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RESEARCH PAPER

Evaluating N-Shaped Environmental Kuznets Curve for Economic Growth, Globalization, and Investment Flows in India: An ARDL Bound Test Approach

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Abstract

India introduced globalization and liberalization measures in 1991 that supported FDI inflows and encouraged massive industrialization. Simultaneously, in the last few decades, India has experienced an upsurge in carbon emissions. Weaker environmental norms might be positioning India as a sought-after destination for production units that are environmentally hazardous. Hence, the present study is an attempt to empirically evaluate whether an upsurge in industrialization, investment inflows, and globalization has been detrimental to India's environment. The study employs the N-shaped EKC hypothesis (for India) to capture the association between carbon emissions and GDP per capita, carbon emissions and FDI inflows, and carbon emissions and globalization, using three different model specifications with time series data for the period 1991–2021. Unit root testing was conducted using the ADF and PP tests to examine stationarity, and the ARDL bounds test was employed to validate the long-run results. The results for the CO_2–GDP per capita model weakly supported the presence of an N-shaped EKC, whereas the outcomes for the CO_2–FDI inflows model strongly endorsed the N-shaped curve for India. The results for the CO_2–globalization model supported the N-shaped EKC, but only for the long-run coefficients. The results indicate that strong policy measures are required, particularly to address India's FDI inflows, as India is likely to face environmental deterioration after reaching the trough point.

Keywords: EKC, environment, economic growth, FDI, globalization.
JEL Classification: F02, F22, N50, O13, O44.

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Introduction

India undertook LPG measures to stimulate economic growth parameters in terms of investment inflows and per capita income. Furthermore, an upsurge in India's FDI inflows gave way to massive industrialization and technology-oriented manufacturing units; the ripple effects of massive unchecked (in environmental terms) industrialization have generated environmental deterioration as a formidable challenge to address. In other words, the spine for development has forced India not to prioritize environment-related norms and their enforcement mechanisms, particularly in the manufacturing sector.

Shahbaz et al. (2015) indicated that globalization is not beneficial for the Indian economy, as it weakens environmental quality. According to the Germanwatch Global Climate Risk Index (2021), India was ranked as the 7th worst-hit economy in terms of climate change, with a CRI score of 16.67. According to a Forbes India report (2022), 63 Indian cities were listed among the most polluted cities in the world, and India was ranked as the 5th most polluted country in the world. India is performing poorly on various environmental parameters, but then why does the environment still take a back seat for policymakers? The answer is relatively simple but uncomfortable. India's major focus is on poverty, basic survival needs, urbanization needs, strengthening the unorganized sector, unemployment, and population. And economic development in terms of income per capita, investment flows, and industrialization seem to be frontline initiatives. Striking a balance between building a globally competitive market and ensuring environmental sustainability is becoming an important issue for India to tackle.

Theoretical Framework

Economies worldwide strive for economic growth, as a surge in economic growth supports a higher standard of living, better infrastructure, and better job opportunities (Kong and Khan, 2019; Acaravci and Akalin, 2017). Within this framework, an increase in consumption and production activities, technology advancements, and extensive manufacturing activities are bound to happen. An increase in industrial activities and consumption of energy-driven products might lead to climate-related problems, and climate issues tend to negate the benefits associated with economic growth (Bergh, 2017), and more so in developing economies with lax environmental norms (Sirag et al., 2018).

Furthermore, with changing dynamics, economies worldwide (particularly developing economies) view globalization and FDI inflows as significant measures for strengthening economic growth and development. Globalization measures support the integration of world economies and hence provide better avenues for economic growth (Aslam and Azhar, 2013). Moreover, developing economies are boosting globalization and investment (FDI) policies to stimulate technological advancement and strengthen manufacturing (and industrial) units. Furthermore, with a rise in global competition for FDI (Demena and Afesorgbor, 2019), developing countries (such as India) tend to invite industrial units with weaker environmental checks. Globalization and liberalization provide developing economies with several discontents, and environmental issues are one such concern. Developing economies tend to support the pollution haven hypothesis (PHH), wherein industrial units from developed economies that face stringent pollution norms and high pollution abatement costs shift toward developing economies, acting as a cushion for polluting industrial units (Zomorrodi and Zhou, 2016; Manocha, 2021). Moreover, the establishment of industrial units leads to an increase in demand for energy, which in turn leads to carbon emissions (Manocha, 2021). Developing economies formulate globalization and FDI policies with the intent to support employment, capital and investment flows, better (and advanced) technology transfers, new processes, and economic growth; however, environmental checks on FDI flows by these economies are either ineffectively framed or insufficiently enforced.

Although globalization and FDI inflows stimulate economic activities and can be viewed as part and parcel of economic growth (GDP per capita), if globalization and investment policies lean toward massive production activities that accelerate the depletion of natural resources, increase energy consumption, and degrade environmental quality, then it becomes vital to study the association between liberalization policies (globalization and FDI) and environmental degradation. Therefore, the present study not only evaluates the EKC for economic growth (GDP per capita) but also captures the EKC for globalization and the EKC for FDI inflows for India. Shahbaz et al. (2017) suggested studying the inverted U-shaped EKC for globalization and carbon emissions, because the shift of pollution-intensive (dirty) industries toward developing economies might be the result of weak environmental enforcement laws accompanied by globalization-supporting norms. Dasgupta et al. (2002) stated that growth in developed and industrial economies has in fact contributed to strengthening environmental quality, as they have adopted liberalization and technical and technological changes alongside compact environmental regulations; however, the concerns of developing economies might be centered on reducing competition and production costs, hence weaker environmental regulations.

In this context, it is important to examine the long-run impact of globalization (and FDI inflows) on India's environment and to provide a watchful eye for policymakers. Studies (Akter et al., 2021; Tsiantikoudis et al., 2019) suggest that the N-shaped environmental EKC framework is more capable of capturing long-run impacts and provides an empirical framework for policymakers to ascertain whether existing investment (and globalization) stimulating policies need to be reviewed, with the aim of achieving sustainable growth rather than growth alone.

Environmental Kuznets Curve (EKC): Inverted U-shaped and N-shaped

Simon Kuznets proposed the Kuznets curve to explain the relationship between per capita income and income inequality as an inverted U-shaped curve (Kuznets, 1995). However, Grossman and Krueger (1991) employed the inverted U-shaped framework to capture the relationship between economic growth and environmental degradation. Since its inception, the inverted U-shaped EKC has been extensively employed by researchers (Shahbaz et al., 2015; Grossman and Krueger, 1995; Selden and Song, 1994; Rothman, 1998; Choi and Cho, 2010; Alam, 2014; Le, 2019; Shahbaz et al., 2012) to study the impact of economic growth parameters on environmental degradation. The traditional EKC assumed that (Stage I) with a rise in economic growth (GDP per capita), an increase in environmental degradation is initially reported, forming an upward slope. However, in due course, a learning effect is registered, and economies become more cautious toward the environment. As per the EKC framework, a negative relationship between economic growth and environmental degradation (Stage II) is depicted, establishing a negative slope.

Contemporary studies have gone a step further and discussed the technology obsolescence stage, or diminishing returns in technological development, as part of Stage III, wherein economies again (after the trough point) witness a positive relationship between economic growth and environmental degradation. Hence, suggesting the presence of an N-shaped EKC (Figure 1).

