, respectively. However, a rise of GDP per capita by one dollar decreases ecological footprint by 0.0002 gha per person.

After the ARDL, the paper check for the post-estimation diagnostics. Thus, Jarque-Bera normality test was done to verify the residuals are normal (Appendix 1). The results indicated that the residuals are normal because the probability associated to the Jarque-Bera statistic 0.085 is >0.05. Similarly, Breusch-Pagan-Godfrey heteroskedasticity test was done to check for the residuals' variance is homogeneous (Appendix 2). Both the probabilities of the Fisher statistic (0.7364) and the Chi2 statistic (0.5427) are >0.05, indicating that the residuals' variance is homogeneous. Finally, Breusch-Pagan-Godfrey Serial Correlation LM Test was applied to test the absence of auto-correlation of residuals (Appendix 3). The probability associated to the Fisher statistic (0.0644) is >0.05, so the residuals is free for serial correlation.

4.3. Robustness Check

To check for the ARDL model robustness, the Fully Modified Ordinary Least Square (FMOLS) as well as the Dynamic Ordinary Least Square (DOLS) techniques were both applied. The outcomes were reported in Tables 7 and 8. Outcomes of the two models showed that renewable energy consumption increase ecological footprint but only the results of the FMOLS model are significant. The results suggest that, a rise of renewable energy consumption by 1% of total final energy consumption increases ecological footprint by 0.013 gha per person for the FMOLS model. However, foreign direct investment decreases ecological footprint when applying the two techniques. Indeed, a rise of foreign direct investment by 1% of GDP decreases ecological footprint by 0.02 gha per person for the FMOLS model and 0.032 gha per person for the DOLS model.

Regarding to the control variables, the outcomes showed that all of them positively influence ecological footprint for both FMOLS and DOLS model, except for GDP per capita which decreases ecological footprint. Indeed, a rise of total greenhouse gas emissions by one kt of CO_2 equivalent increases ecological footprint by 2.42E-07 gha per person for the FMOLS model and by 1.86E-07 gha per person for the DOLS model. Similarly, a rise of (1) industrialization by one percentage of GDP, (2) internet users by one percentage of population, and (3) urbanization by one percentage of total population, increases ecological footprint by 0.023, 0.006 and 0.031 gha per person for FMOLS model, respectively while increasing ecological footprint by 0.039, 0.009 and 0.017 gha per person for DOLS model, respectively. However, a rise of GDP per capita by one dollar decreases ecological footprint by 8.26E-05 gha per person for the FMOLS model but is insignificant for the DOLS model.

4.4. Discussion of Findings

Overall, the outcomes show that renewable energy consumption increases the ecological footprint. On the other hand, a rise in renewable energy consumption is harmful to the environment. The plausible explanation is that China's consumption of renewable energy is still low because on the period 1990-2020, the World Bank (2024) estimated the average value of renewable energy consumption at 21.176% of total final energy consumption. Moreover, the low level of renewable energy consumption is not sufficient to reduce damage create to the environment.

China is known as one of the most polluting countries on the planet, and for this, the country must make significant efforts to promote renewable energy consumption. For this, the country must attract enough investors to invest in renewable energy consumption, and foreign direct investment can be the solution. By the way, the outcomes overall suggested that foreign direct investment reduces environmental degradation, indicating that China can improve the quality of the environment by attracting foreign investors to finance renewable energy consumption. This outcome is similar to Chowdhury et al. (2021) who found on the 70th quantile that the coefficient of FDI is negative and significantly related to ecological footprint and Roy (2024) who found that foreign direct investment is beneficial to improve Indian environmental quality, thus, reducing ecological footprint.

The study reveals that total greenhouse gas emissions, industrialization, internet users, and urbanization positively contribute to explaining ecological footprint. The outcomes underscore the need for government and policymakers to prioritize initiatives that reduce greenhouse gas emissions, promote green industrialization and ecological cities and invest in ICT based technologies, which can reduce ecological footprint and achieve SDG7 and SDG11, aimed at achieving affordable and clean energy and sustainable cities and communities respectively.

