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RESEARCH ARTICLE

Mediation of foreign direct investment and agriculture towards ecological footprint: a shift from single perspective to a more inclusive perspective for India

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Abstract

According to the Carbon Brief Profile report by Timperley (2019), India has been identified as the world's 3rd largest emitter of greenhouse gases (GHGs) after China and the USA. Following the Paris Agreement and India's pledge as among the stakeholders at the global climate talks and how fast India ratified the Paris Agreement within a year on the 2nd of October 2016, it is essential to investigate the country's (India) commitment in reducing its emission towards enhancing a positive environmental performance. Both structural breaks, linear autoregressive distributed lag (ARDL) and nonlinear autoregressive distributed lag (NARDL), were selected simultaneously for this study, but at a later stage, after being bound to cointegration estimation, the NARDL was dropped because of its inability to sustain the claim of cointegration in the analysis. The rest of the analyses were based on liner ARDL model (short-run and long-run) with diagnostic tests, Granger causality estimation. Ecological Footprint (EFP) was chosen as an indicator to environment because of its richness in measuring the environmental performance. The linear (ARDL) output affirms a positive and significant link among ecological footprint and agriculture, energy use, and population with a negative link between ecological footprint (EFP) and foreign direct investment (FDI). The Granger causality test indicates a one-way transmission passing from agriculture, foreign direct investment, energy use, and population to ecological footprint. Also, a one-way transmission was found passing to economic growth (GDP) from foreign direct investment (FDI) and feedback transmission was found between FDI and energy use. This finding has an implication to both economic and environmental performances; hence, the policy framework should be targeting the enhancement of economy via the foreign direct investment and agriculture with a focus on energy use and environmental performance.

Keywords Ecological footprint · FDI · Agricultural sector · Energy use · Economic growth · ARDL-NARDL · India

Highlights • Mediation of the ecological footprint with agriculture and FDI for India.
• Comparison approach (with both linear and nonlinear ARDL) is employed
• Long- and short-run pollutant emission decomposition in India.
• Causality passing from agric, FDI, energy use, and population to ecological footprint.
• Feedback (two-way) transmission was found between FDI and energy use.
• Nexus among the selected variables is established.
• FDI, agriculture, and energy consumption influence pollutant emission.
• Energy portfolio diversification in India is more urgently necessary than ever.

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Introduction

The recent awareness on climate change leading to global warming is currently a universal phenomenon and contemporary issue that demands urgent attention from all walks of life and all stakeholders, including governments (international, national, and local), the private sectors, civil society, local authorities, and other international organizations for solution. Following the upsurge of global warming, there has been an adoption and urgent consideration of the Paris Agreement as a major force to abate the speedy rise of global warming. A task is presented before in both developed and developing countries to limit the global average climate condition to well below 2 °C and to bring it to a minimum of 1.5 °C and above pre-industrial levels. The climate change is mostly triggered by the dilapidated environment that is most affected by the ecological footprint. The ecological footprint summed up all human activities on earth that has to do with geographical and biological harnessing of space (Galli 2015). These activities are found in the areas of excavation of natural resources (mining and oil exploration), economic activities, agricultural activities, construction, deforestation, urban infrastructure, and transportation. As stated by Ulucak and Lin (2017), ecological footprint measures accommodate diverse stocks such as soil, forestry, and exploration of natural resources (mining and oil stocks).

Exploration and the usage of some natural resources such as oil and gas constitute part of the ecological footprint. This is evident in the case of oil spillage within the geographical setting or location of mining of these resources. Most times, the spillage is hazardous both to aquatic life and farm lands which will eventually lead to the death of inhabited animals and fishes and turn them into poisonous sea foods for humans and render the farm lands infertile. The agricultural practice in some countries including India constitutes part of the ecological footprint which eventually leads to an unhealthy environment. Land reclaiming for farming purposes which is done via deforestation often leads to exposing the environment to excessive heat because of inadequate plants and trees to aid in reducing excessive carbon dioxide, and the end result is global warming. Inclusive in agricultural practice in such places like India is the activities of herders and their cows both on land and water bodies. Most times, the animals are agents of environmental degradation by polluting water bodies and the surroundings with methane which is part of the constituents of the greenhouse gas (GHG). Inorganic manures or chemicals such as fertilizers used in farming equally add to climate change by releasing nitrogen oxide. Survey from the Carbon Brief Profile (Timperley 2019) revealed that agriculture and farming constitute 0.16% of Indian ecological footprint (EFP). The result also indicates that pollutants from farming amount to about 30% of the world in total and that farming is among the major emitters of ecological footprint and emissions.

The economic activities by human agents such as manufacturing and production which form part of the investment for foreign investors in the form of foreign direct investments (FDI) also contribute to climate change. This involves the usage of heavy duty machines and factory machines which are powered by excessive nonrenewable energy consumption which in turn emits carbon dioxide, and this emission is considered part of the ecological footprint. Though, some studies have found that economic activities in the form of FDI are a twofold agent in impacting the environment. Some are of the opinion that it addresses the environmental issue favorably such as investments in clean technologies and in renewable energy which is more environmentally friendly and contributes in addressing the issue of ecological footprint (Udemba et al. 2019; Zhang 2011; Katircioğlu and Taşpinar 2017), while others are in contrast with this. They argue that FDI encourages the use of heavy-duty and excessive energy consumption machines which contribute in expanding the business activities which will promote the acquisition of new plants and machines thereby increasing carbon emission settlements in the environment and providing a negative impact to the environment (Zhang 2018; Danish and Wang 2018; Sarkodie and Strezov 2019; Udemba 2019). The trade-off between the sustainability of economic momentum in terms of growth and development and the environmental security has become a challenge to policy makers, and this has constituted a major concern to advocates of the environment. The increasing population of many countries including India amounts to serious pressure on the demand and consumption of natural resources, and this is becoming a global challenge. From this perspective, the ecological footprint is described as the extent of a geographical area of organically useful earth and water occupied by a group of people (population) or action needed to yield all the resources it consumes (Global Footprint Network 2018). The more the increase on the population, the more the increase on the consumption of natural resources and the more the increase on the pollution and dilapidation of the environment. Bagliani et al. (2008), Wang et al. (2013), Al-Mulali et al. (2015), and Uddin et al. (2017) suggest that ecological footprint measures the consumption of natural resources and a reliable parameter for environmental damage

The emergency and the need to curb the rate of global warming and the need to proffer solutions to the environmental problems have paved way for many literature emerging from all walks of life including the energy and environmental economist. Though, most of the literature have really dealt and almost exhausted the research with a target on CO_2 emissions as an indicator to measure environmental dilapidation with less focus on the angle of ecological footprint. Most time, the reason associated with this is the unavailability of data and its correlation with the greenhouse effect. Aside from the CO_2 emissions, other researchers have adopted other single ecological indicators in studying the impact of environmental quality towards climate change. However, it is irrational to focus only on one single indicator among the many indicators that make up the ecological footprint when researching on environmental quality. For this reason, Rees (1992), Wackernagel (1994), and Wackernagel and Rees (1998)) modeled ecological footprint as a comprehensive proxy for environmental degradation. Other scholars have utilized foreign direct investment and ecological footprint to ascertain the environmental state with varied results. Most of the studies adopt panel study instead of a single country's analysis (Ali et al. 2020; Destek and Okumus 2019; Majeed and Mazhar 2019; Baloch et al. 2019; Liu and Kim 2018. These studies differ from our study on the areas of focus and their methodology. This present work is strictly a single country's study with India as a focus. Most times, panel work lacks the power to give in-depth analysis of the sampled countries because of the heterogeneous nature of the merged or pooled countries. India is an open economy with features that are pollution inclined such as population, economy that is mostly dependent on agriculture, and FDI which places the country in a strategic position for emission involvement. According to Ulucak and Lin (2017), this model is encompassing and comprises dilapidation in multiple factors such as soil, forestry, and exploration of natural resources (mining and oil stocks). The ecological footprint comprises the sum of six components, namely, carbon footprints, built-up land, cropland, grazing land, forest land, and fishing grounds. Since the ecological footprint considers several resource stocks, a research based on the ecological footprint will be more effective in considering the environmental quality and modeling of policy measures in the sustainability of the economic activities and controlling of the environmental decadence.