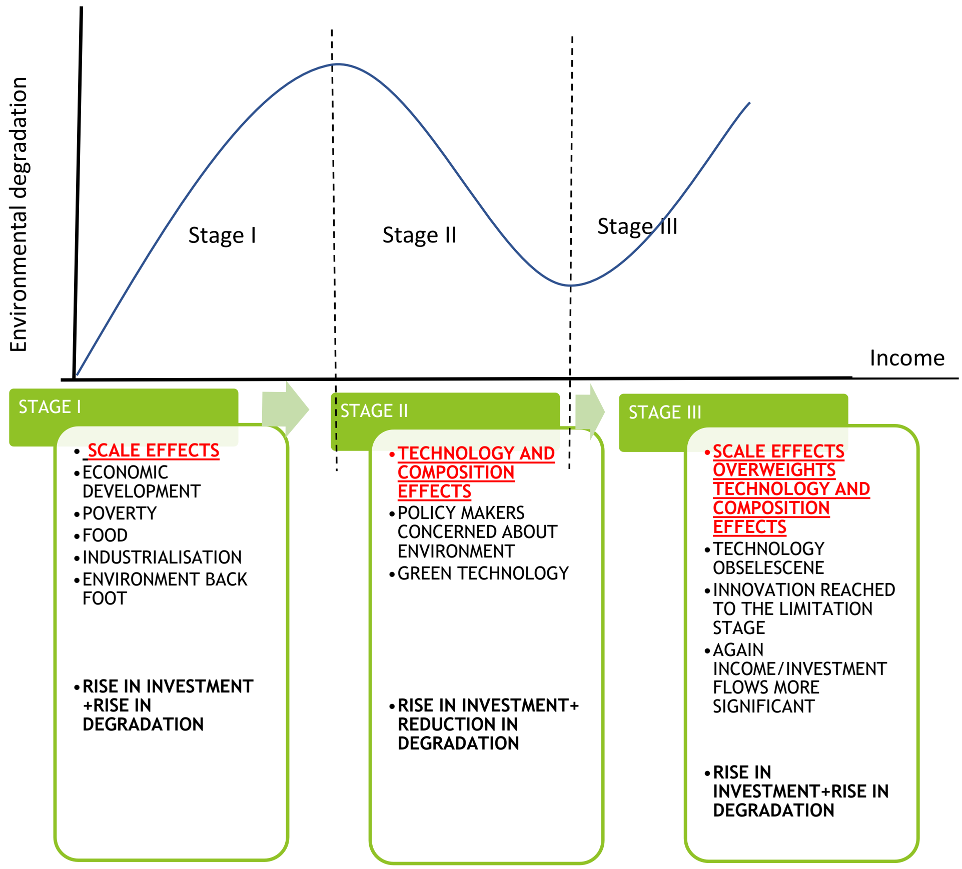

Figure 1. Pictorial representation of stages of N-shaped Environment Kuznets Curve
Source: Research finding based on Sinha and Shahbaz (2018), Rashdan et al. (2021).

Torras and Boyce (1998), Álvarez-Herranz and Balsalobre-Lorente (2015), Shahbaz et al. (2012), Zhang (2021), and Tsiantikoudis et al. (2019) discussed the various stages of the EKC framework for the N-shaped environmental curve. The first stage was referred to as the scale effect, depicting the inclination of economies toward issues such as development, industrialization, and employment rather than the environment and sustainability. The second stage was recognized as the technology and composition effect, indicating a learning impact and, therefore, along with growth and development, a considerable shift toward green technology, the environment, and sustainability. The third stage of the N-shaped EKC suggests the predominance of the scale effect over the composition and technology effects, again suggesting an upward slope between income level and environmental degradation, leading to the deterioration of the environment. Stage III might be associated with technology obsolescence (Zhang, 2021), less desirable policy measures, or a lack of relocation of technology toward green logistics.

Copeland (2012) suggested that scale effects refer to the scaling of economic activities wherein trade, investment, and allied activities contribute to growth. However, a pure scale effect or an overshadowing impact of the scaling effect (accompanied by technology obsolescence) without strong policy measures to adjust economic activities toward pollution abatement or environmental conservation will promote growth without sustainability.

Hence, evaluating not only the EKC for GDP per capita but also globalization measures and FDI inflows within the N-shaped EKC framework for India (a developing economy) is essential to validate the presence (or absence) of technology obsolescence effects over scale effects, given the technology advancement and investment-strengthening measures.

Standard Mathematical Representation

Studies validating the presence of cubic functional form (N-shaped EKC) of pollution and economic growth need to experience ($\alpha_1 > 0$ and $\alpha_2 < 0$ and $\alpha_3 > 0$) cubic polynomial with the assistance of econometric tools. However, in case $\alpha_1 > 0$ and $\alpha_2 < 0$ and α_3 is zero (with no positive association between environmental degradation and economic growth after the trough point) then traditional inverted U-shaped EKC is established.

where C represents environmentally polluting variables such as carbon emissions (CO_2), deforestation, water waste, greenhouse gas (GHG) emissions, and other variables employed to study EKC frameworks. Among these, GHG emissions are said to be a major cause of global warming and highly threatening to human society (Zhang, 2021), but CO_2 constitutes 79% of GHG emissions, according to the United Nations Environmental Protection Agency (2022). Therefore, CO_2 has been extensively employed as a polluting variable in empirical analyses.

G indicates economic growth parameters/variables such as GDP per capita, globalization, investment inflows, technological advancement, etc.

O represents other variables having an impact on the pollution level; α represents the constant term; α_1, α_2, α_3, and α_4 represent the coefficients; and ε stands for the error term.

The sign and direction of α_1, α_2, and α_3 are indicative of the relationship between environmental degradation and economic growth parameters and are also suggestive of the shape that the EKC will adopt (Demena and Afesorgbor, 2020; Grossman and Krueger, 1995).

- $\alpha_1 = \alpha_2 = \alpha_3 = 0$: a flat pattern and no **relationship** between environmental degradation and economic growth.
- $\alpha_1 > 0$ and $\alpha_2 = \alpha_3 = 0$: a **monotonic increasing relationship**, wherein environmental degradation increases with an increase in economic growth parameters.
- $\alpha_1 < 0$ and $\alpha_2 = \alpha_3 = 0$: a **monotonic decreasing relationship**, wherein environmental degradation decreases with an increase in economic growth.
- $\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 = 0$: the **classical inverted U-shaped** EKC.
- $\alpha_1 < 0$, $\alpha_2 > 0$, and $\alpha_3 = 0$: a **U-shaped relationship** between environmental degradation and economic growth.
- $\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 > 0$: a **cubic polynomial or N-shaped relationship** between environmental degradation and economic growth parameters.
- $\alpha_1 < 0$, $\alpha_2 > 0$, and $\alpha_3 < 0$: an **inverted N-shaped relationship** between environmental degradation and economic growth.

Studies validating the presence of a cubic functional form (N-shaped EKC) of pollution and economic growth need to exhibit ($\alpha_1 > 0$, $\alpha_2 < 0$, and $\alpha_3 > 0$) a cubic polynomial with the assistance of econometric tools. However, in case $\alpha_1 > 0$ and $\alpha_2 < 0$ and $\alpha_3 = 0$ (with no positive association between environmental degradation and economic growth after the trough point), then the traditional inverted U-shaped EKC is established.

Literature Review

Extensive work has been done to study the determinants of pollution and to understand the EKC framework as a significant specification for empirical studies capturing environmental degradation. The present study divides the review of literature into a few subsets, namely: (i) country-specific studies (with major emphasis on studies covering India) of the bell-shaped EKC; (ii) region-specific (or group of countries) studies capturing the inverted U-shaped EKC framework; (iii) country-specific studies of the N-shaped EKC; and (iv) region-specific studies of the N-shaped EKC.

Starting with country-specific inverted U-shaped EKC studies, Zambrano-Monserrate et al. (2018) empirically evaluated the existence of the EKC hypothesis for Singapore by employing the ARDL bounds testing approach for the period 1971–2011. The results indicated the presence of EKC specifications both for the short run and the long run. Rafindadi (2016) explored the Japanese environmental

Kuznets curve for the period 1961–2012 to study natural disaster and deteriorating income following the Fukushima energy crisis. The results suggested the existence of an inverted U-shaped EKC despite the deteriorating income for Japan. Kayabas (2023) studied the long-run relationship between trade openness, sea routes, economic growth, energy consumption, and carbon emissions for Mexico over the period 1980–2021. The study employed multiple regression, PP cointegration, and ADF techniques to examine the effects of dependent variables on various explanatory variables. The study suggested that the government needs to adopt renewable and sustainable measures to support the environment in the long run. Wang and Lv (2022) investigated the relationship between grain production and agricultural carbon emissions for the grain-producing region of China for the period 2000–2019. The result indicated presence of EKC at the climbing stage of inverted U-shaped curve. Jalil and Mahmud (2009) also validated the presence of the EKC for China for the period 1975–2005, employing ARDL and Granger causality to examine the relationship between economic growth and environmental pollution. Mahmood et al. (2023) evaluated the inverted U-shaped and N-shaped EKC for China using extensive literature. The study investigated a number of studies associated with China using extensive literature within the EKC framework. The study employed various pollution proxies and samples for China and validated the presence of both inverted U-shaped and N-shaped relationships between pollution variables and economic growth in China. Even studies conducted across various Chinese provinces and city levels supported the presence of the EKC for China, the largest polluting economy in the world. The study also employed logistic regression and found that the probability of the EKC hypothesis being supported was more than 5.08 times that of its absence.

