Anthropocene Science (2022) 1:295–310
https://doi.org/10.1007/s44177-022-00028-y

ORIGINAL ARTICLE

Nexus Between Emission Reduction Factors and Anthropogenic Carbon Emissions in India

Asif Raihan[1] · Almagul Tuspekova[2]

Received: 20 June 2022 / Revised: 6 July 2022 / Accepted: 7 July 2022 / Published online: 20 July 2022

Abstract
Emission reduction and environmental quality improvement have become global priorities to support sustainable growth and mitigate the harmful consequences of global warming and climate change. However, there is limited research employing econometric methodologies to investigate the potential of emission reduction components, particularly in India. Thus, the current research examined the dynamic impacts of economic growth, renewable energy usage, urbanization, industrialization, tourism, agricultural productivity, and forest area on carbon dioxide emissions in India. The Dynamic Ordinary Least Squares method was used to analyze time series data from 1990 to 2020. The empirical results revealed that economic growth, urbanization, industrialization, and tourism all contribute to environmental deterioration by increasing carbon dioxide emissions in India, whereas enhanced renewable energy use, agricultural productivity, and forest area improve the quality of the environment by lessening carbon dioxide emissions. The results provided insights into the possibility of renewable energy utilization, agricultural output, and forest areas to accomplish environmental sustainability in India. This article offers policymakers more reliable and detailed content for designing effective measures focusing on low-carbon economies, promoting renewable energy utilization, sustainable urbanization, green industrialization, eco-friendly tourism, climate-smart agriculture, and sustainable forest management in India. Additionally, the findings of the study may guide other developing nations seeking to implement effective sustainability approaches while also increasing climate change mitigation and adaptation measures.

Keywords Environment · Climate change · CO_2 emissions · Emission reduction · Renewable energy · Sustainability

1 Introduction

Due to anthropogenic emissions of greenhouse gases (GHGs), primarily by carbon dioxide (CO_2), which is mainly emitted by human-caused actions such as fossil fuel burning and deforestation, global warming and climate change are prominent subjects in the twenty-first century (Raihan et al. 2018, 2021a; Chaturvedi et al. 2022). Continuing increases in CO_2 emissions are expected to have devastating impacts on the global climate system, impacting all parts of society (Raihan et al. 2022a). As a result, cutting CO_2 emissions and improving the quality of the environment have become global concerns in order to assure long-term growth and reduce climate change's detrimental consequences (Raihan and Tuspekova 2022a). However, India is an emerging and developing country that is the seventh-most climate change vulnerable country according to the Global Climate Risk Index 2020. However, India is among the fastest-growing economies in the globe (World Bank 2022). India, with its rising economy and population, is reliant on fossil fuel energy which accounts for roughly 74% of energy requirements (World Bank 2022). The use of fossil fuel resources is expanding as a result of rapid economic expansion and greater energy demand, resulting in a significant increase in CO_2 emissions in the country. India is the earth's third-biggest carbon emitter, responsible for 7% of global emissions in 2020. India's CO_2 emissions expanded by 4.8% in 2018, along with the expansion evenly split across power and other sectors as well as transport and other industries (Jayasinghe and Selvanathan 2021). Significant environmental and ecological costs have emerged from India's excessive

✉ Asif Raihan
asifraihan666@gmail.com

[1] Institute of Climate Change, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia

[2] Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia

reliance on fossil fuel sources and a substantial increase in energy consumption, endangering the country's sustainable development. As a result, the nation is very worried about rising emission concentration, particularly in the energy segment. Hence, it's a big question if India's economic progress is linked to improved environmental sustainability.

Environmental sustainability and development plans, on the other hand, are determined by whether continued economic expansion harms the ecosystem or whether it is able to compensate for environmental damages. While the economy is growing, older, harmful methods are scrapped and replaced with newer, cleaner production, resulting in improved environmental quality. Changes in product structure, the adoption of cleaner technology, environmental regulation, and environmental responsibility all help to decouple economic progress and environmental degradation (Raihan et al. 2022b). The importance of renewable energy has been underlined as concerns regarding energy shortage, global climate change, and the concept of sustainability have grown (Sohag et al. 2021; Sharif et al. 2021). Because of the increasing exhaustion of fossil fuel reserves and their devastating environmental consequences, multinational economies are steadily shifting to more sustainable renewable resources (Sohag et al. 2019). The utilization of renewable energy cuts typical energy usage whilst protecting long-term worldwide economic productivity. Renewable energy is extensively acknowledged as a carbon-free supplier of energy with the capacity to address energy crisis concerns, and it is critical to accomplishing the worldwide emission reduction ambition of 50% by 2050 (Raihan et al. 2022b). India, on the other hand, has rich renewable energy resources and has devised and implemented governmental frameworks to boost renewable energy (Jayasinghe and Selvanathan 2021). Despite this, only a small amount of studies have been done in India to look into the possibility of using renewable energy to cut carbon emissions.

India's rapid urbanization undermines economic development's natural character by influencing the formation of industries, dwellings, as well as other forms of infrastructures, all of which lead to environmental degradation. People in India are relocating in significant numbers to urban areas. Rapid urbanization poses a challenge to India's long-term growth because it increased energy usage while also degrading the ecosystem. However, household and commercial energy usage, energy that is used by the building industry for improving infrastructures, transport, and residential areas and forest conversions for urban growth all contribute to CO_2 emissions. Additionally, growing usage of personal household appliances, for instance, air conditioners, and water heaters devour a great deal of electrical energy and increase CO_2 emissions (Raihan et al. 2022c). Furthermore, India's industrialization has opened a new door in the economy, accounting for around 30% of the country's GDP (World Bank 2022). India's economy, on the other hand, is strongly dependent on fossil-fuel-based energy, leading to significant fossil-fuel use. As a result, one of the rising problems for accomplishing sustainability and emission reduction in India is industrialization. Urbanization and industrialization, conversely, have considerable effects on power utilization and carbon emissions, although their interaction varies depending on the level of economic growth (Li and Lin 2015). Surprisingly, urbanization and industrialization have been shown to lessen environmental deterioration indirectly through their impact on incomes (Appiah et al. 2021). In general, advancement in urbanization and industrialization, which begins at a low level of development, advances to industrial revolutions and variations in energy utilization models, which boost energy usage and CO_2 emissions. The increasing level of urbanization and industrialization, alternatively, results in better and further efficient utilization of metropolitan infrastructure as well as industrial aggregation, which has adverse consequences on energy utilization and CO_2 emissions (Li and Lin 2015). As a result, this study motivated researchers to look into the consequences of urbanization and industrialization on carbon emissions in India.