It is on this premises that the researcher chose to study the environmental performance of India with the application of a more comprehensive indicator of ecological footprint and the selected variables which are relevant with the uniqueness of the country (India). The fundamental uniqueness of this paper is based on the combination of different empirical techniques and utilization of the ecological footprint to measure the environmental performance of Indian economy. The empirical analyses of this work are not just based on a single analysis but a combination and comparison of different techniques (ARDL-bound test and Asymmetry-NARDL with the support of causality analyses) to give an unbiased and a robust finding that will aid in policy framing towards sustenance of the economy and acceptable environmental performance. We employ both ARDL-bound test and NARDL with the support of causality analyses which are based on both the short- and long-run versions of the Granger causality. Analyses of structural break are employed to make up the short falls associated with the conventional techniques (ADF, PP, and KPSS) in the stationarity analyses and to ascertain the permanent shocks and the regime effects of policies towards the maintenance of good environment and economy. Also, based on the feature of the country as among the most populated countries of the world, and its reliance on agriculture and industrialization which is rooted heavily on FDI, population, agriculture, and FDI were considered the important variables in this study. Another uniqueness of this paper is seen from a country-specific research which will give in depth a vivid and clear picture of the findings on a particular country instead of the frequent merging of countries under BRICS as seen from many literatures.

The major objective of this study is to investigate the country's (India) commitment in reducing its emission towards enhancing a positive environmental performance which will impact positively in curtailing climate change. The relevance and importance of this study can be seen from India's position in South Asia in the aspects of economy, agriculture, geography, and politics among others as being essential and sensitive. Thus, the uniqueness of the country implies that some of the findings that are peculiar to India in the current study are relatively relevant and important to many of the South Asian countries. For instance, the policies associated with natural agricultural activities and foreign investment and high-energy utilization are expectedly applicable to Pakistan, Bangladesh, Nepal, Sri Lanka, and Afghanistan. In terms of the aforementioned indexes, most of the South Asian countries will share a similar approach to balancing their explorations with the environmental performance.

The rest of this study continues as follows: Part 2 comprises concise empirical works and theoretical background with hypothesis. Part 3 comprises data and methodological presentation as it is applied in this research with the empirical outcomes and discussion of the research in part 4. Part 5 comprises the conclusion and the policy implication of the study.

Brief review of empirical and theoretical literature

Empirical review

Environmental dilapidations emanate from the actions of the human agents to the environment through the utilization of the natural resources and others (Majeed and Mumtaz 2017; Majeed and Mazhar 2019). Environmental performance has been extensively researched by many scholars with the application of different indicators (e.g., carbon emissions, greenhouse gas, pollutant emissions, and even the single components of ecological footprint) as proxy to the environment without a conclusive or unified result that will lead to a general agreement to the solution of the global warming that sparks the need for studies and policies to curb its menace. Most studies (Udemba 2019; Udemba et al. 2019; Bekun et al. 2019; Shahbaz et al. 2010, Shahbaz et al. 2012, Shahbaz et al. 2013; Guangyue and Deyong 2011; Lorente and Alvarez-Herranz 2016b; Álvarez-Herránz et al. 2017; Sinha et al. 2017; Liu et al. 2017; Sarkodie and Strezov 2019; Ullah et al. 2018; Gokmenoglu and Taspinar 2018; Dogan 2016) have applied carbon emission and other variables to ascertain the environmental performance and quality of different countries either as a time series or as a panel study. Shahbaz et al. (2010) studied the relationship among GDP growth and carbon emission for Portugal, accounting for the role of urbanization, trade liberalization, and energy consumption and found the occurrence of the environmental Kuznets curve (EKC) in Portugal. Guangyue and Deyong (2011) applied the same investigation to the province of China and found a positive association among the income level and pollutants. Shahbaz et al. (2012) equally found opposite connection among income level and environmental performance for the Pakistan. Shahbaz et al. (2013) also found EKC hypothesis for the case of Romania in the study of carbon–income nexus. Dogan (2016) worked on Turkish case and found agricultural-induced EKC in the carbon-agricultural investigation of the country. Lorente and Álvarez-Herranz (2016a) researched 17 states in Organization for Economic Cooperation and Development (OECD) in a panel format and found a U-shape design among pollutants and income level. Álvarez-Herránz et al. (2017) also found a positive association among pollutants and income level of China. Sinha et al. (2017) investigate the linkage among the energy consumption and the environmental pollution and found an N-shaped form of the association. Liu et al. (2017) worked on the effects of both agriculture and energy on carbon emission for ASEAN states and established upturned U-shaped form for the EKC hypothesis. Ullah et al. (2018) found a cointegration association among carbon pollutants and agriculture in the tested time for Pakistan. Gokmenoglu and Taspinar (2018) did a work on Turkey as regards the force of FDI to the environmental performance and found that FDI is inducing the greenhouse gas emissions within the researched time. Sarkodie and Strezov (2019) found a validating EKC hypothesis for China and Indonesia. Udemba (2019) found a very interesting result for the case of China. The study exposes a positive relation among economic growth and carbon emission. Udemba et al. (2019) dictates a positive association among income level and carbon emission at the initial stage but changed to a negative relationship in both lags 1 and 2 for Indonesia. They also dictate a uni-directional causal relationship entering from FDI to carbon emission; Bekun et al. (2019) exposes a positive association among the income level and carbon emission for South Africa. The empirical research on environmental performance using ecological footprint as an indicator started with the pioneer studies of Wackernagel et al. (1999)) where they found that ecological footprint depends on the given area population, living standard, income level, consumption pattern, and ecosystem. Currently, few studies (Al-Mulali et al. 2015; Ozturk et al. 2016; Ulucak and Lin 2017; Solarin and Bello 2018; Katircioglu et al. 2018; Duman et al. 2019) have emerged using ecological footprint as an indicator to measure environmental performance. Al-Mulali et al. (2015) researched the potency of EKC hypothesis with the application of ecological footprint as an indicator of environmental performance on 93 countries for the period of 1980–2008. The finding infers an overturned U-shaped connection among ecological footprint and income level in developed countries but not in developing countries. Al-Mulali et al. (2015) for the 14 MENA countries found that ecological footprint, energy, urbanization, merchant liberalization, manufacturing expansion, and political steadiness are impacting each other in the long run, and the causality findings infer causality among ecological footprint and other variables. Ozturk et al. (2016) applied EKC hypothesis for the case of 144 countries and found a negative relationship between the ecological footprint and its determinants. Ali et al. (2020) researched environmental performance of the OIC countries with ecological footprint and FDI and found a negative association between the two indicators. Destek and Okumus (2019) studied environmental performance of newly industrialized countries with ecological footprint and FDI and found a U-shaped relationship between FDI and ecological footprint. Majeed and Mazhar (2019) also researched environmental implication of 131 countries with FDI and ecological footprint and found Pollution Haven Hypothesis (PHH). Baloch et al. (2019) also researched environmental performance of 59 Belt and Road initiative countries with FDI and ecological footprint and found a positive association between FDI and ecological footprint. Liu and Kim (2018) worked on environmental performance of Belt and Road initiative countries with FDI and ecological footprint and found PHH. This result is indicative mostly in the case of developed countries. Ulucak and Lin (2017) researched on the stationarity of the ecological footprint and its components. They found that cropland footprint and bio-capacity are stationary whereas ecological footprint, carbon footprint, grazing land footprint, and ecological deficit are non-stationary. Solarin and Bello et al. (2018) did a stationarity study of ecological footprint on 128 countries and found nonstationarity for ecological footprint for 96 countries. Katircioglu et al. (2018) researched on a group of top 10 tourism destinations and the implication of ecological footprint. They found that environmental performance is induced by the tourist's activities. Ozcan et al. (2019) researched on environmental policies for the low-, middle-, and high-income countries with ecological footprint indicator and found a mean-reverting behavior on ecological footprint for all high-income countries.