Since the present study is confined to India, we would also like to briefly discuss studies that have captured the EKC hypothesis (inverted U-shaped) for India. Behera (2021) examined the EKC for India by employing the ARDL model for the period 1971–2016. The study found pollution haven effects for India both in the short run and the long run. Sinha and Shahbaz (2018) estimated EKC for carbon emissions in India for the period 1971-2015 by employing ARDL model and unit root testing with structural breaks. The study found that renewable energy has negative impact on carbon emissions. Villanthenkodath et al. (2021) studied the EKC framework using the ARDL bounds testing approach to cointegration to capture the long-run and short-run relationship for the period 1971–2014. The results suggested that the traditional EKC hypothesis does not hold true for either the aggregated or disaggregated models for India. De (2023) studied the quadratic relationship between pollution and economic growth for India over the period 1962–2020 using the ARDL approach to cointegration to examine both short-run and long-run coefficients. The results supported the EKC in the long run for carbon emissions, economic growth, the manufacturing sector, and trade openness. EKC validation in the short run was found to be insignificant. The study stated that India needs to develop policy measures in the long run to support the environment as well as economic growth. Gopakumar et al. (2022) also attempted to capture the EKC framework for India for the period 1991–2018 by employing the ARDL cointegration model for economic growth, FDI, renewable energy, stock market size, and private investment. The results supported the existence of bell shaped EKC association between economic growth and CO2 emissions. Tiwari (2011) validated the presence of the EKC for India for the period 1971–2007 using VAR and the Granger causality test. Yang and Zhao (2014) also verified the EKC framework for India for the period 1970–2008 by employing Granger causality and directed acyclic graphs. Tiwari et al. (2013) employed carbon emissions from coal to study the association between environmental degradation and real output for examining the inverted U-shaped EKC framework. Similarly, Sinha and Shahbaz (2018) examined inverted U-shaped EKC for India.

As discussed earlier, the second subset of the literature captures region-specific bell-shaped studies. Shahbaz (2022) studied the relationship between globalization and carbon emissions by employing the bounds testing approach on the sample countries of the Next-11. The results depicted the presence of a U-shaped association between globalization and carbon emissions for Bangladesh, Iran, and South Korea, and suggested an inverted U for Pakistan and South Korea. Manocha (2021) examined the association between economic growth and environmental degradation, and between FDI inflows and the environment (two disaggregated models) by employing panel PMG, panel MG, and panel DFE for the period 1971–2019 for select Asian countries. The study validated the presence of EKC hypothesis for both the models. Tenaw and Beyene (2021) explored the association between environmental degradation and development for 20 sub-Saharan African (SSA) countries for the period 1990–2015. The study employed an error-correction-based panel ARDL model augmented with cross-sectional averages to study the EKC framework. The results supported the existence of EKC for SSA countries. Similarly, Orubu and Omotor (2011) supported the existence of the EKC specification for 47 African countries for the period 1990–2002 by employing longitudinal panel data analysis.

Arouri et al. (2012) studied the inverted U-shaped EKC for 12 MENA countries for the period 1981–2005 by employing bootstrap panel and cointegration techniques; the results validated the presence of the EKC specification for the said sample. Furthermore, Farhani et al. (2014) examined environmental degradation for 10 MENA countries by employing panel data analysis for the years 1990–2010. Balado-Naves et al. (2018) employed panel data for 173 countries for the years 1990–2014 to examine the presence of the EKC augmented by neighbouring per capita income and energy intensity. The results supported EKC framework for most of the regions. Taghvaee et al. (2017) examined economic growth and sustainable energy in Iran using the ARDL framework over the period 1981–2012.

A few regional-based studies have also examined the EKC for developed economies wherein stringent laws have boosted environmental quality. Luo et al. (2017) examined the EKC for both developed and developing economies; the study validated the presence of the EKC for developing economies but found no evidence of the EKC for developed economies. Similarly, Sayed and Sek (2013) evaluated the EKC for developed and developing economies. The results suggested that developed countries had a higher turning point for the EKC as compared to developing economies. Tektüfekçi and Kutay (2016) examined the association between the EPI (Environmental Performance Index) and GDP growth. The study suggested that developed economies spend more on infrastructure, pollution-combating products and materials, and also enforce strict environmental protection laws and norms, hence supporting a healthy and pollution-less environment. Zomorrodi and Zhou (2016) validated the presence of the EKC and PHH for developing economies only, and the results of the study suggested that environmental quality depends on whether the economy is developed or developing and on the imposition of stringent environmental norms.

We can capture country-specific N-shaped EKC studies as the third subgroup. Zhang (2021) validated the presence of the N-shaped curve for China. The study was conducted to empirically examine the long-run relationship between CO_2 emissions and income. The study found a positive relationship with energy consumption and a negative association with urbanization. Tsiantikoudis et al. (2019) evaluated the N-shaped environmental curve for Bulgaria by employing deforestation as an environmental degradation variable. The study found presence of N-shaped curve for the period 1990-2015 by employing ARDL bound technique. Akter et al. (2021) validated the cubic form of the EKC for Bangladesh for the period 1974–2014 by employing the ARDL model for both the short run and the long run; the study suggested that policymakers need to revisit the existing pollution policy of the country. Moreover, Barış-Tüzemen et al. (2020) validated the inverted N-shaped EKC for Turkey for the period 1980–2017.

Bekhet and Othman (2018) employed VECM Granger causality, CUSUM, and CUSUM of squares to test environmental degradation for Malaysia from 1971 to 2015, and the study suggested the presence of an inverted N-shaped EKC. Koc and Bulus (2020) also estimated the presence of N-shaped EKC for Korea for the period 1971 to 2017. Pandey and Mishra (2021) studied the presence of the EKC hypothesis for air pollution and development by employing panel data from 21 Indian states for the period 2001–2016 and examined the results via panel unit root and panel DOLS. The results for long-run coefficients indicated the presence of a cubic relationship.

The fourth and the last section of our literature encompasses region-specific and N-shaped EKC framework. Allard et al. (2018) evaluated the N-shaped EKC for 74 countries from 1994 to 2012 by employing panel quantile regression analysis. Le (2019) examined the association between the environment and economic performance for ASEAN-10 countries by employing panel data analysis. The study found the existence of both inverted U-shaped and N-shaped EKC for the said sample. Caporin et al. (2023) examined the EKC for Central Asia by employing the FMOLS framework. The study examined linear, inverted U-shaped, and N-shaped EKC for the said region. The study suggested that a linear association among the variables is more predominant for Central Asian economies as compared to the N-shaped framework, suggesting that Central Asia is still at the first stage of the EKC framework. However, the study supported a bidirectional association between GDP/economic growth and climate change. Carvalho and Almeida (2011) validated the presence of a global N-shaped EKC framework for a sample of 167 countries for the period 2000–2004 using a fixed-effects regression with spatial dependence.

Gyamfi et al. (2021) investigated the N-shaped EKC for the E-7 countries for the period 1995–2018 by employing the PMG-ARDL estimator and heterogeneous causality tests to capture long-run and short-run results and the direction of causality of the variables. The results negated the presence of an N-shaped curve for the countries but supported the presence of an inverted U-shaped curve. Pala (2018) attempted to study the association between economic growth and CO_2 emissions for MENAP countries for the period 1994–2011 by employing a panel quadratic random coefficient model. The study found that oil-exported MENAP countries validated U-shaped and N-shaped EKC, but for other MENAP countries, the study suggested the presence of both inverted U-shaped and N-shaped EKC. Jahanger et al. (2023) examined U-shaped and N-shaped EKC for top nuclear-energy-producing nations by employing time-series data over the period 1992–2018, and the study empirically examined the explanatory variables using the dynamic common correlated effects method. The results assumed that energy stimulates economic growth and that nuclear nations are highly dependent on fossil-based resources.

