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Exploring the Effects of Economic Complexity and the Transition to a Clean Energy Pattern on Ecological Footprint From the Indian Perspective

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The study explores the association between economic complexity, globalization, renewable and non-renewable energy consumption on the ecological footprint in the case of India from 1990–2018. The autoregressive distributed lag (ARDL) is applied to measure the long-run elasticity, while the vector error correction model (VECM) is applied to classify the causal path. The empirical findings demonstrate that economic complexity, globalization process, and renewable energy consumption play a dominant role in minimizing environmental degradation. In contrast, economic growth and non-renewable energy consumption are more responsible for increasing the pollution level in both the short and long run. Furthermore, the VECM outcomes disclose that there is long-run causality between ecological footprint and economic complexity. Moreover, the empirical outcomes are robust to various robustness checks performed for analysis to the consistency of our main results. The Indian government/policymakers should encourage a more environmentally friendly production process and eco-friendly technologies in exports to minimize environmental degradation.

Keywords: economic complexity, globalization, renewable energy, non-renewable energy, ARDL, India

1 INTRODUCTION

One of the greatest challenges to humankind is environmental degradation which has attracted global attention widely. Environmental challenges such as; global warming, greenhouse gas (GHG) emissions, air pollution, and climate change withstood at the heart of the worldwide agenda of the past 2 decades, particularly amid the COVID-19 pandemic (Yang et al., 2021a). In order to curb environmental degradation, the Kyoto Protocol and Paris Agreement put restrictions on the signatory countries such as environmental regulations, environmental taxes, and promotion of environmentally friendly technologies. Since these global agreements and protocols bound the signatory countries to strive for environmental protection, researchers have documented various aspects of environmental sustainability. In addition, researchers have proposed various factors that are effective in mitigating environmental pollution (Jahanger et al., 2021a; He et al., 2021). One of the greatest threats to the global environment is GHG emissions (Usman et al., 2021a). GHG emission is a threat to human health and the entire ecosystem. In addition, carbon dioxide (CO_2) emission is the major contributor to global anthropogenic GHG, and most of the literature has used CO_2 as a proxy for environmental degradation.

However, the usage of CO_2 emissions as a proxy to capture the environmental damage caused by economic growth received massive criticism and represented a vast debatable topic. Many researchers argued that CO_2 only captures a part of the considerable damage caused by the economic growth that is, ruining the planet (Kamal et al., 2021; Khalid et al., 2021; Qader et al., 2021; Usman and Makhdum, 2021). Furthermore, from a sustainability point of view, CO_2 is not a suitable measure of remnants induced by economic progress. Besides air, the quality and quantity of soil, forest, and water are also vulnerable and need attention. Similarly, researchers have argued that the stock of oil, forest, and mining are ignored if merely focused on CO_2 emissions. These are also important for future generations; therefore, it is not an inclusive proxy. Recently, a more comprehensive indicator that involves water and land pollution is required to cater to the requirement of efficient policy guidelines to curb environmental degradation (Pata and Caglar, 2021). Against this backdrop, the ecological footprint first introduced by (Rees, 1992) serves all the requirements mentioned above of an inclusive, cumulative, and holistic measure of environmental damage caused by humans. This indicator represents human demand from the ecosystem and has six components; crop-land, forest, grazing, fishing, built-up land, and carbon emissions. As a policy tool, the ecological foot is regarded as a better proxy of environmental degradation that offers a more holistic and comprehensive measure of pressure on nature caused by human consumption (Ikram et al., 2021). If the natural resources are consumed faster than they are regenerated, an ecological footprint deficit will occur (Mrabet and Alsamara, 2017). The ecological footprint is a useful measure of resource sustainability and the international distribution of resources consumption (Usman and Hammar, 2021). On the basis of these arguments and discussions existing in previous literature (Al-Mulali et al., 2015), the ecological footprint is acknowledged as a mature and aggregate metric of environmental sustainability and humans' pressure on nature.

Various factors can affect ecological footprint, which includes but are not limited to economic growth (Aşıcı and Acar, 2016), economic complexity (Aşıcı and Acar, 2016), renewable and non-renewable energy (Kongbuamai et al., 2021), and globalization (Figge et al., 2017). The widely covered is economic growth as a factor affecting ecological footprint (Usman et al., 2020a). The literature that covers the nexus between environmental pollution and economic growth is widely available within the framework of the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model framework (Jahanger et al., 2021a) and the environmental Kuznets curve (EKC) (Usman and Jahanger, 2021). Reducing pressure on nature without compromising on continued economic growth is a challenge for policymakers worldwide. For sustainable economic growth in a country, structural changes in various sectors of the economy require the energy mix to transform accordingly (Neagu, 2020). Therefore, economic growth is mainly linked with energy consumption, resulting in a considerable challenge for the environment (Aşıcı and Acar, 2016; Usman and Jahanger, 2021).

In the same vein, energy from fossil fuels is found as an essential source of environmental pollution. A plethora of research has documented the harm of pollution caused by burning fossil fuels (Bölük and Mert, 2014; Ikram et al., 2021). According to a recent International Energy Agency report, from 2017 to 2040, global energy consumption will increase by 30% (IEA, 2017). Prior to the World pandemic, India's energy demand was anticipated to enhance by nearly 50% between 2019 and 2030, but economic growth over this period is now closer to proximately 35% in the STEPS and 25% in the Delayed Recovery Scenario (India Energy Outlook, 2021). In this context, it is recommended by international organizations (energy information agency and British Petroleum) and global treaties (Kyoto protocol, Paris agreement) that fossil fuels should be replaced with renewable energy sources (Hák et al., 2016). On the other hand, renewable energy is widely hailed for reducing ecological footprints (Alper and Onur, 2016). Because of its benefits for the environment, renewable energy has been increasing in the global energy mix.

The benefits of globalization for economic growth are obvious; however, its sensitivity towards the environment is a challenge for policymakers (Ahmed et al., 2019). With the rise of globalization since World War II, the world has been transforming into a global village (Ahmed et al., 2021a). Globalization has changed the world from self-constrained economies to more interdependent ones. On the one hand, globalization enhances economic growth; however, it is a serious issue to be considered from the environmental management point of view (Dreher, 2006). Notably, if clean and green technology is used in consumption and production, globalization may not harm the environment. It is, therefore, important for policymakers to understand the globalization-environmental nexus to control environmental degradation using globalization as a policy tool (Usman and Jahanger, 2021).

In addition, the recent development of economic complexity enhanced our understanding of competitiveness and production structure in a country as well as knowledge associated with it. Economic complexity is a non-monetary metric expressed in the composition of a country's productive output and reflects the structures that emerge to hold and combine knowledge (Hausmann et al., 2014). The concept of economic complexity explains the sophistication of productive structure based on two sub-concepts; diversity and ubiquity. By diversity, it includes how many products are exported to other countries? And ubiquity means the number of countries that export these products (Hidalgo and Hausmann, 2009; Ahmed et al., 2021b). Therefore, the basic intuition behind the idea of economic complexity is that sophisticated economies have diversified exports and a smaller number of other countries export the same products.

On the other hand, economies that are exporting less of those rarely exported products have less economic complexity. The countries that show high economic complexity are those with

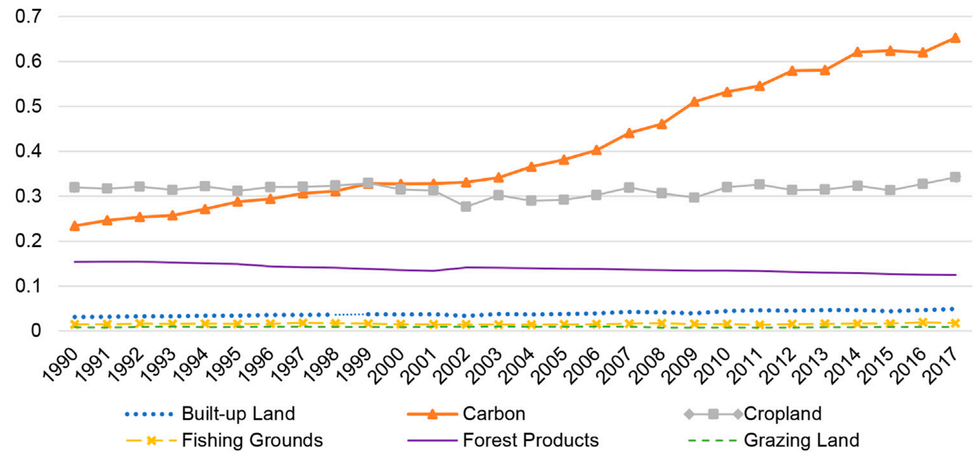

FIGURE 1 | The trends in crop-land, forest, grazing, fishing, built-up land, and carbon footprint.

rapid economic growth and high energy consumption (Hausmann et al., 2007; Ferrarini and Scaramozzino, 2016; Shahzad et al., 2021). Being the country with the highest economic complexity, India seems to be a good case study for our analysis. The graphical outlook of six components of ecological footprint such as crop-land, forest-land, grazing-land, fishing grounds, built-up land, and carbon footprint trends over the study period is presented in **Figure 1**.