Table 5: Summary statistics

Variables	EF	REC	FDI	TGE	GDPPC	INDUS	ICT	URBAN
Mean	2.421	21.176	3.238	7689561.000	6980.188	44.287	21.604	43.024
Median	2.369	17.440	3.487	7263559.000	5334.647	45.536	8.523	42.522
Maximum	3.534	33.910	5.987	12942868.000	16296.610	47.557	70.053	61.428
Minimum	1.347	11.340	0.884	3238859.000	1423.896	37.843	0.000	26.442
Std. Dev.	0.807	8.550	1.317	3524190.000	4814.689	2.915	23.869	11.032
Skewness	0.095	0.194	−0.154	0.187	0.588	−0.869	0.629	0.115
Kurtosis	1.373	1.267	2.141	1.386	1.974	2.364	1.841	1.702
Jarque-Bera	3.467	4.073	1.076	3.546	3.144	4.424	3.781	2.245
Probability	0.177	0.131	0.584	0.170	0.208	0.110	0.151	0.326
Sum	75.048	656.470	100.374	2.38E+10	216385.800	1372.885	669.720	1333.754
Sum Sq. Dev.	19.518	2193.313	52.020	3.73E+14	6.95E+08	254.914	17092.250	3650.901

Source: Authors' own computation

Table 6: ARDL long and short run coefficients

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ARDL long-run coefficients				
C	−2.338	0.408	−5.724	0.0004
EF (-1)	−1.974	0.165	−11.999	0
REC (-1)	0.033	0.007	4.719	0.0015
FDI (-1)	−0.011	0.009	−1.215	0.2591
TGE (-1)	5.30E-07	6.62E-08	8.012	0
GDPPC (-1)	−0.0002	2.37E-05	−6.734	0.0001
INDUS (-1)	0.022	0.007	3.022	0.0165
ICT (-1)	0.009	0.003	2.999	0.0171
URBAN (-1)	0.049	0.008	6.341	0.0002
ARDL short-run coefficients				
CointEq (-1)	−1.9740	0.0868	−22.7521	0
D (EF(-1))	0.8173	0.0603	13.5576	0
D (REC)	0.0222	0.0025	9.0563	0
D (FDI)	−0.0189	0.0022	−8.6359	0
D (FDI(-1))	−0.0100	0.0020	−4.9845	0.0011
D (TGE)	0.0000	0.0000	28.2608	0
D (TGE(-1))	0.0000	0.0000	−9.3946	0
D (GDPPC)	0.0000	0.0000	−3.8533	0.0049
D (INDUS)	0.0034	0.0021	1.6436	0.1389
D (ICT)	−0.0049	0.0013	−3.7404	0.0057
D (ICT(-1))	0.0083	0.0013	6.4431	0.0002
D (URBAN)	0.3579	0.0396	9.0431	0
D (URBAN(-1))	−0.2084	0.0406	−5.1271	0.0009
R-squared	0.995	Mean dependent var		0.075
Adjusted R-squared	0.991	S.D. dependent var		0.075
S.E. of regression	0.007	Akaike info criterion		−6.765
Sum squared resid	0.001	Schwarz criterion		−6.152
Log likelihood	111.093	Hannan-Quinn criter.		−6.573
Durbin-Watson stat	3.387			

Source: Authors' computation

Table 7: Fully modified ordinary least square

Variable	Coefficient	Standard error	t-Statistic	Prob.
REC	0.013	0.004	3.098	0.0053
FDI	−0.020	0.007	−2.824	0.0099
TGE	2.42E-07	2.30E-08	10.50774	0
GDPPC	−8.26E-05	1.61E-05	−5.142898	0
INDUS	0.023	0.006	4.049	0.0005
ICT	0.006	0.002	2.553	0.0181
URBAN	0.031	0.004	7.346	0
Constant	−1.569	0.310	−5.066	0
R-squared	0.9991	Mean dependent var.		2.4567
Adjusted R-squared	0.9988	S.D. dependent var.		0.795
S.E. of regression	0.0278	Sum squared resid.		0.017
Long-run variance	0.0004			

Source: Authors' computation

Table 8: Dynamic ordinary least square (DOLS)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
REC	0.008	0.006	1.422	0.1755
FDI	−0.032	0.011	−2.998	0.009
TGE	1.86E-07	3.01E-08	6.168062	0
GDPPC	−3.60E-05	2.84E-05	−1.266	0.2247
INDUS	0.039	0.009	4.479	0.0004
ICT	0.009	0.003	3.303	0.0048
URBAN	0.017	0.010	1.834	0.0866
C	−1.700	0.378	−4.495	0.0004
R-squared	0.9994	Mean dependent var.		2.457
Adjusted R-squared	0.9989	S.D. dependent var.		0.795
S.E. of regression	0.0263	Sum squared resid.		0.010
Long-run variance	0.0003			

Source: Authors

Pata (2018), Rjoub et al. (2021) and Azam et al. (2022) found that urbanization increase environmental degradation. Pata (2018), Azam et al. (2022) found that industrialization increase environmental degradation. GDP per capita is negatively affected ecological footprint, i.e., GDP per capita decreases environmental degradation.