While summarizing our review of the literature, we can state that the EKC framework has not only been employed to study the relationship between income level (GDP per capita) and environmental degradation but also to capture the association between investment flows (FDI inflows) and environmental degradation (Manocha, 2021; Aminu, 2005; Kheder, 2010), globalization and environmental degradation (Dean, 2002; Baek et al., 2009; Shahbaz, 2022; Shahbaz et al., 2017), technology and environmental degradation (Avenyo and Tregenna, 2021), and economic complexity and environmental pollution (Khezri et al., 2022).

To summarize the literature on the EKC for India, we were able to identify rich literature capturing environmental degradation and growth parameters. As discussed earlier, Behera (2021), Villanthenkodath et al. (2021), Gopakumar et al. (2022), Gupta and Yadav (2016), Tiwari et al. (2013), Sinha and Shahbaz (2018), and a few other researchers suggested an inverted U-shaped EKC (for India) for economic development and carbon emissions. A few studies have also examined the N-shaped EKC association for economic development (GDP per capita) and environmental degradation for India. Mor (2014) studied the N-shaped EKC for India and suggested the presence of an inverted U-shaped EKC. The study stated the need for sustainable policies to avoid the growth of GDP per capita toward the N-shaped EKC. Murthy and Gambhir (2018) also examined the N-shaped EKC for GDP per capita for India in the era of policy changes.

Furthermore, to study the impact of liberalization measures, a few studies also examined the impact of FDI, trade openness, globalization, and other policy change measures as explanatory variables (without capturing the square or cubic form) to study the impact on environmental degradation variables for India. Sinha and Shahbaz (2018) incorporated the volume of foreign trade (along with the quadratic form of GDP per capita) for India, whereas Mor (2014) examined the trade openness variable (along with the cubic form of GDP per capita). Murthy and Gambhir (2018) examined FDI as an explanatory variable along with the cubic form (N-shaped EKC) of GDP per capita for India. Sanjeev and Kaur (2020) and

Bandyopadhyay and Rej (2021) examined the impact of both trade openness and FDI while examining the cubic form of GDP per capita for India. Rajib et al. (2023) examined natural resource rent and carbon emissions for India. However, none of the studies have examined the cubic form of FDI-carbon emissions and globalization-carbon emissions for India. Although Shahbaz (2019) examined the EKC pattern (inverted U-shaped) between globalization and carbon emissions for the N-11 countries, and Manocha (2021) examined the inverted U-shaped hypothesis between FDI and carbon emissions for South Asian economies, a study examining the EKC pattern between globalization and carbon emissions, and between FDI and carbon emissions, is warranted, as the environmental impact of Indian liberalization and investment policies requires a better and more comprehensive investigation. The current study not only attempts to explore the environmental impact of globalization and investment policies but also seeks to evaluate whether the shift of pollution-intensive industrial units from developed economies to India validates the EKC (supporting the PHH for India) or not. Moreover, the study attempts to examine whether environmental degradation is due to the scale effect as a result of an increase in FDI inflows, globalization activities, or overall economic development along with the pollution level for India. Evaluating the impact of globalization and investment measures on environmental quality is essential, as such measures are suggestive for developing economies seeking to enhance long-term economic and sustainable development.

Furthermore, studies capturing the N-shaped EKC not only suggested the validation of the cubic functional form of the EKC but also raised concerns associated with the impact of technology obsolescence on the environment for policymakers. In case policy initiatives are ineffective or enforcement mechanisms for environment-related regulations are weak and fragile, the long-run presence of the N-shaped EKC framework (in terms of predominance of scale effects over composition effects) might turn out to be worrisome.

Rationale of the Study

As discussed in Section 2, numerous studies have captured environmental concerns for India by employing different empirical frameworks. Villanthenkodath et al. (2021), Manocha (2021), Sinha and Shahbaz (2018), and Behera (2021) have reported the presence of an inverted U-shaped environmental curve for India. To address the challenges associated with high consumption and energy usage, a few studies (Pal and Mitra, 2017) have also captured the N-shaped EKC (for per capita income and environmental degradation) for India, but we could hardly find studies that captured the impact of FDI inflows and globalization (along with income per capita) on environmental degradation using the N-shaped EKC hypothesis.

Moreover, as discussed earlier, the presence of an N-shaped curve might suggest a challenge for policymakers. Furthermore, for developing economies with a major emphasis on development and growth, and with lesser concern for the environment, the presence of an N-shaped EKC framework may suggest a long-run impact of environmental degradation (in terms of industrial pollution, deforestation, and water and air contamination) along with the proliferation of macroeconomic parameters such as GDP per capita, investment flows, and industrialization. Simultaneously, India has witnessed a host of liberalization, globalization, and industrialization supporting (and enhancing) policies in the last two to three decades. However, Farooz (2022) suggested that globalization measures are enhancing environmental degradation and are adding to the pollution haven hypothesis for developing economies. Shahnaz (2022) stated that globalization refers to measures and policy initiatives that promote investment flows, cross-border migration of human resources, economic growth, and trade in goods and services; however, in the case of developing economies, such measures might not account for stringent environmental norms and hence promote environmental degradation. Further, investment flows are just one arm of globalization that support international capital inflows (Wani and Mir, 2021). For developing economies, the nature of investment flows might be detrimental to the environment; therefore, evaluating the EKC with FDI flows seems essential. Similarly, developing economies might promote liberal policies at the global level that are less stringent toward the environment (promoting the PHH); hence, evaluating the EKC for globalization also seems significant. Hence, in the given scenario, it becomes essential to evaluate not only the basic N-shaped curve (with the cubic functional form of GDP per capita) but also to encompass the N-shaped curve with FDI inflows and the globalization framework for India. Therefore, the present study is an attempt to empirically ascertain the presence (or absence) of an N-shaped environmental curve for India with the cubic form of income per capita, investment flows, and globalization as three separate models.

Methods and Materials

A significantly large body of empirical studies on environmental degradation has considered the EKC framework, and the EKC hypothesis is based on the non-linear validation of explanatory variables. A few studies have empirically examined the disaggregated EKC framework for FDI, globalization, and economic growth. Manocha (2021) examined the EKC for FDI inflows and the EKC for income level for Asian developing economies, and similarly, Shahbaz et al. (2015) examined FDI-carbon emissions as a separate EKC framework for middle-, low-, and high-income economies. Mehmood and Tariq (2020) examined the EKC for globalization and carbon emissions as a model framework for South Asian economies. Therefore, the present study is an attempt to empirically ascertain the presence (or absence) of an N-shaped environmental curve for India with the cubic form (as three different EKC frameworks) for income per capita, investment flows, and globalization using the ARDL cointegration approach.

Time series data was collected for the period 1991-2021 (post globalisation tenure) for CO_2 (carbon dioxide) emissions (metric tons per capita); foreign direct investment net inflows (in current US$); gross domestic product per capita (current US$); urban population, and energy use (kg of oil equivalent per capita) for India from the World Bank database. CO_2 as a proxy for environmental degradation was taken as the dependent variable for the present study. For globalization data, the KOF Globalization Index was employed, as suggested by Shahbaz (2019) and Wang et al. (2021), to capture the nexus between environmental pollution and globalization. The KOF Globalization Index encompasses political, social, and economic domains and hence captures the overall and comprehensive experience of an economy (Wang et al., 2021). Haelg (2019) suggested that the KOF Globalization Index has been extensively employed to study the multifaceted concept of globalization, as the scope of the index is much broader than merely incorporating trade and investment flows.

As the present study captures the impact of three different parameters — namely, GDP per capita, FDI inflows, and globalization — on environmental degradation for India, the functional form of the model for capturing the association between carbon emissions and growth parameters (such as GDP per capita, FDI inflows, or globalization) can be stated as:

$$C_t = f\,(V_t, EN_t, URB_t)$$

where C_t refers to carbon emissions (CO_2) during the given year t; V_t denotes the parameters, namely, income per capita (GDP per capita), investment inflows (FDI inflows), or the globalization index of India for the given year t; EN_t refers to energy usage of India for the given year t; and URB_t denotes the urban population of India for the year t.

