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Toward a Sustainable Future in India: Examining the role of foreign direct investment and agricultural development in environmental degradation using NARDL framework

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Abstract

Investigating Pollution-Haven Hypothesis (PHH) is main motive of conducting this study, focusing on the asymmetric impacts of Foreign Direct Investment (FDI) and agricultural development on CO_2 emissions in India. Asymmetrical advance econometric model i.e., NARDL model are used to investigates dynamic asymmetrical inter-connectedness among the selected variables using long time series data spanning from 1970-2021. The findings robustly support the Pollution-Haven Hypothesis (PHH) in India, demonstrating that positive shocks in FDI are associated with increased CO_2 emissions, indicative of polluting industries relocating to areas with less stringent environmental regulations. Further results reveal that agricultural activities significantly reduce CO_2 emissions, supporting sustainable agricultural practices, while increased trade openness corresponds with higher emissions. Surprisingly, population growth shows a negative impact on emissions, possibly reflecting urban efficiency improvements and sustainable consumption patterns. These insights underline the importance of stringent environmental regulations to mitigate the adverse effects of FDI and suggest adjustments in trade policies to include environmental considerations, emphasizing the need for balanced and informed policy measures to achieve sustainable development in India.

Keywords: Pollution Haven Hypothesis (PHH), Agriculture Based- Environmental Kuznets Curve (EKC), Foreign Direct Investment (FDI), CO_2 Emissions, NARDL

1. Introduction

Over the past few decades, environmental challenges and climate change has emerged as serios global issues, particularly in India. Recently published IPE global & Esri report (2024) reveals that over 80 per cent district of India are exposed to extreme climatic events such as droughts and floods, with 45 per cent experiencing a 'swapping' trend where flood-prone areas now face droughts and vice versa. This dynamic backdrop of environmental volatility juxtaposed against India's quest for economic prosperity creates a unique context to examine the interplay of economic activities and environmental impacts through established economic theories. According to the IPCC (2023) human activities along with rapid industrialization and construction have unproportionally contribute to environmental pollution and global warming in particularly in developing economies. These kinds of economic and human activities not only intensify global warming but also exacerbate environmental problems, leading to severe health and ecological consequences. The financial implications are significant, as these economies often bear the dual burden of environmental damage and the costs associated with mitigation and adaptation. Furthermore, the lack of expert knowledge and insufficient investment in sustainable practices exacerbate the situation, leaving these countries more vulnerable to the impacts of climate change and less equipped to implement effective solutions. As climate change and environmental challenges are directly and indirectly affected due to various factors such as large population (Zeeshan et al. 2022; Shabbir et al. 2023), rapid industrialisation (Ansari et al., 2020), anthropology activities (deforestation, land degradation, production & consumption activities. Anthropology activities and rapid industrialisation are primary sources of environmental pollution in lower-and middle-income economies (Irfan et al., 2022; Isik et al., 2021). Agriculture's role in environmental degradation is twofold. Traditional, input-intensive farming methods can contribute to carbon emissions through mechanization and chemical use. However, when managed sustainably, agriculture can significantly reduce emissions via carbon sequestration in soils and reduced reliance on fossil fuels. Thus, incorporating agriculture into the PHH and EKC frameworks offers a more holistic understanding of CO_2 dynamics, particularly in agrarian economies like India (Gokmenoglu & Taspinar, 2018; Zafar et al., 2023a) Trade openness is central to the Pollution Haven Hypothesis, which suggests that countries with lenient environmental regulations may become havens for pollution-intensive industries relocating from stricter economies. Simultaneously, trade may also transfer cleaner technologies and improve environmental standards via international competition and regulation (Rana & Sharma, 2019a; Saqib & Dincă, 2024) Therefore, its inclusion is essential for assessing the net environmental effects of economic liberalization.

However, India's endeavours to achieve environmental sustainability, a key goal under Sustainable Development Goal 13 (Climate Action), appear daunting. The interrelation of environmental sustainability, economic development, and financial development forms a critical discourse within environmental economics, particularly in emerging economies like India. This discourse is framed around two pivotal concepts: the Pollution-Haven Hypothesis (PHH) and the Environmental Kuznets Curve (EKC). The PHH suggests that industrialized nations may relocate their most polluting industries to less developed countries with looser environmental regulations, turning these regions into pollution havens. Conversely, the EKC proposes an inverted U-shaped relationship between a country's wealth (GDP-Economic Growth) and its environmental degradation (Carbon Emission-CO_2), where pollution or environmental degradation levels initially increase with economic growth but eventually decline as income continues to rise and societies prioritize environmental quality.

The rise of foreign direct investment (FDI) has become a key driver of economic development, particularly in developing and least-developed countries (LDCs) (Zeng & Eastin, 2012). While FDI promotes economic growth and technological advancement, concerns about its environmental impact have been raised, leading to two contrasting hypotheses: the "Pollution Halo" and "Pollution Haven" theories. The Pollution Halo hypothesis suggests that FDI can introduce eco-friendly technologies and improve environmental quality, (Nguyen-Thanh et al., 2022) while the PHH argues that FDI may relocate polluting industries from developed to developing nations, worsening environmental conditions (Rana & Sharma, 2019a). Green FDI (GFDI), which focuses on clean technologies and sustainable projects, has gained attention as a solution to support both economic growth and environmental sustainability (Amendolagine et al., 2021). The Governments and international organizations have recognized its potential to address climate change (CC) and promote sustainable development (SD).

This underscores the urgent need for global financial support, capacity building, and technology transfer to help these economies transition to more sustainable development pathways while addressing the environmental challenges of rapid industrial growth. However, this piece of work inspects the empirical relationships between foreign direct investment (FDI) inflow and environmental degradation (ED). The study employs the NARDL econometric to analyse the impacts of both positive and negative FDI shocks on environmental quality (EQ). Recognizing an asymmetric relationship among variables is crucial due to the complexity and various channels through which one variable can influence another (Shahbaz et al., 2017, 2018). This is the first study to examine the impact of agriculture value-added on carbon emissions alongside other less-explored variables in the existing literature. In India, the effects of climate change (CC) are intensified due to the economy's heavy reliance on FDI and agriculture. As one of the leading agrarian economies, a significant portion of India's population is engaged in agriculture. As a result, this research also assesses the consequences of trade openness, population increase, and financial development, all while adhering to the Environmental Kuznets Curve, or EKC, theory. This paper aims to investigate the PHH and EKC hypothesis within the Indian context. Given India's focus on attracting foreign direct investment (FDI) to promote economic growth (EG) while simultaneously prioritizing environmental sustainability, it is critical to understand the causal linkages between the factors influencing EG and environmental degradation. The study explores the causal relationships among FDI, economic growth (CO_2 emissions, and international trade indicators such as exports and imports. This analysis is essential for formulating effective strategies to address the environmental challenges associated with economic development.

The paper is structured into six sections. The first section introduces the study and provides background information, followed by a review of relevant literature in the second section. The third section details the methodology and data sources employed in the analysis. The fourth section presents the empirical findings, while the fifth offers commentary on the results. The final section concludes the paper and discusses the policy implications arising from the research.

2. Literature review

Pollution-haven hypotheses developed by (Pethig, 1976), used basic Ricardian trade model to illustrate two nearly identical countries, with the only distinction being that the higher pollution taxes in the northern country compared to the southern one primarily drive trade between these nations. The disparity in pollution taxes motivates transferring older or more pollution-intensive technologies to developing countries, explained by three fundamental theories: the pollution haven hypothesis, the race-to-the-bottom hypothesis, and the stuck-in-the-mud hypothesis (the latter two being interrelated). The race-to-the-bottom hypothesis asserts that a nation should eliminate its environmental standards to attract more foreign investment. Similarly, the 'stuck-in-the-mud' or 'regulatory chill' theory suggests that developing countries hesitate to enhance their environmental standards for fear of losing Foreign Direct Investment (FDI) to competing nations. While some scholars (Caetano et al., 2023; Saqib & Dincă, 2024; Uche et al., 2023) argue that FDI can bring cleaner technologies to developing countries, whereas a significant body of literature demonstrates that FDI inflows are linked to environmental degradation (Achuo & Ojong, 2023; Manocha, 2024; Sapkota & Bastola, 2017).

Numerous studies have been explored the relationship between FDI and the environment (Saqib & Dincă, 2024; Villanthenkodath & Arakkal, 2020; Zameer et al., 2020; Zhu et al., 2016) . Still, many rely on panel data (Ansari et al., 2019) (Uzair Ali et al., 2022) (Uche et al., 2023) and fail to account for panel or cross-sectional dependencies in their analyses. As an illustration, one study done by (Baek, 2016) examined the relationship between income and CO_2 emissions; this study looks at energy and foreign direct investment (FDI) in five ASEAN members from 1981 to 2010. The findings support the PHH, suggesting that FDI increases CO_2 emissions in the ASEAN region. Researchers utilized an ARDL to analyse the short- and long-term relationships among FDI, economic growth, and environmental conditions in China and India (Azam et al., 2019; Luo et al., 2022; Nepal et al., 2021; Ren et al., 2014; Sreenu, 2022). Their findings reveal that in the case of China, FDI has a detrimental effect on environmental quality (EQ) both in the short and long run (Baek & Koo, 2017). Another study by (Nguyen-Thanh et al., 2022) They address a research gap in rich and developing countries by providing evidence for the theory of pollution havens using panel data for 96 nations collected between 2004 and 2014. (Ur Rahman et al., 2019) This study revisits the pollution haven hypothesis within Pakistan's context, spanning 1975 to 2016. The analysis utilizes a non-linear autoregressive distributed lag approach. It confirms a symmetric relationship between Foreign Direct Investment and carbon emissions, which is evident in the short and long run. (Ahmad et al., 2018) investigates the drivers of carbon dioxide (CO_2) emissions, specifically focusing on the effect of financial development in conjunction with economic expansion and energy consumption in China spanning the years 1980 to 2014. The study employed NARDL model followed by ARDL technique to account for the asymmetry stemming from positive or negative aspects of financial development.