The plausible explanation for this result is that when countries reach a certain level of economic growth, they tend to take actions to reduce environmental degradation: this is concept of Environmental Kuznets Curve (EKC) introduced by Grossman and Krueger (1991). The China context lends itself well to this, as the country, having already developed by degrading its environment, has been trying in recent years to reduce the damage caused to the environment. The outcome is similar to Roy (2024), Byaro et al. (2022) and Rjoub et al. (2021) who found economic growth decreases environmental degradation and Sabir and Gorus (2019) who found that from a certain threshold economic growth decreases environmental degradation. Roy (2024) argues that FDI primarily brings efficient and clean technology to emerging nations to worsen pollution levels.

The paradoxical finding that renewable energy usage amplifies the ecological footprint necessitates further examination. A potential answer resides in the environmental costs inherent in the lifecycle of renewable energy technology, encompassing raw material extraction, manufacturing, deployment, and disposal. Although renewable energy sources like solar and wind diminish carbon emissions during operation, their manufacturing and infrastructure (e.g., solar panels, wind turbines, and battery storage) may have significant environmental impacts if not managed responsibly. Integrating a lifecycle assessment methodology into forthcoming evaluations would provide profound insights into these hidden costs and facilitate differentiation between clean energy implementation and its overall ecological effects.

Regarding foreign direct investment (FDI), our analysis employs aggregate net inflows of FDI as a percentage of GDP due to data constraints; nevertheless, a sectoral disaggregation of FDI inflows, if accessible, would provide a more refined perspective. For instance, foreign direct investment in heavy industries may exacerbate ecological degradation, but investment in green technologies or service-oriented sectors could foster environmental enhancements. Consequently, subsequent research may investigate country-specific sectoral FDI data (depending on data availability) to distinguish these effects and facilitate more precise policy suggestions that promote green investments while deterring ecologically detrimental capital inflows.

While the study provides critical insights into China's ecological footprint dynamics, it would indeed benefit from a comparative contextualization with other high-emission countries or BRICS nations. Although our primary focus remains on China due to its unique policy and industrial structure, findings from comparable studies such as Balsalobre-Lorente et al. (2023) on BRICS economies and Roy (2024) on India suggest similar complexities regarding FDI and renewable energy impacts. These comparative insights help situate our results within the broader literature and highlight shared sustainability challenges among fast-growing, high-emission economies.

5. CONCLUSION

The study investigates the relationships among foreign direct investment (FDI), renewable energy consumption, and the ecological footprint in China over the period from 1990 to 2022, using the Autoregressive Distributed Lag (ARDL) model. The ecological footprint, measured in global hectares (gha) per person, serves as an indicator of environmental sustainability. The study draws on data from the World Development Indicators (WDI) to analyse how variations in FDI inflows and renewable energy consumption influence the ecological footprint both in the short and long term.

The results suggest that renewable energy consumption paradoxically affects the ecological footprint. In the short run, a 1% increase in renewable energy consumption leads to a 0.022 gha per person increase in the ecological footprint. In the long run, the effect is more pronounced: a 1% increase in renewable energy consumption contribute to a 0.033 gha. FDI is found to have a significant negative impact on the ecological footprint in the short run, suggesting that increased FDI flows help reduce the ecological footprint. However, in the long run, FDI has no statistically significant effect on the ecological footprint.

The findings of the study suggest that, contrary to expectations, renewable energy consumption does not reduce the ecological footprint in either the short or long term but rather contributes to an increase. This could be due to the high environmental costs associated with the initial stages of renewable energy infrastructure development and integration into the energy mix. Additionally, the negative short-run impact of FDI on the ecological footprint suggests that foreign investment in China may contribute to environmental improvements, likely through the transfer of cleaner technologies and sustainable business practices.

In the long run, however, the impact of FDI on the ecological footprint becomes insignificant, potentially indicating that the environmental benefits of FDI are short-lived or that other factors overshadow its influence on environmental sustainability over time.

The study's findings offer valuable insights for policymakers looking to balance economic growth and environmental sustainability. Specifically, the short-run benefits of FDI on reducing the ecological footprint highlight the importance of encouraging environmentally friendly investments. On the other hand, the increase in the ecological footprint associated with renewable energy consumption underscores the need to address the potential environmental costs of transitioning to renewable energy. However, this study is not without limitations.

One of the major limitations of the study is the counterintuitive finding that renewable energy consumption increases the ecological footprint. This result contradicts the commonly held view that renewable energy is more environmentally sustainable than fossil fuels. While the study acknowledges that the environmental costs of renewable energy infrastructure might explain this, further analysis is needed to clarify the underlying mechanisms. Furthermore, the lack of a significant long-term relationship between FDI and the ecological footprint may suggest that the positive environmental impacts of FDI are temporary. However, the study does not explore why this is the case, leaving room for further research to examine whether other factors, such as diminishing returns to FDI or changes in the types of foreign investments, explain this finding.