The choice of India for the current investigation is pertinent for numerous reasons. According to the Global Carbon Project (2020) reports, the largest contributions to global CO_2 emissions in the atmosphere are approximately China 28%, the United States 14%, and India 7% (GCB, 2020). These three economies spread 49% of global fossil CO_2 emissions, while the rest of the global contributed 51%. Moreover, CO_2 emissions are driven by energy, and India has achieved quick economic growth via high utilization of energy. India is the 3rd biggest global energy consumer after China and the United States (GER, 2020). Primary energy utilization in India rose by 8% in 2018. Around 80% of electricity generation derives from fossil fuels. Besides, with renewable energy production contributing 208 Mtoe in 2016, India classified 2nd number after China (IEA, 2018). India tops the fastest-growing economies leading up to 2025 and is projected to grow at 4.4% annually.

The major contribution of the present study is in three folds; firstly, there is no study on India focused on the association between pollution and economic complexity in the context of globalization. Secondly, to the best of the author's knowledge, this is the first study to analyze an emerging developing country's (EDC) CO_2 emissions, economic complexity, and globalization nexus. Thirdly, the policy guidelines suggested by the present study for India are based on disaggregated energy information which is rare for India in the context of globalization. The up-to-date series data is used for econometric examination such as autoregressive distribution lag (ARDL) approach and then inspection the causal relationship among the concern variables through the Vector error correction model (VECM) Granger causality approach. Besides, we have used the path analysis model to predict the direct and indirect relationship between the variables. Additionally, this paper also used Fully Modified Ordinary Least Square (FMOLS), Dynamic Ordinary Least Square (DOLS), and Canonical Cointegration Regression (CCR) approaches to examine the robustness check of our main findings.

The remaining part of the paper follows; **Section 2** provides a brief review of literature related to economic complexity, globalization, and energy concerning environmental pollution, particularly ecological footprints. Later, **Section 3** discusses the data and methodology used in this research. Subsequently, **section 4** offers details of empirical findings and insights obtained from it. Lastly, **section 5** carries the conclusion along with policy implications.

2 LITERATURE REVIEW

The dynamic nexus between economic complexity, renewable and non-renewable energy utilization, globalization, economic growth, and the ecological footprint has been documented in various empirical studies. This study parts the previously published literature into the following sub-sections with these subheadings: 1) The economic complexity-environment nexus; 2) The globalization-economic growth-environment nexus 3) The renewable and non-renewable energy utilization-environment nexus. We discuss these in detail below.

2.1 The Economic Complexity-Environment Nexus

According to Boleti et al. (2021), high economic complexity implies a shift from a low-productivity agricultural economy to higher-productivity sectors and the production of more sophisticated products. This shift necessitates enlarged utilization of energy resources, which contributes to raising ecological footprint and environmental pollution. A few studies conducted in the last years have examined the association between environmental degradation and economic complexity. For instance, Romero and Gramkow (2021) discuss the economic complexity-environment nexus. The result confirmed that economic complexity has a negative impact on environmental degradation. On the contrary, a strand of literature discovered that economic complexity increases environmental pollution in the case of top economic complexity countries (Abbasi et al., 2021). On the other hand, the economic complexity-emission nexus was investigated by Balsalobre-Lorente et al. (2021). The result of the examination shows that economic complexity enhances the level of environmental degradation. Along with this, there is a study for the United States where economic complexity and energy utilization significantly enhance environmental pollution (Shahzad et al., 2021). Furthermore, economic complexity enhances environmental degradation in low-income countries. At the same time, it significantly minimizes the environmental pollution for upper-middle- and high-income countries, as was examined by Adedoyin et al. (2021). Additionally, the economic complexity-renewable consumption in 16 major exporting economies was investigated by Zheng et al. (2021). The findings display that economic complexity contributes to the carbon neutrality goal. Similarly, Boleti et al. (2021) analyzed the association between economic complexity and environmental degradation in 88 global samples. The outcomes investigated that higher levels of economic complexity led to better overall environmental performance. Moreover, Ahmad et al. (2021) show that economic complexity enhances environmental pollution by worsening ecological footprint, while a high level of economic complexity alleviates environmental degradation. In summary, the influences of economic complexity on environmental degradation are mixed as a consensus is yet to be reached in the literature. Based on the outcomes from the above studies, the first hypothesis is specified as follows:

Hypothesis H1: The existence of a negative effect of economic complexity on the ecological footprint.

2.2 The Globalization-Economic Growth-Environment Nexus

Theoretically, the existing published literature documented three channels through which globalization influence the environment: scale, composition, and techniques (Yang et al., 2021a; Jahanger et al., 2021b). The scale effects emerge when liberalization causes an increase in economic growth that enhances the utilization of energy and thus increases CO_2 emissions due to globalization. The composition channel proves that the influence of globalization on CO_2 emissions depends on the disparities of the industrial system that can vary from country to country due to globalization (Yang et al., 2021b). Moreover, the technique effect demonstrates that globalization could influence the environment through many channels. For instance, technology (eco-friendly) shifts from one country to another due to globalization (Yang et al., 2021c). However, other empirical studies have described a negative effect of globalization on environmental quality (Yang et al., 2021b). Their empirical indication is that globalization significantly leads to degradation of the environmental quality since most of the industries are based on fossil fuel (oil, coal, and natural gas) energy consumption in the sample countries. Many other studies, i.e., Mehmood et al. (2021), Yang et al. (2020), have supported the view that globalization reduces environmental dilapidation due to eco-friendly technologies. Moreover, Saint Akadiri et al. (2020) claimed that globalization has no significant impact on the environment in the case of Turkey. Furthermore, Kihombo et al. (2021) analyzed the association between financial development, urbanization, and ecological footprint in West Asia and the Middle East (WAME) countries. The outcomes proved that financial development stimulates ecological degradation while urbanization raises ecological footprint levels and contributes adversely to ecological performance. Moreover, Ahmed et al. (2021c) indicated that overall globalization and economic globalization enhance environmental degradation while social globalization improves the environment. Furthermore, positive shocks to political globalization stimulate environmental degradation. Based on the relevant studies on the globalization-environmental degradation nexus, the second hypothesis to be tested in this study is as follows:

Hypothesis H2: The existence of a negative effect of globalization on the ecological footprint in India.

2.3 The Renewable and Non-Renewable Energy Utilization-Environment Nexus

Shafiei and Salim (2014) investigated the nexus between renewable, non-renewable energy utilization and environmental degradation. Their empirical result indicates that non-renewable energy utilization enhances environmental degradation, whereas renewable energy utilization minimizes environmental pollution in the case of OECD countries from 1980 to 2011. Nathaniel and Iheonu (2019) demonstrate that in the long run, renewable energy utilization prevents environmental degradation insignificantly, whereas non-renewable energy utilization enhances environmental pollution significantly in the case of Africa. In the case of Pakistan, Hussain and Rehman (2021) find that environmental degradation has an adverse interaction with renewable energy utilization, while FDI and population show a positive association with environmental pollution. Furthermore, Usman et al. (2020b) investigate the relationship between environmental degradation and financial development, renewable and non-renewable energy utilization in the top fifteen emitting countries. The long-run elasticity outcomes attained using the AMG method demonstrate that financial development and renewable energy utilization help to minimize environmental pollution. Besides, Usman and Makhdum (2021) explored that non-renewable energy utilization and financial development increase environmental degradation, whereas renewable energy utilization significantly improves environmental quality. Destek and Sinha (2020) concluded that enhancing renewable energy utilization minimizes environmental degradation, and enhancing non-renewable energy utilization raises environmental pollution in the case of 24 OECD countries. Kirikkaleli and Adebayo. (2020) outcomes display that renewable energy utilization and financial development have a long-run significant positive effect on

TABLE 1 | Summary of the published literatures between EC, NRE, RNE, GLO, GDP-environment nexus.