Moreover, numerous researchers have explored the relationships among trade openness (TO), energy, urbanization, financial growth, and population within the Environmental Kuznets Curve hypothesis framework.;

These studies encompass a broad spectrum of geographical contexts and include (Jalil & Mahmud, 2009) for China; (He & Richard, 2010) for Canada; (Saboori et al., 2012) in the case of Malaysia; (Shahbaz et al., 2013) for Indonesia;(Ozturk & Acaravci, 2013) for Turkey; (Farhani et al., 2014) for Tunisia; (Farhani et al., 2014) for China; (Boutabba, 2014) for India; These studies have yielded mixed empirical results, showing varying degrees of causality and both positive and negative, significant and insignificant impacts of different factors on environmental quality. Khan et al., (2023) indicate that urbanization in India has long-term environmental benefits, while high energy consumption has detrimental environmental effects. The study reveals that both positive and negative influences of energy and urbanization have uneven impacts on the ecological footprint. While there has been a scarcity of research examining the nexus between agricultural activities and carbon dioxide (CO_2) emissions.

Both studies (Liu et al., 2017; Orhan et al., 2021) highlight that energy consumption and agriculture significantly impact CO_2 emissions in India and ASEAN-4 countries. Renewable energy and agriculture help reduce emissions, while non-renewable energy increases them. No evidence supports the Environmental Kuznets Curve. The findings emphasize the need for sustainable agriculture and clean energy policies to combat environmental degradation. (Dar & Asif, 2017) indicate that the advancement of the financial sector and the utilization of energy in India have a detrimental impact on the environment. In contrast to prior research, this study finds no statistical proof of a sustained correlation between economic expansion and environmental deterioration. (Bibi and Li, 2022) demonstrate the impacts of utilizing renewable energy and advancements in the financial sector. Growth differs markedly in the short and long term. Noteworthy is the discovery that renewable energy consumption exerts a favourable and substantial influence on economic growth over both short and long periods, while financial development displays a robust, asymmetric impact on economic growth in the short term, with positive and negative effects in the long term. The increasing global attention towards climate change has investigated the complex interplay between financial development (FD) and carbon emissions (CE). Despite previous studies examining the influence of FD on CE, there remains a need to comprehensively understand the nature of this relationship, given the varied findings in existing literature (S. Rehman et al., 2024). (Shahbaz et al., 2017) findings in the asymmetric causality analysis indicate that adverse energy consumption fluctuations solely influence economic growth. Similarly, adverse perturbations in financial development exclusively affect economic growth. Conversely, the relationship between capital formation and economic growth exhibits symmetry, with capital formation leading to economic growth. (Hdom and Fuinhas, 2020) Use cointegration regression techniques, such as dynamic ordinary least squares (DOLS) and completely modified ordinary least squares (FMOLS), to investigate these correlations. His findings on Brazil's economy indicate positive and negative impacts stemming from electricity generation, GDP, and trade liberalization. (Boutabba, 2014) Investigates the long-term equilibrium and assesses the presence and direction of causality among CO_2, financial development, energy consumption, economic prosperity, and trade openness in the context of India. The findings indicate the existence of long-term relationships and causal connections among carbon emissions, financial development, income levels, energy utilization, and trade openness. 2020). The study aims to analyze the dynamic interplay between trade openness and environmental pollution, considering potential determinants of environmental quality across 66 developing economies from 1971 to 2017. The research employs the robust two-step generalized method of moments (GMM) estimators with a finite sample correction to enhance inference accuracy. The principal empirical finding is that trade openness potentially harms the environment, supporting an EKC hypothesis.

(Ohlan, 2015) Utilizing annual data from 1970 to 2013, this investigation examines the influence of population density, energy usage, economic development, and trade openness on CO_2 emissions in India. The results indicate that population density, energy consumption, and economic growth significantly positively impact CO_2 emissions in both the short term and long term. Population density emerges as the primary influencing factor in the changes observed in CO_2 emissions.

While numerous studies have examined the Pollution Haven Hypothesis (PHH) and Environmental Kuznets Curve (EKC), our study makes several unique contributions to the existing literature. First, it is among the few to simultaneously test both the PHH and EKC hypotheses in the Indian context using a nonlinear and asymmetric modeling approach (NARDL), which captures the differential impact of positive and negative shocks in FDI on environmental degradation. Second, unlike many previous studies that focus predominantly on industrial factors, our research uniquely integrates agricultural value-added as a core explanatory variable, shedding light on agriculture's role in reducing CO_2 emissions and promoting sustainability. Third, the study includes a broader set of explanatory variables such as financial development, trade openness, and population growth, offering a more comprehensive analysis of the environmental impacts of economic activities. Lastly, the paper contributes methodologically by applying dynamic multiplier effects and asymmetry tests, which enrich the understanding of long-run versus short-run effects—an area often overlooked in linear models.

The primary objective of this research is to examine the PHH and EKC hypotheses in the context of India, using a long-period time series dataset spanning from 1970 to 2021. By employing the Nonlinear Autoregressive Distributed Lag (NARDL) model, the study investigates the asymmetric relationships between FDI inflows and environmental degradation, specifically focusing on carbon emissions (CO_2). The analysis assesses the impact of both positive and negative FDI shocks on environmental quality. Additionally, it evaluates the effects of agricultural growth, economic growth, trade openness, population growth, and financial development on CO_2 emissions, offering a comprehensive perspective on the factors influencing India's environmental sustainability within its economic development trajectory. Summary of previous studies are shown in table 1.

Table 1: Summary of existing literature review

Authors	**Objectives**	**Variables**	**Country**	**Findings**
Pethig, R.	Examine the comparative advantages in pollution and welfare policies.	CO_2, Trade Policies	Comparative analysis	Analyzes welfare impacts and environmental policies.
Broock et al.,	Test for nonlinearity and independence in economic data models.	Economic Growth, Financial Models	Various countries	Tests independence in economic models using correlation dimension.
Barnett et al.,	Compare tests for chaos and nonlinearity in economic datasets.	Nonlinearity in Economic Data	Controlled data set	Tests for chaos and nonlinearity among econometric models.
Pesaran, H., Smith, R., & Shin, Y.	Analyze level relationships among FDI, CO_2, and energy use.	FDI, CO_2, Energy Use	Panel data approach	Analyzes level relationships in economic data.

Zivot, E., & Andrews, D. W. K.	Investigate the impacts of major economic shocks on growth models.	Unit-root Hypothesis	Data across economic shocks	Investigates economic impacts of significant historical events.
Jalil, A., & Mahmud, S. F.	Explore the Environmental Kuznets Curve for CO_2 in China.	CO_2, GDP, Energy Consumption	China	Tests the Environmental Kuznets Curve for CO_2 emissions.
Pant, K. P.	Study the effect of agriculture on climate change across countries.	Agriculture, CO_2 Emissions	Cross-country	Examines agriculture's impact on climate change.
He, J., & Richard, P.	Examine the EKC hypothesis for CO_2 emissions in Canada.	CO_2, GDP	Canada	Confirms Kuznets curve for Canadian emissions data.
Saboori, B., Sulaiman, J., & Mohd, S.	Analyze the relationship between economic growth and CO_2 emissions.	Economic Growth, CO_2	Malaysia	Analyzes relationship between growth and emissions.
Zeng, K., & Eastin, J.	Assess the environmental effects of FDI from less-developed countries.	FDI, Environmental Effects	Developing Countries	Studies environmental effects of FDI from less developed countries.
Kaika, D., & Zervas, E.	Investigate the causes and concepts of the EKC in ASEAN.	CO_2, GDP	ASEAN	Tests the EKC hypothesis for ASEAN nations.
Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C.	Link economic growth, trade, and energy consumption to CO_2 emissions.	Economic Growth, CO_2, Trade	Indonesia	Links trade and energy consumption to CO_2 emissions.
Sehrawat, M., Giri, A. K., & Mohapatra, G.	Explore financial and economic impacts on environmental quality in India.	Financial Development, CO_2, Energy	India	Studies the impact of financial and trade development on emissions.
Boutabba, M. A.	Analyze sustainability impacts of financial development in emerging markets.	Environmental Policies	Panel data	Analyzes the sustainability impacts of financial policies.
Farhani, S., Mrizak, S., Chaibi, A., & Rault, C.	Assess the environmental quality impact of FDI in Turkey.	FDI, Trade Openness, CO_2	Turkey	Explores the FDI impact on Turkish environmental quality.
Ohlan, R.	Investigate the nexus between FDI, income, and environment in ASEAN.	FDI, Energy Use, CO_2	ASEAN	Analyzes the nexus between FDI, income, and emissions.
Seker, F., Ertugrul, H. M., & Cetin, M.	Explore global scenarios of decoupling economic growth from environmental impact.	Global Economic Pressures	Global Scenarios	Explores decoupling economic growth from environmental pressures.