Furthermore, tourism contributes significantly to India's economy. The country welcomed 18 million international tourists, making it the most visited country in South Asia and globally 29th in 2019 (World Bank 2022). In accordance with the United Nations' World Tourism Organization (UNWTO), the overall number of foreign tourists will be equal to 2 billion by 2030, generating USD2 billion in annual revenue worldwide (Raihan et al. 2022c). These figures demonstrate that the tourism industry has a substantial influence on global economic progress. Tourism, on the other hand, is related to a greater demand for energy for transport systems, food, housing, services and facilities, and tourist site administration, which are often prone to deteriorate the ecosystem (Raihan et al. 2022c). Tourism comprises approximately 5% of total global emissions, according to the UNWTO, with the transport system responsible for 75% of tourist industry emissions and accommodation responsible for 20% (IPCC 2014). The connection between tourism growth and carbon emissions is therefore pointed out in the framework of financial and transport services by domestic energy utilization. India holds the world's fourth-largest carbon footprint from tourist activities (Lenzen et al. 2018). On the other side, tourism-driven economic growth encourages countries to spend more on environmentally friendly and cutting-edge innovative solutions to reduce emissions. Nonetheless, because of the general opinion that the tourist industry favorably contributes to economic growth, notably in India, tourist expansion has been conspicuously ignored in emission modeling.

Moreover, agriculture, forestry, and other land use (AFOLU); and land use, land-use change, and forestry (LULUCF) operations represent nearly one-fifth of worldwide annual emissions, putting them the second-biggest producer of carbon emissions and contributing immensely to the worldwide climate change (IPCC 2014). Agriculture is critical in progressive countries such as India, where the agricultural industry contributed 18.31% of GDP in 2020 (World Bank 2022). Agricultural productivity is tied to the commercial expansion, which boosts the need for better, healthier environments, goods, and services, and also the authority's power to implement environmentally friendly laws (Raihan et al. 2022a). The yearly burning of fossil fuels in agriculture, on the other hand, releases billion of tons of greenhouse gases into the environment, resulting in global warming and climate change (Raihan et al. 2022a; Raihan and Tuspekova 2022a). As a result, an investigation exploring the link between agricultural productivity and pollution is essential for India's implementation of an effective sustainable agriculture policy. Furthermore, the need for food, shelter, agriculture, mass transport, and other infrastructures is increasing, putting pressure on forest areas. Forest cover has been lost as a result of urbanization, industrialization, settlements, mining, and agriculture (Jaafar et al. 2020). Land use changes such as rapid urbanization and forest loss can cause considerable carbon emissions and worldwide climate change. Forests, on the other hand, serve as both carbon sources and sinks, having a significant impact on the overall climate pattern (Raihan et al. 2019). Forests help to ease climate change by taking CO_2 from the air and preserving it in plant biomass, a process known as carbon sequestration (Raihan et al. 2021b). Nearly 300 billion tons of CO_2 from the environment are captured annually by worldwide forests, with an additional three billion tons expected to seep out into the ambiance owing to logging (Raihan et al. 2022a). The contribution of forest areas in capturing atmospheric carbon has become increasingly crucial since temperatures are expected to rise by 1.5 degrees Celsius over the preindustrial stages within 2030–2052, according to the projected global warming and climate change scenarios (IPCC 2018). India's forest area accounts for 24.3% of the total land mass (World Bank 2022), and it performs a crucial part in the country's carbon stock. As a result, it's critical to look at the forest's capacity for reducing CO_2 emissions in India.

However, policymakers must acknowledge India's potential to cut emissions in order to achieve an equilibrium in the middle of climate change mitigation and long-term progress. The question of how India might cut emissions is a serious dilemma, which can be handled by assessing the impact of CO_2 emission drivers. Despite the fact that it has become a popular issue among numerous researchers globally, there is a paucity of exploration investigating the nexus between emission and emission reduction elements in India employing econometric methodologies. To satisfy this research gap, the present investigation aims to explore the dynamic effects of economic progress, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on carbon dioxide emissions in India by using the dynamic ordinary least squares (DOLS) method. This research is anticipated to add to the latest literature and Indian policymaking in a variety of circumstances. First, by providing fresh insights from a rigorous empirical estimation to investigate the association between CO_2 emissions and emission reduction elements, this study fills a research demand in the present academic literature. Second, the investigation used the most current and extensive data across 31 years (1990–2020). Third, various unit root tests (ADF, DF-GLS, P-P), cointegration regression approaches (DOLS, FMOLS, CCR), and diagnostic tests were used to confirm the accuracy of the outcomes. Fourth, the novelty of this investigation is the assessment of the possible consequences of industrialization, tourism, agricultural production, and forest area on carbon emissions in India, which is a pioneering attempt to demonstrate the connection between carbon emissions and emission reduction variables in the situation of India. Finally, the assessment offers policymakers more reliable and detailed content for designing effective measures focusing on low-carbon economies, promoting renewable energy utilization, sustainable urbanization, green industrialization, eco-friendly tourism, climate-smart agriculture, and sustainable forest management in India. Furthermore, the findings of this research are beneficial for environmental policy assessment and future implementation of policy to start preparing India for a 1.5 °C planet by bolstering policy and action plans to reduce the impacts of climate change, thereby ensuring long-term sustainability and environmental quality. The findings of this study could help other developing countries establish viable strategies for achieving environmental sustainability while also increasing climate change mitigation and adaptation initiatives.