Log-transformed frameworks are more normal and symmetric than the original model and hence enhance the interpretability of the coefficients[1]. Therefore, log-linear frameworks better reflect empirical results as compared to

[1]. How can i interpret log transformed variables in terms of percent change in linear regression? https://stats.oarc.ucla.edu/sas/faq/how-can-i-interpret-log-transformed-variables-in-terms-of-percent-change-in-linear-regression/

simple regression models. Hence, the basic Equations (1), (2), and (3) for the present study, capturing the log form for the N-shaped EKC framework, can be stated as follows:

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnGDPpc_t + \alpha_2 lnGDPpc_t^2 + \alpha_3 lnGDPpc_t^3 + \alpha_4 lnEN_t + \alpha_5 lnURB_t + \mu_i \quad (1)$$

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnFDI_t + \alpha_2 lnFDI_t^2 + \alpha_3 lnFDI_t^3 + \alpha_4 lnEN_t + \alpha_5 lnURB_t + \mu_i \quad (2)$$

$$lnCO_{2t} = \alpha_0 + \alpha_1 lnGlob_t + \alpha_2 lnGlob_t^2 + \alpha_3 lnGlob_t^3 + \alpha_4 lnEN_t + \alpha_5 lnURB_t + \mu_i \quad (3)$$

The study employs the Autoregressive Distributed Lag (ARDL) bounds testing approach suggested by Pesaran et al. (2001). ARDL is recognized as one of the most general dynamic unrestricted frameworks for time series analysis, wherein the dependent variable is a function of the lagged and current values of the explanatory variables, and the lagged value of the dependent variable itself (Abonazel and Elnabawy, 2020). Gupta and Varshney (2022) employed the ARDL framework to examine the lags for India–US exports. Chetty (2018) suggested the use of the ARDL model for better capturing economic variables wherein the long-run association between the variables is under consideration.

It adopts cointegration to empirically evaluate the association among the variables irrespective of whether they are stationary at level, at first difference, or a mix of both (Pesaran and Shin, 2001; Kalim and Hassan, 2014). However, the model is not recommended if the variables are stationary at an order of integration greater than one, i.e., I(2). ARDL is a single-equation framework and hence resolves the problem of reverse causality (Harris, 2003). Further, ARDL works on appropriate lag selection; hence, the method provides less biased estimates and mitigates endogeneity issues (Jalil and Ma, 2008; Ali et al., 2017; Menegaki, 2019; Solarin and Shahbaz, 2013).

There are several advantages associated with the ARDL framework. Firstly, the model can generate robust results for a finite and small sample (Liew and Khim, 2004). Secondly, ARDL is suggested when we have a mix of stationarity issues whereby variables are integrated either at level, at first difference, or a mix of both is detected (Abonazel and Elnabawy, 2020). Thirdly, the method employs both exogenous and endogenous variables, unlike the Vector Autoregression (VAR) model. Finally, the technique helps to capture long-run coefficients and short-run relationships via the error correction term (Zhang, 2021).

To capture the ARDL bounds cointegration technique for Equations (1), (2), and (3), three distinct model specifications can be stated as follows:

Model 1

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \Delta lnCO_{2t-i} + \sum_{i=1}^{n} \alpha_2 \Delta lnGDPpc_{t-i} + \sum_{i=1}^{n} \alpha_3 \Delta lnGDPpc_{t-i}^2 + \sum_{i=1}^{n} \alpha_4 \Delta lnGDPpc_{t-i}^3 + \sum_{i=1}^{n} \alpha_5 \Delta lnEN_{t-i} + \sum_{i=1}^{n} \alpha_6 \Delta lnURB_{t-i} + \varphi_1 lnCO_{2t-1} + \varphi_2 lnGDPpc_{t-1} + \varphi_3 lnGDPpc_{t-1}^2 + \varphi_4 lnGDPpc_{t-1}^3 + \varphi_5 lnEN_{t-1} + \varphi_6 lnURB_{t-1} + \mu_i \quad (4)$$

Model 2

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \Delta lnCO_{2t-i} + \sum_{i=1}^{n} \alpha_2 \Delta lnFDI_{t-i} + \sum_{i=1}^{n} \alpha_3 \Delta lnFDI_{t-i}^2 + \sum_{i=1}^{n} \alpha_4 \Delta lnFDI_{t-i}^3 + \sum_{i=1}^{n} \alpha_5 \Delta lnEN_{t-i} + \sum_{i=1}^{n} \alpha_6 \Delta lnURB_{t-i} + \varphi_1 lnCO_{2t-1} + \varphi_2 lnFDI_{t-1} + \varphi_3 lnFDI_{t-1}^2 + \varphi_4 lnFDI_{t-1}^3 + \varphi_5 lnEN_{t-1} + \varphi_6 lnURB_{t-1} + \mu_i \quad (5)$$

Model 3

$$\Delta lnCO_{2t} = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \Delta lnCO_{2t-i} + \sum_{i=1}^{n} \alpha_2 \Delta lnGlob_{t-i} + \sum_{i=1}^{n} \alpha_3 \Delta lnGlob_{t-i}^2 + \sum_{i=1}^{n} \alpha_4 \Delta lnGlob_{t-i}^3 + \sum_{i=1}^{n} \alpha_5 \Delta lnEN_{t-i} + \sum_{i=1}^{n} \alpha_6 \Delta lnURB_{t-i} + \varphi_1 lnCO_{2t-1} + \varphi_2 lnGlob_{t-1} + \varphi_3 lnGlob_{t-1}^2 + \varphi_4 lnGlob_{t-1}^3 \varphi_5 lnEN_{t-1} + \varphi_6 lnURB_{t-1} + \mu_i \quad (6)$$

where Δ represents the first difference operator; *n* captures the optimal lag length; $\alpha_1, \alpha_2, \alpha_3, \ldots$ denotes short run coefficients; and $\varphi_1, \varphi_2, \varphi_3, \varphi_4, \ldots$ are coefficient for long run dynamics.

Before employing the ARDL framework, it is essential to conduct unit root stationarity tests to verify that none of the variables is integrated at an order higher than one, i.e., I(2). To test for stationarity, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were employed. Furthermore, to test for cointegration, the ARDL bounds test approach was employed. The null hypothesis (which suggests no cointegration among the variables) for the ARDL bounds test for cointegration is rejected if the upper bound critical value is less than the F-statistic, and is accepted if the F-statistic is less than the upper bound critical value. The result is inconclusive if the F-statistic lies between the lower and upper bound critical values. The ARDL regression framework for long-run and short-run dynamics can be employed only after the cointegration results are found to be supportive. For optimal lag selection, the study selects the model lag length via the Akaike Information Criterion (AIC). Liew (2004) suggests that the AIC criterion is more reliable when the sample size is less than 60 observations (i.e., a small sample size).

The final step of the ARDL procedure is to examine the short-run dynamics via the error correction term. The regression for short-run coefficients capturing the ECM (error correction model) can be stated as follows:

$$lnCO_{2t} = \alpha_0 + \sum_{i=1}^{n} \alpha_1 \Delta lnCO_{2t-i} + \sum_{j=1}^{5} \sum_{i=0}^{q} \omega_j \Delta V_{jt-1} + \theta ECT_{t-1} + \mu_i \quad (7)$$

ω_1 *and* ω_j represent short-term coefficients; θ denotes the speeding of turning parameter; ECT_{t-1}, the error correction term resulting from the error cointegration model. The value of θ must lie between -1 and 0 and it is indicative of long run convergence within the variables.

Several diagnostic tests were also conducted, namely, the heteroscedasticity test (ARCH), the serial correlation test (Breusch-Godfrey LM test), and the structural stability test (Ramsey RESET test), to check the goodness of fit of the regression equations under study. Model stability was also checked by plotting the CUSUM and CUSUMSQ statistics. CUSUM plots are pictorial representations used to verify the stability of the intercept, while CUSUMSQ plots are employed to check the stability of the variance of the regressors.

Results and Analysis

Unit Root Testing

Descriptive statistics are presented in Table 1, the correlation matrix is summarized in Table 2, and the unit root test results are presented in Table 3. Unit root tests were conducted for both intercept only, and intercept and trend, using the ADF and PP unit root testing techniques for levels and first differences.