Baek, J.	Quantify the effects of FDI, energy use, and economic growth on CO_2 emissions.	FDI, GDP, CO_2	ASEAN-5	Quantile regression on FDI and environmental effects.
Schandl, H., Hatfield-Dodds, S., Wiedmann, T., et al.	Model asymmetric impacts of defense spending on economic growth in India.	Defense Spending, GDP	India	Analyzes nonlinear impact of defense spending on growth.
Zhu, H., Duan, L., Guo, Y., & Yu, K.	Explore the FDI-environment relationship in China and India.	FDI, CO_2	China, India	Dynamic FDI-environmental analysis.
Liu, X., Zhang, S., & Bae, J.	Examine financial development's role in carbon mitigation in India.	Financial Development, CO_2	India	Impact of financial shifts on emissions mitigation.
Ahad, M., & Dar, A. A.	Investigate agriculture's role in CO_2 emissions in ASEAN countries.	Agriculture, CO_2	ASEAN	Investigates agriculture's impact on the EKC.
Baek, J., & Koo, W. W.	Analyze the impact of income, trade, and urbanization on CO_2 in emerging economies.	Income, Trade, Urbanization	Emerging Economies	Studies CO_2 impacts from trade and development.
Dar, J. A., & Asif, M.	Examine asymmetrical impacts of financial development on CO_2 in China.	CO_2, FD, RE	China	NARDL application to asymmetric impacts on CO_2.
Saidi, K., & Mbarek, M. Ben.	Test the EKC hypothesis for agriculture's effect on CO_2 in Pakistan.	CO_2, RE, Financial Development	Pakistan	Tests EKC hypothesis for agriculture-induced CO_2 in Pakistan.
Ahmad, M., Khan, Z., Ur Rahman, Z., & Khan, S.	Analyze globalization's effect on CO_2 emissions in BRICS countries.	CO_2, Globalization, FD	BRICS	Analyzes CO_2 impact under globalization context.
Gokmenoglu, K. K., & Taspinar, N.	Examine trade and energy production's impact on CO_2 emissions.	Energy Production, CO_2	Various	Explores trade and economic growth impacts on emissions.
Haseeb, A., Xia, E., Danish, Baloch, M. A., & Abbas, K.	Assess global impacts of iron and steel production on CO_2 emissions.	Steel Production, CO_2	Global Trade	Impact of iron and steel trade on global emissions.
Hdom, H. A. D., & Fuinhas, J. A.	Study FDI, renewable energy, and economic factors affecting environmental degradation.	FDI, RE, CO_2	BRICS	Studies the impact of development factors on emissions.

Liu, Y., Li, H., Huang, S., An, H., Santagata, R., & Ulgiati, S.	Explore the impact of trade and investment on sustainability in India.	FDI, Trade, Energy Security	India	Analyzes trade and investment impacts on sustainability.
Muhammad, B., Khan, M. K., Khan, M. I., & Khan, S.	Test the pollution halo hypothesis using the STIRPAT model.	CO_2, Economic Growth	Global	Tests pollution halo hypothesis using the STIRPAT model.
Nepal, R., Paija, N., Tyagi, B., & Harvie, C.	Investigate asymmetric effects of defense burden on environmental degradation.	Defense Spending, CO_2	NATO	Analyzes defense burden's asymmetric effects on emissions.
Nguyen-Thanh, N., Chin, K. H., & Nguyen, V.	Examine the linkage between energy use, economic growth, and CO_2 in Algeria.	RE, Economic Growth, CO_2	Algeria	New evidence on the energy-environment growth nexus.
Çolak, O., Özuyar, S. E. G., & Bölükbaşı, Ö. F.	Analyze the dynamic linkages among energy consumption, urbanization, and CO_2.	CO_2, Urbanization, Energy	Various	Studies linkages between urbanization and environmental footprint.
Elbadri, M., Bsikre, S., Alamari, O., & Balcilar, M.	Assess agricultural development's role in carbon mitigation in India.	Agriculture, CO_2	India	Assesses agricultural development's role in carbon mitigation.
Khan, Y., Khan, M. A., & Zafar, S.	Analyze the impact of key factors on environmental outcomes.	CO_2, FD, Trade Openness, NR, RE	Various (e.g., BRICS, ASEAN, G8, India, China, etc.)	Significant impact of CO_2, FD, and RE on sustainability.
Zafar et al.,	Analyze the impact of key factors on environmental outcomes.	CO_2, FD, Trade Openness, NR, RE	Various (e.g., BRICS, ASEAN, G8, India, China, etc.)	Significant impact of CO_2, FD, and RE on sustainability.

3. Research Methodology

3.1. Data and Methodology

For the empirical investigation and data analysis, the most recent annual data has been used spanning from 1970-2021, extracted from WDI (word development indicators). Trend of data series are shown in figure 1.

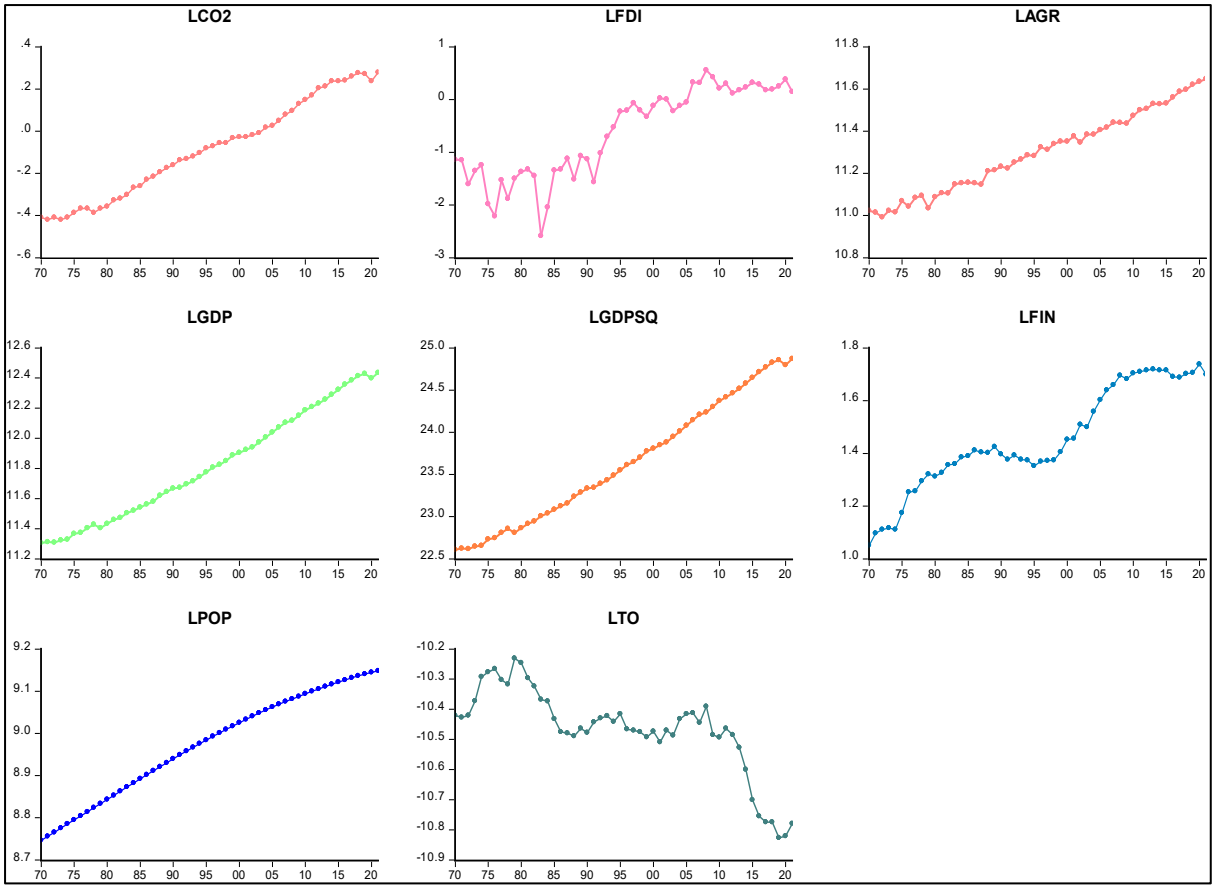


Figure 1: The trend of variables in this study

Table 2 shows the selection of variables in this study is grounded in established environmental and economic theories, particularly the Pollution Haven Hypothesis (PHH) and the Environmental Kuznets Curve (EKC). CO_2 emissions are used as the primary indicator of environmental degradation. Foreign Direct Investment (FDI) is included to test the PHH, as it may lead to increased emissions through the relocation of pollution-intensive industries. Trade openness (TO) captures globalization effects that can either exacerbate or mitigate environmental harm. Agricultural growth (AGR) is considered due to its dual role—while traditional methods may increase emissions, sustainable practices can reduce them, especially in an agrarian economy like India. GDP and its square term test the EKC hypothesis, exploring the nonlinear relationship between income and emissions. Financial development (FIN) influences both industrial growth and investment in green technologies. Population growth (POP) reflects demographic pressure on resources and emissions, with potential variation depending on urbanization and consumption patterns. Together, these variables provide a comprehensive framework for analyzing the economic and environmental dynamics in India.