2 Methods

2.1 Data

India is a leading tourist destination country experiencing continuous economic growth and rapid urbanization which is causing higher energy utilization and CO_2 emissions. Alternatively, renewable energy is playing a key role in global emission reduction. Moreover, the AFOLU and LULUCF sectors are the second-biggest supplier of carbon emissions following energy consumption. Therefore, the present study selected economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area as illustrative variables intending to explore their dynamic impacts on CO_2 emissions. This study employed the DOLS approach of cointegration by Pesaran et al. (2001) to conduct an empirical analysis by using India's time series annual data from 1990 to 2020. The data were taken from the dataset of the World Development Indicator (WDI). Carbon dioxide emissions were used as a dependent parameter in this study, with economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area serving as independent parameters. To confirm that the data are normally distributed, the parameters were transformed into a logarithm. Table 1 lists the variables with logarithmic representations, measurement units, as well as the source of data. Additionally, the yearly trends of the assessment parameters in India are depicted in Fig. 1.

2.2 Empirical Model Generation

The dynamic effects of economic growth, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions were investigated using the following economic function generated in the context of the standard Marshallian demand (Friedman 1949) function at the time t:

$$CO_{2t} = f\left(GDP_t; RNE_t; URB_t; IND_t; TR_t; AVA_t; FA_t\right) \quad (1)$$

where CO_{2t} is the CO_2 emissions at time t, and GDP_t is the economic growth at time t, RNE_t is the renewable energy use at time t, URB_t is the urbanization at time t; IND_t is the industrialization at time t; TR_t is the tourism at time t; AVA_t is the agricultural productivity at time t, and FA_t is the forest area at time t.

The empirical model is represented by the following equation:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 URB_t + \tau_4 IND_t + \tau_5 TR_t + \tau_6 AVA_t + \tau_7 FA_t \quad (2)$$

Equation (2) can also be used as an econometric model in the following way:

$$CO_{2t} = \tau_0 + \tau_1 GDP_t + \tau_2 RNE_t + \tau_3 URB_t + \tau_4 IND_t + \tau_5 TR_t + \tau_6 AVA_t + \tau_7 FA_t + \varepsilon_t \quad (3)$$

where τ_0 and ε_t stand for intercept and error term, respectively. In addition, τ_1, τ_2, τ_3, τ_4, τ_5, τ_6, and τ_7 denote the coefficients.

Furthermore, Eq. (3) can be arranged logarithmically as follows:

$$LCO_{2t} = \tau_0 + \tau_1 LGDP_t + \tau_2 LRNE_t + \tau_3 LURB_t + \tau_4 LIND_t + \tau_5 LTR_t + \tau_6 LAVA_t + \tau_7 LFA_t + \varepsilon_t \quad (4)$$

2.3 The Analytical Flow Chart

The analytical flow chart of the study to investigate the dynamic effects of economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions in India is portrayed in Fig. 2. The present study used the EViews 12 software for data analysis. The EViews is statistical software for Windows that is mostly used for time-series driven econometric analysis.

2.4 Data Stationarity Techniques

Unit root testing is needed to avoid erroneous regression. It ensures that parameters in the regression analysis are stationary by contrasting them and estimating the equations of interest utilizing stationary processes. The empirical literature recognizes the importance of defining the order of integration before investigating cointegration among variables. According to a number of research, it is necessary using more than a unit root test to assess the integration order of the series because the efficacy of unit root tests varies with effect size (Raihan and Tuspekova

Table 1 Variables with logarithmic representations, units, and sources of data

Variables	Description	Logarithmic forms	Units	Sources
CO_2	CO_2 emissions	LCO2	Kilotons (kt)	WDI
GDP	GDP	LGDP	Constant Indian rupee	WDI
RNE	Renewable energy use	LRNE	% of total final energy use	WDI
URB	Urbanization	LURB	Number of urban population	WDI
IND	Industrialization	LIND	Industry value added (% of GDP)	WDI
TR	International tourism	LTR	Number of tourist arrivals	WDI
AVA	Agricultural productivity	LAVA	Agricultural value added (% of GDP)	WDI
FA	Forest area	LFA	Square kilometers (sq. km)	WDI