Authors	Countries	Period	Variables	Methods	Findings
A) The economic complexity-environment nexus					
Romero and Gramkow, (2021)	67 countries	1976–2012	GHG, and NRE	Fixed effect, and GMM method	EC help to minimize environmental degradation
Abbasi et al. (2021)	18 countries	1990–2019	CO_2, TUR, GDP, and EPI	CS-ARDL, and AMG	EC and GDP increase pollution level while TUR and EPI reduce it in the long run
Shahzad et al. (2021)	USA	1965–2017	EC, EF, and FFE	QARDL approach	EC and FFE significantly increase ecological footprint
Ikram et al. (2021)	Japan	1965–2017	EC, GDP, and EF	QARDL approach	EC and GDP have an asymmetric positive impact on EF.
Doğan et al. (2021)	28 OECD countries	1990–2014	EC, and REN	DOLS, FMOLS approach	EC and RENG might help in mitigating the environmental pollution problems
Rafique et al. (2021)	Top 10 complex countries	1980–2017	EF, NRE, HC, URB, REN, GDP, and EXP	DOLS, and FMOLS approach	EC, GDP, TRD and URB, increase environmental degradation while HC and REN help mitigates environmental pollution
Balsalobre-Lorente et al. (2021)	PIIGS countries	1990–2019	EC, FDI, REN, URB, and CO_2	DOLS method	The EC based environmental Kuznets curve and pollution heaven hypotheses are validated, and REN reduces CO_2 emissions
He et al. (2021)	Top 10 energy transition countries	1990–2018	EC, GLO, REN, and CO2	CS-ARDL and CCEMG estimators	EC, GLO, REN significantly protect the environmental quality in the short- and long-run
B) The globalization-economic growth-environment nexus					
Usman et al. (2022)	10 Financially resource-rich countries	1980–2018	FD, NR, GLO, NRE, REN, and EF	CCMG, and AMG approach	FD, NR, and NRE positively affect environmental pollution, while GLO and REN reduce pollution
Kamal et al. (2021)	105 countries	1990–2016	GLO, FD, and GDP	DOLS, and FMOLS method	GLO, FD and GDP significantly increase environmental pollution in the long-run
Kirikkaleli et al. (2021)	Turkey	1990–2018	GLO, GDP, and EF	Dual-adjustment approach	GLO impacts environmental degradation positively in the long run, while environmental pollution is negatively affected by GDP in both the short and the long run
Yang et al. (2020)	97 countries	1990–2016	RMT, NRE, GLO, and CO_2	GMM method	RMT and NRE increase environmental pollution; however, GLO reduces environmental degradation
Khalid et al. (2021)	SAARC countries	1990–2017	EF, TRD, NRE, FD, REN and GDP	AMG and CCEMG approach	GDP and NRE significantly deteriorate the atmosphere quality in the long-run
Mehmood et al. (2021)	5 South Asian countries	1965–2016	GDP, NRE, GLO, and CO_2	ARDL approach	GDP and NRE increase environmental degradation, while GLO can bring innovation in cleaner technologies, improving environmental quality
Pata and Caglar, (2021)	China	1980–2016	GLO, TRD, INC, HC, and CO_2	ARDL approach	GLO, TRD, and INC drive environmental pollution, while HC enhances the environmental quality
C) The renewable and non-renewable energy utilization-environment nexus					
Shafiei and Salim, (2014)	29 OECD countries	1980–2011	NRE, REN, and CO_2	AMG method	NRE increases environmental degradation, whereas REN decreases environmental pollution
Nathaniel and Iheonu, (2019)	19 African countries	1990–2014	REN, NRE, and CO_2	AMG estimator	REN inhibits environmental degradation insignificantly, whereas NRE increases environmental pollution
Usman et al. (2020b)	15 Highest emitting countries	1990–2017	FD, REN, TRD, GDP, NRE, and EF	MG, AMG, and CCEMG approach	FD, REN and TRD significantly contribute to overcoming pollution, while GDP and NRE increase pollution levels
Usman et al. (2020c)	20 Highest emitting countries	1995–2017	EF, FD, TUR, NRE, and GDP	AMG, PMG, and FMOLS	FD and NRE enhance the pollution level, while TOU reduces IT.
Usman and Makhdum, (2021)	BRICS-T countries	1980–2018	NENG, FD, REN, and EF	AMG and CCEMG estimators	NRE and FD increase pollution levels, while REN significantly improves environmental quality
Hussain and Rehman, (2021)	Pakistan	1975–2019	CO_2, FDI, and POP	ARDL approach	CO_2 has an adverse relation with REN while the variable FDI and POP showing a positive association with environmental degradation
Usman et al. (2021b)	20 Asian countries	1990–2014	EF, GDP, NRE, FD, REN, and TRD	MG, AMG and CCEMG estimators	NRE, and GDP significantly accelerate the EF and RNE reduces the total EF in the long-run

(Continued on following page)

TABLE 1 | (*Continued*) Summary of the published literatures between EC, NRE, RNE, GLO, GDP-environment nexus.

Authors	Countries	Period	Variables	Methods	Findings
Usman et al. (2021c)	7 South Asian countries	1995–2017	GDP, NRE, REN, TUR, and CO_2	FMOLS and D-H causality approach	GDP, NRE, and TUR development significantly increase the CO_2 emissions. However, REN has some ability to protect the environmental quality

Note: GHGs represents the Greenhouse gases; EC stands for economic complexity; CO_2 denotes the carbon emission; TUR expresses the tourism; GDP stands economic growth; URB stands for urbanization process; EPI stands for energy prices indices; GMM stands for generalized method of moments; CS-ARDL stands for cross-sectionally augmented autoregressive distributed lag; MG stands for mean group; AMG stands for Augmented Mean Group; CCEMG stands for common correlated effect mean group; QARDL stands for quantile autoregressive distributed lag; D-H stands for Dumitrescu and Hurlin causality; EF stands for ecological footprint; FFE stands for fossil fuel energy use; OECD expresses the Organisation for Economic Co-operation and Development; SAARC shows the South Asian Association for Regional Cooperation; POP stands for population; FMOLS represents the Full Modified Ordinary Least Square; DOLS represents the Dynamic Least Square; ARDL represents the Autoregressive Distributed Lag; INC represents the income per capita; CCEMG stands for Common Correlated Effects Mean Group; NRE stand for Non-renewable energy consumption; REN stands for renewable energy consumption; BRICS-T stands for Brazil, Russia, India, China, South Africa, and Turkey; PIIGS stands for Portugal, Ireland, Italy, Greece, and Spain; RMT stands for remittance inflow; EXP stands for exports; and HC stands for human capital index.

environmental degradation while economic growth enhances environmental pollution spreading worldwide. Furthermore, Adebayo et al. (2021) showed that CO_2 emissions trigger economic growth. Additionally, the energy-induced growth hypothesis is confirmed. Moreover, Adebayo and Rjoub (2021) results show that non-renewable energy utilization and economic growth contribute to environmental pollution in the short and long term. Besides, Ahmed et al. (2021d) demonstrated that positive and negative changes in public renewable energy research and development budgets do not affect environmental degradation, suggesting that renewable energy technology budgets are not enough to minimize environmental pollution. Additionally, Ahmed et al. (2021e) showed that economic growth increases environmental degradation while democracy and environmental regulations positively contribute to environmental sustainability by minimizing environmental pollution.

Based on the relevant studies on the nexus between renewable and non-renewable energy utilization-environment, the third and fourth hypothesis to be tested in this study is as follows:

Hypothesis H3: Renewable energy consumption reduces the ecological footprint figures in the Indian economy.

Hypothesis H4: Non-renewable energy consumption increases the ecological footprint figures in the Indian economy.

Table 1 summarizes some of the previously published literature that focuses on the association among economic complexity, globalization, renewable, and non-renewable energy consumption. Several studies have emphasized the economic complexity-environment, globalization-economic growth-environment nexus, renewable and non-renewable energy utilization-environment nexus, but none of them has discovered the economic complexity, globalization, renewable and non-renewable energy use, especially in the context of India.