Theoretical background

The theoretical foundation of this study is anchored on two theories; EKC and ecological modernization theory. The EKC was first established by Kuznets (1955) and adopted by other scholars starting with the likes of Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), and Panayotou (1993). This theory postulates the trade-off among economic growth and ecological performance. The economic growth comes in three different stages with effect on environmental performance: scale-effect stage, structural- or composition-effect stage, and technique-effect stage. The first sage is a reflection of economic growth and development without attention to the environmental implication of the growth. This is seen in most of the developing countries that are in the spirit of economic growth competition. The second stage spelled the situation of awakening on the citizens on the effect of the growth with neglect on environmental effect. This stage is likened to the structural effect because structural changes such as modernized ways of farming or entirely movement from agricultural economy to industrialized conscious economy with much investments and policies to attract foreign investors started taking place with more attention to the cleaner environment. This is sometimes called transition economy and mostly observed in emerging economies. The final stage which is established within the maximum threshold of the income level is the stage that balances the economic growth with the environmental performance. This is achieved through the full awareness of cleaner energy and the importance of clean environmental quality. At this stage, most of the structural changes are triggered by the technological exposures and adoption. This is observed in developed economies or countries. Secondly, the theory of ecological modernization postulates that poor environmental performance is associated with economic transition which stems from low to middle stage of economic growth and development because much attention and priority are given to the growth than the environmental performance. However, further step into modernization via structural change brings about change in priority towards balancing growth and environmental performance. The priority will be directed to growth sustainability, environmental sustainability, technological innovations, and service-based economy which will be targeted on minimal environmental degradation.

In continuation of this investigation and as part of the study, the author hypothesized that.

H_1 Relationship between economic growth and the ecological footprint is determined by GDP.

H_2 Relationship between FDI and the ecological footprint is determined by FDI.

H_3 Relationship between agriculture and the ecological footprint is determined by Agric.

H_4 Relationship between energy use and the ecological footprint is determined by GDP.

H_5 Relationship between population and the ecological footprint is determined by POP.

Data, methodology, empirical findings, and discussion

Data

This study utilizes Indian data which covered the period from 1975 to 2016. The data for the current study are the following indicator and selected variables; ecological footprint (per capita) comprises "built-up land, carbon emissions, cropland, fishing grounds, forestry products, and grazing land" sourced from Ecological Footprint Network (GFN), GDP per capita (constant 2010 US$), energy use (kilograms of oil equivalent per capita), agricultural sector (forestry and fishing, value added (% of GDP)), foreign direct investment, net inflow (% of GDP), and urban population are all taken from the current World Bank Development Indicator (WDI). With the exception of agriculture and FDI that are already in percentage form, all the variables are expressed in natural logarithm form for the purpose of uniformity and homoscedasticity. A concise summary of the variables is listed in Table 1.

Methodology

The methods adopted by the present study are descriptive statistics, test of stationarity, optimal lag selection, dynamic and nondynamic autoregressive distributed lag (ARDL and NARDL), and causality estimates. Descriptive statistics was employed to test the normality and conformity of the data and the test via Jarque-bera, skewness, and kurtosis. Stationarity test is equally employed in this current study to confirm if the designated variables are stationary or integrated in order I(1) or combined. The applications utilized in ascertaining the stationarity of this present study are Philip-Perron Perron 1990, augmented Dickey-Fuller Dickey and Fuller 1979 (ADF), Kwiatkowski-Philips-Schmidt-Shin (Kwiatkowski et al. 1992 (KPSS), and Zivot and Andrew's (1992) structural break for the robustness of the stationarity tests. Vector autoregressive (VAR) lag-order selection criterion with consideration of Akaike information criteria (AIC) was used to determine the optimal lag-selection order. The linear ARDL with bound testing for long-run estimation (Pesaran and Shin 1998; Pesaran et al. 2001) and NARDL for nonlinear relationship between the variables in both short and long runs (Shin et al. 2014) are employed in the analyses for better estimation of both long- and short-run relationships that exist among the selected variables (EFP, GDP, AGRIC, FDI, EU, and POPULATION). Causality (long-run and short-run) estimations are utilized in the analyses for the establishment of a clear nexus and direct impact of the variables among themselves.

Model specifications

This paper aimed at determining the mediation of FDI and agriculture towards ascertainment of the environmental performance represented by an ecological footprint indicator. Model specification of the present study is anchored on ARDL and NARDL approaches to expose both linear and nonlinear relations among the selected variables specifically on the EFP model.

The first consideration is given to the linear ARDL model according to Pesaran and Shin (1998) and Pesaran et al. (2001)), bearing in mind the bound-testing procedure; the error correction representations of the linear ARDL model can be stated as follows;

Table 1 Variables and their dimensions

Definition of the variables	Variables in brief form	Measurement/calculations
Ecological footprint	EFP	Global hectare, per capita
GDP per capita	GDP	Constant 2010 US$
Agricultural sector	Agric	Forestry and fishing, value added (% of GDP)
Foreign direct investment, net inflow	FDI	Net inflow (% of GDP)
Energy use	Energy use	kg of oil equivalent per capita
Urban population	Pop	Urban population

With the exception of agriculture and FDI that are already in percentage form, all the variables are expressed in natural logarithm form

Source: Authors' compilation

$$\begin{aligned}\Delta \mathrm{LEFP}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} \\ & + \mathrm{ECM}_{t-i} + \varepsilon_t \end{aligned} \quad (1)$$

$$\begin{aligned}\Delta \mathrm{LGDP}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} \\ & + \mathrm{ECM}_{t-i} + \varepsilon_t \end{aligned} \quad (2)$$

$$\begin{aligned}\Delta \mathrm{FDI}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} + \mathrm{ECM}_{t-i} \\ & + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned}\Delta \mathrm{AGRIC}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} \\ & + \mathrm{ECM}_{t-i} + \varepsilon_t \end{aligned} \quad (4)$$

$$\begin{aligned}\Delta \mathrm{LEU}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} + \mathrm{ECM}_{t-i} \\ & + \varepsilon_t \end{aligned} \quad (5)$$

$$\begin{aligned}\Delta \mathrm{LPOP}_t = {} & \mu + \beta_1 \mathrm{LEFP}_{t-1} + \beta_2 \mathrm{LGDP}_{t-1} + \beta_3 \mathrm{FDI}_{t-1} \\ & + \beta_4 \mathrm{AGRIC}_{t-1} + \beta_5 \mathrm{LEU}_{t-1} + \beta_6 \mathrm{LPOP}_{t-1} \\ & + \sum_{i=0}^{\rho-1} \delta_1 \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q-1} \delta_2 \Delta \mathrm{LGDP}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_3 \Delta \mathrm{FDI}_{t-i} + \sum_{i=0}^{q-1} \delta_4 \Delta \mathrm{AGRIC}_{t-i} \\ & + \sum_{i=0}^{q-1} \delta_5 \Delta \mathrm{LEU}_{t-i} + \sum_{i=0}^{q-1} \delta_6 \Delta \mathrm{LPOP}_{t-i} \\ & + \mathrm{ECM}_{t-i} + \varepsilon_t \end{aligned} \quad (6)$$

Equations (1) to (6) are constructed to investigate ARDL (symmetric) cointegration associations among the variables. EFP, GDP, FDI, AGRIC, EU, and POP are the ecological footprint, gross domestic product, foreign direct investment, agriculture sector, energy use, and population, and they are all in logarithms with the exemption of FDI and AGRIC. This sign Δ represents the first difference of the selected variables. β_1 and δ_1 denote the long- and short-run coefficients for the variables with i represents 1, 2, 3, 4, 5, and 6, while error correction model $(\mathrm{ECM})_{t-1}$ exposes the speed of regulation over a period of time inferred as long-run period. The long run or cointegration relationship among the variables is determined with the bound test and an application of Wald (F-statistics) test. In determination of the long run or cointegration association among the variables, there is a comparison between the F-statistics value and critical values of lower and upper bounds (Pesaran et al. 2001), if F-statistics is less than both the lower and upper bounds, it means there is no cointegration, if the F-statistics is greater than both bounds, it is the confirmation of cointegation or long-run relationship among the variables, while the result is inconclusive when the value of F-statistics falls in between both bounds. The null hypothesis states that there is no cointegration among the variables against the alternative hypothesis of cointegration. This is stated as follows: H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$ (if F-statistics < both bounds) against H_1: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 \neq 0$ (if F-statistics > both bounds).