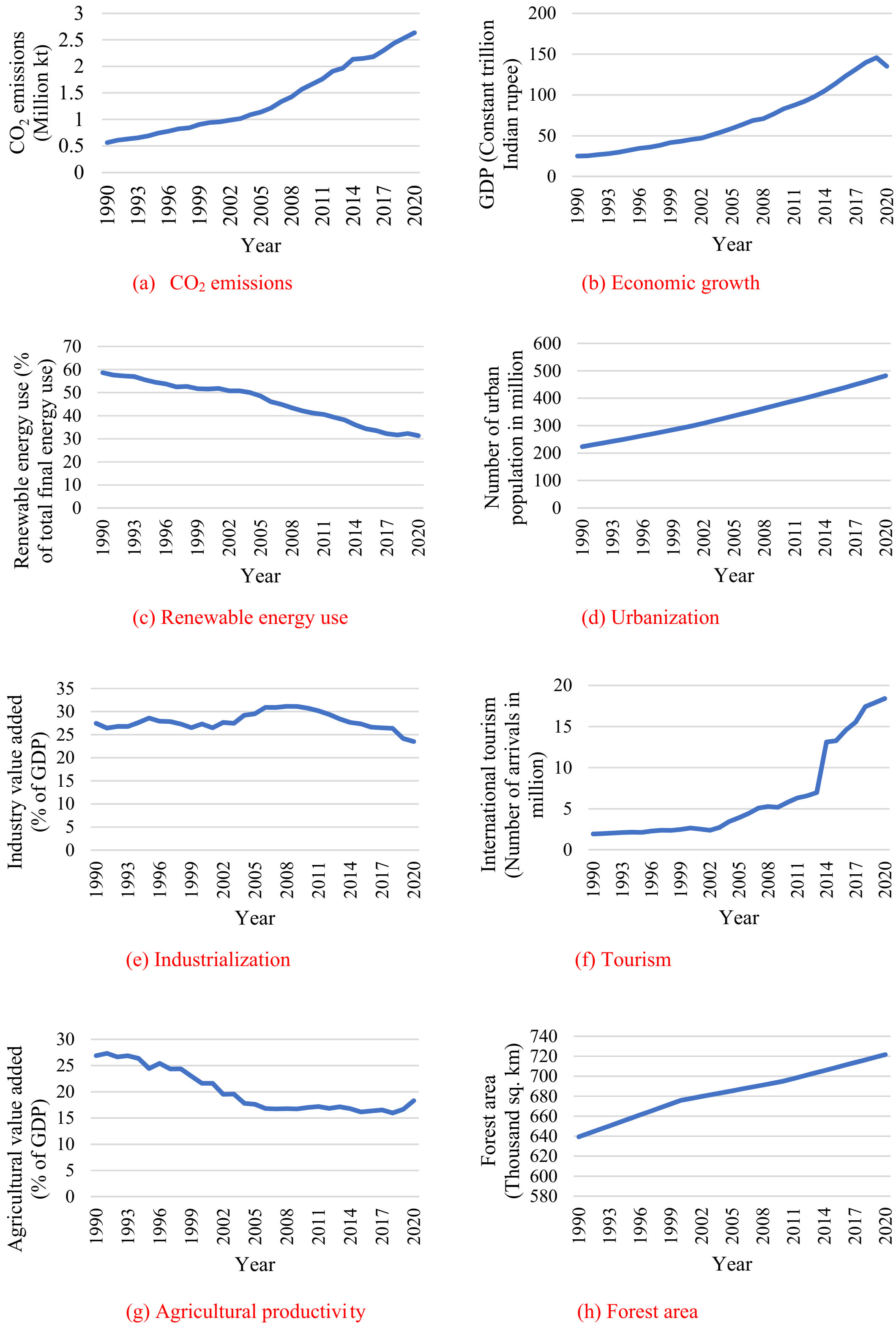

Fig. 1 Yearly trends of the assessment parameters in India

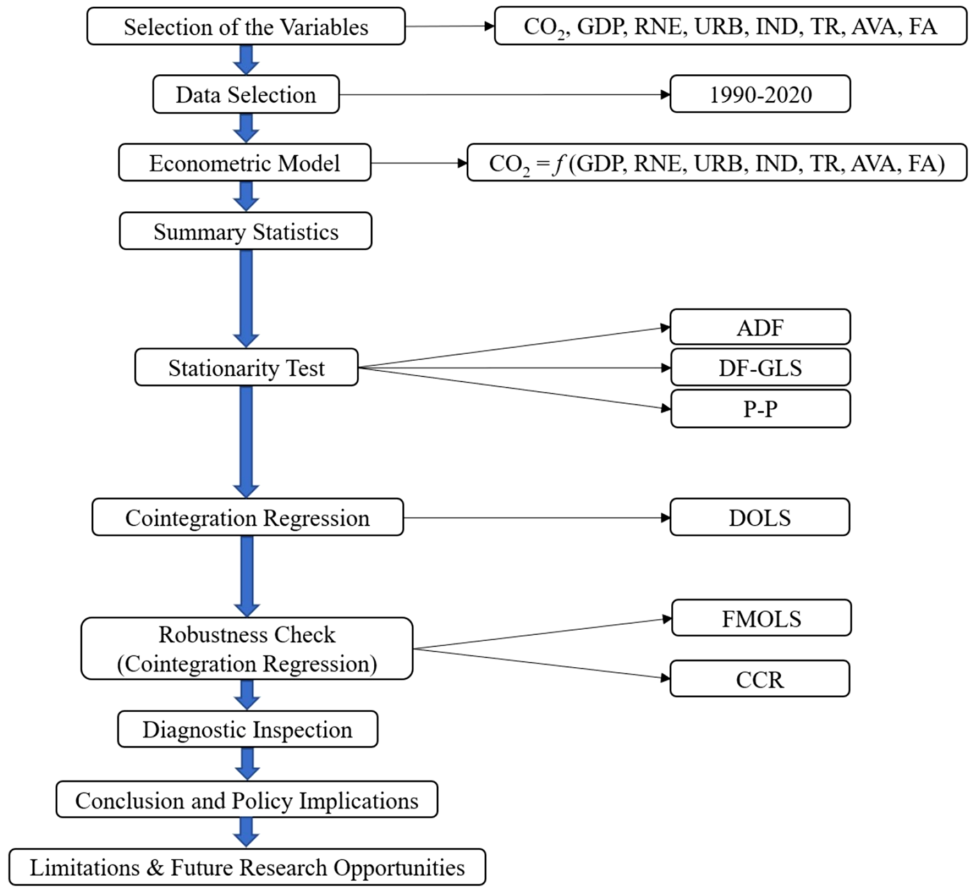

Fig. 2 The analytical flow chart of the study

2022b; Raihan et al. 2022b). The current study used the Augmented Dickey–Fuller (ADF) theory suggested by Dickey and Fuller (1979), the Dickey–Fuller generalized least squares (DF-GLS) theory suggested by Elliott et al. (1992), as well as the Phillips–Perron (P–P) test proposed by Phillips and Perron (1988) to detect the autoregressive unit root (Phillips and Perron 1988). In this study, the unit root test was performed to ensure that no variable surpassed the integration order and to validate the usage of the DOLS method over conventional cointegration methods.