Table 2: Variables, measurements, source, and justification

Variables	Measurements	Sources	justification
CO_2	CO_2 emissions (mt)	WDI	(Uzair Ali et al., 2022)(A. Rehman et al., 2021)(Manzoor Ahmad Zeeshan Khan & Khan, 2018)
AGR	Agriculture growth	WDI	(Gokmenoglu & Taspinar, 2018)(Zafar et al., 2023b)

GDP	GDP growth (constant 2015 US in per capita)	WDI	(Kaika & Zervas, 2013)(Sreenu, 2022)(Schandl et al., 2016)
FIN	Domestic private-sector credit	WDI	(Haseeb et al., 2018) (Qayyum et al., 2021) (Godil et al., 2021)
FDI	Foreign Direct Investment	WDI	(Muhammad et al., 2021)(Abid et al., 2022)
TO	Trade openness	WDI	(Rana & Sharma, 2019b)(Saidi & Mbarek, 2017)
POP	population growth (annual %)	WDI	(Uzair Ali et al., 2022)(Rasool et al., 2020)

Notes: WDI: World Development Indicators

Empirical Framework

The functional form of the empirical model is as given below.

CO_2 = f (FDI, GDP, GDP^2, FIN, AGR, TO, POP) (1)

Functional form the empirical model transformed into equation which is given below.

$$Y = \alpha_0 + \alpha_i X_i + \varepsilon_t \quad (2)$$

Equation[2] extended into main empirical model which is given below.

$$LCO_{2t} = \beta_0 + \beta_1 LFDI_t + \beta_2 LGDP_t + \beta_3 LGDPSQ_t + \beta_4 LAGV_t + \beta_5 LTO_t + \beta_6 FIN_t + \beta_7 POP_t + \varepsilon_t \quad (3)$$

The empirical model structure in this study is underpinned by the theoretical foundations of the Pollution Haven Hypothesis (PHH) and the Environmental Kuznets Curve (EKC). The inclusion of FDI, GDP, and trade openness aligns with the PHH, which posits that countries with lax environmental regulations may attract pollution-intensive foreign investment and industries. The EKC framework justifies the use of GDP and GDP², capturing the potential nonlinear relationship between economic growth and environmental degradation. Agricultural growth is incorporated to account for its critical role in shaping environmental outcomes, especially in a predominantly agrarian economy like India. While unsustainable agricultural practices may harm the environment, sustainable methods can help mitigate emissions. Financial development is added to assess whether increased credit availability leads to green investments or further industrial expansion. Trade openness serves as a proxy for globalization, reflecting both the spread of polluting industries and cleaner technologies. Population growth is included to capture demographic pressure on natural resources. These variables form a robust framework to empirically assess the complex, asymmetric relationships between economic development and environmental quality. LCO_{2t} represents the total carbon dioxide emissions for period t; $LFDI_t$ shows foreign direct investment during a specific time frame; The *LGDPt* denotes the GDP per capita throughout period t. The GDP per capita square for time t is denoted by *LGDPSQt*; LTO_t denotes trade openness in time t; $LFIN_t$ indicates financial progress in period t; and *LAGVt* represents agricultural value added during period t. $LPOP_t$ expresses the estimated population growth in the period t; The constant β_0 is accompanied by the coefficients β_1; β_2; β_3; β_4; β_5; $\beta_6$and β_7, and the residual ε_t. The following is an equation used in the asymmetric co-integration model:

Preliminary test

Prior to run the non-linear dynamic and complex regression, conducted preliminary analysis, including descriptive statistics and correlation analysis, should be performed to draw statistical inference from underlying datasets. It is crucial to understand the integration of the underlying variables for better prediction and analysis, as this ensures

significant inferences using reliable and consistent results and outcomes. To investigate of integration of underlying variables, Augmented Dicky Fuller and Philips-Perron unit root test are employed. Furthermore, Broock, Dechert, & Scheinkman mainly known as BDS test is employed to detect non-linearity and chaotic behaviour in the time series datasets, ensuring a robust analysis.

Broock, Dechert and Scheinkman test

The BDS test, developed & formulated by Broock, Dechert, and Scheinkman (Broock et al., 1996) is used to identify non-linear dependencies in time series data. Later, (Barnett et al., 1997) This test demonstrated strong power against various linear and non-linear alternatives.

$$\{x_i\} = [X_1, X_2, X_3, X_4 \dots \dots \dots \dots \dots \dots \dots \dots . . X_N] \quad (4)$$

The BDS statistics are defined as:

$$BDS_{\varepsilon,m} = \frac{\sqrt{N}\left[C_{\varepsilon,m} - (C_{\varepsilon,m})^m\right]}{\sqrt{V_{\varepsilon,m}}} \quad (5)$$

Here, $\sqrt{V_{\varepsilon,m}}$ is the standard deviation of $\sqrt{N}\left[C_{\varepsilon,m} - (C_{\varepsilon,m})^m\right]$: A null hypothesis is rejected when the BDS test statistic is outside the range specified by the lower and upper crucial values. The BDS analysis is a two-tailed test. (Ur Rahman et al., 2019), respectively (Ahad & Dar, 2017).

Asymmetrical test- Non autoregressive distributed lag model

Shin et al., (2014) introduced and developed advance non-linear auto-regressive distributed lag model (NARDL) approach to account for potential asymmetries caused by both positive and negative foreign direct investment (FDI) shocks. This approach is an advanced version of the linear ARDL model developed by Pesaran et al., (2001). The NARDL technique incorporates a dynamic error correction framework that captures asymmetry caused by shocks in both the short-run and long-term macroeconomic variables (Manzoor Ahmad Zeeshan Khan & Khan, 2018). A significant advantage of the NARDL method is its applicability regardless of whether the data series comprises I(0), I(1), or a combination of order integration using a small sample size (Çolak et al., 2023). Equation[6] presents positive and negative shock of underlying variables is given below.

$$LCO_{2t} = \beta_0 + \beta_1 LFDI_t^+ + \beta_2 lFDI_t^- + \beta_3 LGDP_t + \beta_4 LGDPSQ_t + \beta_5 LAGV_t + \beta_6 LTO_t + \beta_7 FIN_t + \beta_8 POP_t + \varepsilon_t \quad (6)$$

The complete version of the nonlinear ARDL model is given:

$$\Delta LCO_{2t} = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta LCO_{2t-1} + \sum_{i=0}^{p} \beta_2 \Delta LFDI_{t-i}^+ + \sum_{i=0}^{p} \beta_3 \Delta LFDI_{t-i}^- + \sum_{i=0}^{p} \beta_4 \Delta LGDP_{t-i} + \sum_{i=0}^{p} \beta_5 \Delta LGDPSQ_{t-i} + \sum_{i=0}^{P} \beta_6 \Delta LAGV_{t-i} + \sum_{i=0}^{P} \beta_7 \Delta LTO_{t-1} + \sum_{i=0}^{P} \beta_8 \Delta LFIN_{t-1} + \sum_{i=0}^{P} \beta_9 \Delta LPOP_{t-1} + \delta_1 LCO_{2t-1} + \delta_2 \Delta LFDI_{t-i}^+ + \delta_3 \Delta LFDI_{t-i}^- + \delta_4 LGDP_{t-1} + \delta_5 LGDPSQ_{t-1} + \delta_6 LAGV_{t-1} + \delta_7 LTO_{t-1} + \delta_8 LFIN_{t-1} + \delta_9 LPOP_{t-1} + \varepsilon_t \quad (7)$$

The main goal is determining whether FDI affects CO_2 emissions symmetrically or asymmetrically. To account for asymmetric impacts, Shin et al. (2014) divide FDI into two variables: FDI^{+}_{t} for positive shocks and FDI^{-}_{t} for adverse shocks.

$$LFDI_t^+ = \sum_{n=1}^{t} \Delta LFDI_n^+ = \sum_{n=1}^{t} max\ (\Delta LFDI_n^+,\ 0) \tag{8}$$

$$LFDI_t^- = \sum_{n=1}^{t} \Delta LFDI_n^- = \sum_{n=1}^{t} min\ (\Delta LFDI_n^-,\ 0) \tag{9}$$

The equation (8) explains the calculation of positive shocks in Foreign Direct Investment (FDI), denoted as $LFDI_t^+$ .This involves summing up all the positive changes in FDI up to time *t*. Here is the detailed breakdown: Where: $LFDI_t^+$ Shows cumulative positive changes in the log of FDI up to time *t*. $\Delta LFDI_n^+$Represents the change in the FDI log at the time (*n*). $max\ (\Delta LFDI_n^+,\ 0)$ ensure that only positive changes in FDI are considered. If $\Delta LFDI_n^+$ is positive, it is included in the sum; if it is negative, it is treated as zero. This formula captures the accumulation of positive shocks in FDI over time, allowing the model to distinguish between the effects of increasing and decreasing FDI on CO_2 emissions.