However, when the estimated result of the ARDL is misleading which can cause a misleading conclusion because of the existence of nonlinear relationships among the variables, it is advisable to utilize the asymmetric ARDL (NARDL) model which captures long- and short-run nonlinearities for a robust results and valid conclusion (Shin et al. 2014). Conceptualizing the nonlinear long-run cointegration, this study adopts Shin et al. (2014) as follows:

$$y_t = \beta^+ x_t^{\,+} + \beta^- x_t^{\,-} + \varepsilon_t \quad (7)$$

where y_t and x_t denote LEFP, LGDP, FDI, AGRIC, LEU, and LPOP. β^+ and β^- represent the related long-run variables. x_t is a k*1 vector of the independent variables defined as $x_t = x_0 + x_t^+ + x_t^-$ where x_0 is the initial value. The asymmetric (NARDL) model applies the decomposition of the exogenous variables into negative and positive partial sums for decreases and increases in this way;

Positive partial sum; $x_t^+ = \sum_{i=1}^{t} \Delta x_i^{\,+} = \sum_{i=1}^{t} \max(\Delta x_i, 0)$ (8).

Negative partial sum; $x_t^- = \sum_{i=1}^{t} \Delta x_i^{\,-} = \sum_{i=1}^{t} \max(\Delta x_i, 0)$ (9).

The asymmetric (NADRL) model incorporated in the extended version of ARDL models is stated as follow;

$$\begin{aligned}
\Delta \mathrm{LEFP}_t = {} & \mu + \chi \mathrm{LEFP}_{t-1} + \theta_1^{\,+}\mathrm{LGDP}_{t-1^+} \\
& + \theta_1^{\,-}\mathrm{LGDP}_{t-1^-} + \theta_2^{\,+}\mathrm{FDI}_{t-1^+} \\
& + \theta_2^{\,-}\mathrm{FDI}_{t-1^-} + \theta_3^{\,+}\mathrm{AGRIC}_{t-1^+} \\
& + \theta_3^{\,-}\mathrm{AGRIC}_{t-1^-} + \theta_4^{\,+}\mathrm{LEU}_{t-1^+} \\
& + \theta_4^{\,-}\mathrm{LEU}_{t-}1^{-} + \theta_5^{\,+}\mathrm{LPOP}_{t-1^+} \\
& + \theta_5^{\,-}\mathrm{LPOP}_{t-1^-} + \sum_{i=0}^{\rho-1} \lambda \Delta \mathrm{LEFP}_{t-i} \\
& + \sum_{i=0}^{q-1} \phi_1^{\,+} \Delta \mathrm{LGDP}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_1^{\,-}\ \Delta \mathrm{LGDP}_{t-i^-} + \sum_{i=0}^{q-1} \phi_2^{\,+} \Delta \mathrm{FDI}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_2^{\,-} \Delta \mathrm{FDI}_{t-i^-} + \sum_{i=0}^{q-1} \phi_3^{\,+} \Delta \mathrm{AGRIC}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_3^{\,-} \Delta \mathrm{AGRIC}_{t-i^-} + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LEU}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_4^{\,-} \Delta \mathrm{LEU}_{t-i^-} + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LPOP}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LPOP}_{t-i^+} + \varepsilon_t
\end{aligned} \quad (10)$$

$$\begin{aligned}
\Delta \mathrm{LGDP}_t = {} & \mu + \chi \mathrm{LGDP}_{t-1} + \theta_1^{\,+}\mathrm{LEFP}_{t-1^+} \\
& + \theta_1^{\,-}\mathrm{LEFP}_{t-1^-} + \theta_2^{\,+}\mathrm{FDI}_{t-1^+} \\
& + \theta_2^{\,-}\mathrm{FDI}_{t-1^-} + \theta_3^{\,+}\mathrm{AGRIC}_{t-1^+} \\
& + \theta_3^{\,-}\mathrm{AGRIC}_{t-1^-} + \theta_4^{\,+}\mathrm{LEU}_{t-1^+} \\
& + \theta_4^{\,-}\mathrm{LEU}_{t-}1^{-} + \theta_5^{\,+}\mathrm{LPOP}_{t-1^+} \\
& + \theta_5^{\,-}\mathrm{LPOP}_{t-1^-} + \sum_{i=0}^{\rho-1} \lambda \Delta \mathrm{LGDP}_{t-i} \\
& + \sum_{i=0}^{q-1} \phi_1^{\,+} \Delta \mathrm{LEFP}_{t-i^+} + \sum_{i=0}^{q-1} \phi_1^{\,-}\ \Delta \mathrm{LEFP}_{t-i^-} \\
& + \sum_{i=0}^{q-1} \phi_2^{\,+} \Delta \mathrm{FDI}_{t-i^+} + \sum_{i=0}^{q-1} \phi_2^{\,-} \Delta \mathrm{FDI}_{t-i^-} \\
& + \sum_{i=0}^{q-1} \phi_3^{\,+} \Delta \mathrm{AGRIC}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_3^{\,-} \Delta \mathrm{AGRIC}_{t-i^-} + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LEU}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_4^{\,-} \Delta \mathrm{LEU}_{t-i^-} + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LPOP}_{t-i^+} \\
& + \sum_{i=0}^{q-1} \phi_4^{\,+} \Delta \mathrm{LPOP}_{t-i^+} + \varepsilon_t
\end{aligned} \quad (11)$$

$$\Delta FDI_t = \mu + \chi FDI_{t-1} + \theta_1{}^{+}LGDP_{t-1^{+}} + \theta_1{}^{-}LGDP_{t-1^{-}} + \theta_2{}^{+}EFP_{t-1^{+}} + \theta_2{}^{-}EFP_{t-1^{-}} + \theta_3{}^{+}AGRIC_{t-1^{+}} + \theta_3{}^{-}AGRIC_{t-1^{-}} + \theta_4{}^{+}LEU_{t-1^{+}} + \theta_4{}^{-}LEU_{t-}1^{-} + \theta_5{}^{+}LPOP_{t-1^{+}} + \theta_5{}^{-}LPOP_{t-1^{-}} + \sum_{i=0}^{\rho-1}\lambda\Delta FDI_{t-i} + \sum_{i=0}^{q-1}\phi_1{}^{+}\Delta LGDP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_1{}^{-}\,\Delta LGDP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_2{}^{+}\Delta LEFP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_2{}^{-}\Delta LEFP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_3{}^{+}\Delta AGRIC_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_3{}^{-}\Delta AGRIC_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LEU_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{-}\Delta LEU_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \varepsilon_t \quad (12)$$

$$\Delta AGRIC_t = \mu + \chi AGRIC_{t-1} + \theta_1{}^{+}LGDP_{t-1^{+}} + \theta_1{}^{-}LGDP_{t-1^{-}} + \theta_3{}^{+}LFDI_{t-1^{+}} + \theta_3{}^{-}LFDI_{t-1^{-}} + \theta_2{}^{+}EFP_{t-1^{+}} + \theta_2{}^{-}EFP_{t-1^{-}} + \theta_4{}^{+}LEU_{t-1^{+}} + \theta_4{}^{-}LEU_{t-}1^{-} + \theta_5{}^{+}LPOP_{t-1^{+}} + \theta_5{}^{-}LPOP_{t-1^{-}} + \sum_{i=0}^{\rho-1}\lambda\Delta AGRIC_{t-i} + \sum_{i=0}^{q-1}\phi_1{}^{+}\Delta LGDP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_1{}^{-}\,\Delta LGDP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_2{}^{+}\Delta FDI_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_2{}^{-}\Delta FDI_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_3{}^{+}\Delta LEFP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_3{}^{-}\Delta LEFP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LEU_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{-}\Delta LEU_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \varepsilon_t \quad (13)$$

$$\Delta LEU_t = \mu + \chi LEU_{t-1} + \theta_1{}^{+}LGDP_{t-1^{+}} + \theta_1{}^{-}LGDP_{t-1^{-}} + \theta_2{}^{+}FDI_{t-1^{+}} + \theta_2{}^{-}FDI_{t-1^{-}} + \theta_3{}^{+}AGRIC_{t-1^{+}} + \theta_3{}^{-}AGRIC_{t-1^{-}} + \theta_4{}^{+}LEFP_{t-1^{+}} + \theta_4{}^{-}LEFP_{t-}1^{-} + \theta_5{}^{+}LPOP_{t-1^{+}} + \theta_5{}^{-}LPOP_{t-1^{-}} + \sum_{i=0}^{\rho-1}\lambda\Delta LEU_{t-i} + \sum_{i=0}^{q-1}\phi_1{}^{+}\Delta LGDP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_1{}^{-}\,\Delta LGDP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_2{}^{+}\Delta FDI_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_2{}^{-}\Delta FDI_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_3{}^{+}\Delta AGRIC_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_3{}^{-}\Delta AGRIC_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LEFP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{-}\Delta LEFP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LPOP_{t-i^{+}} + \varepsilon_t \quad (14)$$