Table 1. Descriptive Statistics

Statistics	Mean	Standard Deviation	Kurtosis	Skewness	Minimum	Maximum
lnCO2	0.08	0.137	-1.537	0.087	-0.132	0.26
lnGDPpc	2.909	0.3	-1.64	0.001	2.479	3.322
lnGDPpc^2	8.547	1.745	-1.637	0.069	6.144	11.038
lnGDPpc^3	25.367	7.665	-1.621	0.136	15.231	36.673
lnFDI	9.939	0.755	0.396	-0.96	7.867	10.704
lnFDI^2	99.328	14.508	-0.108	-0.805	61.882	114.581
lnFDI^3	997.777	210.529	-0.506	-0.67	486.795	1226.501
lnEN	2.688	0.093	-1.659	0.078	2.553	2.804
lnGLOB	1.711	0.092	-0.518	-0.883	1.513	1.798
lnGLOB^2	2.937	0.308	-0.657	-0.827	2.289	3.233
lnGLOB^3	5.055	0.776	-0.785	-0.773	3.463	5.813
lnURB	8.535	0.018	-1.218	-0.087	8.360	8.697

Source: Research finding.

Following the descriptive statistics, the study also performs Pearson correlation analysis, as suggested by Villanthenkodath et al. (2021). The correlation results (see Table 4) indicate positive and significant relationships for all studied variables with carbon emissions in India. The correlation matrix suggests that energy consumption, FDI flows, globalization measures, urbanization, and economic growth variables are positively associated with environmental degradation (carbon emissions).

Table 2. Correlation Matrix

Variables	lnCO2	lnGDPpc	lnFDI	lnGLOB	lnURB
lnCO2	1				
lnGDPpc	0.988	1			
lnFDI	0.9732	0.917	1		
lnGLOB	0.9672	0.9225	0.9677	1	
lnURB	0.9827	0.9848	0.9313	0.9436	1

Source: Research finding.

The unit root test results (see Table 3) indicate that the variables are stationary either at first difference or at level. The unit root test results suggest a mixed order of integration; therefore, the ARDL approach is the most appropriate for generating reliable estimates.

Table 3. Unit Root Testing Results

	At level (Intercept)		First difference (Intercept)		Order of integration (Intercept)	
Variable	ADF Fisher's chi-square	PP Fisher chi-square	ADF Fisher's chi-square	PP Fisher chi-square	ADF Fisher's chi-square	PP Fisher chi-square
lnCO2	-0.927 (0.765)	-0.870 (0.783)	4.205 *(0.002)	-4.284 * (0.002)	I(1)	I(1)
lnURB	-2.455 (0.136)	-6.279* (0.000)	-0.247*** (0.092)	-0.0796 (0.942)	I(1)	I(0)
lnEN	-1.339 (0.596)	-0.747 (0.819)	-1.872** (0.0395)	-3.786* (0.007)	I(1)	I(1)
lnFDI	-4.146* (0.003)	-4.146* (0.0031)	-4.751* (0.0007)	-5.0008* (0.0004)	I(1)	I(1)
lnFDI^2	-3.542** (0.0136)	-3.423** (0.0179)	-3.159 *** (0.101)	-4.806* (0.0006)	I(1)	I(1)
lnFDI^3	-3.019** (0.044)	-2.876*** (0.06)	-4.754* (0.0007)	-4.790* (0.0006)	I(1)	I(1)
lnGDPpc	-0.695 (0.833)	-0.687 (0.835)	-4.17* (0.003)	-4.144* (0.003)	I(1)	I(1)
lnGDPpc^2	-0.487 (0.880)	-0.505 (0.876)	-4.098* (0.003)	-4.054* (0.004)	I(1)	I(1)
lnGDPpc^3	-0.301 (0.913)	-0.343 (0.906)	-4.024* (0.004)	-3.966* (0.005)	I(1)	I(1)

lnGLOB	-4.437* (0.001)	-5.748* (0.000)	-2.186 (0.214)	-2.186 (0.214)	I(0)	I(0)
lnGLOB^2	-4.165* (0.003)	-5.379* (0.0001)	-2.226 (0.2017)	-2.226 (0.2017)	I(0)	I(0)
lnGLOB^3	-3.896* (0.005)	-4.459* (0.001)	-2.272 (0.187)	-2.272 (0.1871)	I(0)	I(0)
	At level (Intercept and trends)		**First difference (Intercept and trends)**		**Order of integration (Intercept**	
lnCO2	-2.347 (0.396)	-1.481 (0.813)	-4.191* (0.013)	-4.268* (0.011)	I(1)	I(1)
lnEN	-4.443*** (0.008)	-1.452 (0.8236)	-1.943*** (0.065)	-3.775 ** (0.0328)	I(1)	I(1)
lnURB	1.5695 (0.987)	1.2676 (0.999)	-2.386** (0.0378)	-1.310*** (0.086)	I(1)	I(1)
lnFDI	-3.726** (0.035)	-3.726** (0.035)	-4.969** (0.002)	-5.761* (0.0003)	I(1)	I(1)
lnFDI^2	-4.720* (0.0007)	-3.133 (0.1171)	-4.953* (0.0022)	-5.323* (0.0009)	I(1)	I(1)
lnFDI^3	-2.732 (0.2316)	-2.753 (0.2241)	-4.972* (0.0021)	-5.176* (0.0013)	I(1)	I(1)
lnGDPpc	-1.154 (0.901)	-1.531 (0.795)	-4.109** (0.015)	-4.062** (0.017)	I(1)	I(1)
lnGDPpc^2	-1.433 (0.829)	-1.740 (0.707)	-3.982** (0.020)	-3.924** (0.023)	I(1)	I(1)
lnGDPpc^3	-1.671 (0.739)	-1.896 (0.631)	-3.874** (0.026)	-3.888** (0.025)	I(1)	I(1)
lnGLOB	-1.481 (0.813)	-0.313 (0.986)	-4.901* (0.002)	-4.903* (0.002)	I(1)	I(1)
lnGLOB^2	-1.149 (0.902)	-0.085 (0.992)	-4.836* (0.002)	-4.859* (0.002)	I(1)	I(1)
lnGLOB^3	-0.868 (0.946)	0.058 (0.995)	-4.719* (0.003)	-4.719* (0.003)	I(1)	I(1)

Source: Research finding.

Note: *, **, and *** indicate 1%, 5% and 10% significance levels respectively.

Bound Test Results

To identify cointegration between the dependent and independent variables, the F-statistic bounds test was performed both with and without a trend (see Table 4). The bounds test results for all three equations (Equations (4), (5), and (6)) suggest that the computed F-statistic is greater than the upper bound critical value; therefore, the null hypothesis of no long-run relationship between the variables is rejected.

Table 4. Bound Test Results

	With trends			Without trends		
Critical Value Bounds	**Lower Bound value**	**Upper bound value**	**Computed F-statistics**	**Lower Bound value**	**Upper bound value**	**Computed F-statistics**
For Eq1: lnCO2t =α0 + α1lnGDPpct+α2lnGDPpct2+α3lnGDPpct3+α4lnENt+α5lnURBt +µi						
10%	2.49	3.38	7.341648	2.08	3	12.501481
5%	2.81	3.76		2.39	3.38	
2.50%	3.11	4.13		2.7	3.73	
1%	3.5	4.63		3.06	4.15	
For Eq2: lnCO2t =α0 + α1lnFDIt+α2lnFDIt2 +α3lnFDIt3+α4lnENt+α5lnURBt+µi						
10%	2.49	3.38	9.457148	2.08	3	22.05414
5%	2.81	3.76		2.39	3.38	
2.50%	3.11	4.13		2.7	3.73	
1%	3.5	4.63		3.06	4.15	
For eq3: lnCO2t =α0 + α1lnGlobt+α2lnGlobt2 +α3lnGlobt3+α4lnENt+α5lnURBt+µi						
10%	2.08	3	16.37961	2.75	3.79	8.818642
5%	2.39	3.38		3.12	4.25	
2.50%	2.7	3.73		3.49	4.67	
1%	3.06	4.15		3.93	5.23	

Source: Research finding.

Hence, the F-statistic bounds test results indicate a long-run association between carbon emissions and income per capita, carbon emissions and investment inflows, and carbon emissions and globalization.

Long and Short-Run Coefficients

The results for carbon emissions and income per capita, carbon emissions and investment inflows, and carbon emissions and globalization are reported in this section.

Results for Carbon emissions and GDP per capita (Model 1)

The outcomes for carbon emissions and GDP per capita — both long-run and short-run coefficients — are presented in Table 6.