The equation (9) explains the calculation of adverse shocks in Foreign Direct Investment (FDI), denoted as $LFDI_t^-$. This involves summing up all the negative changes in FDI up to time (*t*). Here is the detailed breakdown:

Where: $LFDI_t^-$ represents the cumulative negative changes in the log of FDI up to time *t*. $\Delta LFDI_n^-$ represents the change in the log of FDI at the time (*n*). $min\ (\Delta LFDI_n^-,\ 0)$ ensures that only negative changes in FDI are considered. If $\Delta LFDI_n^-$ is negative, it is included in the sum; if it is positive, it is treated as zero. This formula captures the accumulation of adverse shocks in FDI over time, allowing the model to distinguish between the effects of increasing and decreasing FDI on CO_2 emissions.

$$\begin{aligned}\Delta LCO_{2t} = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta LCO_{2t-1} + \sum_{i=0}^{p} \beta_2 \Delta LFDI_{t-i}^+ + \sum_{i=0}^{p} \beta_3 \Delta LFDI_{t-i}^- + \sum_{i=0}^{p} \beta_4 \Delta LGDP_{t-i} \\ + \sum_{i=0}^{p} \beta_5 \Delta LGDPSQ_{t-i} + \sum_{i=0}^{P} \beta_6 \Delta LAGV_{t-i} + \sum_{i=0}^{P} \beta_7 \Delta LTO_{t-1} + \sum_{i=0}^{P} \beta_8 \Delta LFIN_{t-1} \\ + \sum_{i=0}^{P} \beta_9 \Delta LPOP_{t-1} + \partial ECT_{t-1} + \varepsilon_t\end{aligned} \tag{10}$$

The provided equation is an error correction model (ECM) used to analyse the short-term dynamics and long-term relationship between carbon emissions. ΔLCO_{2t} And various explanatory variables, including favourable and adverse shocks to foreign direct investment (FDI).

This model allows for examining both short-term dynamics through the lagged changes in the variables and the long-term relationship through the error correction term. By considering both, the asymmetrical impacts of FDI on carbon dioxide emissions are captured. $\Delta LFDI_{t-i}^+$ and $\Delta LFDI_{t-i}^-$. In this context, ΔLCO_{2t} denotes the first difference of CO_2 emissions in period t; $\Delta LFDI_{t-i}^+$represents the initial difference foreign investment at period t

with a lagged value k; $\beta_1$to β_9 are short-term coefficients; δ_1 to δ_9 are long-term coefficients. ε_t represents the error correction term, and ∂ signifies the coefficients of the lagged Error Correction Term (ECT). Equation (4) evaluates the possibility of a long-term co-integration relationship among the variables by testing the combined significance of the lagged levels using an F-test. This involves checking the null hypothesis $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = \delta_9 = 0$. Because the F-statistic does not follow the standard normal F-distribution under the null hypothesis, conventional critical values cannot be used. Instead, Pesaran et al. (2001) suggest employing two critical values, an upper and a lower bound. The null hypothesis is accepted only if the F-statistic is less than the upper critical value. If the sample variables show signs of co-integration, The impact of inflows of FDI on the release of CO_2 over the short and long terms can be determined using Equation (4). A Wald test is used to find the symmetrical impacts of FDI on carbon dioxide emissions after Equation (3) has been estimated. This involves two steps: first, identifying short-run asymmetrical effects if the null hypothesis $-\beta_2/\beta_1 = -\beta_3/\beta_1$ is rejected; and second, identifying long-term symmetrical effects if the null hypothesis $-\delta_2/\delta_1 = -\delta_3/\delta_1$ is rejected. The application of the NARDL model involves the following steps:

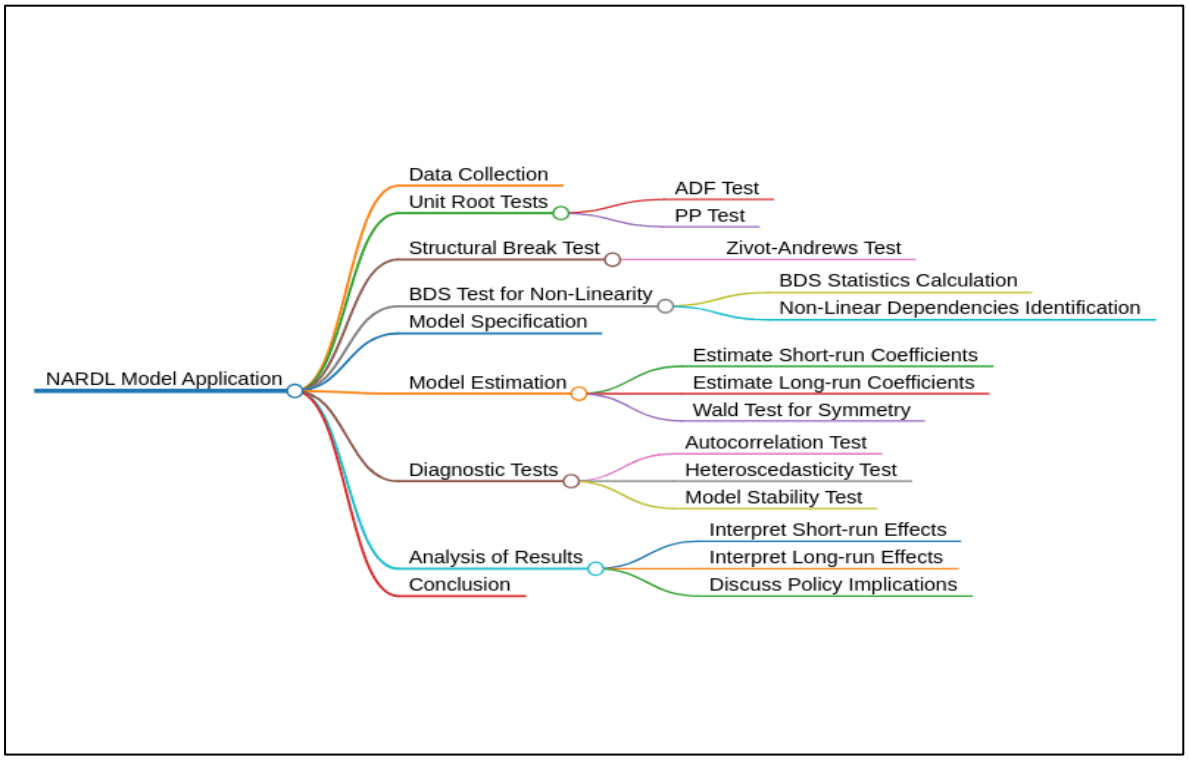


FIG 2. MINDMAP OF NARDL MODEL APPLICATION

Empirical results and discussion

Result of pre-liminary analysis

Results of preliminary analysis, including descriptive statistics, correlation analysis, unit root test, and BDS test for non-linearity, are presented in Table 3-7.

Descriptive statistics

Table 3 presents outcomes of descriptive statistics that help to understand the nature and distribution of underlying variables.

Table 3: Summary of descriptive statistics

Variables	LCO_2	LGDP	LAGR	LFDI	LFIN	LPOP	LTO
Mean	-0.085	11.820	11.297	-0.551	1.454	8.973	-10.467
Median	-0.075	11.791	11.299	-0.217	1.403	8.984	-10.454
Maximum	0.278	12.435	11.647	0.558	1.737	9.148	-10.230
Minimum	-0.420	11.304	10.992	-2.587	1.050	8.746	-10.826
Std. Dev.	0.230	0.364	0.193	0.810	0.196	0.123	0.145
Skewness	0.080	0.200	0.111	-0.477	-0.108	-0.267	-0.989
Kurtosis	1.737	1.740	1.845	2.039	2.077	1.792	3.702
Jarque-Bera	3.512	3.786	2.993	3.740	1.946	3.779	9.556
Probability	0.172	0.150	0.223	0.154	0.377	0.151	0.008

Carbon dioxide (CO_2) indicates overall carbon emissions, while GDP denotes a nation's Gross Domestic Product. POP represents the Population, while FDI signifies the Foreign Direct Investment. FIN pertains to the level of financial development within an economy, AGR denotes the value added by the agricultural sector, and TO refers to the degree of trade openness.

Table 3 summarizes descriptive statistics, including central tendencies, relative dispersion & distribution of the chosen variables to conduct this study. As per outcome, median values are very close the average value for the most of the variables, indicating a symmetrical distribution of the datasets except FDI reveals difference due to skewness or outliers. Likewise, FDI shows the wides range of data, with values ranging from -2.58 to 0.55, indicating significant volatility in FDI inflows, whereas, GDP and POP shows relatively stable ranges, indicating less variability in datasets. Kurtosis value close to 2 for most the variables, suggesting they are less peaked than normal distribution, except technological innovation (TO) with stands highest kurtosis (3.7), indicating a high peaked compared to other variables. In the last, Jarque-Bera statistics & probability suggests that most of the variable are normal distribution except technological innovation which implying protentional issues with outliers or non-normal distribution.

Correlation Analysis

Table 4 represents the correlation matrix relationship between the variables.

Table 4: Result of Correlation analysis

	LCO_2	LFDI	LGDP	LPOP	LFIN	LTO	LAGR
LCO_2	1.000						
LFDI	0.868	1.000					
LGDP	0.995	0.864	1.000				
LPOP	0.988	0.909	0.989	1.000			
LFIN	0.918	0.765	0.930	0.902	1.000		
LTO	-0.766	-0.508	-0.774	-0.716	-0.635	1.000	
LAGR	0.989	0.856	0.994	0.986	0.901	-0.789	1.000

Author's calculations

The correlation matrix reveals significant relationships between carbon emissions (LCO_2) and various economic variables, particularly highlighting strong positive correlations with foreign direct investment (LFDI), gross domestic product (LGDP), population growth (LPOP), financial development (LFIN), and agricultural growth

(LAGR). These findings suggest that economic growth, investment, and development activities contribute to increased carbon emissions, reflecting the environmental challenges tied to India's economic expansion. In contrast, trade openness (LTO) demonstrates a negative correlation with carbon emissions, indicating that greater trade integration may help reduce emissions by facilitating cleaner technologies or outsourcing polluting industries, consistent with the Pollution Haven Hypothesis (PHH). This dynamic also resonates with the Environmental Kuznets Curve (EKC), where early stages of economic growth worsen environmental degradation before improvements occur as cleaner technologies are adopted. Heat map of correlation matrix are shown in figure 3.