3 RESEARCH DATA AND METHODOLOGY

This research analyzes the impact of economic complexity, non-renewable energy, renewable energy, globalization, and economic growth on the ecological footprint (an alternative measure of environmental pollution) using India's annual data from 1990 to 2018. The variable ecological footprint is measured/calculated as a cumulative of six indictors (i.e., carbon footprint, grazing land, fishing grounds, forestland footprints, cropland, and grazing land) as the global hectares per capita; economic growth (GDP) is projected in per capita in constant 2010 US$. Renewable energy (RNE) is measured in thousand toes, a tone of oil equivalent; non-renewable energy consumption (NRE) is measured as fossil fuel energy consumption % of the total, and EC (economic complexity) represents the Economic Complexity Index; globalization index (GLO) is constructed by Gygli et al. (2019) is calculated in the index from (0 to 100). The RNE, NRE, and GDP growth data are gathered from the World Bank Indicator Website (WB, 2020), and the GLO data are collected for the website of the KOF Swiss Economic Institute (KOF, 2020). The EF data is attained from the Global Footprint Website (GFPN, 2020), and the EC data is collected from the website of Atlas Media database (AEC, 2020). All the variable descriptions and data sources are demonstrated in **Table 2**. The descriptive statistics of all concerned variables are presented in **Table 3** and further specify the summary statistics of our selected variables from 1990 to 2018 through box plots (see **Figure 2**).

3.1 Methodology

This study examines the ecological footprint for India and studies the link between the ecological footprint, economic complexity, economic growth, and globalization process, non-renewable and renewable energy. The general functional form of the specific ecological footprint model is given in **Eq. 1** as follows:

$$EFP_t = f\,(EC_t, GDP_t, GLO_t, NRE_t, RNE_t) \tag{1}$$

Where EFP_t, EC_t, GDP_t, GLO_t, NRE_t, *and* RNE_t ecological footprint, economic complexity, economic growth, globalization, non-renewable and renewable energy, and t refers to periods 1,2,3 … 36, respectively. Since the log-linear model is more consistent compared to the simple regression model, we use the log-linear transformation of the data in econometric analysis (Amna Intisar et al., 2020; Yang et al.,

TABLE 2 | Variables description and data sources.

Variables	Acronym	Definition	Sources
Ecological footprint	EF	Global hectares per person	GFPN (2020)
Economic complexity	EC	Country productive composition appearance by combining the information on their variety number of commodities it exports	AEC (2020)
Per capita economic growth	GDP	GDP per capita (constant 2010 US$)	WDI (2020)
Globalization	GLO	Index between 0 and 100	Dreher (2006)
Renewable energy use	RNE	% Of total final energy use	WDI (2020)
Non-renewable energy use	NRE	Fossil fuel energy consumption (% of total)	WDI (2020)

Note: GFPN, stands for Global Footprint Network; WDI, stands for world development Indicators; AEC, stands for Atlas Media database.

TABLE 3 | Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
lnEFP	29	0.55788	0.0183	0.5181	0.59039
lnEC	29	0.40532	0.03533	0.35738	0.46166
lnGLO	29	1.92906	0.01819	1.88649	1.94939
lnRNE	29	1.63681	0.06706	1.56282	1.79916
lnNRE	29	1.93116	0.02926	1.89981	1.97604
lnGDP	29	5.64486	0.02367	5.60605	5.68812

2020). The determinants of ecological footprint are rewritten in logarithmic form as follows:

$$lnEFP_t = \beta_0 + \beta_1 lnEC_t + \beta_2 lnGDP_t + \beta_3 lnGLO_t + \beta_4 lnNRE_t + \beta_5 lnRNE_t + \varepsilon_t \tag{2}$$

Where ln presents the logarithmic form, and ε_t shows the error term with normal distribution. Economic complexity improves environmental quality if $\beta_1 < 0$; otherwise, ecological footprint pressure is increased with a rise in economic complexity development. We suppose $\beta_2 > 0$ when there is a positive link between economic development and ecological footprint, if not $\beta_2 < 0$. Studies have highlighted globalization as a potential factor of environmental pollution in the literature. However, views are divided on the effect of globalization on ecological footprint. The technology transfer may be energy-intensive that contribute to pollution; that is, why globalization development promotes environmental pollution if $\beta_3 > 0$. However, the expected sign of the coefficient of globalization would be negative in the case of the pollution haven hypothesis (Naz et al., 2018). Non-renewable energy usage raises ecological footprint and hinders environmental balance if $\beta_4 > 0$ if not $\beta_4 < 0$. We expect $\beta_5 < 0$ renewable energy usage is not environment-friendly, otherwise $\beta_5 > 0$, and ε is the error term.

For the empirical estimation of time series data, the order of stationarity for the variables under consideration in the study must be tested to avoid the issue of spurious regression. Most prior studies use the augmented Dickey-Fuller, the Phillips–Pearson, and the Ng–Perron unit tests to check the stationary level. However, this study uses Zivot and Andrews (1992) (ZA) unit root test because the more traditional unit root test does not provide information about structural breaks in the data, and the ZA unit root test does. In addition, the ZA unit root test considers structural breaks in the series. For this reason, the null hypothesis of non-stationary is tested against the alternative hypothesis of stationary for both ZA unit root tests with one and two structural breaks.

The focus of this study is to explore the relationship between the ecological footprint, economic complexity, economic growth, and globalization, non-renewable and renewable energy. Several econometrics techniques have been suggested in the literature to find the long-run and short-run dynamics. To estimate **Eq. 2**, we use the ARDL test approach proposed by Pesaran et al. (2001). The ARDL method is preferred over other econometric techniques (Engle and Granger 1987; Johansen and Juselius, 1990) due to its advantages. Firstly, the ARDL approach is more appropriate for a small sample size of data to validate the cointegration relation. Secondly, the ARDL procedure can be applied whether the regressions are integrated at I (0), or I (1). Thirdly, we choose appropriate lag selection before using the ARDL approach based on various criteria, for example, Schwarz Bayesian criterion (hereafter SBC) and Akaike information criterion (hereafter AIC). Lastly, compared to the conventional cointegration procedure, the ARDL technique permits regressors to have different optimal lag lengths. The long-run and short-run dynamics can be achieved through a single linear transformation using the ARDL approach. The unrestricted error correction model of **Eq. 2** is given as follows:

$$\begin{aligned} lnEFP_t = {} & \pi_0 + \theta_1 lnEC_{t-1} + \theta_2 lnGDP_{t-1} + \theta_3 lnGLO_{t-1} \\ & + \theta_4 lnNRE_{t-1} + \theta_5 lnRNE_{t-1} + \sum_{i=1}^{\rho} \delta_1 \Delta lnEFP_{t-i} \\ & + \sum_{j=0}^{\rho} \delta_2 \Delta lnEC_{t-i} + \sum_{j=0}^{\rho} \delta_3 \Delta lnGDP_{t-i} + \sum_{j=0}^{\rho} \delta_4 \Delta lnGLO_{t-i} \\ & + \sum_{j=0}^{\rho} \delta_5 \Delta lnNRE_{t-i} + \sum_{j=0}^{\rho} \delta_6 \Delta lnRNE_{t-i} + \mu_t \end{aligned} \tag{3}$$

The first difference operation is represented by "Δ," and μ_t represents the residual term. In the case of **Eq. 3**, the null hypothesis of cointegration $(H_0\colon \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0)$ is to be

