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Interactions among technological innovation, foreign direct investment, and agriculture: A symmetric and asymmetric study of inclusive sustainable development

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Abstract

This study examines the Indian inclusive sustainable development. India ranked third in global carbon emissions amidst its economic performance. This tells more about one-sided sustainable development policy of the country. With this trend of development anchored only on Indian economic activities, we consider it important to research the economy with instruments (such as technological innovation, foreign direct investment (FDI), and agriculture) that are unique to the country. India's data from 1980 to 2019 are applied to this study with two models for testing both economic and environmental developments. We utilized two scientific methods (non-linear autoregressive distributive lag (NARDL) and dynamic ordinary least squares (DOLS)) to demonstrate both symmetric and asymmetric technical analyses. Findings from NARDL show that technological innovation and FDI are mitigating carbon emissions, while economic growth and agriculture are increasing carbon emissions thereby impacting negatively the environment. Also, the result from the economic model confirms that all variables are impacting favorably on economic development except carbon emission. The findings from DOLS support the findings

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from NARDL. The result confirmed that India is yet to attain inclusive sustainable development, however, it is evident that with the right policy framed on tech innovation and FDI, the country could attain balanced sustainable development. Having seen, the dual capacity of both technological innovation and FDI toward strengthening both the economy and environment, it is worthy to consider these instruments as among the sustainable policies

Keywords
Technological innovation, foreign direct investment, agriculture, Indian sustainable development, non-linear autoregressive distributive lag

Introduction

Climate change is a core research of environmental economics that has gained substantial attention from scholars around the globe because of its potential risks to inclusive sustainable development.[1] Carbon dioxide (CO_2) emissions are instigating potential global hazards, deteriorating the environment and thus putting human lives in jeopardy. Human activities that involve excessive utilization of fossil fuel sources such as consumption, transportation, and production will continue to exacerbate the problem unless significant efforts are made to alternate these sources with clean energy sources. Some countries are adopting a variety of strategies to offset the detrimental effects of CO_2 on climate change, ecosystems, and global warming. Consequently, understanding the causes of environmental degradation is crucial for policy decisions. Thus, empirical research has uncovered numerous factors that retrograde the environment like energy use,[2,3] industrialization,[4,5] economic growth,[6,7] tourism,[8,9] agriculture,[10,11] and sectoral output.[12–14]

Energy is a crucial component for a country's economy to progress in the long run. Its ever-increasing demand has accelerated in recent times and keeps accelerating. Population growth, better lifestyles, technological improvements, and economic competitive ability are all contributing to the escalating requirement for energy. As a result, between 1971 and 2014, global energy consumption increased by 44%.[15,16] Consequently, nearly two-thirds of global greenhouse gas (GHG) emissions are caused directly by global energy production and consumption (International Energy Agency (IEA).[17] This emphasizes the significance of separating economic growth from emissions caused by energy use. In comparison to anticipated global economic growth from 2013 to 2030, the IEA (2017) research reveals that the increase in energy-related emissions fell to roughly 8%, reaching nearly 34.4 Gt. Due to decreased energy intensity in global output productivity, the scenario is ascribed to as "energy-productivity bonus." As a result, increasing energy efficiency and decreasing energy intensity are assisting in the reshaping of the global energy system.

Empirical literature also points to the significance of foreign direct investment (FDI) in supporting and increasing energy efficiency, particularly through the diffusion of green technology adaptation, market competition, and knowledge diffusion. The ability to balance energy efficiency and intensity (increase energy efficiency and decrease energy intensity) will mitigate excessive carbon emissions and increase inclusive sustainable development.

Industrialization is also thought to be culpable for the displacement of the traditional sector as resources are redistributed amongst sectors heading from the agricultural to the industrial sector.[18] Despite structural changes amidst different sectors, the agriculture sector is still a source of worry for many economies as it could have either favorable or unfavorable effects on the environment. One cannot, for instance, overlook the negative externalities of agricultural inputs because of production activities, which may result in environmental degradation through

GHG emissions, such as phosphorus and excessive nitrogen.[19] However, in some cases, environmental deterioration speeds up when an economy shifts from the agricultural to the industrial sector, while raising the revenue share of agriculture may help to conserve the environment. As a result, the expansion of agriculture might promote a green environment, which ultimately aids in the reduction of pollution. Additionally, agriculture innovation can contribute to resolving environmental problems.[20] Agriculture-related technologies and innovation can lessen GHG sensitivity as well as CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions. According to Cole et al.,[21] technological advancements in the agricultural sector have lowered CO_2 emissions by 32%, the development of biofuels can offset carbon emissions by 42%, CH_4 can be reduced by 16%, and N_2O can be reduced by 10%.

Indian economy is heavily dependent on both FDI and agricultural sectorial inputs[22] and Emerick.[23] Currently, the share of the agricultural sector (comprising forestry, animal husbandry and herders, fishing, mining, and quarrying) to its gross domestic product (GDP) is about 20.19%. Agricultural activity such as excessive utilization of energy sources by some of the machines powered by fossil fuels constitute harm to environmental development. Transportation of agricultural products involves emitting harmful substances from the heavy utilities used in conveying the products. Most times, chemicals in form of fertilizers that are utilized in farming practices constitute both environmental and aquatic hazards. The activities of the herders and miners also impact the environment negatively.

FDI is a crucial indicator of Indian economic performance which may either contribute positively or negatively to the development of its environment. Most times, the investors engage in dirty economic activities due to the laxity of environmental regulations. The economic importance of foreign investors in the host countries (especially the developing countries) always outweighs the environmental importance of the countries because of the quest to catch up with the trend of economic growth by the authorities of some of the countries. The environmental implication of FDI has been studied by many authors[24–30] who come up with non-unified results. As a result, theory of the impact of FDI on environmental performance has been proposed, hence, the pollution haven hypothesis and pollution halo hypothesis. The situation where the FDI is seen impacting well on the environment is considered the halo hypothesis, while the haven hypothesis depicts where FDI is degrading the environment of the host countries. It has been argued that haven is mostly noticed in emerging countries with relaxed laws while the halo hypothesis is noticed in the advanced countries.[31]

To this end, we attempt to investigate the level of Indian sustainable development given the moderate development of its economy. This study seeks to examine the inclusive sustainable development of India. This involves studying both the improvement and sustaining of the economic and environmental development of the country. India has been identified as the third in the rank of global carbon emissions with a moderate and steady increase in economic growth. This trajectory is capable of jeopardizing its environmental development. For this reason, we attempt to study inclusive sustainable development in the case of India. The uniqueness of this study is the inclusive nature of researching the Indian economy. We utilized some of the important variables (such as Tech. innovation, FDI, agriculture, CO_2 emissions, and economic growth) to scientifically investigate the sustainable development of the country. Two models (economic and environmental models) are adopted to test the inclusive sustainable development of India. The idea is to expose both the economic and environmental performance of the country which will guide our discussion and conclusion on the nature of the sustainable development obtained in India.