2.5 Regression with DOLS Cointegration

DOLS, an expanded formulation of ordinary least squares estimation, was used in this work to examine time series data. The DOLS cointegration test integrates explanatory factors along with leads and lags of their baseline differential terms to control unobserved heterogeneity and compute standard deviations utilizing a covariance matrix of errors that is resistant to serial correlation. The inclusion of the separate terms' leads and lags proves that its error term is orthogonalized. The DOLS estimator's standard deviations have such a normal exponential distribution, hence they provide a credible assessment of the statistically significant parameters (Raihan and Tuspekova 2022c). When there is a mixed order of integration, the DOLS approach allows individual parameters in the cointegrated framework to be incorporated by evaluating the dependent variable on explanatory factors in levels, leads, and lags (Raihan and Tuspekova 2022d). The fundamental advantage of the DOLS estimation is the existence of mixed-order integration of individual parameters in the cointegrated framework. In DOLS estimation, for example, one of the $I(1)$ parameters was regressed against those other parameters, and some were $I(1)$ parameters with leads (p) and lags ($-p$) of the first differences, while some were $I(0)$ parameters with a single equation (Begum et al. 2020). This estimate addresses small sample error, endogeneity, and autocorrelation concerns by aggregating the leads and lags across explanatory factors. However, after establishing the variables' cointegration, the study moves on to the DOLS estimates of the long-run coefficients using Eq. (5).

$$
\begin{aligned}
\Delta LCO2_t = & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LGDP_{t-1} + \tau_3 LRNE_{t-1} \\
& + \tau_4 LURB_{t-1} + \tau_5 LIND_{t-1} + \tau_6 LTR_{t-1} \\
& + \tau_7 LAVA_{t-1} + \tau_8 LFA_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta LCO2_{t-i} \\
& + \sum_{i=1}^{q} \gamma_2 \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta LRNE_{t-i} \\
& + \sum_{i=1}^{q} \gamma_4 \Delta LURB_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta LIND_{t-i} \\
& + \sum_{i=1}^{q} \gamma_6 \Delta LTR_{t-i} + \sum_{i=1}^{q} \gamma_7 \Delta LAVA_{t-i} + \sum_{i=1}^{q} \gamma_8 \Delta LFA_{t-i} + \varepsilon_t
\end{aligned}
\tag{5}
$$

where Δ is the first difference operator and q is the optimum lag length in Eq. (5).

2.6 Robustness Check

This investigation utilized the fully modified OLS (FMOLS) and Canonical Cointegrating Regression (CCR) to validate the robustness of the DOLS results. Hansen and Phillips (1990) created the FMOLS regression to integrate the finest cointegrating regression estimations. The FMOLS method extends least squares to adjust for serial correlation problems and endogeneity in independent variables caused by cointegrating. To aid with erroneous regressions, the FMOLS approach employs standard regression methods (OLS) for nonstationary (unit root) data. Additionally, Park (1992) proposed the CCR technique, which involves transforming data by using the stationary portion of a cointegrating theory. A cointegrating link given by the cointegrating paradigm will remain unaltered after such data processing. The CCR transformation in a cointegrating model to make the error term reported in this section with regression coefficients at zero frequency (Raihan and Tuspekova 2022e). As a consequence, the CCR technique yields asymptotically efficient estimation techniques as well as asymptotic chi-square tests with no nuisance parameters. Asymptotic consistency can be generated utilizing FMOLS and CCR techniques by studying the impact of serial correlation. As a result, long-term elasticity was calculated using Eq. (5) utilizing the FMOLS and CCR estimators.

3 Results

3.1 Summary Statistics of the Variables

Table 2 shows the results of the summary measures among variables, together with the analyses of several normality tests (skewness, probability, kurtosis, and Jarque–Bera). Each indicator had 31 samples of India's yearly data from 1990 to 2020. The skewness values near zero indicate that all of the variables are normal. Furthermore, kurtosis was used in the study to determine if the trend is light-tailed or heavy-tailed in comparison to the normal distribution. According to the empirical observations, all of the series is platykurtic, with values less than 3. Furthermore, the lower scores of the Jarque–Bera probability indicate that all of the parameters are normal. Moreover, we checked for multicollinearity after choosing the variables. Whenever independent variables in a regression model are substantially associated with one another, multicollinearity occurs. It makes the model difficult to comprehend and causes an overfitting problem. The values of the independent variable's centered variance inflation factors (VIF) are less than 10, indicating that there is no severe multicollinearity in the model, and we can proceed. The findings from the summary statistics of the variables lead us to conduct the unit root test of the variables.

Table 2 The summary statistics of the variables

Variables	LCO2	LGDP	LRNE	LURB	LIND	LTR	LAVA	LFA
Mean	14.020	31.721	3.8063	19.622	3.3276	15.340	2.9860	13.435
Median	13.945	31.711	3.8822	19.631	3.3188	15.181	2.8800	13.438
Maximum	14.784	32.612	4.0716	19.993	3.4384	16.728	3.3081	13.489
Minimum	13.240	30.856	3.4458	19.223	3.1579	14.478	2.7707	13.368
Std. Dev	0.8444	0.5647	0.2051	0.2347	0.0685	0.7784	0.1946	0.0346
Skewness	0.0661	0.0398	−0.4836	−0.0787	−0.1986	0.5991	0.5148	−0.2759
Kurtosis	1.6731	1.7285	1.8465	1.7765	2.0854	1.9318	1.5910	2.0877
Jarque–Bera	2.2966	2.0965	2.9269	1.9655	0.2132	2.3280	2.3398	1.4684
Probability	0.3172	0.3506	0.2314	0.3743	0.3989	0.1894	0.1399	0.4799
Sum	434.64	983.36	117.99	608.29	103.16	475.55	92.567	416.47
Sum Sq. Dev	7.0406	9.5674	1.2625	1.6519	0.1406	18.175	1.1359	0.0359
Observations	31	31	31	31	31	31	31	31
Centered VIF		7.4694	2.3414	6.4475	1.5351	1.8570	1.4591	2.0526