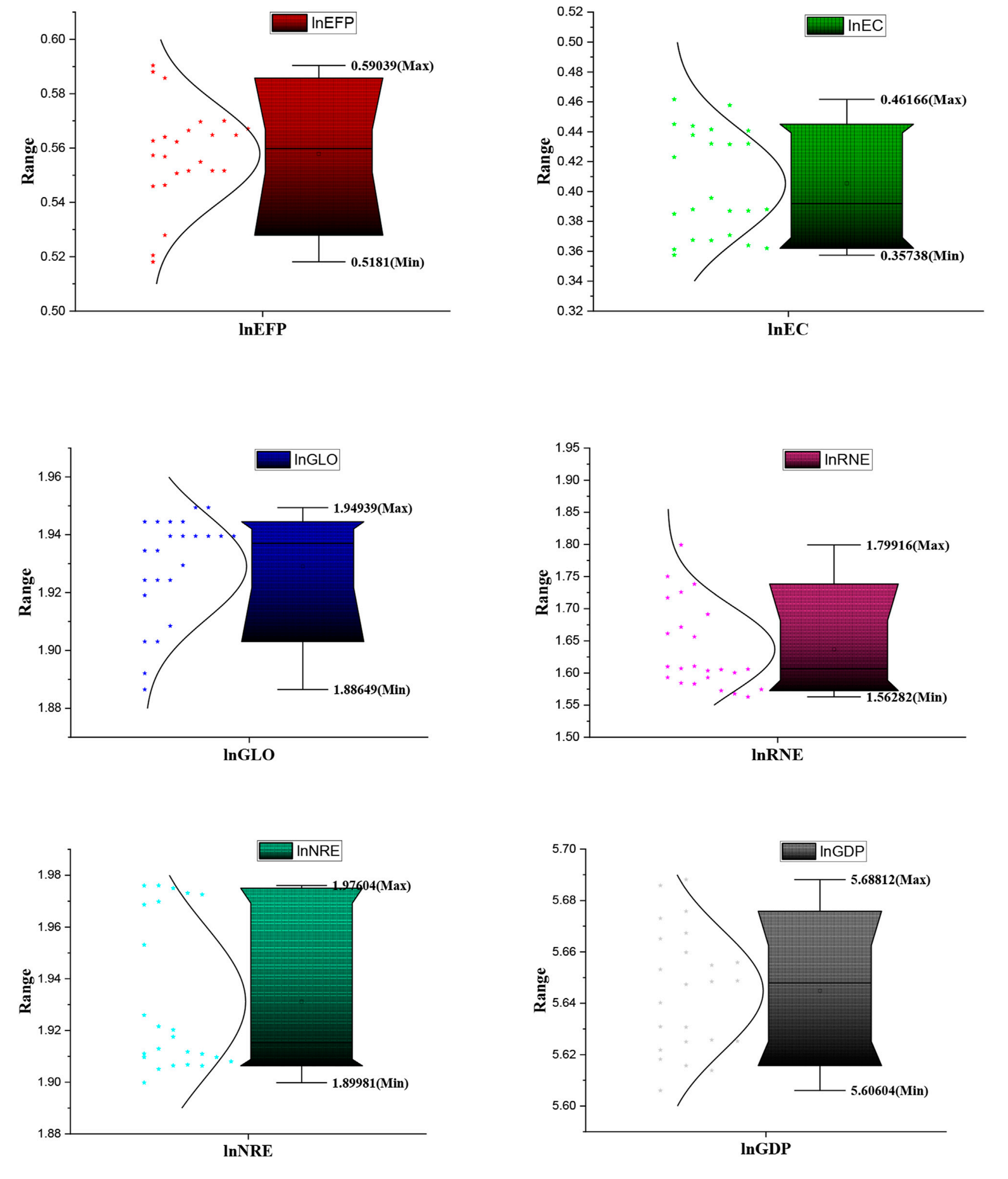

FIGURE 2 | Summery statistics of the Box-plot of the concerned series.

verified with the alternative hypothesis (H_1: $\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$) to estimate the long-run relationship among the variables using ARDL bounding testing approach. We depend on the evaluation of the F-value using the binding test procedure to analyze cointegration. If the F-statistic value surpasses the upper limit, the cointegration between the

TABLE 4 | Results of Zivot-Andrew unit root test with structural breaks.

Variables	At level		At first difference	
	Statistic	Time break	Statistic	Time break
lnEFP	−4.7639*	2009	−5.0547**	2008
lnEC	−2.7015	2000	−6.1072***	2001
lnGDP	−4.3983	2009	−6.0657***	2008
lnGLO	−4.5949*	2008	−5.6509***	2007
lnNRE	−9.5395***	2011	−5.0834**	2011
lnRNE	−3.4654	2013	−5.5923***	2008

*Note: Critical values of 1, 5, and 10% level of significance are –5.34, –4.93, and –4.58 respectively *, **, and *** shows acceptance of the alternate hypothesis at 10, 5, and 1% level of significance.*

variables is supported. However, if the F-statistic exists below the lower limit, there is no cointegration, showing that no cointegration hypothesis is accepted. The F-statistic indicates inconclusive results within the upper and lower limits. Cointegration validation allows the long-term and short-term dynamics to be evaluated on the ARDL model. We also take various diagnostic tests for robust control and model reliability, such as the Ramsey Reset, ARCH, LM, CUMSUM, and CUMSUMSQ.

In addition, to investigate the robustness of our outcomes, we use fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and canonical cointegration regression (CCR) methods. FMOLS, recommended by Phillips and Hansen (1990), is a semi-parametric technique to removing correlation issues and is asymptotically impartial and accurate. General form the FMOLS and DOLS are presented as **Eqs 4**, **5**, respectively:

$$\hat{\theta} = \begin{bmatrix} \alpha \\ \hat{\beta} \end{bmatrix} = \left(\sum_{t=2}^{T} Z_t Z_t^{'} \right)^{-1} \left(\sum_{t=2}^{T} Z_t y_t^{+} - T \begin{bmatrix} \hat{\theta}_{12}^{+} \\ 0 \end{bmatrix} \right) \quad (4)$$

Where $Z_t = (X_t^{'}, D_t^{'})$. However, the key to FMOLS estimation is long-term covariance matrix estimation.

$$Y_t = X_t^{'}\alpha + D_1^{'}\beta_1 + \sum_{j=-q}^{r} \Delta X_{t+j}\sigma + \nu_{1t} \quad (5)$$

Comparable to FMOLS, CCR reflects a simple mixture distribution, ensures asymptotic Chi-square validation, and solves the issue of non-scalar disturbance specifications. DOLS adds lags and leads to predictor variables, allowing the error term in the cointegrating equation orthogonal to stochastic regressor trends. FMOLS and DOLS can help tackle serial correlation and endogeneity issues (Pedroni, 2001; Kirikkaleli et al., 2021).

The last stage is to investigate the causality among the described time series data. We utilize the vector error correction model (VECM) suggested by Engle and Granger (Engle and Granger, 1987) to assess causality. If the time series data in the model are all cointegrated, an appropriate methodology of the VECM Granger causal mechanism can be represented as follows:

$$\begin{pmatrix} \Delta \ln EFP_t \\ \Delta \ln EC_t \\ \Delta \ln GDP_t \\ \Delta \ln GLO_t \\ \Delta \ln NRE_t \\ \Delta \ln RNE_t \end{pmatrix} = \begin{pmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \\ \theta_6 \end{pmatrix} + \begin{pmatrix} \partial_{11}\partial_{12}\partial_{13}\partial_{14}\partial_{15}\partial_{16} \\ \partial_{21}\partial_{22}\partial_{23}\partial_{24}\partial_{25}\partial_{26} \\ \partial_{31}\partial_{32}\partial_{33}\partial_{34}\partial_{35}\partial_{36} \\ \partial_{41}\partial_{42}\partial_{43}\partial_{44}\partial_{45}\partial_{46} \\ \partial_{51}\partial_{52}\partial_{53}\partial_{54}\partial_{55}\partial_{56} \\ \partial_{61}\partial_{62}\partial_{63}\partial_{64}\partial_{65}\partial_{66} \end{pmatrix} \times \begin{pmatrix} \Delta \ln EFP_{t-j} \\ \Delta \ln EC_{t-j} \\ \Delta \ln GDP_{t-j} \\ \Delta \ln GLO_{t-j} \\ \Delta \ln NRE_{t-j} \\ \Delta \ln RNE_{t-j} \end{pmatrix} + \begin{pmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \\ \mu_6 \end{pmatrix} ECT_{t-1} + \begin{pmatrix} \sigma_{1t} \\ \sigma_{2t} \\ \sigma_{3t} \\ \sigma_{4t} \\ \sigma_{5t} \\ \sigma_{6t} \end{pmatrix} \quad (6)$$

Where Δ expresses the difference operator and ETC_{t-1} is the lagged error correction term. If the $ECT_{(t-1)}$ is statistically significant with a negative sign; it is the indication of long-run causality. We also calculate short-run and long-run joint causality. n Represents the rate of change, and its value represents the extent to which inconsistencies can be resolved over a period of time. $\sigma_{1t} \rightarrow \sigma_{6t}$ Corresponds to the error term, which is possible because it must be continuously uncorrelated around the zero means.

4 EMPIRICAL ANALYSIS

This study aims to analyze the link between ecological footprint, economic complexity, economic growth, and globalization, non-renewable and renewable energy of India. The first step in our methodology is to determine whether the variables we use are stationary or non-stationary. Hence, we used the Zivot-Andrews unit root testing method to confirm that ecological footprint, economic complexity, economic growth, globalization, renewable and non-renewable energy of India are integrated at "I (0) or I (1) or I (0)/I (1)" for a structural break trend. The results are displayed in **Table 4**. Zivot-Andrews unit root test fixes all points as having a potential for possible time breaks and

TABLE 5 | Results of Johansen cointegration model.