The objective of this research is grouped with questions as follows: (a) Is Indian economic growth promoting environmental dilapidation? (b) What is the role of technological innovation toward the achievement of sustainable development? (c) What is the role of FDI toward the achievement of Indian sustainable development? (d) What is the role of agriculture in Indian sustainable development? (e) Are the roles of technology, FDI, and agriculture engineering inclusive or one-sided development? (f) Which among the instruments is mitigating and improving CO_2 and economic development at the same time? This study will add to the research community by answering the above-mentioned objectives of the research. Again, drawn from the work of Zhao et al.[32] and Awan et al.[33] findings from our studies will help in strategizing and realigning Indian policy toward the development of renewable energy for Indian sustainable development. Also, our work will add to the research community through its unique method of adopting different models to test both the economic and environmental performances of India. This is targeted to justify the inclusive sustainable development of the country, India. We adopt two methods, the novel non-linear autoregressive distributive lag (NARDL) and dynamic ordinary least square (DOLS) for a dual scientific estimation. The idea of choosing both methods is to test both the symmetric and asymmetric relationship amongst the selected variables which helps the authors balance the findings and justify the findings of this study. The advantage of choosing NARDL as among the methods is because of its decomposing nature of displaying the impact of explanatory variables on the dependent variables. It equally reduces the likelihood of endogeneity problems of econometrics in scientific estimation and analysis.

Brief literature review

There are two different hypotheses regarding the impact of technological innovation on environmental degradation in developed and developing countries.[34] On one side, scholars claim technological innovation has caused mitigation of carbon emissions, and on the other side, it caused an increase in carbon emissions. These hypotheses have drawn much attention from environmentalists and economists. For example, Lin and Ma[35] have reported that green technology innovation has caused carbon emission mitigation. Meirun et al.[36] reported that green technology innovation has a negative impact on carbon emission in the context of Singapore by applying the bootstrap autoregressive distributive lag (ARDL) approach. For China, Godil et al.[37] have documented that technology innovation negatively impacts transport sector carbon emission. Du et al.[38] have documented with ample evidence that green technology significantly contributes to reducing carbon emissions. In contrast, Xu et al.[39] have documented with empirical evidence that green technology innovation has a positive impact on carbon emissions in Chinese cities. In the same direction, Weina et al.[40] examine the nexus between green inventions and carbon emissions. Their study reported ample empirical evidence that green technology innovation has no significant impact on carbon emission mitigation. However, there is no general consensus among relevant literature on the relationship between green technological advances and CO_2 emissions.

The second stream of the literature related to our work focuses on the interlink between foreign investment and carbon emission. There are two hypotheses (pollution haven hypothesis and pollution halo hypothesis) that have become hotspot discussions among scholars. The pollution haven hypothesis exists when a foreign investment has positive nexus with carbon emission and there are several studies that confirm the validation of the pollution haven hypothesis.[24–28] On the other hand, many scholars confirmed the negative impact of foreign investment on carbon emissions.[29,30]

Furthermore, the stream of the literature related to our work focuses on the interconnection between economic performance and environmental quality. There is a hypothesis, environmental Kuznets curve (EKZ) hypothesis, which has become a hot roundtable discussion among environmentalist and economist scholars from many moons, respectively. In recent years, Bekun et al.[41] studied the affiliation between economic performance and environmental degradation from 1995 to 2016 for E7 countries by applying second-generational panel econometrics strategies (e.g. augmented mean group, common correlated effects mean group estimator, Driscoll-Kraay and Dumitrescu, and Hurlin causality analysis). Their study of statistical results indicates that economic performance has a positive impact on environmental degradation, while the study confirms the EKZ curve. Abbasi et al.[42] and Iqbal et al.[43] confirm the positive impact of economic performance on environmental degradation by using different approaches. For China, Abbasi et al.[42] have reported that economic growth has a positive impact on environmental degradation in long run but the adverse impact in the short run by applying the dynamic ARDL econometrics approach. For Brazil, Russia, India, China, and South Africa (BRICS) economies, Caglar et al.[44] have studied the affiliation between economic performances with environmental degradation using a panel dataset for BRICS economies. Their study result reported that economic growth has a positive impact on environmental degradation. Abbasi and Adedoyin[45] and Abbasi et al.[46] have confirmed a similar result (economic performance has a positive impact on environmental degradation) in their studies. In contrast, Bekun[47] has studied the affiliation between economic performance with environmental degradation using time series data of India by applying DOLS and fully modified ordinary least square. The econometrical approaches result reported a negative impact exists on economic performance with environmental degradation.

Another stream of our works' literature focuses on the link between agriculture and carbon emission. For example, Paustian et al.[48] have documented that carbon emission is mitigated by agriculture. Jebli and Youssef[49] have confirmed that agriculture reduces carbon emissions in North African economies. For BRICS countries, Pata[50] has documented that agriculture has bidirectional causality with carbon emissions. Adebayo et al.[51] found that agriculture has a positive correlation with carbon emission through the wavelet coherence test. Eyuboglu and Uzar[52] have observed the impact of agriculture on carbon emission and their study indicates that agriculture has positive effects on carbon emission. Yurtkuran[53] has validated the progressive effect of agriculture on carbon emissions by applying a novel bootstrap ARDL approach.