$$\Delta LPOP_t = \mu + \chi LPOP_{t-1} + \theta_1{}^{+}LGDP_{t-1^{+}} + \theta_1{}^{-}LGDP_{t-1^{-}} + \theta_2{}^{+}FDI_{t-1^{+}} + \theta_2{}^{-}FDI_{t-1^{-}} + \theta_3{}^{+}AGRIC_{t-1^{+}} + \theta_3{}^{-}AGRIC_{t-1^{-}} + \theta_4{}^{+}LEU_{t-1^{+}} + \theta_4{}^{-}LEU_{t-}1^{-} + \theta_5{}^{+}LEFP_{t-1^{+}} + \theta_5{}^{-}LEFP_{t-1^{-}} + \sum_{i=0}^{\rho-1}\lambda\Delta LPOP_{t-i} + \sum_{i=0}^{q-1}\phi_1{}^{+}\Delta LGDP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_1{}^{-}\,\Delta LGDP_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_2{}^{+}\Delta FDI_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_2{}^{-}\Delta FDI_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_3{}^{+}\Delta AGRIC_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_3{}^{-}\Delta AGRIC_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_4{}^{+}\Delta LEU_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_4{}^{-}\Delta LEU_{t-i^{-}} + \sum_{i=0}^{q-1}\phi_5{}^{+}\Delta LEFP_{t-i^{+}} + \sum_{i=0}^{q-1}\phi_5{}^{+}\Delta LEFP_{t-i^{+}} + \varepsilon_t \quad (15)$$

From Eqs. (10) to (15), θ and ϕ denote the long- and short-run coefficients with $i = 1, 2, 3, 4,$ and 5. The current study estimates both the short-run ($\phi = \phi^{+} = \phi^{-}$) and long-run

($\theta = \theta^{+} = \theta^{-}$) asymmetry with the aid of Wald/F-statistics test for all the indicators. $LEFP_t$ represents ecological footprint; $LGDP_t$ represents the gross domestic products per capita; FDI_t represents foreign direct investment; $AGRIC_t$ represents agriculture sector; LEU_t represents energy use and, $LPOP_t$ represents the population. While the short run measures the immediate effect of exogenous/independent variable change on the regresant variable, the long run measures the connection among these variables in the long-path equilibrium. The asymmetric coefficients are estimated according to $Lmi^{+} = \theta^{+}/\rho$ and $Lmi^{+} = \theta^{-}/\rho$. These asymmetric coefficients measure and determine the long-run equilibrium with respect to positive and negative variations. ρ and q represent the optimal lags for both dependent ($LEFP_t$) and independent ($LGDP_t$, FDI_t, $AGRIC_t$, $LPOP_t$) variables which are determined by the Akaike Information Criterion (AIC), respectively.

To estimate the existence of an asymmetric long-run cointegration, the author adopts the bound test as proposed by Shin et al. (2014) which is a combined test of all the lagged levels of the repressors. Both t-statistics and F-statistics of Banerjee et al. (1998) and Pesaran et al. (2001) are applied. The t-statistics tests the null hypothesis $\theta = 0$ against the alternative $\theta < 0$, while the F-statistics tests the null hypothesis of $\theta = \theta^{+} = \theta^{-} = 0$ against the alternative of $\theta = \theta^{+} = \theta^{-} < 0$. If the null hypothesis is rejected, it means there is existence of long-run cointegration among the variables. The outcome of this empirical study with detailed discussions is presented in the next section.

Empirical results and discussion

This section displays all the empirical estimations and the outputs with clear interpretations and discussion of the results. The author first presents the descriptive statistics of the indexes and also the output of the stationarity test with consideration of the structural breaks as well. The optimal lag length selection was performed with the choice of the AIC as a selection criterion for its stronger features above other criteria (Shahbaz et al. 2012). The comparison of both the symmetric and asymmetric measures was determined with the cointegration investigation of the linear ARDL and nonlinear ARDL model, respectively. Bound with F-statistics test was used to estimate the linear and nonlinear cointegration relationships, and the results were presented in two different panels (A and B). The bound test result displayed in panel A shows the presence of linear cointegration (long run) relationships between the selected variables of the author's interest EFP model, while the panel B fails to deviate from the null hypothesis of no nonlinear cointegration among the variables in the same EFP model. This finding determines the choice of the researcher to base the rest of this analysis on the investigation of the linear relationship between the variables via ARDL approach. Series of stability and diagnostic tests are utilized to ascertain the robustness of the considered ARDL model. There is no departure from the standard assumption. Since the focal points of this study is to ascertain the mediation that are passed on to the ecological footprints from the selected variables (FDI, AGRIC, EU, GDP, and POP) in determination of the Indian environmental performance, the author considers the first model of the ARDL with Eq. 1, and LEFP as the dependent variable while other variables as the independent variables.

Descriptive statistics and stationarity estimates

Among the analyses is the descriptive statistics which is presented in Table 2.

From the descriptive analysis, the normality of the analysis by the disposition of the Jarque-Bera and Kutrtosis is respectively observed. Apart from the GDP and FDI with significant outcomes, all other variables are not significant in the case of Jarque-Bera, which shows the normality of the data and test. The result shows all the variables at less than 3 except for FDI which displays a light tail. In addition, the test result reports the mean, standard deviation, and maximum and minimum output with ecological footprint and population showing the highest mean, median, and maximum output. FDI displays the minimum output.

The next test was done to ascertain the stationarity features of the variables and make sure that none of the variables was integrated at order I(2), and the result is displayed in Table 3. This is to be on the same page with the requirement of NARDL that order I(2) is not established among the variables (Shin et al. 2014). The applications utilized in ascertaining the stationarity of this present study are Philip-Perron Perron 1990, augmented Dickey-Fuller (Dickey and Fuller 1979), Kwiatkowski et al. (1992), and Zivot and Andrew's (1992) structural break. The result of the above-mentioned tests showed that all the variables are integrated in order I(1) except the agriculture with a mixed order of I(0) and I(1). In other to avoid the problem of biased empirical results capable of emanating from the use of the traditional unit test approaches such as ADF, DF which are weak in the face of structural break, the current study adopts the structural break analysis. This is to accommodate intermediate shocks that have a permanent shock on the time series, and if possible, get rid of any illogical result from the conventional techniques. Zivot and Andrew's (1992) approach which is a modification of Perron's (1990) approach was utilized, and the result is presented in Table 4. With the application of the structural break analysis, it is observed that the variables have unit roots in the existence of the structural changes that took place in 2000, 1998, 20,006, 2004, 2001, 2002, 2007, 1989, and 2003. India as a country is known with much structural changes

Table 2 Descriptive statistics of the variables

	EFP	GDP	FDI	AGRIC	EU	POPULATION
Mean	8.25E+08	740.2745	0.700252	24.71105	397.7650	2.61E+08
Median	7.84E+08	606.0062	0.385015	25.90286	379.5178	2.52E+08
Maximum	1.51E+09	1645.326	3.620522	35.26954	637.4286	4.19E+08
Minimum	4.23E+08	372.6426	− 0.029682	16.74426	276.7077	1.33E+08
Std. Dev.	3.14E+08	369.6436	0.872115	6.040406	101.8962	85,125,237
Skewness	0.577278	1.011109	1.454391	0.029382	0.798869	0.247823
Kurtosis	2.327294	2.865908	4.722397	1.737652	2.686908	1.888339
Jarque-Bera	2.975887	6.845583	19.04610	2.661626	4.417987	2.469091
Probability	0.225837	0.032621	0.000073	0.264262	0.109811	0.290967
Sum	3.30E+10	29,610.98	28.01009	988.4420	15,910.60	1.04E+10
Sum Sq. Dev.	3.84E+18	5,328,818.	29.66277	1422.974	404,930.8	2.83E+17
Observations	40	40	40	40	40	40

Source: Authors' computation

which always leave them with permanent shocks. Over the sample period, the country adopted and implemented several economic and energy policies to improve its economic growth performance. Such policies include the liberalization policies of 1990s and 2000s which were targeted on the trade expansion and investment attraction to the economy for the