Hypothesized no. of CE(s)	Trace statistic	Prob**	Max-Eigen statistic	Prob
None*	149.8327	0.0000	47.2902	0.0065
At most 1*	102.5425	0.0000	43.8532	0.0024
At most 2*	58.6893	0.0035	32.5495	0.0106
At most 3*	26.1398	0.1246	19.4017	0.0858
At most 4	6.7381	0.6083	3.4135	0.9155
At most 5	3.3246	0.0682	3.3246	0.0682

*Note: **shows the rejection of the hypothesis at the 0.05 level.*

TABLE 6 | Results of bound testing approach.

Estimated model	Lag selection	F-value	Remarks
lnEFP = *f* (lnEC, lnGDP, lnGLO, lnNRE, lnRNE)	2, 0, 1, 0, 1, 1	6.8322***	cointegrated
Critical Value Bounds			
Significance	I0 Bound	I1 Bound	—
10%	2.26	3.35	
5%	2.62	3.79	
2.5%	2.96	4.18	
1%	3.41	4.68	

*Note: *** shows acceptance of the alternate hypothesis at 1% level of significance.*

TABLE 7 | Results of long-run and short-run estimation (ARDL).

Regressor	Coefficient	Standard error	t-statistics	*p*-value
Long run estimate				
LnEC	−1.4130***	0.1899	−7.4393	0.0000
LnGDP	0.8362***	0.1692	4.9425	0.0004
LnGLO	−0.0363	0.0581	−0.6253	0.5445
LnNRE	0.1985*	0.0946	2.0985	0.0598
LnRNE	−0.2807***	0.0409	−6.8591	0.0000
C	2.0796*	1.1567	1.7978	0.0997
Short run estimate				
LnEC	−1.5313***	0.2716	−5.6382	0.0002
LnGDP	1.3865***	0.1701	8.1515	0.0000
LnGLO	−0.0394	0.0654	−0.6019	0.5594
LnNRE	0.3661**	0.1379	2.6550	0.0224
LnRNE	−0.1506***	0.0399	−3.7768	0.0031
CointEq (-1)	−1.0837***	0.1586	−6.8351	0.0000
R^2	0.9610			
F-Statistics	27.1145			0.0000
DW Stat	2.9727			
Jarque-Bera Normality Test	0.7120			0.7005
Breusch-Godfrey Serial Correlation LM Test	3.5273			0.1639
ARCH Test	0.4799			0.4968
Ramsey RESET Test	0.2641			0.7971

*Note: *, **, and *** show acceptance of the alternate hypothesis at 10, 5, and 1% level of significance.*

provides an estimation of time breaks through performing successive regression analysis for all possible break points.

After checking the stationary level, the next phase is to confirm cointegration among variables. Therefore, we applied the Johansen cointegration test to investigate the cointegration for long-term relationships between the series, which can be divided into two parts, trace, and maximum eigenvalues statistics. **Table 5** showed that the values of trace statistics and eigenvalue statistics indicate the existence of at least three cointegration equations. It confirms that ecological footprint, economic complexity, economic growth, globalization, renewable and non-renewable energy are cointegrated in the long run. In order to check the robustness of cointegration, the ARDL Bounds test method is used to verify the accuracy of the Johansen cointegration test. The findings of the ARDL Bounds test also support the long-run cointegration among the candidate variables that are shown in **Table 6**.

After the confirmation of cointegration, the key estimation of this study followed, namely the use of the ARDL method to obtain long - and short-term dynamics. The results obtained by applying the ARDL method are shown in **Table 7**. The empirical findings provide some significant evidence about the connection between India's economic complexity and ecological footprint. An important finding in our study is that the value of economic complexity is negative and significant, which means that economic complexity reduces India's pace of ecological footprint in the long- and short-run path. The coefficient of economic complexity concludes that considering other things constant, a 1% rise in economic complexity improves the environmental performance by decreasing 1.4130 and 1.5313% ecological footprint, respectively. This empirical result suggests that enhancing economic complexity in India's economy leads to reducing environmental degradation and improving environmental quality. Higher economic complexity leads to enhance in the energy efficiency of the production process. Enhancing economic complexity leads to implementing eco-friendly (cleaner) production technologies, as the outcomes presented by Romero and Gramkow (2021) suggest. India policymakers should support skill-intensive product exports for enhancing environmental quality. The government will

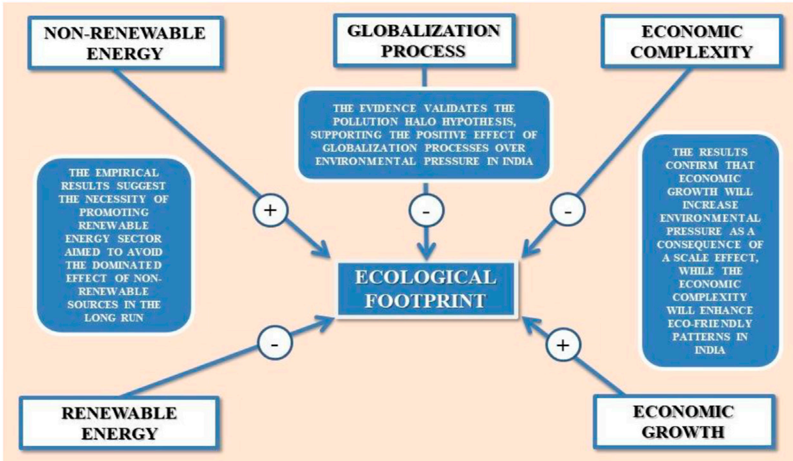

FIGURE 3 | Graphical presentation of empirical findings.

have to provide further tax exemptions/subsidies to invest in eco-friendly technologies or cleaner energy sources. Therefore, India can enhance the export of pollution-free products/high value-added goods and minimize ecological footprint and environmental degradation. This outcome is in line with Romero and Gramkow (2021), Boleti et al. (2021).

The coefficient of GDP is positive and significant; this means that economic growth enhances the rate of ecological footprint in the long-term and short term. These findings of the study reveal that a 1% enhances in GDP boosted environmental degradation by 0.8362 and 1.3865%, respectively. According to Schandl et al. (2016), carbon emissions have been associated with global economic growth for 40 years. Thus, economic activity essentially involves carbon emissions production. The sign of the coefficients is intuitive enough to be understood easily. The significant relationship between economic growth and environmental deterioration can be explained by the excessive burnings of fossil fuel in the major sectors of the economy, for example, the industrial sector, agriculture sector, and transport sector deplete the environmental quality.

In terms of other explanatory variables, globalization has no impact on the ecological footprint in India. Particularly, a 1% improvement in globalization will cause a decrease in environmental degradation of 0.0363 and 0.0394% in the long and short-run, respectively. This result is inconsistent with the findings of Saint Akadiri et al. (2020), Yang et al. (2021b). The possible reason is that the Indian economy has better access to eco-friendly (energy-efficient) technologies due to globalization. The use of eco-friendly technologies increases environmental performance by minimizing environmental degradation. India could be noticed as a fast-growing economy in the globalization index during the last few decades. The higher level of globalization and more increased investment is projected to bring more FDI by multinational enterprises/investors. Consequently, these investors will bring the latest and eco-friendly technologies to the Indian economy. The Indian government will vigorously develop the world's green

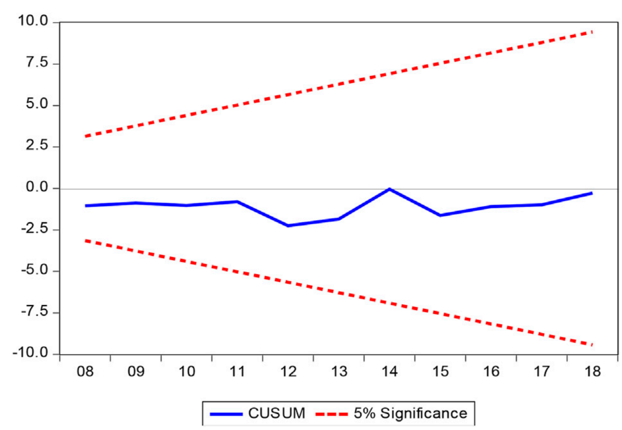

FIGURE 4 | The plot of the cumulative sum of recursive residuals.

economy and develop international green trade, and properly handle and effectively coordinate the globalization process economic and environmental disputes between developed countries, seeking to establish a green economy in the world.