Table 6. Results for long-run and short-run coefficients (Model 1); Carbon emissions and GDP per capita

Long run coefficient				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
lnEN*	0.981	0.286	3.422	0.003
lnGDPpc	1.763	9.591	0.183	0.856
lnGDPpc^2	-0.527	3.301	-0.159	0.874
lnGDPpc^3	0.053	0.379	0.140	0.889
lnURB	0.202	0.357	0.565	0.578
Short run coefficient				
DlnEN*	1.018	0.310	3.280	0.004
DlnGDPpc***	16.26	8.288	1.961	0.065
DlnGDPpc^2***	-5.654	2.913	-1.940	0.068
DlnGDPpc^3***	0.648	0.339	1.909	0.072
DlnURB	-5.847	6.101	-0.958	0.350
Constant	-4.073	5.632	-0.723	0.478
ECT(-1)**	-0.662	0.237	-2.792	0.012
RMSE	0.008			
R-square	0.997			
Adj R-squa	0.995			
Log-likelihood	107.96			

Source: Research finding.

Note: *, **, and *** indicate 1%, 5% and 10% significance levels respectively.

The optimal lag structure selected for Equation (4) is ARDL (1,1,1,1,1). The model results are admissible, as the F-statistic (see Table 4) is found to be significant and the R-squared (coefficient of determination) is estimated at 99.7%. Moreover, the error correction term (ECT) is significantly negative (-0.662), indicating that carbon emissions adjust toward equilibrium at a speed of 66.2%. Also, the negative coefficient of the ECT implies convergence of short-run results to the long-run equilibrium, and confirms that CO_2 emissions affect energy consumption and income per capita.

The long-run and short-run coefficients for GDP per capita, GDP per capita squared, and GDP per capita cubed carry the expected signs to support the presence of an N-shaped EKC for carbon emissions and income per capita in India; however, the results are insignificant. This may be because environment-control technologies and renewable energy measures introduced at the domestic level are marginally contributing to carbon neutrality, but are not sufficient to eliminate the presence of the EKC. However, the coefficient for energy consumption is found to be positive and significant, indicating that energy consumption is deteriorating India's environment. The coefficient for urbanisation is found to be positive but insignificant.

The results for Model 1 suggest a weak N-shaped curve for India. However, cautious measures are required on the policy front, as the presence of the N-shaped curve is evident even though the results are not statistically significant.

Results for Carbon Emissions and FDI Inflows (Model 2)

The results for carbon emissions and FDI inflows in cubic form are presented in Table 6. The optimal lag structure for Model 2 is ARDL (1,0,0,0,0). For Model 2, the R-squared (coefficient of determination) is estimated at 99.7%, and the error correction term (ECT) is found to be negative (-0.728) and highly significant.

Table 6. Results for Long-Run and Short-Run Coefficients (Model 2); Carbon Emissions and FDI Inflows

		Long run coefficient		
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
lnEn*	1.235	0.116	10.632	0.000
lnFDI**	6.944	2.651	2.619	0.015
$lnFDI^2$**	-0.732	0.276	-2.647	0.014
$lnFDI^3$**	0.025	0.009	2.681	0.013
lnURB	0.052	0.128	0.405	0.688
		Short run coefficient		
DlnEn*	0.900	0.151	5.929	0.000
DlnFDI**	5.059	2.196	2.303	0.030
$DlnFDI^2$**	-0.533	0.229	-2.326	0.029
$DlnFDI^3$**	0.018	0.007	2.356	0.027
DlnURB	0.037	0.096	0.391	0.699
Constant**	-18.666	7.373	-2.531	0.018
ECT(-1)*	-0.728	0.115	-6.332	0.000
Sample		1991-2021		
RMSE		0.006		
R-square		0.997		
Adj R-squ		0.996		
Log-likelihood		107.299		

Source: Research finding.

Note: *, **, and *** indicate 1%, 5% and 10% significance levels respectively.

Hence, convergence of short-term results to the long run is observed, along with a causal relationship between carbon emissions and FDI inflows in India. The long-run and short-run coefficients for FDI inflows, FDI inflows squared, and FDI inflows cubed are found to be highly significant and carry the expected signs to validate the N-shaped EKC for India. The results for India's investment inflows indicate that policymakers need to impose stricter checks on foreign manufacturing and processing units establishing operations in India. Sanjeev and Kaur (2021) found that the Indian economy is liberal and open to attracting investment, capital, and trade flows from abroad; hence, it is likely to account for technology and obsolescence effects with increases in economic growth and FDI inflows. Rigorous environmental norms should be designed so that India attracts only sustainable manufacturing plants — those that are greener and less environmentally degrading.

Results for Carbon Emissions and Globalisation (Model 3)

For the association between carbon emissions and globalization, the results are presented in Table 7, and the optimal lag structure for the model is ARDL (1,1,0,0,0). The R-squared is estimated at 83.4% for Model 3, and the error correction term (ECT) is negative (-0.834) and highly significant.

Table 7. Results for Long-Run and Short-Run Coefficients (Model 3); Carbon Emissions and Globalisation

Long run coefficient				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
lnEN*	1.174	0.170	6.907	0.000
lnGlob***	26.334	66.137	0.398	0.069
lnGLOb^2**	-15.179	40.101	-0.378	0.070
lnGlob^3**	2.837	8.079	0.351	0.072
lnURB	5.033	3.652	1.378	0.182
Short run coefficient				
DlnEN*	0.980	0.241	4.059	0.0006
DlnGlob	21.982	55.08	0.399	0.169
DlnGlob^2	-12.671	33.391	-0.379	0.170
DlnGlob^3	2.368	6.726	0.3521	0.172
DlnURB	4.201	2.918	1.439	0.164
Constant	-50.09	46.151	-1.085	0.290
ECT(-1)*	-0.834	0.161	-5.172	0.00
RMSE	0.009			
R-square	0.997			
Adj R-square	0.994			
Log-likelihood	105.73			

Source: Research finding.

Note: *, **, and *** indicate 1%, 5% and 10% significance levels respectively.

The globalization coefficients for both the long run and short run suggest the presence of an N-shaped EKC for India. However, the short-run coefficients are insignificant, whereas the long-run coefficients are significant and carry the expected signs. The presence of an N-shaped EKC in the long run for globalization indicates that globalization measures provide environmentally supportive technology that only weakens the EKC in the short run, but is inadequate to work toward carbon neutrality in the long run. Policies supporting globalization have contributed to India's economic growth and investment inflows; however, these measures appear to fall short of promoting sustainable economic growth. Shahbaz (2022) found similar results for globalization and carbon emissions for a few Next-11 countries while capturing an inverted U-shaped EKC framework.

The coefficients for energy consumption are found to be positive and significant across all three models, suggesting a detrimental impact on the environment due to increased use of energy-driven products and processes. However, the coefficients for urbanisation are found to be positive but insignificant across all models.

Diagnostic Test

To test the goodness of fit of the ARDL models, a few diagnostic and stability tests were conducted for all three models under study. To address volatility issues associated with time series data, the ARCH heteroskedasticity test was conducted. Additionally, to examine the influence of the variables on themselves over time, the Breusch–Godfrey LM test for serial correlation was performed for each of the three model specifications separately. The results for heteroskedasticity and serial correlation for all three ARDL models indicate homoscedasticity and no serial correlation (see Table 8).

Table 8. Diagnostic Test Results

Model	Test	Statistics	p-value
Model 1: CO2-GDPpc	ARCH Heteroskedasticity test	F(1,27)	0.2333
	Breusch-Pagan LM test for serial correlation	F(2,20)	0.4174
	Ramsey RESET test	(1, 21)	0.1838
Model 2: CO2-FDI inflows	ARCH Heteroskedasticity test	F(1,27)	0.4417

	Breusch-Pagan LM test for serial correlation	F(1,21)	0.9550
	Ramsey RESET test	(1, 21)	0.5996
Model 3: CO2-Globalisation	ARCH Heteroskedasticity test	F(1,27)	0.1501
	Breusch-Pagan LM test for serial correlation	F(2,22)	0.1521
	Ramsey RESET test	(1, 22)	0.5722

Source: Research finding.