Table 3 Stationarity test

Variables	@ level		1st diff		Decision
	With intercept	Intercept and trend	With intercept	Intercept and trend	
ADF					
LNEFP	3.0653	− 0.7660	− 5.4297***	− 6.7342***	I (1)
LNGDP	11.3416	3.2836	− 1.9007	− 4.6874***	I (1)
LNEU	5.0385	1.2103	− 1.6588	− 5.4406***	I (1)
AGRIC	− 1.2667	− 2.4646	− 9.4296***	− 9.4152***	I (1)
FDI	− 1.3706	− 3.0261	− 7.3748***	− 7.1354***	I (1)
LNPOP	2.6816	1.1936	0.3150	− 2.2058**	I (1)
PP					
LNEFP	2.4167	− 0.4372	− 3.8835***	− 4.4320***	I (1)
LNGDP	− 0.8677	− 3.1395	− 7.0744 ***	− 6.8957***	I (1)
LNEU	− 1.1387	− 1.4931	− 6.7505***	− 7.3533***	I (1)
AGRIC	− 1.2398	− 3.4326*	− 8.0636***	− 7.9614***	I (1)
FDI	− 1.0017	− 2.5300	− 6.4526***	− 6.3099***	I (1)
LNPOP	− 1.981	− 2.911**	− 7.203***	− 2.161	I (0 and 1)
KPSS					
LNEFP	0.7842***	0.1860**	0.5209**	0.0715	
LNGDP	0.7417***	0.2096**	0.7332**	0.2366***	
LNEU	0.7430***	0.1756**	0.6104**	0.1286*	
AGRIC	0.7913***	0.0750	0.1622	0.0800	
FDI	0.6863**	0.1230*	0.0717	0.0567	
LNPOP	0.8084***	0.2143**	0.7711***	0.1496**	

Notes: *p* value according to MacLean and MacKinnon (1996); one-sided *p* values according to Kwiatkowski et al. (1992). Source: Authors' computation

*Significant at 10%; **significant at 5%; ***significant at 1%

Table 4 Structural breaks

Variable	ZA	p value	Lag	Break date	CV (1%)	CV (5%)
LEFP	− 4.41	0.02***	4	2000	− 5.57	− 5.08
LGDP	− 3.01	0.459	4	1998	− 5.57	− 5.08
FDI	− 5.65	0.046**	4	2006	− 5.57	− 5.08
AGRIC	− 3.47	0.045**	4	2004	− 5.57	− 5.08
LEU	− 4.442	0.001***	4	2001	− 5.57	− 5.08
LPOP	− 5.298	0.001***	4	2002	− 5.57	− 5.08
DLEFP	− 4.72	0.05**	4	2001	− 5.57	− 5.08
DLGDP	− 2.47	0.196	4	2002	− 5.57	− 5.08
DFDI	− 5.70	0.01***	4	2007	− 5.57	− 5.08
DAGRIC	− 3.22	0.152	4	1989	− 5.57	− 5.08
DLEU	− 4.44	0.05**	4	2002	− 5.57	− 5.08
DPOP	− 5.19	0.01***	4	2003	− 5.57	− 5.08

Notes: *p* value according to MacLean and MacKinnon (1996); one-sided *p* values. Source: Authors computation

*Significant at 10%; **significant at 5%; ***significant at 1%

wellbeing of the country. This really affected the local production and the entire economic performance of the country (India). As for the energy sector, the policies of abolishing the Administrative Price Mechanism (APM) on the 1st of April 2002 was instrumental for the availability of energy sources such as liquefied petroleum gas (LPG) and other oil for the masses and the manufacturing sectors at subsidized prices. The 1997/1998 global financial meltdown contributed to the Indian structural beak, and this date was accounted for in the analysis. The structural changes that took place in the banking sector in 1980–1990 because of the nationalization of the commercial private banks and the taking over of some distressed private banks by the central bank were part of the policies. Similarly, the involvement of the International Monetary Fund (IMF) in the local financial activities in India in 1990s positively impacted the economic performance of India's economy through increased capitalization stability of the financial sector.

Cointegration and diagnostic results

The ARDL results are displayed in Table 5. The goodness of fit of the analysis shows that the selected independent variables (GDP, FDI, AGRICULTURE, ENERGY USE, and POPULATION) explain 99.9% ($R^2 = 0.999110$) of the ecological footprints while the error term in the model accounts for the rest of the variations in the ecological footprints. The Durbin Watson (DW) test statistics is 2.545 approximately in affirmation of the nonappearance of autocorrelation in the model assessment which indicates that the selected independent variables in the model can describe the deviation in the dependent variable (EFP) in the absence of autocorrelation. The author observed the absence of heteroscedasticity problem from the model. The author equally found the CUSUM and CUSUM of squares well positioned, that is, the blue lines in both Figs. 1 and 2 well placed inside the two dotted red lines. These findings show the reliability, stability, and consistency of the empirical outputs. More also, this study found that F-statistics test is greater than the upper critical bound even at 1% level of significance for the case of ARDL. This confirms the existence of cointegration or long-run linear relationship among the selected variables for the period of 1975–2016. Even the t-statistics validates the existence of the cointegration among the variables at 1% significant level. These findings from both the F-statistics and t-statistics tests indicate the existence of a long-run symmetric relationship in the Indian ecological footprints. The results of both the long run and the short run are presented in a detailed way in Table 5. The table contains the result of the above-mentioned estimations and diagnostics. The optimal lag length selection was performed with the choice of the AIC as a selection criterion for its stronger features above other criteria (Shahbaz and Rahman 2012). The selected lag was 2, and it is considered good because of the sample size of the study. The result is with the author and will be made available on request. Among the findings of this analysis is the ECM which is highly significant at 1% significant level with a negative coefficient of 0.52 (− 0.52). This indicates the speed of regulation in re-establishing the disequilibrium in the dynamics model to equilibrium at − 0.52%, and the confirmation of the long-run relationship that exists among the variables. The effects of the explanatory variables on the LEFP are displayed in Table 6 and can be interpreted and explained with references as follows: a long-run (elasticity) positive and highly significant relationship between the economic growth and ecological footprint. Numerically, a 1% increase in economic growth impacts ecological footprint positively at the rate of 0.32%. This means that the economic performance of India is impacting negatively on its environment with the positive association established between EFP and GDP. In other words, as the economic growth is increasing positively, the environmental degradation is increasing. This finding supports the early stage (scale-effect stage) of the EKC theory which stated that at this stage, the country is encouraging economic growth at the expense of the environment because all attention is towards boosting economic growth which is typical of a developing economy like India. In other words, it is a reflection of economic growth and development without attention to the environmental implication of the growth. Some of the developing countries like India most times frame the policies on soft landing of foreign activities into their countries such as foreign investors and trade without the same measure on protecting the environment from any unduly activities from foreigners. The foreign investors will explore all the loopholes to increase their investment and manufacturing activities in

Table 5 ARDL assessments of EFP equation

Variables	Coefficients	SE	t-statistics	*p* value
Short path				
D(AGRIC)	0.012	0.002	5.682	0.0000***
D(AGRIC (− 1))	0.008	0.002	3.959	0.0005***
D(LEU)	0.371	0.132	2.805	0.0092***
D(LPOP)	7.832	1.205	6.495	0.0000***
CointEq(− 1)*	− 0.520	0.069	− 7.489	0.0000***
Long path				
LGP	0.315	0.084	3.763	0.0008***
FDI	− 0.008	0.005	− 1.496	0.1461
AGRIC	0.012	0.003	3.835	0.0007***
AGRIC (− 1)	0.0002	0.003	0.072	0.9426
LEU	0.371	0.168	2.202	0.0364**
LEU (− 1)	− 0.588	0.233	− 2.527	0.0177***
LPOP	7.832	2.444	3.205	0.0035***
C	4.551	2.193	2.075	0.0476**
R^2	0.999			
Adj. R^2	0.998			
D. Watson	2.5			
Bound test (long path)				
F-statistics	7.9***	$K = 5$, @ 1%	I(0)bound = 4.05	I(1)bound = 5.89
t-statistics	− 7.5***	$K = 5$, @1%	I(0)bound = − 3.4	I(1)bound = − 4.8
Wald test (short path)				
F-statistics	22.025***			
p value	0.000			
Serial correlation test				
F-statistics	3.966			
R^2	9.153			
p value	0.032			
Heteroscedasticity test				
F-statistics	2.002			
R^2	16.18			
p value	0.5313			