Summarily, unlike many other studies that have pooled many countries as a bloc to study their sustainable development, our study has singled out India for this study considering the peculiarity and relevance of the selected variables to the Indian economic and environmental development. Again, several studies have based their analysis on just one approach in an attempt to expose the sustainable development of those pooled countries, but our study has combined two different dynamics of scientific approaches (symmetric and asymmetric) in researching the sustainable development of India. This will give a clear and comprehensive insight into the country's sustainable development. Lastly, one unique difference between our study and other studies presented here is the inclusive nature of our study in studying the sustainable development of India. The majority of the studies on sustainable development are one-sided in studying sustainable development which contradicts the United Nation's (UN's) agenda of sustainable development come 2030. To achieve the UN 2030 sustainable development agenda, we incorporate inclusive sustainable development which views sustainable development from two perspectives, economic growth and environmental development.

Data and methodology

This study tries to assess the short-run and long-run symmetric and asymmetric association between technological innovation, agriculture, economic performance, FDI, and environmental quality for India in determining its ability to achieve its sustainable development agenda.

Theoretical background

The selected variables are part of indices to measure sustainable development and will aid in exposing both the environmental and economic implications of Indian sustainable development. Hence, technological innovation is akin to controlling environmental damage[35–37] through the improvement of a conventional method of executing economic activities to more advanced methods that are rooted in clean energy use. Technological innovation impacts almost every significant sector of an economy such as the energy sector and petroleum sector. This is achieved through improving and developing the sectors. Technology impacts both health and educational sectors which are part of the human development index, thus, technology is multifaceted in impacting sustainable development. In the scientific analysis of the impact of technological innovation, the expected result and relationship with the environment are positive. Also, FDI and agriculture are part of the drivers of the environment and economic growth and their impacts could be either positive[29,30] or negative[24–28] to the development of both environment and economic growth. The spillover effect of FDI through the introduction and sharing of skills and knowledge across the board of the host economy will amount to economies scale and the betterment of the environment with new technologies from developed economies. Agricultural practices impact the environment[50–53] through their methods of practice. Improved mechanized farming may impact positively environmental development, while crude practices may harm the quality of the environment.

To this end, the data on all investigated variables have been obtained from the World Bank World Developing Indicators. Annual data from 2018 to 2019 are used for this study. All the variables have been used in their logarithmic forms to find a proportionate rate of change and reduce the heteroscedasticity and multicollinearity problems to get more consistent results. The details about the indicators for investigated variables and their measurements are given in Table 1.

As a developing economy, India aims to achieve its sustainable development goals to be categorized in the developed economies list. However, India needs to balance development between economy and the environment to achieve its sustainable goals. Therefore, to assess the short-term and long-term association among investigated variables, and measure their significance for India, two different models have been constructed. The models can be presented as follows:

$$\ln \mathrm{CO}_2 = \beta_0 + \beta_1 \ln \mathrm{INN}_t + \beta_2 \ln \mathrm{AGR}_t + \beta_3 \ln Y_t + \beta_4 \ln \mathrm{FD}_t + \varepsilon_t \quad (1)$$

$$\ln Y_2 = \alpha_0 + \alpha_1 \ln \mathrm{INN}_t + \alpha_2 \ln \mathrm{AGR}_t + \alpha_3 \ln \mathrm{CO}_{2t} + \alpha_4 \ln \mathrm{FD}_t + \nu_t \quad (2)$$

Here, β_0 and α_0 are the intercepts, whereas $\beta_1, \ldots, \beta_4$and $\alpha_1, \ldots, \alpha_4$ are the coefficients of independent variables. The sample size is represented by t and ε and ν stand for error terms.

Table 1. Variables and measurements.

Variable name	Measurement
Carbon dioxide (ln CO_2)	Metric tons per capita (used as an indicator of environmental quality)
Technological innovation (ln INN)	Total patent applications by residents and non-residents
Agriculture (ln AGR)	Agriculture, forestry, and fishing, value added (% of gross domestic product (GDP))
Economic performance (ln Y)	GDP per capita (constant 2015 US$)
Foreign direct investment (ln FD)	Foreign direct investment, net inflows (% of GDP)

Source: Authors' computation.

NARDL method

In previous studies, the short- and long-term associations among these investigated variables have been analyzed by using symmetric and ordinary time series methods such as ARDL model and followed by error correction modeling and several causality tests. However, recent studies started to focus on asymmetric short-run and long-run associations among variables to get sufficient results. This helps researchers to attain conceivable asymmetries among investigated variables. To this end, in this study, the nonlinear autoregressive distributed lag model (NARDL) has been utilized to explore the short-run and long-run asymmetric effects of independent variables on dependent variables in both models. The NARDL model was proposed by Shin et al.[54] and detailed by Abbasi et al.[55] This model is also adopted by many researchers in terms of providing cointegration possibilities for the variables which have mixed order of integration.[56] In our study, the NARDL model has been constructed to assess the asymmetric effect of independent variables on environmental degradation and economic growth can be presented as follows:

$$\begin{aligned}\ln \mathrm{CO}_2 = \beta_0 + \beta_1 \ln \mathrm{INN}_t^+ + \beta_2 \ln \mathrm{INN}_t^- + \beta_3 \ln \mathrm{AGR}_t^+ + \beta_4 \ln \mathrm{AGR}_t^- + \beta_5 \ln Y_t^+ + \beta_6 \ln Y_t^- \\ + \beta_7 \ln \mathrm{FD}_t^+ + \beta_7 \ln \mathrm{FD}_t^- + \varepsilon_t\end{aligned} \tag{3}$$

$$\begin{aligned}\ln Y_2 = \alpha_0 + \alpha_1 \ln \mathrm{INN}_t^+ + \alpha_2 \ln \mathrm{INN}_t^- + \alpha_3 \ln \mathrm{AGR}_t^+ + \alpha_4 \ln \mathrm{AGR}_t^- + \alpha_5 \ln \mathrm{CO}_{2t}^+ + \alpha_6 \ln \mathrm{CO}_{2t}^- \\ + \alpha_7 \ln \mathrm{FD}_t^+ + \alpha_8 \ln \mathrm{FD}_t^- + \nu_t\end{aligned} \tag{4}$$