Table 3 The outcomes of the unit root tests

Logarithmic form of the variables	Augmented Dickey–Fuller (ADF)		Dickey–Fuller generalized least squares (DF-GLS)		Phillips–Perron (P–P)	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LCO2	−0.3602	−5.0079***	−0.0989	−4.6542***	−0.3515	−5.0850***
LGDP	−0.6164	−1.9788***	−1.8312*	−2.5214***	−0.6164	−2.9788***
LRNE	1.4784	−3.7789***	0.6355	−3.8485***	1.1982	−3.8490***
LURB	−0.8576	−2.1080**	0.4520	−2.3364**	−1.4449	−5.2041***
LIND	−1.0501	−2.2492*	−1.2625	−2.3517*	−0.5345	−4.8295***
LTR	0.8002	−5.1631***	1.1669	−5.1361***	0.9626	−5.1631***
LAVA	−1.6385	−2.5124*	−1.3140	−2.5309*	−1.6082	−5.3476***
LFA	−0.6151	−2.6359*	−0.6151	−2.6359*	−0.6352	−2.6209*

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Table 4 The results of dynamic ordinary least squares estimation: dependent variable LCO2

Variables	Coefficient	Standard Error	t-Statistic
LGDP	0.256490***	0.145999	1.745999
LRNE	−0.513595**	0.285052	−1.801758
LURB	1.977600***	0.471511	4.194171
LIND	0.338502**	0.132256	2.559433
LTR	0.069565*	0.080213	0.866008
LAVA	−0.428657***	0.113756	−3.768224
LFA	−2.873859***	1.955676	−1.469497
C	6.302824	21.10334	0.298665
R^2	0.997458		
Adjusted R^2	0.996684		
Standard error of the estimate	0.027898		
F-statistic	1289.064		
Prob (F-statistic)	0.000000		
Root mean square error (RMSE)	0.024030		
Mean absolute error (MAE)	0.018260		

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

3.2 Results of Unit Root Tests

By ensuring that no parameter surpassed the integration order, the unit root test was used to demonstrate the feasibility of using the DOLS estimation model rather than just cointegration. The results of unit root testing utilizing the ADF, DF-GLS, and P–P tests are presented in Table 3. The variable is stationary at combined levels either in level or first-order integration, indicating that the DOLS technique is preferable to traditional cointegration approaches.

3.3 DOLS Outcomes

Table 4 displays the results of the DOLS evaluation. The estimated long-run coefficient of LGDP is positively significant at a 1% level while other factors remain constant, meaning that a 1% increase in economic growth may lead to a 0.26% increase in CO_2 emissions. Furthermore, the estimated coefficient of renewable energy consumption is negative at a 5% significant level, suggesting that expanding renewable energy use by 1% is associated with a 0.51% reduction in CO_2 emissions in the long run. Besides, at a 1% level, the predicted long-run coefficient of LURB is positively significant, implying that a 1% growth in urbanization causes a 1.98% increase in CO_2 emissions. Furthermore, at a 5% level, the projected long-run coefficient of LIND is significantly positive, indicating that an increase of 1% in industry value added is associated with an increase of 0.34% in CO_2 emissions. Additionally, the estimated long-run coefficient of tourism is positive at a 10% significant level, denoting that a 1% spike in the tourism industry results in a 0.07% rise in CO_2 emissions. Furthermore, at a 1% level, the projected coefficient of agricultural productivity is significantly negative, implying that a 1% boost in agricultural productivity advances to a 0.43% decline in CO_2 emissions. Finally, at a 1% level, the long-run coefficient of forest area is significantly negative, demonstrating that growing forest area by 1% results in a 2.87% drop in carbon dioxide emissions. The empirical results expose that economic expansion, urbanization, industrialization, and tourism all degrade India's environmental quality, but rising renewable energy use, agricultural productivity, and forest area all assist India to attain sustainable development, improving the quality of the environment, and climate change mitigation by lowering carbon emissions.

Furthermore, from both a conceptual and a pragmatic viewpoint, the indications of the predicted coefficients are identical. The calculated model's goodness of fit was also evaluated using a range of diagnostic tests in this study. The R^2 and adjusted R^2 estimates, correspondingly, are 0.9975 and 0.9967, implying that the derived regression model fits quite perfectly. This signifies the explanatory factors can describe 99% of the overall changes of the predictor variables. Next, the F-statistic demonstrates that the dependent and independent parameters corroborate the DOLS model that has been constructed. With a p-value of 0.0000, the F-statistic suggests that the regression model is statistically significant. Third, model predictions were accurately estimated using the root mean square error (RMSE) along with mean absolute error (MAE). The RMSE and MAE figures are nearly zero and non-negative, showing that the DOLS modeling produced findings that were close to flawless match to the data.

Table 5 The results of fully modified ordinary least squares estimation: dependent variable LCO2

Variables	Coefficient	Standard error	t-Statistic
LGDP	0.370026**	0.192997	1.917265
LRNE	−0.458142**	0.282890	−1.619503
LURB	2.057955***	0.412367	4.990589
LIND	0.360207**	0.131081	2.747969
LTR	0.092609*	0.045056	2.055424
LAVA	−0.453909***	0.135311	−3.354569
LFA	−4.438872**	1.663091	−2.669049
C	22.14679	17.77725	1.245794
R^2	0.997060		
Adjusted R^2	0.996125		
Standard error of the estimate	0.029270		

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

Table 6 The results of canonical cointegrating regression estimation: dependent variable LCO2

Variables	Coefficient	Standard error	t-Statistic
LGDP	0.533160*	0.339279	1.571449
LRNE	−0.572094*	0.468884	−1.220118
LURB	1.507200***	0.622021	2.423070
LIND	0.356225**	0.152315	2.338739
LTR	0.129232**	0.064650	1.998958
LAVA	−0.367302**	0.197676	−1.858103
LFA	−3.718306**	1.744907	−2.130948
C	19.36198	18.29077	1.058566
R^2	0.992981		
Adjusted R^2	0.990641		
Standard error of the estimate	0.026239		