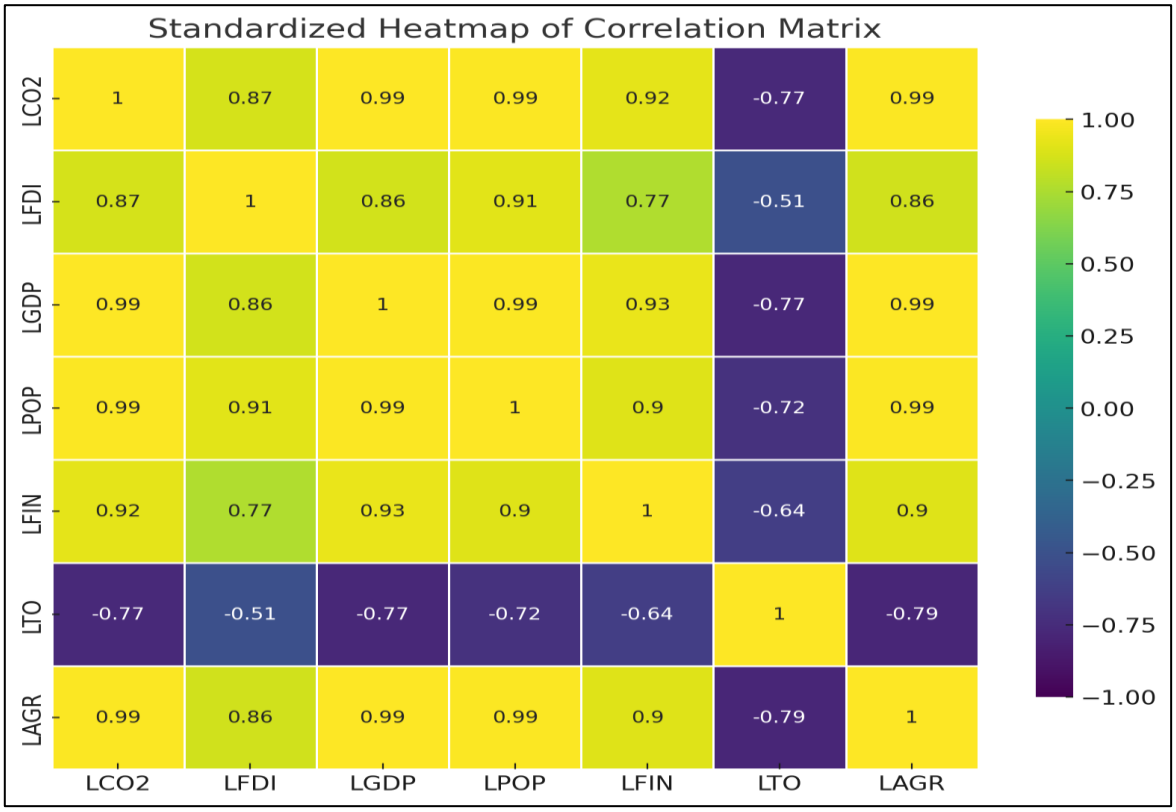


Figure 3 : Heatmap of correlation analysis.

Traditional Unit root tests

Traditional Unit root tests check the stationarity level of series

Table 5: Augmented Dickey-Fuller and Phillips Perron test

	Level		*First difference*	
Variables	ADF	PP	ADF	PP
LCO_2	0.3979	0.4115	-7.1049***	-7.1049***
LFDI	-1.6488	-1.4544	-7.3722***	-8.6073***
LGDP	11.610	1.5098	-6.9895***	-6.9896***
GDPSQ	1.5098	1.5098	-6.9895***	-6.9896***
LAGV	0.8961	1.5911	-11.658***	-15.372***
LTO	0.2302	-0.1398	-5.7998***	-5.8379***
LFIN	3.3312	-1.8308	-2.9724***	-6.3231***

LPOP	-3.1903***	-7.4919***	-0.4558	4.0368

***, **, and * shows variables are stationary at a 1%, 5%, and 10% level

The table 5 presents the results of stationarity tests, specifically the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, conducted at both the level and first difference for the variables under investigation. At this level, most variables' ADF and PP test statistics fail to reject the null hypothesis of non-stationarity, with values exceeding the critical thresholds. For instance, LCO_2 shows ADF and PP statistics of 0.3979 and 0.4115, respectively, while LFDI has ADF and PP values of -1.6488 and -1.4544, none statistically significant at conventional levels. However, after taking the first difference, all variables exhibit significant negative test statistics, indicating stationarity. For example, the ADF and PP test statistics for LCO_2 at first difference are -7.1049, highly significant at the 1% level, denoted by the triple asterisks (***). Similarly, LFDI becomes stationary with first difference ADF and PP values of -7.3722 and -8.6073, respectively, both significant at the 1% level. Other key variables, such as LGDP, LTO, and LFIN, also show stationarity in their first differences, as evidenced by significantly negative test statistics (e.g., LGDP's ADF value of -6.9895, LTO's ADF value of -5.7998, and LFIN's PP value of -6.3231). These results indicate that while the variables are non-stationary in levels, they become stationary after differencing, suggesting that they are integrated of order one, I (1). This is a crucial finding for the econometric model, implying that cointegration or error-correction modelling is appropriate for analysing the long-term relationships between these variables.

Structural breaks test for unit roots

The test accounts for potential structural breaks in the time series while testing for unit roots, allowing for endogenous identification of one structural break.

Table 6: Zivot and Andrews Test Results for Unit Roots with Structural Breaks

Variables	*I (0)*		*I (1)*	
LCO_2	2007	-0.17	2012	-7.68
LFDI	1983	-3.61	1985	-4.56
LGDP	1979	-4.43	1980	-7.68
LGDPSQ	1979	-4.43	1980	-7.64
LAGR	2010	-6.92	2000	-6.07
LFIN	2004	-5.41	1999	-4.28
LPOP	2014	-0.04	2014	-0.81
LTO	2013	-3.43	2013	-0.01

Authors calculations

Table 6 presents the results of the Zivot and Andrews test (Zivot & Andrews, 2002) for unit roots, accounting for structural breaks in the time series data. The test results, conducted at levels (I (0)) and first differences (I(1)), show the presence of structural breaks at specific points in time for each variable. At levels (I (0)), several variables, including LFDI, LGDP, LGDPSQ, and LFIN, exhibit structural breaks in earlier periods such as 1983, 1979, and 2004, with the test statistics indicating non-rejection of the null hypothesis of a unit root for some

variables. For instance, LCO_2 had a structural break in 2007 but remains non-stationary with a Zivot-Andrews statistic of -0.17. However, after differencing (I (1)), most variables show significant improvements in stationarity, with stronger test statistics suggesting rejecting the null hypothesis of a unit root. For example, CO_2 exhibits a structural break in 2012 with a test statistic of -7.68, indicating stationarity after accounting for the break. Similarly, LGDP and LGDPSQ become stationary with test statistics of -7.68 and -7.64, respectively, following breaks in 1980. Some variables, such as LPOP and LTO, show minimal change between levels and first differences, with test statistics remaining close to zero, suggesting persistent non-stationarity even after accounting for structural breaks. The test results underscore the importance of incorporating structural breaks in unit root testing to capture shifts in the time series that may affect stationarity and long-term modelling.

Broock, Dechert and Scheinkman (BDS) test for Linearity

The Broock, Dechert, and Scheinkman (BDS) test assesses whether a time series exhibits linearity or nonlinearity by testing for independence in the residuals.

Table 7: BDS test for non-linearity

Variables/					
BDS statis-	*D=2*	*D=3*	*D=4*	*D=5*	*D=6*
Tics					
LCO_2	0.1927*	0.3274*	0.4192*	0.4836*	0.5293*
LFDI	0.1139*	0.1763*	0.2161*	0.2433*	0.2539*
LGDP	0.1971*	0.3316*	0.4234*	0.4876*	0.5332*
LGDPSQ	0.1971*	0.3316*	0.4234*	0.4876*	0.5332*
LAGR	0.1781*	0.3002*	0.3873*	0.4502*	0.4962*
LFIN	0.1749*	0.2891*	0.3684*	0.4221*	0.4622*
LPOP	0.2072*	0.3511*	0.4523*	0.5249*	0.5784*
LTO	0.1356*	0.1989*	0.2205*	0.2092*	0.1672*

Authors estimation * shows P< 0.01.

The table presents the Broock, Dechert, and Scheinkman (BDS) test results for nonlinearity applied to the residuals of key variables at different embedding dimensions (D=2 to D=6). The BDS statistics, marked by asterisks (*), indicate significant departures from the null hypothesis of independence and linearity in the residuals, implying nonlinear dependence in the time series.