The positive and negative signs on the independent variables indicate the partial sum of positive and negative changes, respectively. The βs and αs are the unknown long-run coefficients for investigated variables. The partial sum of these variables can be expressed as follows:

$$X_t^+ = \sum\nolimits_{i=1}^{t} \Delta X_i^+ = \sum\nolimits_{i=1}^{t} \Delta \max\left(\Delta X_t^+, 0\right) \tag{5}$$

$$X_t^- = \sum\nolimits_{i=1}^{t} \Delta X_i^- = \sum\nolimits_{i=1}^{t} \Delta \max\left(\Delta X_t^-, 0\right) \tag{6}$$

Also, the short-run and long-run specifications of the NARDL model can be presented as follows:

$$\begin{aligned}\Delta \ln \mathrm{CO}_{2t} = \delta_0 + \sum\nolimits_{k=0}^{\rho} \delta_1 \Delta \ln \mathrm{CO}_{2t-k} + \sum\nolimits_{k=0}^{\rho} \delta_2 \Delta \ln \mathrm{INN}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \delta_3 \Delta \ln \mathrm{INN}_{t-k}^- \\ + \sum\nolimits_{k=0}^{\rho} \delta_4 \Delta \ln \mathrm{AGR}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \delta_5 \Delta \ln \mathrm{AGR}_{t-k}^- + \sum\nolimits_{k=0}^{\rho} \delta_6 \Delta \ln Y_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \delta_7 \Delta \ln Y_{t-k}^- \\ + \sum\nolimits_{k=0}^{\rho} \delta_8 \Delta \ln \mathrm{FD}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \delta_9 \Delta \ln \mathrm{FD}_{t-k}^- + \Phi_1 \ln \mathrm{CO}_{2t} + \Phi_2 \ln \mathrm{INN}_t^+ + \Phi_3 \ln \mathrm{INN}_t^- \\ + \Phi_4 \ln \mathrm{AGR}_t^+ + \Phi_5 \ln \mathrm{AGR}_t^- + \Phi_6 \ln Y_t^+ + \Phi_7 \ln Y_t^- + \Phi_8 \ln \mathrm{FD}_t^+ + \Phi_9 \ln \mathrm{FD}_t^- + \varepsilon_t\end{aligned} \tag{7}$$

$$\begin{aligned}\Delta \ln Y_{2t} = \chi_0 + \sum\nolimits_{k=0}^{\rho} \chi_1 \Delta \ln Y_{t-k} + \sum\nolimits_{k=0}^{\rho} \chi_2 \Delta \ln \mathrm{INN}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \chi_3 \Delta \ln \mathrm{INN}_{t-k}^- \\ + \sum\nolimits_{k=0}^{\rho} \chi_4 \Delta \ln \mathrm{AGR}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \chi_5 \Delta \ln \mathrm{AGR}_{t-k}^- + \sum\nolimits_{k=0}^{\rho} \chi_6 \Delta \ln \mathrm{CO}_{2t-k}^+ + \sum\nolimits_{k=0}^{\rho} \chi_7 \Delta \ln \mathrm{CO}_{2t-k}^- \\ + \sum\nolimits_{k=0}^{\rho} \chi_8 \Delta \ln \mathrm{FD}_{t-k}^+ + \sum\nolimits_{k=0}^{\rho} \chi_9 \Delta \ln \mathrm{FD}_{t-k}^- + \phi_1 \ln Y_t + \phi_2 \ln \mathrm{INN}_t^+ + \phi_3 \ln \mathrm{INN}_t^- + \phi_4 \ln \mathrm{AGR}_t^+ \\ + \phi_5 \ln \mathrm{AGR}_t^- + \phi_6 \ln \mathrm{CO}_{2t}^+ + \phi_7 \ln \mathrm{CO}_{2t}^- + \phi_8 \ln \mathrm{FD}_t^+ + \Phi_9 \ln \mathrm{FD}_t^- + \nu_t\end{aligned} \tag{8}$$

$$\Delta \ln CO_{2t} = \delta_0 + \sum_{k=0}^{\rho} \delta_1 \Delta \ln CO_{2t-k} + \sum_{k=0}^{\rho} \delta_2 \Delta \ln INN_{t-k}^{+} + \sum_{k=0}^{\rho} \delta_3 \Delta \ln INN_{t-k}^{-}$$
$$+ \sum_{k=0}^{\rho} \delta_4 \Delta \ln AGR_{t-k}^{+} + \sum_{k=0}^{\rho} \delta_5 \Delta \ln AGR_{t-k}^{-} + \sum_{k=0}^{\rho} \delta_6 \Delta \ln Y_{t-k}^{+} + \sum_{k=0}^{\rho} \delta_7 \Delta \ln Y_{t-k}^{-} \quad (9)$$
$$+ \sum_{k=0}^{\rho} \delta_8 \Delta \ln FD_{t-k}^{+} + \sum_{k=0}^{\rho} \delta_9 \Delta \ln FD_{t-k}^{-} + \gamma_0 ECT_{t-1} + \varepsilon_t$$

$$\Delta \ln Y_{2t} = \chi_0 + \sum_{k=0}^{\rho} \chi_1 \Delta \ln Y_{t-k} + \sum_{k=0}^{\rho} \chi_2 \Delta \ln INN_{t-k}^{+} + \sum_{k=0}^{\rho} \chi_3 \Delta \ln INN_{t-k}^{-}$$
$$+ \sum_{k=0}^{\rho} \chi_4 \Delta \ln AGR_{t-k}^{+} + \sum_{k=0}^{\rho} \chi_5 \Delta \ln AGR_{t-k}^{-} + \sum_{k=0}^{\rho} \chi_6 \Delta \ln CO_{2t-k}^{+} + \sum_{k=0}^{\rho} \chi_7 \Delta \ln CO_{2t-k}^{-}$$
$$+ \sum_{k=0}^{\rho} \chi_8 \Delta \ln FD_{t-k}^{+} + \sum_{k=0}^{\rho} \chi_9 \Delta \ln FD_{t-k}^{-} + \eta_0 ECT_{t-1} + \nu_t \quad (10)$$

Here, k and Δ denote the number of lags and the difference operator, respectively. $\Phi_1 - \Phi_9$ and $\phi_1 - \phi_9$ represent long-term coefficients of explanatory variables, while $\delta_0 - \delta_9$ and $\chi_1 - \chi_9$ signify the short-term coefficients in the models. γ_0 and η_0 indicate the coefficient of error correction terms in the models.