***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively

3.4 FMOLS and CCR Tests to Confirm the Robustness of DOLS Evaluation

The FMOLS and CCR approaches were used in this study to test the accuracy of DOLS estimation. Tables 5 and 6 provide the FMOLS and CCR regression coefficients for the model. The FMOLS and CCR results demonstrate the robustness of DOLS prediction. The FMOLS and CCR results validated the coefficients of economic growth, urbanization, industrialization, and tourism are positive and significant. Furthermore, The FMOLS and CCR tests verified the inverse relationship of renewable energy use, forest area, and agricultural productivity with CO_2 emissions. As a result, economic expansion, urbanization, industrial growth, and tourism contribute to environmental degradation in India by increasing CO_2 emissions, whereas continuing to increase renewable energy utilization, forest area, and agricultural productivity contributes to improved environmental quality in India by lowering CO_2 emissions. The FMOLS and CCR results are consistent with the findings of the DOLS. The FMOLS and CCR estimation R^2 and adjusted R^2 values represent the model's goodness of fit, suggesting that the factors can account for 99% of the variability of the dependent variable's changes.

3.5 Diagnostic Inspection

To validate the intensity of the cointegration valuation, this study used normality, heteroscedasticity, and serial correlation analysis. The diagnostic test findings are presented in Table 7. The model indicates normality and it also reveals that there is neither autocorrelation nor heteroscedasticity. We also used the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive

Table 7 The outcomes of diagnostic testing

Diagnostic tests	Coefficient	*p*-Value	Decision
Jarque–Bera test	2.627161	0.1337	Residuals are normally distributed
Lagrange multiplier test	1.566581	0.2311	No serial correlation exits
Breusch–Pagan–Godfrey test	0.949745	0.4891	No heteroscedasticity exists

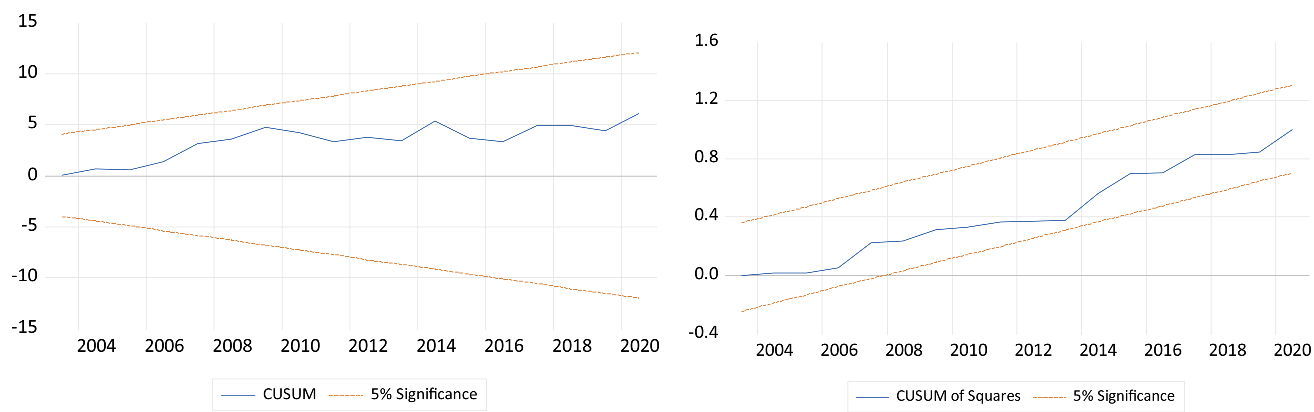

Fig. 3 The plots of the cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) tests (critical bounds at 5% significance level)

residuals (CUSUMQ) tests to ensure the model's stability. Figure 3 depicts the CUSUM and CUSUMQ graphs at a 5% level of significance. The residual values are shown as blue lines, whereas the levels of confidence are shown as red lines. The calculated findings show that the analyzed residuals' values continue to stay inside the boundaries of confidence at a 5% level of significance, confirming the model's stability.

4 Discussion

In the case of India, the current study explored the link between economic progress and environmental damage. In the long run, economic expansion causes environmental degradation, according to the findings. As per the results, higher economic growth in India is associated with a decline in environmental sustainability. Furthermore, other studies in India, including Jayasinghe and Selvanathan (2021), and Qayyum et al. (2021) found a positive relationship between GDP and CO_2 emissions. Greater social demands engendered by increased consumption and development projects lead to an increase in pollution, garbage generation, and damage to the environment as a result of rising economic growth (Raihan et al. 2022b). Subsequently, commercial factors seem to be applicable for eco-friendly promotion and preservation, in preference to pretending a long-term danger to ecosystems. India is an energy-dependent nation and its progress in the economy is crucial for providing the supplies needed for continuous production. Enhancing renewable energy would not only promote India's economic expansion and minimize environmental deterioration, but it would also give the country the chance to play a leading role in the global structure and increases its competition with more advanced nations.

Moreover, this study looked into the possibility of using renewable resources to accomplish environmental sustainability in India. As per the findings of the study, renewable energy use seems to have a vital function in controlling carbon emissions in India. According to the results, renewable energy usage has a negative and significant effect on CO_2 emissions, inferring that incorporating more renewable sources of power into India's total energy mix could assist the nation cut emissions. The outcome of this study is coherent with Qayyum et al. (2021) who assert that renewable energy helps India's environment by lowering CO_2 emissions. As climate change plaguing, using renewable resources for power generation is vital to guaranteeing sustainable growth, and climate change mitigation (Raihan et al. 2022d). Switching India's energy budget to renewables is critical to facilitating the usage of sustainable power and the establishment of a naturally healthy environment as a result of rising global environmental awareness. Solar, wind, hydro, geothermal, and biomass are examples of renewable resources that can assist India in resolving its energy problem. Amidst this, technological, organizational, societal, governmental, and financial barriers have hampered the acquisition and utilization of sustainable resources.