Additionally, the Ramsey RESET test was conducted to examine whether non-linear combinations of the fitted values help explain the response variable in the estimated equations. In other words, the test was employed to assess the functional form of the model. The null hypothesis of the Ramsey RESET test, which suggests a functional form problem with the model, was rejected (see Table 8). Moreover, the graphical representation (Figures 2, 3, and 4) of the CUSUM and CUSUM of squares tests confirms the stability of the models, as the plots for all three specifications lie within the critical bounds at the 5% significance level.

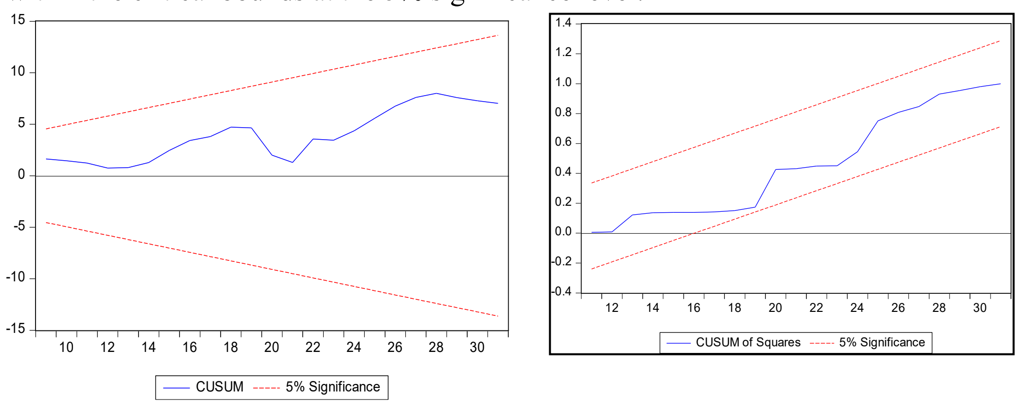

Figure 2. Pictorial representation of CUSUM and CUSUM square for estimated ARDL model (CO2-GDPpc)

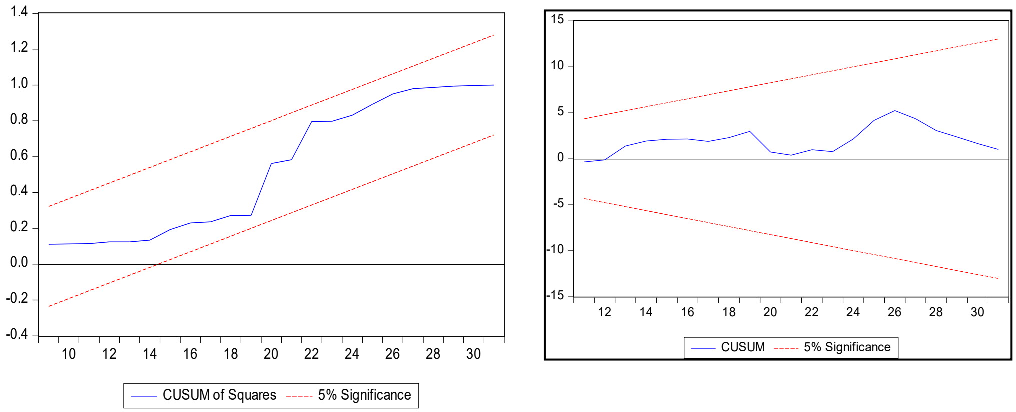

Figure 3. Pictorial Representation of CUSUM and CUSUM Square for Estimated ARDL Model (CO2-FDI Inflows)

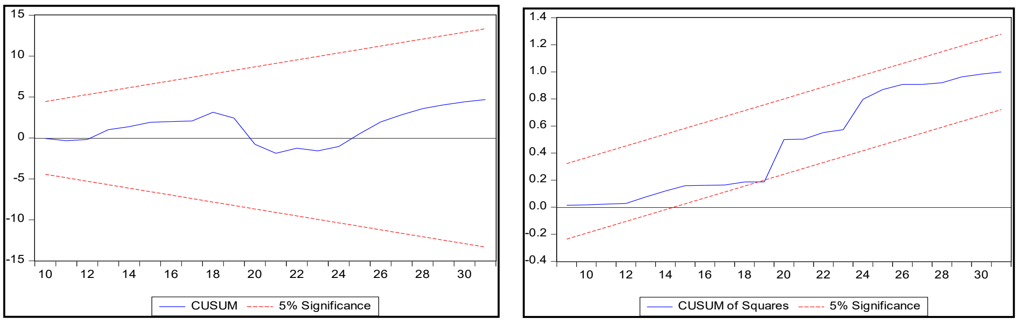

Figure 4. Pictorial Representation of CUSUM and CUSUM Square for Estimated ARDL Model (CO2-Globalisation)

Source: Research finding, based on the results of CUSUM and CUSUM square test.

Conclusion and Policy Implications

In the last few decades, India has not only liberalized policies towards globalization and foreign investment but has also witnessed an upsurge in carbon emissions. Hence, the present study is an attempt to empirically validate the presence (or absence) of an N-shaped EKC framework for three varied model specifications, namely, CO2-income per capita, CO2-FDI inflows, and CO2-globalization, using the ARDL bounds testing approach. EKC with FDI flows was examined to study the nature of investment flows received and to explore whether India is likely to enrol technology obsolescence impact with respect to FDI inflows. Further, Jahanger (2022) stated that developing economies are stimulating manufacturing sectors via extensive globalisation policy to promote growth at the cost of environmental degradation. Hence, EKC with globalization was explored to study whether the policy initiatives undertaken by India are sufficient to reduce (or eliminate) the technology obsolescence impact in the years to come. The major findings of the study are stated as follows:

1. For Model 1 (CO_2-GDP per capita), the results are suggestive of an N-shaped EKC with relevant signs but insignificant coefficients. Hence, the results for EKC with GDP per capita suggest that environment-supportive technologies, green and clean production processes, and renewable energy measures introduced at the domestic level are weakening the presence of EKC for GDP per capita, but the measures are not considerable enough to completely nullify the association between carbon emissions and income per capita. Consistent and impactful renewable energy measures in consumption and productive activities are expected to significantly improve environmental quality in the years to come.

2. The findings of the study suggest a well-defined N-shaped EKC for CO_2-investment flows (Model 2), as the results significantly support the cubic form of EKC in both the long run and short run. The results indicate that India is attracting FDI inflows into pollution-intensive manufacturing units, possibly due to less stringent or inadequate environment-supportive norms. The results support PHH for India wherein a shift of pollutive-intensive industrial units from developed economies to developing economy (India) can be observed. Further, the presence of an N-shaped EKC for FDI inflows suggests that with lax environmental norms, India is likely to register a technology obsolescence impact in the years to come. The results for FDI suggest that India needs to keep a check on the nature of FDI received and penalize (and regulate) the flows that are hazardous to the environment. Further, measures should be taken to promote green investment opportunities.

3. Furthermore, the findings for CO_2-globalization (Model 3) depict an N-shaped EKC for long-run specifications and an insignificant (weak) EKC for the short run. The results indicate that policy measures towards globalization should incorporate strong environment protection norms to eliminate likely technology obsolescence effects associated with globalization in the long run. India should draft norms to enhance environment-friendly trade, investment, and technology. Further, law enforcement mechanisms should be well defined to facilitate the inflow of green and clean technology, investment, products, and services. Stringent checks on the quality of inflows are essential to eliminate PHH in the long run. Policy initiatives for globalization should serve as a monitoring tool, not only to support growth but also to enroute sustainability and greener checkers.

In a nutshell, globalization measures and foreign investments have contributed to the promotion of manufacturing units and massive industrialization, which in turn has added to carbon emissions in India. Tektüfekçi and Kutay (2016) suggested that developed economies are spending more on infrastructure and pollution-combating products and materials, and enforce strict environmental protection laws and norms, hence supporting a healthy and pollution-free environment. Hence, policymakers in India need to take stock of the nature of investments flowing into the country and revisit globalization policy so that India is able to attract sustainable and eco-friendly investments in the coming years. Moreover, a surge in global warming may worsen the results; therefore, prompt measures towards green technology and better recycling of industrial waste should be promoted. Revisiting globalization policies and augmenting them with sustainable investment initiatives can help India achieve not only economic growth but also sustainable development.

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