Empirical results and discussions

As a prior condition for the NARDL model, it is essential to scrutinize the integration order of each series. This helps to check the applicability of the test and prevents from obtaining spurious results. To this end, the augmented Dickey-Fuller (ADF)[57] unit root test and Philips-Perron (PP)[58] unit root test are employed to check the stationarity of the variables. However, these tests cannot account for possible structural breaks in the series. Thus, the Zivot-Andrews unit root test was employed for this purpose. Table 2 shows the details about the stationarity level of the investigated variables. It is seen that all selected instruments are stable at the differenced level and they are integrated at the order I(1), at a 1% significance level. This satisfies the prior condition for the applicability of the NARDL model. Both ADF and PP tests confirm each other's results. Moreover, the structural break for CO_2 emission occurs in 2007, economic performance occurs in 1991, agriculture occurs in 1999, innovation occurs in 2005, and lastly, FDI occurs in 1992. Especially, in 1991 and 1992, breaks for economic performance and FDI, the collapse of the Soviet Block negatively affected the Indian economy and caused a significant balance of payments deficit due to excess reliance on imports and other external factors. On the other hand, the Indian economy was faced with healthy growth in 2004 (7.5%) and this was reflected in the creation of innovative new products which positively affected the use of environmentally friendly technology in the production process and indirectly improved environmental quality in the country. Based on the outcomes of these unit root tests, the NARDL test can be employed to test the asymmetric impact of investigated variables on selected dependent variables.

Before estimating the NARDL model, the cointegration (*long run steady-state relationships among investigated variables*) were tested for both models by using the Bounds test. In Table 3, the test results show that the calculated F-statistics (4.138 and 7.684) are both greater than the upper critical bound (3.77) at a 1% significance level. This reveals that the null hypothesis of no cointegration occurring amongst investigated instruments will be rejected and the alternative hypothesis of cointegration relationship amongst investigated variables will be accepted. In other words, the outcome of this test proves the existence of an asymmetric cointegration relationship among investigated variables.

Table 2. Unit root test.

Variables	ADF		PP		Zivot-Andrews	
	Level	Δ	Level	Δ	*t*-Statistics	Time-break
ln CO_2	0.041	−7.262***	0.046	−7.159***	−3.6459(0)	2007
ln *Y*	3.063	−4.840***	2.684	−4.840***	−2.8333(0)	1991
ln AGR	−1.383	−7.077***	−1.398	−7.478***	−3.1272(3)	1999
ln INN	−0.173	−5.523***	−0.135	−5.499***	−3.6142 (0)	2004
ln FDI	−1.362	−6.698***	−1.084	−7.598***	−4.3572(0)	1992

Note. ADF: augmented Dickey-Fuller; PP: Philips-Perron. **Stands for the significance level at 1%. Numbers in the parenthesis signify the lag length selected for Zivot-Andrews[59] unit root test.
Source: Authors' construction.

Table 3. Bound test results.

			1%		5%		10%	
	K	Calculated *F*-stat	B_L	B_U	B_L	B_U	B_L	B_U
ln CO_2	8	4.138***	2.62	3.77	2.11	3.15	1.85	2.85
ln Y	8	7.684***	2.62	3.77	2.11	3.15	1.85	2.85

$B_{U\text{ and }}$ B_L: upper and lower critical bound.
Source: Authors construction.

After proving the presence of the cointegration relationship among variables, the NARDL test was employed, and the short-run and long-run asymmetric relationship coefficients are estimated. The details of these test results are reported in Tables 4 and 5. The table shows that all investigated variables are statistically significant and have a positive and negative association with dependent variables in the two models (ln CO_2 and ln Y).

In the short run, a positive shock to FDI reduces CO_2 emission in India by 0.028%, on average, whilst this level of reduction has a greater reduction in the long term and is measured as 0.446%, on average. This may depend on the better and environmentally friendly capital inflow to India from other developed or developing countries. Furthermore, a 1% increase in the negative shocks on FDI in India, will cause a 0.029% reduction in environment value in the short run, and this magnitude increases to 0.043% in the long run. This aligns with the outcomes from Zameer et al.[60] for India and Haq et al.[61] for Pakistan.

Additionally, a 1% increase in technological innovation will lead to improving environmental quality by 0.082%, in the short period, whereas a percent increase in negative shocks on innovation will deteriorate the environment value by 0.081%, on average. Interestingly, the same magnitudes of the changes in the shocks on technological innovation are calculated for the long run. This aligns with the findings from Udemba et al.[62] and Meirun et al.[36] for Singapore, Godil et al.[37] for China, and Du et al.[38] and, in contrast, Xu et al.[39] for Chinese cities.

Moreover, the estimated elasticities of economic performance relating to environment value are 0.243 and −0.487 in the short period, while they are 0.398 and −0.488 in the long run for positive and negative shocks, respectively. These results indicate that a percent surge in economic development will worsen the environment value by 0.243% in the short period and 0.398% in the long period, respectively. Besides, a percent reduction in economic performance will heal the

Table 4. Estimation output of dependent variable: environmental quality (ln CO_2).

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
Short-run coefficients				
D(ln FD^+)	−0.028***	0.006	−4.758	0.0002
D(ln FD^-)	0.029***	0.005	5.286	0.0001
D(ln INN^+)	−0.082***	0.024	−3.376	0.0036
D(ln INN^-)	0.081***	0.026	3.144	0.0059
D(ln Y^+)	0.243*	0.131	1.865	0.0794
D(ln Y^-)	−0.487***	0.148	−3.287	0.0043
D(ln AGR+)	2.314***	0.297	7.769	0.0000
D(ln AGR-)	−0.223**	0.085	−2.594	0.0189
ECT(−1)	−0.447***	0.044	−9.990	0.0000
Long-run coefficients				
ln FD^+	−0.446***	0.122	−3.656	0.0020
ln FD^-	0.043*	0.024	1.811	0.0879
ln INN^+	−0.082**	0.037	−2.159	0.0454
ln INN^-	0.081**	0.038	2.106	0.0503
ln Y^+	0.398***	0.99	4.002	0.0009
ln Y^-	−0.488*	0.241	−2.026	0.0587
ln AGR^+	−1.813***	0.356	−5.078	0.0001
ln AGR^-	0.029**	0.011	2.489	0.0235
C	−0.374**	0.133	−2.802	0.0123

Note. ECT: error correction term. ***, **, and * stand for the significance levels at 1%, 5%, and 10%, respectively.
Source: Authors computation.

environmental quality by 0.487% in the short period and 0.488% in the long period. This aligns with the findings from Udemba et al.[62] for Malaysia and Udemba and Tosun[63] for Brazil.