Across all dimensions, LCO_2, LGDP, LFDI, and other variables exhibit progressively increasing BDS statistics, such as LCO_2 ranging from 0.1927 at D=2 to 0.5293 at D=6, suggesting the presence of strong nonlinear dynamics. Variables like LPOP and LTO also show evidence of nonlinearity, with LPO recording the highest BDS statistic at D=6 (0.5784), indicating substantial nonlinear dependence. LTO, although displaying significant statistics at lower dimensions, shows a decrease in nonlinearity at higher dimensions (D=6: 0.1672), suggesting a weaker nonlinear structure. these results provide strong evidence against the linearity assumption for the variables, indicating that nonlinear models may be more appropriate for capturing the underlying dynamics in this dataset.

Table 8: Long and short-run asymmetry results

Test	F-statistics	Prob	Decision
WLR	7.444	0.015	Long-term asymmetry exists

WSR	0.353	0.561	Short-term symmetry exists

W_{LR} shows long-run asymmetry, and WSR shows short-run symmetry results.

Hypothesis Testing for Asymmetries

Table 9 presents the estimated short- and long-term coefficients of the non-linear ARDL model. Due to the detected non-linearity in the data, the NARDL model was chosen. The Wald test findings are also displayed in the table; they reject the alternative statement of short-term asymmetry, support short-term symmetry, and reject the null hypothesis for long-term symmetry. Analyzing asymmetry in the relationship between Foreign Direct Investment and CO_2 emissions involves testing both long-run and short-run asymmetries. Two tests are employed: the Wald Long-Run (WLR) asymmetry test and the Wald Short-Run (WSR) symmetry test.

Table 9: Nonlinear ARDL results, both short- and long-term

Short run coefficients			
Variables	coefficients	t-stats	Probability
C	20.7028*	3.46	0.003
LCO_2 (-1)	-0.4945	2.32	0.034
$\Delta LFDI^+$	-0.0030	-0.49	0.628
$\Delta LFDI^-$	-0.0158***	-1.87	0.080
ECT (-1)	-0.46911*	-2.66	0.017
R-Squared	0.9014		
Adjusted R-Squared	0.7658		
Long-run coefficients			
LGDP	0.4376	0.01	0.991
LGDPSQ	-0.2066	0.01	0.992
LAGR	- 0.2274**	-2.23	0.040
LFIN	0.0231	0.31	0.764
LTO	0.1288*	2.85	0.012
LPOP	-3.0272*	-3.98	0.001
$LFDI^+$ (-1)	0.0234*	2.14	0.004
$LFDI^-$ (-1)	-0.0300*	-3.58	0.002
Diagnostic test			
χ^2 Ramsey		0.8006	0.5154
χ^2 J-B		0.8689	0.6476
χ^2 S-C		22.77	0.1570
χ^2 B-G		0.1035	0.7477

*, ** and *** denote significant values of 1%, 5% and 10% respectively. The J-B test demonstrates that null is normal. Ramsey's reset reveals that the functional form is accurate, the Breusch-Pagan-Godfrey (B-G) test shows no heteroskedasticity at null, the functional form is valid, and SC indicates no serial correlation.

The following abbreviations are used in the analysis: Carbon emissions (LCO_2), Gross Domestic Product (LGDP), Gross Domestic Product Squared (LGDPSQ), Positive Foreign Direct Investment shocks (LFDI+), Negative Foreign Direct Investment shocks (LFDI-), Trade Openness (LTO), Population (LPOP), Agricultural Growth (LAGR), and Financial Development (LFIN). R^2 denotes the coefficient of determination. Four different diagnostic tests were run after the model was estimated, and the findings of all of them were not statistically significant, suggesting that the model does not exhibit non-normality, autocorrelation, heteroscedasticity, or misspecification.

Long-run estimation results

The long-run results of the NARDL model provide crucial insights into the factors affecting CO_2 emissions in India, particularly concerning the effects of Foreign Direct Investment (FDI), economic output, the agricultural sector, financial development, trade openness, and population growth.

The analysis reveals that positive shocks in FDI (LFDI+ (-1)) are significant and positive, with a coefficient of 0.0234. This indicates that a 1% increase in FDI results in a 0.0234% rise in CO_2 emissions, suggesting that higher FDI inflows contribute to increased pollution levels. Conversely, negative shocks in FDI (LFDI- (-1)) are significant and negative, with a coefficient of -0.0300. This implies that a 1% decrease in FDI leads to a 0.0300% reduction in CO_2 emissions. These findings support the pollution haven hypothesis in the long run, as reductions in FDI are associated with lower emissions in India. Other researchers' findings corroborate these results. (Baek & Koo, 2017; Nguyen-Thanh et al., 2022; Sreenu, 2022). This implies that the host nation's weak environmental laws and regulations will likely attract more foreign direct investment (FDI) in filthy industry areas from companies under stringent rules in their home nations. India has laws and regulations, but enforcement often needs to catch up due to bureaucratic inefficiencies and systemic challenges. The long-run impact of economic output on CO_2 emissions, represented by GDP (LGDP) and its squared term (LGDPSQ), is found to be insignificant and supported by some. (Alam & Adil, 2019; Villanthenkodath et al., 2021) The Kuznets Hypothesis, or the Environmental Kuznets Curve (EKC), is invalid in supporting my findings based on the provided results. Many studied (Boutabba, 2014; Dar & Asif, 2017; Shahbaz & Sinha, 2019) A significant inverted U-shaped relationship between GDP growth and Carbon emissions. The agricultural sector (LAGR) significantly negatively impacts CO_2 emissions, with a coefficient of -0.2274. This indicates that a 1% increase in agricultural growth reduces carbon emissions by 0.02274%. This finding is supported by (Pant, 2009; Zafar et al., 2023b) Underscores the role of sustainable agricultural practices in mitigating environmental pollution in India. Promoting environmentally friendly agricultural activities could be a strategic approach to reducing overall emissions. Financial development (LFIN) does not significantly impact CO_2 emissions, as indicated by a coefficient of 0.0231. (Sehrawat et al., 2014) Findings positively related, and (Sahoo et al., 2021) study shows negative related to carbon emissions. Trade openness is significant and positive, with a coefficient of 0.1288, which shows that increased trade openness leads to increased CO_2 emissions in the long run and is supported by (Zameer et al., 2020). Some researchers found a significant negative reinforcement of trade openness. (Nepal et al., 2021; Orhan et al., 2021).Population growth (LPOP) significantly negatively impacts CO_2 emissions, with a coefficient of -3.0272. This indicates that higher population growth is associated with reduced CO_2 emissions (Uzair Ali et al., 2022).

Short-run estimation results

The (ECT_{-1}) is significant and negative, with a coefficient of -0.46911, suggesting that deviations from the long-run equilibrium are adjusted over time. The results confirm the presence of co-integration among the variables. The short-run coefficients reveal several vital insights. The constant term (C) is significant, with a value of 20.7028, indicating a substantial baseline impact on CO_2 emissions. The lagged CO_2 term (LCO_2 (-1)) has a coefficient of -0.4945, suggesting that past values of CO_2 emissions significantly influence current levels. Positive changes in FDI (ΔLFDI+) have a coefficient of -0.0030, indicating that a 1% expansion in FDI decreases carbon emissions by 0.0030%, statistically insignificant. Conversely, adverse changes in FDI (ΔLFDI-) show a marginally significant impact with a coefficient of -0.0158, indicating that a 1% decrease in FDI is projected to decrease in CO_2 emissions by 0.0158%, suggesting that decreases in FDI slightly reduce CO_2 emissions in the short run (Pradhan et al., 2022). Positive shocks in FDI (LFDI+ (-1)) are significant and positive, with a coefficient of 0.0234, indicating that a 1% increase in FDI is about 0.0234%, suggesting that increases in FDI lead to higher emissions (Ahmad et al., 2018) . Negative shocks in FDI (LFDI- (-1)) are significant and negative, with a coefficient of -0.0300, indicating that decreases in FDI lead to lower emissions (Adamu et al., 2019) . The elasticity of a decrease in FDI shows that a 1% decrease in FDI leads to a decline in carbon emissions by 0.0300%. Furthermore, the dynamic multiplier graph for FDI, illustrated in Figure 4, shows the effects of both positive and negative shocks. It indicates that CO_2 emissions respond more quickly to increased FDI inflows than to decreased FDI inflows in India. The middle-dotted line (asymmetry curve) represents a linear combination of dynamic multipliers associated with positive and negative shocks.