Sources: Authors' computation

*1%, **5%, ***10%—levels of rejection of the null hypothesis

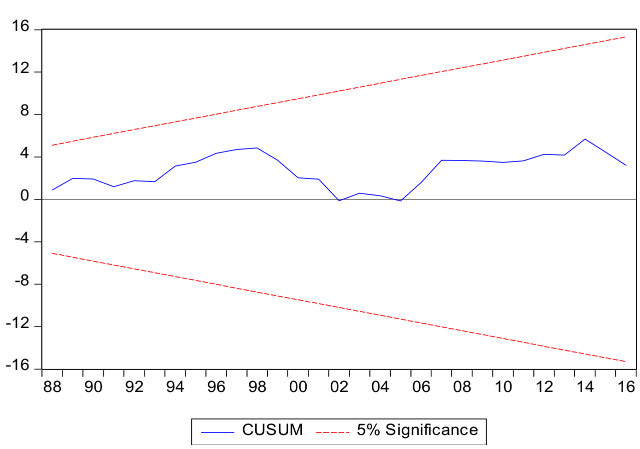

Fig. 1 CUSUM residual graphical plot

the country with less concern on maintaining the environment with clean energy. This finding is in consonance with the works of Alola et al. (2019) for large economies of Europe, Emir and Bekun (2019) for Romanian, and Udemba et al. (2019) for China. A long run (elasticity) negative but not significant is observed between ecological footprint and foreign direct investment. This is a good trend for both the economic and the environmental performance of the country even though the negative relationship that exists between the ecological footprint and FDI is not yet significant; so far, there is a long-run relationship between the two indicators. This is a typical example of a transition economy where there is awakening of consciousness of the masses on the need for a cleaner energy for a better environment. This can be seen from the

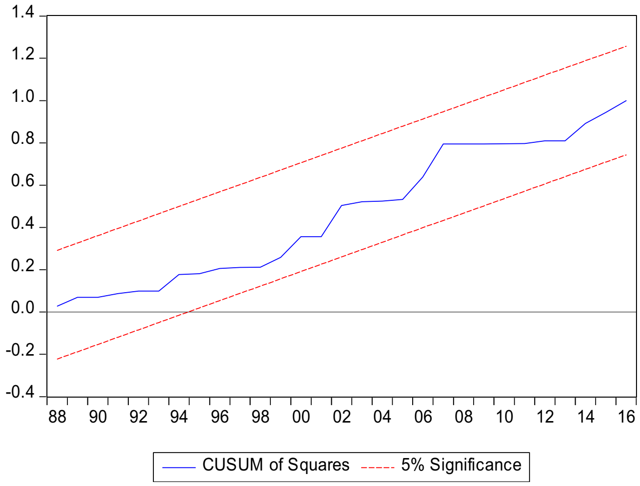

Fig. 2 CUSUM square residual graphical plot

second (structural- or composition-effect stage) stage of the growth and development as derived from the EKC theory. At this stage, there is a shift from crude means of handling some sectors of the economy such as agriculture to a more industrialized means with manufacturing sectors and investments (domestic and foreign) rising more than the other sectors. This output is in affirmation with the exposés of Zhang (2018), Danish and Wang (2018), Sarkodie and Strezov (2019), Udemba et al. (2019), and Muḥammad and Balsalobre (2019) for MENA, Paramati et al. (2017) for EU, G20 and, OECD, Pazienza (2015) for OECD, and Udemba et al. (2019) for Indonesia. Also, the agricultural sector is found to be impacting negatively on the environmental performance of India with a positively significant relationship (both in the short and long run) that exists between the agricultural sector and ecological footprint. Numerically, a 1% increase in agricultural activities (*as it relates to both fishing and forest activities*) increases the ecological footprint by 0.12%. This amounts to an increase in the environmental dilapidations in India. The finding supports the findings of Dogan (2016) for Turkish, Liu et al. (2017) for ASEAN, and Ullah et al. (2018) for Pakistan. This is very much understood in the case of a highly populated country like India whose majority of its masses are into agricultural activities such as farming, fishing, and cattle rearing. Most of these activities such as rice farming which involves the usage of fertilizers and other chemical substances for a quick and large production contaminate the environment. Fishing and cattle rearing contaminate the water bodies and impact negatively on the grazing lands, and all these are part of the ecological footprint. The author also found a positive and highly significant relationship (short and long runs) among energy use, population, and ecological footprint. Both variables (energy use and population) are observed to be impacting negatively on the environmental performance of India with a positive relationship that is already established between the variables and the ecological footprint. This is not far-fetched from the definition of the ecological footprint by the Global Footprint Network (2018) as it relates to population. Ecological footprint is described as the extent of a geographical area of organically useful earth and water, a group of people (population), or action needed to yield all the resources it consumes. Among the pronounced features of India is its population which is among the determinant factor of environmental performance through the activities of the populace in other sectors (e.g., agricultural sector) and the energy utilization of the population. According to statistics from the Carbon Brief Profile (Timperley 2019), India is home to 18% of the world's population, but has only 2.4% of land area with a great amount of pressure being placed on all the country's resources. This is part of the definition of the ecological footprint. Numerically put, a 1% increase in population increases the ecological footprint by 7.8%. India as a country on the speed lane of economic growth increased its energy consumption from different sources mainly nonrenewable energies such as coal, crude oil, and others. These nonrenewable energies emit higher percentage of pollutant emissions into the environment via air which hamper the positive performance of the environment. This can be seen from among the policies of the Indian government in the energy sector. This comes with the abolishing of the Administrative Price Mechanism (APM) on the 1st of April 2002 which was instrumental for the availability of energy sources such as LPG and other oil for the masses and the manufacturing sectors at subsidized prices. Such policies trigger the energy consumption which when it is not moderated, affect the environmental performance negatively, and this is the picture of the finding of this study with positive relationship that exists between the energy use and ecological footprint. Numerically, a 1% of increase in energy use increases the ecological footprint by 0.3%. This finding

Table 6 Bound with *F* test linear and nonlinear cointegration

F test output for the ARDL models			*F* test output for the NARDL models		
Cointegration hypothesis	F-statistics	Upper bound	Cointegration hypothesis	F-statistcs	Upper bound
$F(LEFP_t/LGDP_t, FDI_t, AGRIC_t, LEU_t, LPOP_t)$	7.9***	5.2	$F(LEFP_t/LGDP_t^+, LGDP_t^-, FDI_t^+, FDI_t^- AGRIC_t^+, AGRIC_t^-, LEU_t^+, LEU_t^-, LPOP_t^+, LPOP_t^-)$	5.7	7.2

supports the findings of Al-Mulali et al. (2015) for the 14 MENA; Ozturk et al. (2016) for the case of 144 countries; Bekun et al. (2019) for 16 EU countries; Saint Akadiri et al. (2019) for Saudi Arabia; and Sarkodie and Strezov (2019) for developing countries.

However, the findings of this study cut across different sectors ranging from the agricultural sector to the energy sector with interesting relationships which expose the hiding nature of environmental performance and call for a good policy frame work targeting the reduction of ecological footprint.

Diagnostic tests (CUSUM and CUSUM of squares)

Granger causality

The linear ARDL estimation and analysis can only indicate the relationship impact among the selected variables but lack the power to exhibit the direct transmission or feedback that exist among the variables. Even though ECM is considered a test of short-path causality among the variables, it is not sufficient to determine the direct transmission between the variables. This led to the adaptation of the Granger causality to explicitly show the direct transmission among the variables. However, this present study does not entirely depend on the Granger causality. The author applied many methods (*of which the Granger causality is among them*) in trying to arrive at efficient results and validation of the findings. The author applied the Granger causality for a clear identification of the direction in the relationship that exists between the dependent and independent variables and to determine the variable that causes the other.

The author applied VAR approach to estimate the Granger causality. The current paper adopts the Block exogenuity Wald test (long-path causality) for the Granger causality test, and the output is seen in Table 7.