On the other hand, a 1% increase in the share of the agricultural sector in the GDP of India will lead to deterioration of the environmental quality by 2.314% in the short run, but a 1% reduction in the share of agriculture to GDP will lead to improving environmental quality by 0.223% on average. However, depending on the improvement in technology and using more environmentally friendly technologies in the agricultural sector and using fewer chemicals, and having fewer wastes in agricultural sectors, a 1% increase in the agricultural sector will decrease CO_2 emission by 1.813% in the long run and a 1% reduction in the agriculture sector will cause 0.029% improvement in the environmental deterioration level. This aligns with the findings from Adebayo et al.,[51] Eyuboglu and Uzar,[52] and Yurtkuran.[53]

Model 2 shows the asymmetric association of environmental quality, FDI, technological innovation, and share of the agriculture sector on economic performance in India. The idea for the inclusion of an economic performance model is for the purpose of inclusive sustainable development in India. Instead of the half hazard approach of considering either sustainable economic growth or sustainable environmental development, we are particularly interested in exposing inclusive sustainable development in India in view of operations of both economic and environmental agents. This will give a holistic picture of the sustainable development level of the country and the best approach to enhance and foster the sustainable development of India as a country.

In the short run, the findings indicate that a 1% increase in environmental deterioration level will lead to a decrease in the economic performance which also causes a decrease in standards of living

Table 5. Estimation output of dependent variable: economic performance (ln *Y*).

Variable	Coefficient	Std. error	*t*-Statistic	Prob.
Short-run coefficients				
D(ln CO_2^+)	−0.337***	0.081	−4.149	0.0010
D(ln CO_2^-)	0.729***	0.217	3.353	0.0047
D(ln FDI^+)	0.021***	0.004	4.494	0.0005
D(ln FDI^-)	−0.039***	0.005	−8.870	0.0000
D(ln INN^+)	0.082***	0.017	4.764	0.0003
D(ln INN^-)	−0.061***	0.016	−3.816	0.0019
D(ln AGR^+)	0.295***	0.065	4.519	0.0005
D(ln AGR^-)	−0.152**	0.066	−2.298	0.0375
C	5.571***	0.361	5.425	0.0000
ECT(−1)	−0.221***	0.018	2.212	0.0000
Long-run coefficients				
D(ln Y^{-1})	0.779***	0.117	6.660	0.0000
D(ln CO_2^+)	−0.337***	0.113	−2.997	0.0096
D(ln CO_2^-)	0.729**	0.317	2.301	0.0373
D(ln FDI^+)	0.021*	0.011	−1.935	0.0735
D(ln FDI^-)	−0.039*	0.022	−1.826	0.0892
D(ln INN^+)	0.082***	0.0278	2.948	0.0106
D(ln INN^-)	−0.061***	0.018	−3.372	0.0046
D(ln AGR^+)	0.296***	0.074	3.985	0.0014
D(ln AGR^-)	−0.262**	0.115	−2.284	0.0385
C	1.229**	0.726	1.6933	0.0125

Note. ECT: error correction term. Significance levels at 1%, 5%, and 10%, are represented as ***, **, and *, respectively.
Source: Authors construction.

in India by 0.337%, on average. Moreover, 1% less CO_2 emissions to the environment will increase economic growth by 0.729%.

Moreover, on average, a 1% increase in FDI, technological innovation, and the share of the agriculture sector will contribute to the economic performance by 0.021%, 0.082%, and 0.295% in India, respectively. However, a 1% increase in negative shocks on these variables will deteriorate economic performance and cause 0.039%, 0.061%, and 0.152% reductions, on average. On the other hand, in the long run, a 1% increase (decrease) in CO_2 emission will cause a 0.337% (0.729%) reduction (raise) in economic performance. Moreover, a 1% increase in the FDI, technological innovation, and the share of the agriculture sector will contribute to economic performance by 0.021%, 0.082%, and 0.296% in India, respectively. Nevertheless, a 1% reduction in these variables will lead to a deterioration in economic performance by 0.039%, 0.061%, and 0.262%, respectively. This aligns with the findings from Awunyo-Vitor and Sackey[64] for Ghana and Kang and Martinez-Vazquez.[65]

The coefficient of error correction terms for model 1 and model 2 are estimated as −0.447 and −0.221 and found statistically significant at a 1% significance level, respectively. This indicates the speed of convergence of investigated variables to the equilibrium. Therefore, for model 1, it can be said that 44.7% of deviation from short-run equilibrium is corrected gradually through a series of partial long-run adjustments. However, for model 2, the speed of adjustment to restore the short-term equilibrium is 22.1%.

Table 6. DOLS estimation output.

Dependent variable CO_2	Coefficient	Std. error	*t*-Statistic	Prob.
ln FD	−0.037*	0.017	2.211	0.0781
ln INN	−0.218***	0.038	−5.699	0.0023
ln *Y*	0.764***	0.057	3.306	0.0000
ln AGR	0.704**	0.235	2.999	0.0301
C	−1.079**	0.061	−3.016	0.0355
R-squared	0.99	9 Adjusted R-squared		0.997
Dependent variable *Y*	**Coefficient**	**Std. error**	***t*-Statistic**	**Prob.**
ln FD	0.019**	0.009	−2.119	0.0412
ln INN	0.097*	0.048	1.993	0.0542
ln AGR	0.089*	0.193	0.464	0.0645
ln CO_2	−0.955***	0.104	9.183	0.0000
C	6.129***	0.009	3.122	0.0000
R-squared	0.99	1 Adjusted R-squared		0.990

Note. DOLS: dynamic ordinary least square; CO_2: carbon dioxide. The significance levels at 1%, 5% and 10%, are represented by ***, ** and *, respectively.
Source: Authors construction.