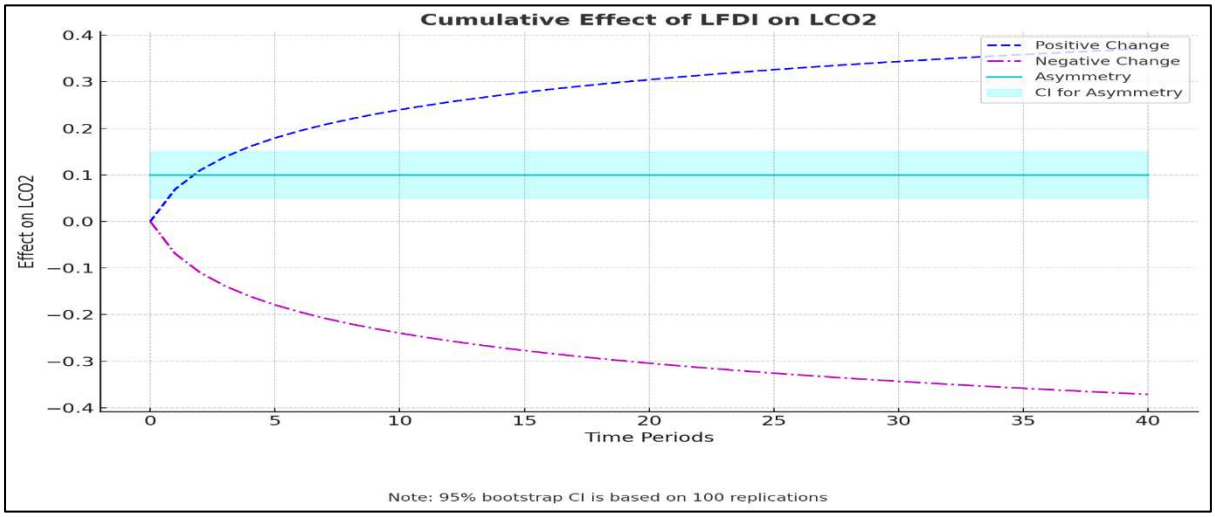


Figure 4: A dynamic foreign direct investment multiplier graph. Note: CI stands for Cumulative.

Diagnostic test and stability

The diagnostic tests conducted in this study provide key insights into the robustness of the model. The Ramsey RESET test ($\chi^2 = 0.8006$, $p = 0.5154$) indicates that the model's functional form is correctly specified, confirming that no relevant variables have been omitted. The Jarque-Bera (J-B) test ($\chi^2 = 0.8689$, $p = 0.6476$) demonstrates that the residuals are normally distributed, supporting the validity of the model's assumptions. The Breusch-Godfrey Serial Correlation LM test ($\chi^2 = 22.77$, $p = 0.1570$) reveals no serial correlation in the residuals, ensuring

the estimates are efficient and unbiased. Lastly, the Breusch-Pagan-Godfrey test ($\chi^2 = 0.1035$, $p = 0.7477$) shows no presence of heteroskedasticity, confirming that the error variance is constant across observations. These diagnostic tests suggest that the model is well-specified and free from autocorrelation, heteroskedasticity, and non-normality, making it suitable for reliable inference and policy recommendations. The stability of the NARDL model is verified using the CUSUM and CUSUMSQ tests, which plot the cumulative sum and the 5% critical lines. As shown in Figure 5, the observed line stays well within the critical boundaries at the 5% significance level., indicating that the parameters are stable throughout the sample period. The figure shows that the parameters remain stable over time. However, the CUSUMSQ plots suggest a brief period of instability, where the parameters temporarily fall outside the 5% critical bound before quickly stabilizing. Therefore, all tests confirm that the model possesses favorable econometric properties and is suitable for policy formulation.

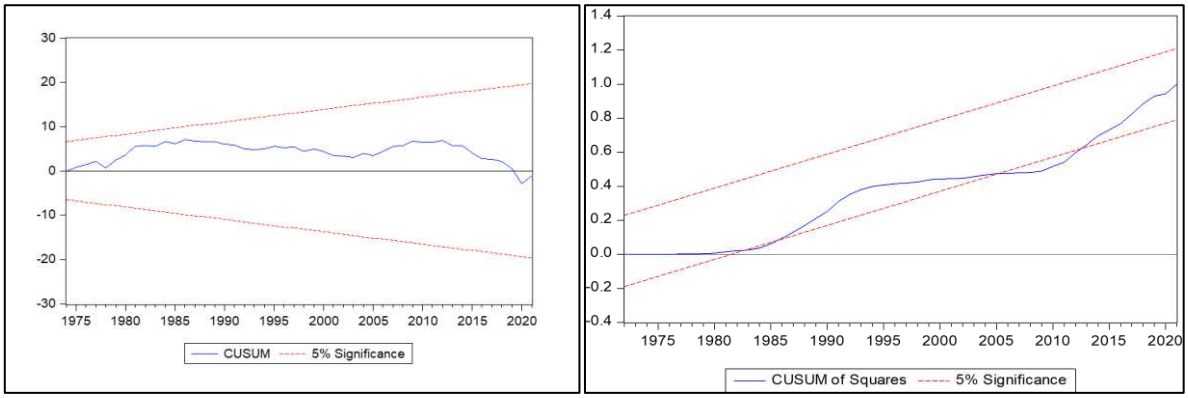


Figure 5: The NARDL model's CUSUM and CUSUM squared.

Conclusions and Policy Suggestions

This research analyses the asymmetric relationship between Foreign direct investment and environmental degradation, specifically focusing on CO_2 emissions in India. Utilizing the NARDL model provides significant insights into the impact of FDI, economic growth, agricultural activities, financial development, trade openness, and population growth on environmental quality. The long-run NARDL estimations provide valuable insights for policymakers in India. The positive relationship between FDI inflows and CO_2 emissions suggests that attracting foreign investments should be coupled with stringent environmental regulations to mitigate pollution. The insignificant impact of GDP on emissions highlights the need for a comprehensive approach that integrates economic growth with sustainable practices. The agricultural sector's potential to reduce emissions emphasizes the importance of promoting sustainable agriculture. Finally, the significant impact of trade openness on emissions calls for policies that ensure environmental considerations are integrated into trade agreements and practices. In conclusion, these findings highlight the need for balanced and informed policy measures to address the environmental impacts of economic activities in India, ensuring sustainable development in the long run.

The Wald test results indicate a significant asymmetry in the long-term relationship between FDI and CO_2 emissions, as a null hypothesis of long-run symmetry is rejected at a 5% significance level. This means that positive and negative shocks in FDI have different long-term impacts on CO_2 emissions. In contrast, the short-run symmetry null hypothesis is not rejected, suggesting that both positive and negative impacts on FDI do not have significantly different impacts on CO_2 emissions in the short run. These findings suggest that while immediate changes in FDI do not significantly alter CO_2 emissions, the long-term effects are asymmetric. Policy measures

should, therefore, consider these different long-term environmental impacts. For example, increasing FDI might lead to higher CO_2 emissions due to new industries, whereas decreasing FDI might reduce emissions through industrial contraction or improved efficiency. The results reveal a significant asymmetrical impact of FDI on CO_2 emissions in the long run. Positive shocks in FDI lead to increased CO_2 emissions, supporting the pollution haven hypothesis, where lax environmental regulations in host countries attract more polluting industries. Conversely, adverse shocks in FDI result in reduced emissions, indicating that decreases in FDI can contribute to environmental improvements.

The EKC hypothesis, which suggests an inverse U-shaped relationship between environmental deterioration and economic growth, is not supported by the study's findings. The results suggest that economic growth alone can only address environmental issues with targeted environmental policies and regulations. Agricultural growth significantly reduces CO_2 emissions, emphasizing the potential of sustainable agricultural practices to mitigate environmental pollution. This finding highlights the importance of promoting environmentally friendly agricultural activities. Increased trade openness is associated with higher CO_2 emissions, suggesting that India's integration into global markets may have environmental costs. Financial development, however, shows a long-term impact on CO_2 emissions. Surprisingly, population growth has a significant negative impact on CO_2 emissions. This counterintuitive finding may reflect the role of urbanization and shifts in consumption patterns towards more efficient resource use and sustainability practices.

To mitigate the environmental impact of FDI, it is crucial to implement and enforce stringent environmental regulations. Strengthening the political and judicial systems to ensure compliance with environmental laws will discourage the relocation of polluting industries to India. Encouraging sustainable agricultural practices can significantly reduce CO_2 emissions. Policies should focus on supporting environmentally friendly farming techniques and promoting research and development in sustainable agriculture. While trade openness is vital for economic growth, environmental concerns must be considered when developing trade policies. This can be achieved by setting environmental standards for imports and exports and encouraging green technologies. Policies promoting economic growth should include sustainability measures to ensure that progress does not result in environmental degradation. This includes promoting clean energy, efficient resource use, and reducing reliance on fossil fuels. Policymakers should focus on managing urbanization and population growth through sustainable development practices. Urban planning and infrastructure development should prioritize energy efficiency and low-carbon technologies. While this study provides meaningful insights into the asymmetric impacts of FDI, agriculture, and economic variables on environmental degradation in India, it opens several avenues for future research. Upcoming studies could explore sector-specific FDI flows (e.g., into manufacturing vs. services) to better understand which industries drive emissions. Further, the analysis can be extended to regional-level data within India to capture spatial environmental disparities. Additionally, other environmental indicators such as water pollution, ecological footprint, or biodiversity loss can be incorporated for a more holistic assessment. Methodologically, future work could apply threshold models, panel NARDL, or machine learning techniques to capture nonlinearities and structural changes over time. Lastly, integrating policy effectiveness variables, such as environmental regulation indices, may help evaluate how institutional quality moderates the FDI–environment nexus.

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Consent to Participate : Not Applicable

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Abbreviations

Here are some abbreviations from your document:

FDI: Foreign Direct Investment

CO_2: Carbon Dioxide

GDP: Gross Domestic Product

FIN - Financial Development

AGR: Agricultural Growth

TO: Trade Openness

POP: Population Growth

EKC: Environmental Kuznets Curve

PHH: Pollution Haven Hypothesis

WDI: World Development Indicators

ADF: Augmented Dickey-Fuller

PP: Phillips-Perron

NARDL: Non-linear Autoregressive Distributed Lag

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