The coefficient of non-renewable energy consumption is positive and significant; this means that non-renewable energy consumption accelerates the ecological footprint in the long-run and short-run path. The results can be justified; as a developing country, India actively pursues rapid economic growth in the early stage of economic development, thus consuming more fossil fuel energy and ignoring environmental quality, resulting in human pressure on the environment. In addition, the findings are consistent with that Shafiei and Salim (2014) suggest that the use of non-renewable energy leads to environmental degradation. Regarding the relationship between renewable energy consumption and ecological footprint, we see that the coefficient of renewable energy consumption is negative and statistically significant as expected in the long and short run. A 1% rise in renewable energy consumption cuts ecological

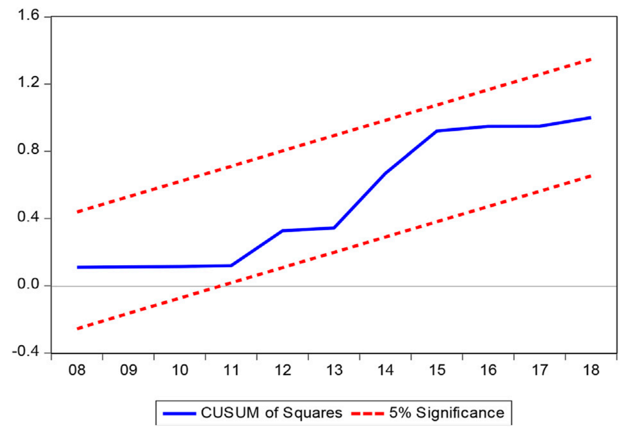

FIGURE 5 | The plot of the cumulative sum of squares of recursive residuals.

footprint by 0.2807 and 0.1506%, respectively. In other words, the use of renewable energy contributes to environmental improvements. Our work suggests that energy production from renewable energy sources has far less environmental impact than fossil fuels, and augmenting renewable energy exploitation could be a valuable policy approach for refining environmental performance in India. This finding follows the studies of Yang et al. (2021b), Usman et al. (2021d), who also validated that energy production from renewable sources improves environmental quality in the region. An adverse environmental impact of energy production is one of India's critical challenges presently, specifically GHG emissions or ecological footprint pressure (Kang et al., 2019). The government of India must encourage investments in renewable energy projects and support and promote traditional energy companies to strengthen green technology innovation that might contribute to the efforts of climate mitigation (Solarin and Bello, 2021). Moreover, the graphical presentations of empirical findings are presented in **Figure 3**.

Finally, the error correction term (ECT) demonstrates the speed of the adjustment process to restore a deviation from the long-term equilibrium. At a 1% level, the error correction term has a negative and statistically significant coefficient. This finding shows the presence of a long-term relationship between the dependent variable and the regressors. In addition, the value of the ECT coefficient is −1.0837, which signifies strong and a faster speed of adjustment to equilibrium. This indicates that convergence to equilibrium occurs approximately 1 year later. Finally, we used a variety of diagnostic tests to confirm that there are no issues of serial correlation, heteroscedasticity, and multicollinearity in the model. The results of these diagnostic tests are also shown at the bottom of **Table 7**. Diagnostics check findings eliminate all hurdles that could have occurred in the model. This specifies that the analysis model is correct and that policy recommendation can be based on it.

To ensure the robustness of our results, we employ structural stability tests on the parameters of the long-run results based on the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests as suggested by Pesaran and Pesaran (1997). In order to check the model stability, **Figures 4**, **5** show the plots of the CUSUM and CUSUMSQ graphs. Both the plots indicate that the plotlines for both tests are within the critical limits, endorsing the accuracy of the long-run estimates.

We checked the accuracy and effectiveness of our results using additional methods. In addition to the ARDL estimator, we also performed Fully Modified Ordinary Least Square (FMOLS), Dynamic OLS (DOLS), and Canonical Cointegrating Regression (CCR). **Table 8** shows the long-term coefficient obtained from the three estimators. The results of FMOLS, DOLS, and CCR methodologies are similar to the outcomes of ARDL. Therefore, it can be said that the estimated long-term coefficients are reliable and stable. All four estimators offer strong empirical support for the positive and significant association between economic complexity and India's ecological footprint.

Similarly, economic growth and non-renewable energy consumption have an increasing effect on environmental degradation, respectively. In addition, results also confirm the presence of a negative and significant influence of renewable consumption on the ecological footprint in the long run. The FMOLS method found that globalization can reduce the ecological footprint and thus improve the environment, whereas the results of other methods are consistent with the ARDL results.

The following step is the VECM analysis, which is used to determine the relationship between these variables. The existence of long-run cointegration between ecological footprint, economic complexity, economic growth, globalization, non-renewable energy consumption, and renewable consumption leads us to apply the VECM Granger causality approach to analyze the direction of a causal relationship between these series. The results are reported in **Table 9**. The negative and significant sign of (ETC_{t-1}) outcomes show that the long-run causality can be identified in the equations of economic complexity. These results of long-run causality links are

TABLE 8 | Robustness checks.

Variables	FMOLS	DOLS′	CCR
LnEC	−1.2893*** (−8.3407) [0.0000]	−1.3254*** (−7.2045) [0.0000]	−1.2796*** (−8.4113) [0.0000]
LnGDP	0.7987*** (5.6003) [0.0000]	0.8237*** (4.5104) [0.0003]	0.7826*** (4.6578) [0.0002]
LnGLO	−0.1184* (−2.1014) [0.0508]	−0.0881 (−1.264) [0.2359]	−0.1125 (−1.6659) [0.1140]
LnNRE	0.2366** (2.5971) [0.0188]	0.2313* (1.9981) [0.0610]	0.2546** (2.5186) [0.0221]
LnRNE	−0.2499*** (−6.7155) [0.0000]	−0.2387*** (−5.0111) [0.0001]	−0.2649*** (−5.0584) [0.0000]
R^2	0.7780	0.8142	0.7701
Adjusted R^2	0.7127	0.7626	0.7025

*Note: *, **, and *** shows acceptance of the alternate hypothesis at 10, 5, and 1% level of significance. () contains t-statistics, [ ] includes* p-values.

TABLE 9 | Results of VECM Granger causality.

Variables	Wald χ^2 statistics						Long-term t-statistics
	LnEFP	**LnEC**	**LnGDP**	**LnGLO**	**LnNRE**	**LnRNE**	**ECM (−1)**
LnEFP	—	−0.6719 (0.556)	−0.098 (0.887)	−0.2756 (0.185)	0.0705 (0.818)	−0.0525 (0.819)	−0.5699 (0.533)
LnEC	0.1504 (0.119)	—	−0.0394 (0.793)	−0.1166** (0.010)	0.0087 (0.896)	0.1074** (0.032)	−0.4935** (0.013)
LnGDP	0.2127 (0.376)	0.2791 (0.652)	—	−0.2657** (0.019)	0.1558 (0.350)	0.0815 (0.513)	−0.4897 (0.323)
LnGLO	−0.1225 (0.821)	−1.2499 (0.370)	1.0545 (0.210)	—	0.1135 (0.762)	−0.0624 (0.824)	−0.7060 (0.527)
LnNRE	0.3394 (0.335)	−1.0958 (0.227)	−0.2199 (0.687)	−0.1532 (0.354)	—	−0.0099 (0.957)	0.3672 (0.613)
LnRNE	2.2439** (0.018)	0.7781 (0.750)	−2.3430 (0.111)	0.2981 (0.503)	−0.2389 (0.716)	—	−2.9435 (0.132)

*Note: ** shows acceptance of the alternate hypothesis at 5% level of significance.*