To check the validity of the results and confirm the significance of estimated coefficients obtained from the NARDL test, the DOLS model has been employed. Like the NARDL outcome, in both models, estimated coefficients of the investigated explanatory variables are found statistically significant determinants of the dependent variables. The details for DOLS estimations are presented in Table 6

The results of the DOLS test for model 1 indicate that a 1% increase in FDI will lead to improving environmental quality by 0.037%, while this coefficient for technological innovation was estimated as 0.218%. Moreover, a percent surge in economic development and the share of the agricultural sector to GDP will increase CO_2 emission in India and deteriorates the environmental value by 0.764% and 0.704%, respectively. On the other hand, a percent surge in FDI, technological innovation, and the agricultural sector will lead to improve economic performance and increase the real GDP of India by 0.019%, 0.097%, and 0.089% in the long run. However, a 1% increase in environmental quality will burden economic performance and cause a 0.955% reduction, on average.

Lastly, the stabilities of the estimated parameters are assessed by utilizing cumulative sum (CUSUM) and CUMSUM of square (CUSUMsq) tests (Figures 1 and 2). The figures for both models present the blue line falls within the 5% significance level. The results prove that all estimated coefficients are stable for both models.

Conclusion and policy recommendation

This is an expository study into the sustainable state of both Indian economic and environmental developments. The study attempts to research the inclusive sustainable development of India. The uniqueness of this study is the inclusive nature of researching the Indian economy. This involves studying both the improvement and sustaining of the economy and environment. India is among the top carbon-emitting countries in the world with a moderate and steady increase in economic growth. This trajectory is capable of permitting only economic development at the expense

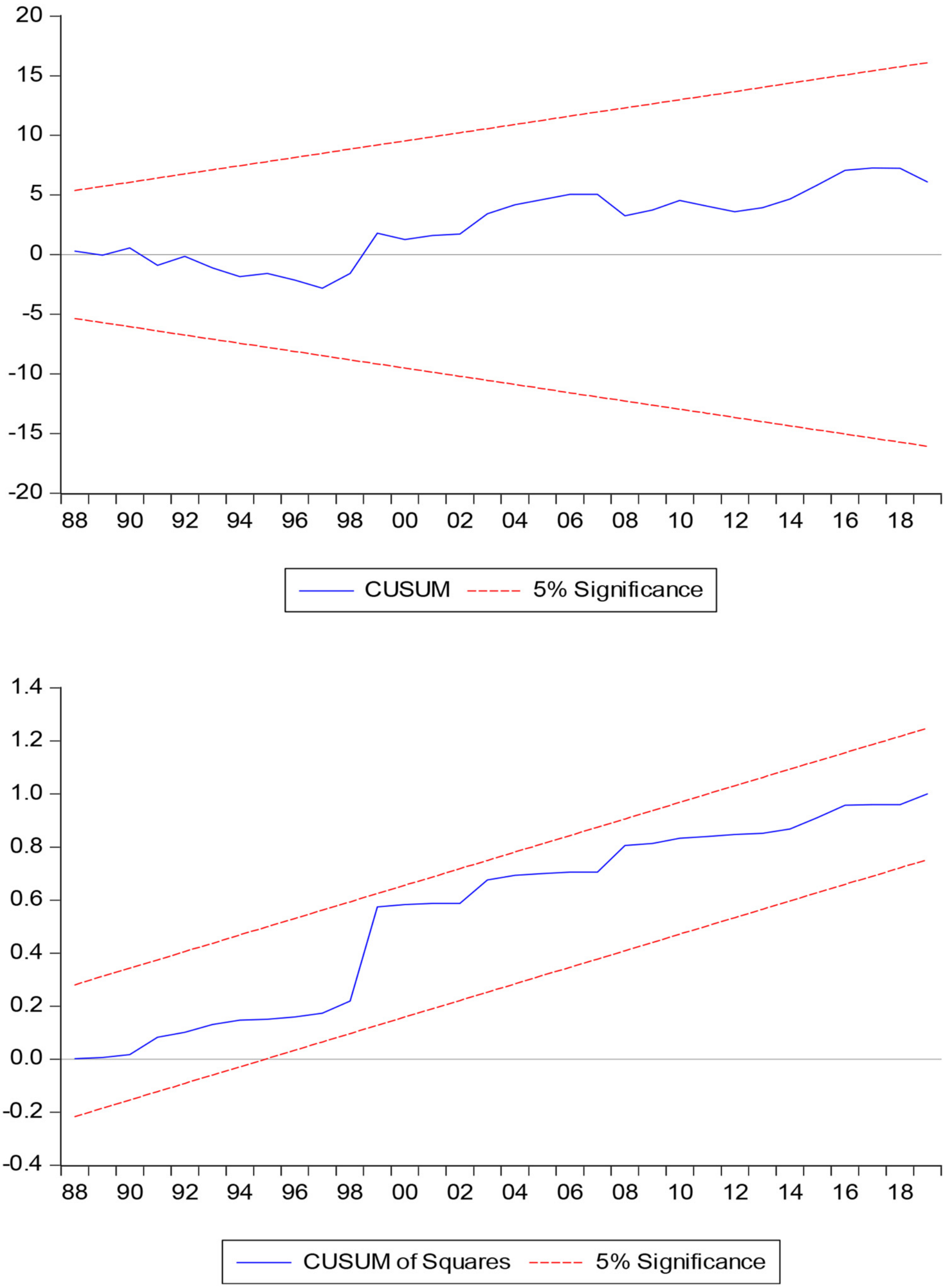

Figure 1. CUSUM and CUSUMSq for model 1. *Source*: Authors' Computation.
CUSUM: cumulative sum; CUSUM: CUMSUM of square.