Regarding the data that ended 2022, we clarify that the analysis is limited by the accessibility of consistent data beyond the period. To ensure robustness within the specified range, we have utilised alternative estimation methods (e.g., FMOLS and DOLS) and confirmed data consistency across reputable sources. Future research may integrate emerging data as it becomes accessible or broaden the analysis to include additional BRICS nations for cross-national comparisons. While the focus on China provides important insights, the study's results may not be generalizable to other countries, especially those with different economic structures and environmental policies. Comparative studies across countries or regions could provide a broader perspective on the relationships between FDI, renewable energy, and environmental sustainability.

As a policy recommendation, the short-term negative impact of FDI on the ecological footprint suggests that FDI can play a key role in reducing environmental degradation. Policymakers should therefore prioritize attracting green FDI, which involves investments that promote environmental sustainability. This could include incentives for foreign companies to invest in clean technologies, energy-efficient processes, and sustainable infrastructure. The finding that renewable energy consumption increases the ecological footprint suggests that the current methods of renewable energy production and distribution may not be as environmentally friendly as assumed. Governments and energy companies should focus on improving the lifecycle environmental performance of renewable energy technologies. This includes minimizing the environmental impact of manufacturing, transportation, and waste disposal associated with renewable energy systems.

While renewable energy is crucial for reducing dependence on fossil fuels, the study highlights the need for a diversified approach to energy transition. Policymakers should encourage a mix of energy sources that not only reduce carbon emissions but also limit other environmental impacts, such as land use and resource depletion. Similarly, the lack of a significant long-term effect of FDI on the ecological footprint underscores the need for stronger environmental regulations that ensure sustained environmental benefits from foreign investments. This could include more stringent environmental standards for foreign companies, monitoring and reporting requirements, and penalties for non-compliance.

Since FDI often brings new technologies, future studies should examine the role of technological innovation in mediating the relationship between FDI and environmental sustainability. Specifically, research could explore whether the introduction of cleaner technologies through FDI can offset the environmental costs of economic growth and energy consumption in the long term. Future studies could explore the sectoral composition of FDI to determine which industries contribute the most to reducing or increasing the ecological footprint. A sector-specific analysis would provide more targeted recommendations for policymakers on which types of FDI to promote or regulate more strictly.

Extending the analysis to other countries or regions would help validate the findings and provide a more global perspective on the impact of FDI and renewable energy on environmental sustainability. Comparative studies across developed and developing countries could reveal whether the relationships observed in China hold true in different economic and regulatory contexts. To better understand the environmental costs associated with renewable energy consumption, future research could focus on conducting a lifecycle analysis of various renewable energy technologies. This would provide insights into the specific stages of renewable energy production and distribution that contribute to the ecological footprint and identify opportunities for reducing these impacts. Given the increasing importance of environmental regulation, future research could examine how different environmental policies, such as carbon pricing, emissions trading schemes, and renewable energy subsidies, influence the relationship between FDI, renewable energy consumption, and the ecological footprint.

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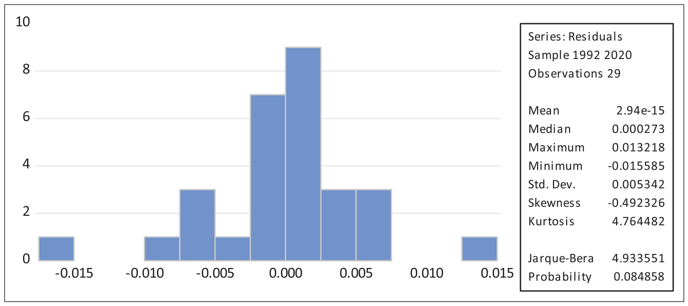
APPENDICES: DIAGNOSTIC TEST FOR ARDL MODEL

Appendix 1: Normality test



Source: Authors

Appendix 2: Heteroskedasticity test

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.723989	Prob. F (20,8)	0.7364
Obs*R-squared	18.67962	Prob. Chi-square (20)	0.5427
Scaled explained SS	2.675637	Prob. Chi-square (20)	1

Source: Authors

Appendix 3: Serial correlation test

Breusch-Godfrey Serial Correlation LM Test			
F-statistic	4.485836	Prob. F (2,6)	0.0644
Obs*R-squared	17.37805	Prob. Chi-Square (2)	0.0002

Source: Authors