The output of the causality estimation is presented in Table 7. The output gives credence to the findings of the EFP model of Eq. (1) which is displayed in the linear ARDL table. The result shows a one-way transmission passing to EFP from EU, FDI, AGRIC, and POPULATION. Also, a one-way causality is seen passing to GDP, AGRIC, and POPULATION from energy use and from population to agriculture. A more interesting result is the two-way transmission passing between energy use and foreign direct investment. This shows that both variables are impacting each other directly and to the good of both economic performance and environmental performance; hence, energy use is transmitting to GDP, and FDI has a negative relationship with ecological footprint depicting reduction of environmental damage as FDI upsurge. These outcomes indicate that the ecological footprint of India is determined by the selected variable (energy use, foreign direct investment, agriculture sector, and population). The finding really exposes the direction of the relationship that existed among the variables. This finding also exposes the impact of energy utilization in India, and this supports the cited structural break impact of energy reform policy of 2000s which sees the leveraging of the price of the energy sources and making it accessible by both individuals and industries. Hence, energy use is transmitting to GDP, AGRIC, and POPULATION. The typical example of the ecological footprint is the impact of the population on the land and water and to the resources as put by Global Footprint Network (2018). This is not far-fetched from the definition of the ecological footprint by the Global Footprint Network (2018) as it relates to population. These findings support the findings of Al-Mulali et al. (2015) for the 14 MENA, Ozturk et al. (2016) for the case of 144 countries, Bekun et al. (2019) for the 16 EU countries, and Sarkodie and Strezov (2019) and Udemba (2019) for China.

Conclusion

According to the Carbon Brief Profile report (Timperley 2019), India has been identified as the world's 3rd largest emitter of GHGs after China and the USA. Its emissions are derived from energy sources such as coal power plant, rice factories, and cattle farming, and all these sources are classified under index as ecological footprint. Following the Paris Agreement and India's pledge as among the stakeholders at the global climate talks, and how fast India ratified the Paris Agreement within a year on the 2nd of October 2016, it is essential to investigate the country's (India) commitment in reducing its emission towards enhancing a positive environmental performance. Recently, there is increased awareness in renewable or clean-energy investments because of environmental concerns. Previous researches on the performance of the environment have been focused on the utilization of single indicator such as pollutant emission, carbon emissions, fossil fuel, and others to proxy and measure the environmental impact which is weak in giving a clear and total submission of the dilapidations in the environment. Following this pitfall on the side of measuring the environmental effect, this present paper has considered ecological footprint a more reliable indicator for accounting for environmental quality because of its accommodation of many emission sources as one indicator. The current paper utilizes different approaches to see to the richness of the study. Both linear ARDL (symmetric) and nonlinear ARDL (asymmetric) were selected simultaneously for this study, but at a later stage after bound cointegration estimation, the NARDL was dropped because of its inability to sustain the claim of cointegration from the model of our interest (EFP model) in the analysis. The rest of the analyses were based on liner ARDL model (short and long runs) with diagnostic tests, the Granger causality estimation. The study and the results derived are consistent with the hypothesis of

Table 7 Causality test/block erogeneity Wald test (long-path causality)

Null hypothesis	Causality	Chi-sq	Prob	Remark paths	Decision
EFP does not Granger cause GDP	No	2.609	0.271	NEUTRA GDP ≠ CO_2	ACCEPT H_0
GDP does not Granger cause EFP		0.759	0.684		
EU does not Granger cause EFP	Yes	9.768	0.008***	Uni-direction EU → EFP	REJECT H_0
EFP does not Granger cause EU		2.084	0.352		
FDI does not Granger cause EFP	Yes	8.613	0.041**	Uni-direction FDI = EFP	REJECT H_0
EFP does not Granger cause FDI		2.081	0.353		
AGR does not Granger cause EFP	Yes	7.410	0.041**	Uni-direction AGR → EPP	REJECT H_0
EFP does not Granger cause AGR		0.018	0.992		
POP does not Granger cause EFP	Yes	7.463	0.033**	Uni-direction POP → EPP	REJECT H_0
EFP does not Granger cause POP		0.173	0.917		
EU does not Granger cause GDP	Yes	6.618	0.036**	Uni-direction EU → GDP	REJECT H_0
GDP does not Granger cause EU		0.515	0.773		
EU does not Granger cause FDI	Yes	6.602	0.049**	Bi-direction EU → ← FDI	REJECT H_0
FDI does not Granger cause EU		7.618	0.018***		
EU does not Granger cause AGR	Yes	14.6	0.001***	Uni-direction EU → AGR	REJECT H_0
AGR does not Granger cause EU		0.667	0.797		
EU does not Granger cause POP	Yes	12.235	0.002***	Uni-direction EU → POP	REJECT H_0
POP does not Granger cause EU		0.616	0.798		
FDI does not Granger cause GDP	No	0.534	0.765	Neutral GDP ≠ FDI	ACCEPT H_0
GDP does not Granger cause FDI		3.326	0.186		
AGR does not Granger cause GDP	Yes	1.859	0.311	Uni-direction GDP → AGR	REJECT H_0
GDP does not Granger cause AGR		11.411	0.003***		
POP does not Granger cause GDP	No	0.362	0.307	Neutral POP ≠ GDP	ACCEPT H_0
GDP does not Granger cause POP		3.859	0.240		
POP does not Granger cause AGR	Yes	6.676	0.037**	Uni-direction POP → AGR	REJECT H_0
AGR does not Granger cause POP		4.859	0.111		

Notes: The statements under null hypothesis are all definitions of hypothesis which will be valid or not based on the outcome of *p* value and expressed in the decision. The decision is made at 5%. The remark paths clearly show the direction of the causal effects (bi-directional or unidirectional)

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$

this work which is in line with the expectations of the author except for the case of foreign direct investment which is impacting favorably on the environmental performance with the establishment of a negative relationship with the ecological footprint. This is a good story for the Indian authority; it shows the consciousness of policy makers in framing environment-friendly policies in line with foreign investors' engagements in the country. The output from both ARDL and the Granger causality points out that India is still in between the scale-effect stage and the transitional stage of development with much interest in economic growth and development but little or no interest in the environmental performance, hence the economic growth (GDP) is increasing (positive) and the ecological footprint is increasing (positive). The findings of this study portray the sensitivity of energy use in India's economic and environmental performance, hence energy is transmitting directly to all the variables (AGRIC, ENERGY USE, and POPULATION) with a feedback transmission existing between energy use and foreign investment (FDI), and also, a positive link is established between energy use and the ecological footprint. The agriculture and population which are considered main ingredients in the formation of ecological footprint are consistent with the author's hypothesis; hence, the output in both ARDL (positive link to EFP) and Granger causality (one-way causality from AGRIC and POPULATION to ECOLOGICAL FOOTPRINT) depicts the author's claim and hypothesis.

At this point, the policy development and implementation of India should focus on attracting and regulating FDI with a good environmental condition. The policy will look towards sustaining both economic performance and good environmental performance: increase taxation on the energy sources that emit high pollution while reduce tax on the low carbon energy sources. The Indian authority should look into the agriculture sector and the population and frame a policy that will encourage the boosting of the agricultural performance with less harm to the environment as this sector is seen as a very vital sector in India. A campaign to discourage population growth such as child birth control is needed in a country like India. Again, there is a need for a revisit to energy policy in India as energy use is seen dominating all the sectors in India. Policies that will see to the shifting of energy use to a cleaner energy sources such as wind and solar energy sources are to be framed and implemented.

Conclusively, as India is working towards achieving its economic target, the country should also up its game in bettering its environmental performance.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Appendix

Definition of terms

Terms	Full meaning
ARDL	Autoregressive distributed lag
NARDL	Nonlinear autoregressive distributed lag
FDI	Foreign direct investment
GC	Granger causality
GDP	Gross domestic product (rep. as GDP per capita)
EFP = ecological footprint	Ecological Footprint (The Global Footprint Network (2018) describes the ecological footprint as “a measure of how much area of biologically productive land and water an individual, population, or activity requires to produce all the resources it consumes and to absorb the waste it generates, using prevailing technology and resource management practices).”
CO_2 = carbon emission	Carbon emission (according to World Bank (2018), carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.)
Pollution = environmental degradation	According to Environmental Management (2017) “Environmental pollution is defined as ‘the contamination of the physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected’.”
AIC	Akaike Information Criterion
ADF	Augmented Dickey-Fuller test
PP	Philip-Perron
KPSS	Kwiatkowski-Philip-Schmidt-Shin
EU	Energy use
DW	Durbin Watson
POP	Population
CUSUM and CUSUM square	Cumulative sum and cumulative sum square

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