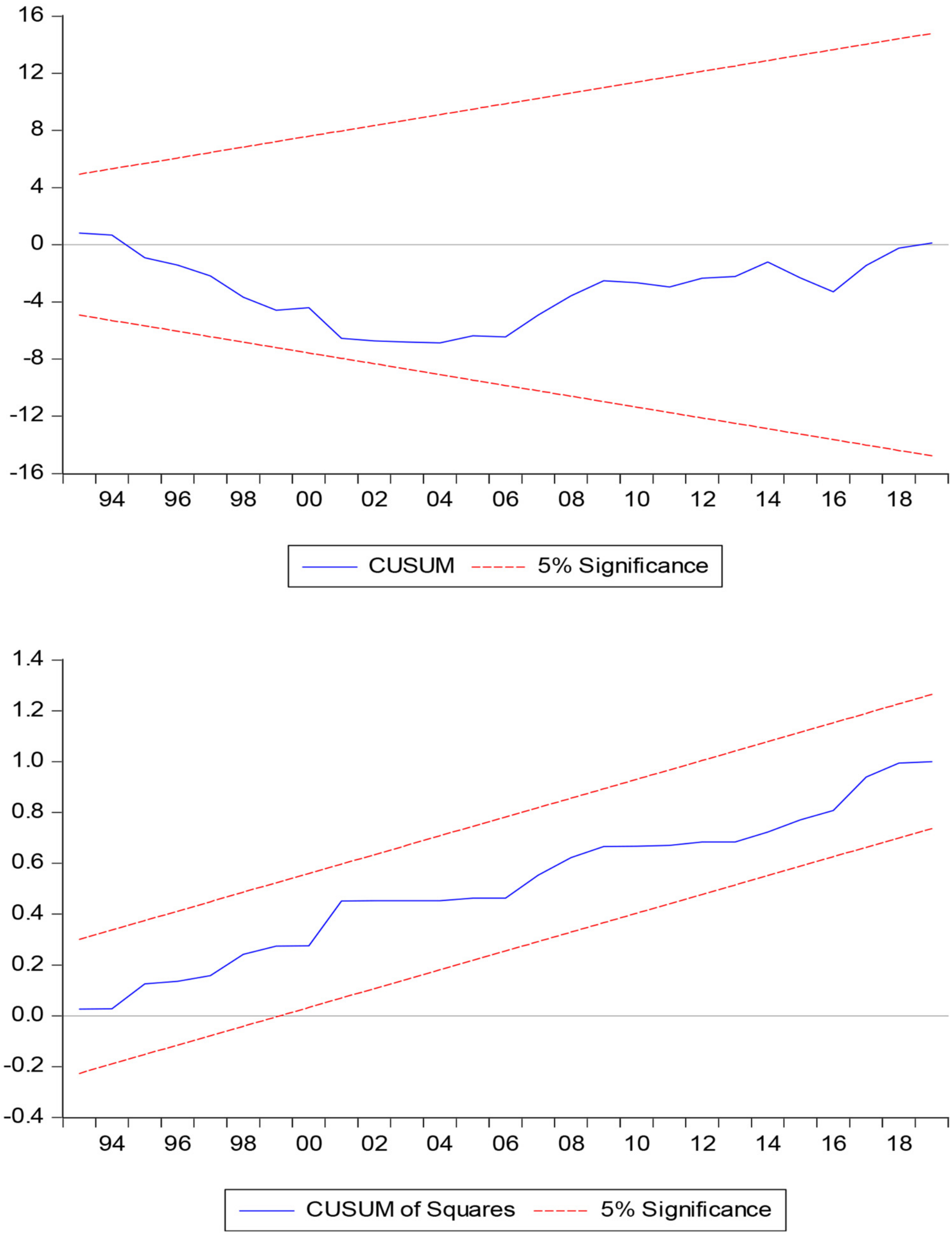

Figure 2. CUSUM and CUSUMSq for model 2. Source: Authors' Computation.
CUSUM: cumulative sum; CUSUM: CUMSUM of square.

of environmental performance, hence stalling inclusive sustainable development. For this reason, we attempt to study inclusive sustainable development in the case of India. In an attempt to come up with holistic findings and justification for our research, we adopt a dual model of both economic and environmental with relevant instruments (FDI, Tech. Innovation, Agriculture, GDP per capita, and carbon emission) that are unique to India. Also, dual scientific approaches (NARDL and DOLS) were adopted for clarity in our study.

The findings from both approaches exposed the tendency of the Indian economy to improve at the expense of its environmental development, hence, all the instruments applied in our study are contributing toward environmental degradation (except Tech. innovation and FDI) and improvement in economic development (except CO_2). This trend of finding is also confirmed with the second approach (DOLS).

The findings have clearly shown the impact of each of the selected variables, and this will inform the authorities and policymakers on the kind of policies to frame in pursuit of inclusive sustainable development for the case of India. Having seen, the dual capacity of both technological innovation and FDI toward strengthening both the economy and environment, it is worthy to consider these instruments as among the sustainable policies. Conscious and carefully attractive policies (void of laxity in law) in securing the investors' confidence should be the priority. Policies such as effective monetary and fiscal policies in moderating the both exchange and inflation rates of the country can build the investors' confidence and motivate foreign investors to consider India as a safe and investment heaven/environment. Quantitative easing and budget deficits targeting lending and investments through the increased money supply and contraction of tax are among the policies that could attract investors into the economy. The multiplier effects of attraction of foreign investors into the economy will be seen in the technological advancement of the country, hence, investors come with advanced human and machinery capital. The authorities can invest in research and development (R&D) in a bid to advance technological innovation. Reviving the technical schools through capital-intensive projects and funding will be a boost to technological innovation. Both FDI and technological innovation can moderate and mitigate the negative impact of agriculture on the environment through green policies in the agricultural sector. The above-mentioned policies are capable of shaping the country's sustainable development by improving technological development through the attraction of investors (both domestic and foreign investors).

Among the limitations of our study is the likelihood of omission of important instruments (e.g. financial development and renewables) in this sensitive subject. Also, a comparative study involving more than just one country would have been a good justification for this subject. For this reason, this topic is still open for further studies that may like to expand it on panel style or by including other important instruments.

Conclusively, our study has implications for some emerging countries in the category of India especially, the Asian countries.

Highlights

- Time series study of India's inclusive sustainable development.
- Symmetric (DOLS) and asymmetric (NARDL) approaches are applied.
- Instruments of Tech. Innovation, FDI, and agriculture are applied.
- We find Instruments of Tech. innovation and FDI mitigating emissions.
- India could attain balanced sustainable development when policies are framed around the Tech. innovation and FDI.

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