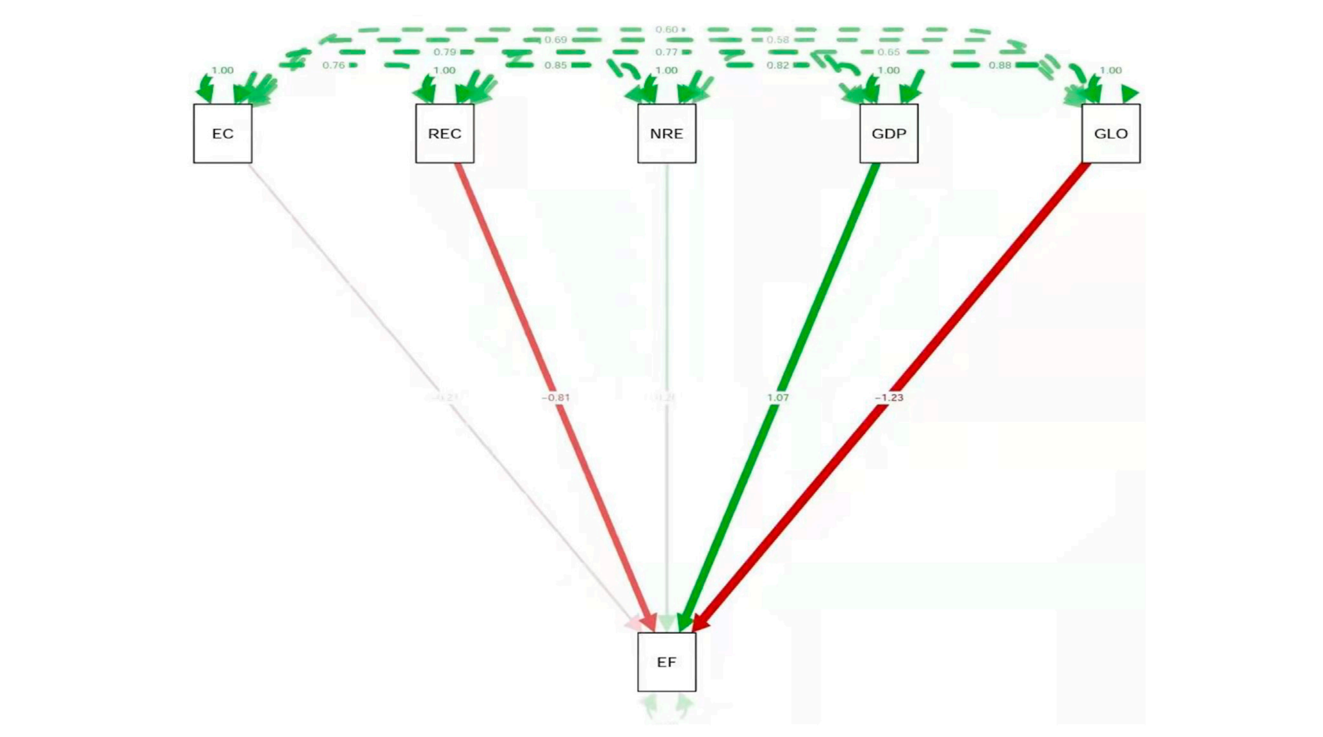

FIGURE 6 | A path diagram of how key variables impact ecological footprint.

consistent with Boleti et al. (2021). Furthermore, there are unidirectional Granger causal associations in the short run between globalization and economic complexity, renewable consumption and economic complexity, globalization and economic growth, and ecological footprint and renewable consumption.

4.1 Path Analysis Implementation

Path analyses were used to find the relationship of variables. Therefore, we calculated the relationship of EF (dependent variables) with other variables LnEC, LnREC, LnNRE, LnGDP, and LnGLO (independent variables). Path analysis has been utilized in the prior literature (Gui et al., 2017; Wakiyama and Zusman, 2021). The path analysis model was used to predict the direct and indirect relationship between variables (Please see **Figure 6**). The results from path analysis show LnEF has a strong positive relationship with LnGDP. In contrast, strong negative relationships with GLO and REC in the overall model that predict 80% variation are explained by these five variables (LnEC, LnREC, LnNRE, LnGDP, and LnGLO). It means these variables (Positive: LnGDP; Negative: LnGLO and LnREC) have a major impact on LnEF. These results are consistent with the ARDL results.

5 CONCLUSION AND POLICY RECOMMENDATIONS

This paper explores the effects of the economic complexity, globalization, economic growth, renewable and non-renewable energy consumption on the ecological footprint in India during 1990–2018. To measure the long-run elasticity between series, we used the ARDL method. The VECM Granger causality approach was used to determine the causal relationship among the concern variables. The unit root method was applied to measure the stationarity among the variables. Finally, CUSUM and CUSUMSQ approaches were used to check the model's reliability. Moreover, we also inspected the robustness checks of our outcomes applying the FMOLS, DOLS, and CCR methods.

Additionally, the path analysis method was used to predict the direct and indirect relationship between variables. According to the empirical outcomes, economic complexity, globalization, and renewable energy consumption process significantly enhance the environmental quality while economic growth and non-renewable energy consumption significantly accelerate environmental pollution in both the short and long run. Additionally, the VECM Granger causality results demonstrate unidirectional Granger causal associations in the short run between globalization and economic complexity, renewable consumption and economic complexity, globalization, and economic growth, and ecological footprint and renewable consumption.

The empirical outcomes recommend many vital policy implications that can help the Indian government. First, since the on-grid price of wind power and solar power is closely related to technological progress, it is necessary to strengthen scientific research investment in this area and lower the on-grid tariff. The price can reduce the cost of electricity purchase, thereby reducing the cost of renewable energy in the future. Second, to avoid the instability of wind power and solar power, the undesirable impact of the power grid, the huge cost of grid construction required for the development of wind power and solar energy, and most of this part of the cost is borne by the State Grid, which will hit the State Grid's pro-activeness in the development of renewable energy. In the future, it is necessary to establish a more reasonable cost and benefit-sharing. A mechanism, the power grid bears the cost while guaranteeing its due benefits. Third, in the balance cost of the network system, the pumped storage power station will adjust a considerable part of the power loss. In the future, a variety of adjustment methods can be used in combination with the least cost; the corresponding mechanism shall be established to ensure the healthy development of the pumped storage power station. Fourth, encourage the development and progress of renewable energy technologies. Improve energy source conversion efficiency: follow clean production methods, reduce pollutant emissions in the production process, and fundamentally reduce fossil fuels/non-renewable energy consumption. Fifth, through publicity, education, supervision, and management, etc., strengthen local Government departments at all levels, attach importance to the environmental management of renewable energy development, have a deep understanding of environmental issues in the development of renewable energy, and guide the development of the renewable energy industry in a scientific and reasonable manner. Sixth, promote the optimization of industrial organization structure and technological structure. The industrial organization structure represents the industry's economies of scale, and the technical structure determines the ability of a company to recycle waste. In general, the organizational structure of the industry directly determines the overall technical structure of the industry. Promoting the optimization of industrial organization structure in terms of policies and technical standards, realizing the agglomeration and scale effect of industrial development, accelerating enterprise technological innovation, and using the industrial park model to promote industrialization are the basic requirements for the development of the circular economy. Seventh, rebuild the cost of the national economy and the price system. Price is the baton of production and consumption. Various economic policies will not produce long-term effects if they do not take effect through the cost-price mechanism. The cost-price mechanism is formed and operated within a certain system and policy framework. Therefore, through institutional innovation and policy adjustments, a new cost-price system that is, conducive to resource, energy conservation, and environmental protection can be reconstructed. For example, by increasing the system innovation of energy resource tax and consumption tax, and by improving the comparative benefits of recycling resources and waste, recycling waste represents a major solution to reduce the costs. In addition, regulatory policies should be proposed in order to increase public awareness of using renewable energy for a clean environment. An optimal project to sustain the aim of keeping global warming below 2C° above pre-industrial levels and consequently leave a clean environment to the next generations is to raise the share of renewable sources in the energy mix. India should spend enough effort to accomplish the targets. Furthermore, the Indian government should give tax reductions, subsidies, and low-interest/discount loans to those enterprises/private investors that bring eco-friendly technologies. The policymakers should encourage FDI/international trade only in environmentally sustainable areas and welcome those investors/enterprises that bring eco-friendly technologies, methods, and skills to the Indian economy.

While the current study has significant policy implications/suggestions, it also has some limitations that can be addressed in future research. Future scholars could augment the literature by inspecting the relation between green macro-prudential regulations, technological innovations, and ecological footprint. Moreover, indicators like remittance inflows, human capital, and financial development could also be added while examining the association between economic complexity and ecological footprint for India.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

Conceptualization, AJ and YY; Methodology, AJ, MU, and YY Software, AJ and MU; Formal Analysis, AJ and MU; Data

Collection, AJ, MU, and YY; Writing original draft preparation, AJ, MU, MR, DB-L, and YY; Revised draft, MU; Writing, Review and Editing, MU, MR, DB-L, and XW; Supervision, AJ; Project Administration, AJ. All authors have read and agreed to the published version of the manuscript. XW has to be at Writing original draft preparation and at Revised Draft.

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