The influence of urbanization was analyzed, and it demonstrated a positive and significant impact on India's carbon emissions in the long run. This illustrates that the massive growth of the urban population is endangering the environment's long-term sustainability. The current research's finding on urbanization is compatible with those of other Indian studies, such as Qayyum et al. (2021). According to the results of this study, India's urbanization caused a rise in energy consumption bolstered by non-renewable fossil fuels, resulting in higher CO_2 emissions. It's not unexpected that CO_2 emissions respond so strongly when their sources are three channels: electronic component usage; construction, infrastructure development; and mass transport. Rapid urbanization raises energy needs, which raises GHG emissions and wreaks havoc on the environment in urban regions (Raihan et al. 2022c). In addition, because the metropolitan zone is among the most electricity-intensive regions of the economic system, an increase in the need for electronic devices (conditioning, appliance, lights, refrigeration, and so on) led to increased CO_2 emissions. Nevertheless, urbanization has a favorable influence on economic growth, which in turn relates to carbon emissions (Raihan et al. 2022c). Furthermore, the analysis found a long-term positive and strong link between industrialization and CO_2 emissions. The evidence reveals that growing emissions in India are partly attributable to industrialization. Moreover, industrialization might generate pollution from industrial effluents, hazardous commodities, and heavy metals, damaging the atmosphere's performance while also increasing GHGs and energy usage. At the beginning of industrialization, there is a shift from agricultural to resource-related heavy industrial, together with modifications mostly in the size and mix of production rather than the rate of technological advancement (Appiah et al. 2021). CO_2 emissions are higher in the early stages of industrialization because of the high demand for energy and the lack of energy-saving equipment. This course of evolution may result in changes in industrialization, resulting in fewer polluting operations.

This investigation uncovered a significant positive connection between tourism and CO_2 emissions in India, implying that increased tourism activities worsen air quality through accelerating environmental degradation in the country. According to the findings, growth in foreign visitor arrivals in India boosts energy usage while having a negative impact on climate change. The findings of this study align with Jayasinghe and Selvanathan (2021), who discovered a positive involvement between the tourist industry and CO_2 emissions in India. Nevertheless, the tourist industry is one of the major causes of poor environmental conditions, leading to CO_2 emissions from not only transportation but also heat and electricity generation (Raihan et al. 2022c). Deforestation is one of the most significant environmental consequences of widespread tourism extension. Tourism also has an environmental impact in terms of physicochemical and socio-cultural factors. The tourist industry leads to environmental pollution by releasing smoke, sulphur dioxide, nitrogen oxides, and other hazardous compounds into the atmosphere. Tourism events degrade the ecological landscape and detract from its allure. The accumulation of rubbish can turn a lovely spot into a landfill. In addition, tourism adds substantially to noise pollution, which comprises both physical and vehicle noise. Furthermore, airplanes, hotel accommodations, and motorized water supply activities all contribute to increased carbon emissions (Raihan et al. 2022c). Therefore, to offset tourism's negative impacts on society, the environment, the climate, and the economy, sustainable tourism should be established. Tourism, on the other hand, is unquestionably important for India's economic growth and ought to be properly promoted and expanded. India's focus on long-term tourism growth is crucial, as the nation is quickly discovering the need of understanding the interaction between growth and environmental protection, amidst worries that tourism is straining the nation's unstable ecosystem.

Agricultural and environmental concerns are not always conflicting, according to this study, but rather complementary, because increasing agricultural productivity and effectiveness also supports the protection of the environment in India. Agricultural production benefits the environment by absorbing carbon dioxide from the environment and storing it as biomass or soil carbon. Agricultural production, according to Raihan et al. (2022d), first improves the quality of the environment before harming the environment, rendering the agriculture industry a CO_2 emitter. Conventional farming techniques, on the other hand, should be updated with new techniques, which might enhance agriculture productivity and cut emissions whilst assuring food and nutrition security for India's rising population. According to the IPCC (2014), attaining the potential to cut GHG emissions from agriculture might not only lead to a clean and healthy environment but could also bring new revenue opportunities as more agricultural activities might be conducted. Carbon emitted by agricultural operations can be captured and used to reduce one's carbon footprint if treatment and technology are used appropriately. For the transformation of the food and agricultural sectors to more ecologically friendly and climate-resilient methods, many worldwide organizations have recently created an initiative called climate-smart agriculture (CSA).

Forest ecosystems enhance the level of India's environment, according to this study, because forests capture CO_2 from the atmosphere and preserve it in forest vegetation and soil. In the long run, boosting forest carbon sinks via expanding forest reserves mitigates environmental deterioration, according to the empirical findings. Forest degradation has been viewed as a cause of the destruction of the environment since it is the second-leading emitter of emissions in the world (IPCC 2014). As a result, limiting deforestation may be the most straightforward strategy to minimize CO_2 emissions. Increasing forest carbon sequestration is by far the most cost-effective path to preventing pollution and mitigating climate change (Raihan et al. 2019). Restoring, enhancing, and conserving forests is a critical goal for mitigating climate change, and this is a sticking point in today's climate science community. Additionally, forestry-based mitigation techniques (forest protection, afforestation, natural regeneration) might well have multiple functions, such as carbon sequestration, biodiversity conservation, ecosystem rejuvenation, and societal production of products and services (Raihan and Said 2021). Through the extensive application of forestry-based mitigation strategies, India's forestry sector has a significant ability to alleviate global climate change by lowering CO_2 emissions and improving forest biomass thereby expanding the nation's carbon sink. In a nutshell, enhancing forest areas could be a good way to cut India's carbon emissions.

5 Conclusions and Policy Implications

5.1 Conclusions

Employing time series data from 1990 to 2020, this research examined the dynamic implications of economic growth, renewable energy consumption, urbanization, industrialization, tourism, agricultural productivity, and forest area on CO_2 emissions in India. The ADF, DF-GLS, and P–P unit root tests were used in this study to determine the integration order of the dataset. To assess the long-run effects of environmental factors, the DOLS model was used. The empirical outcomes revealed that economic growth, urbanization, industrialization, and tourism all contribute to environmental deterioration by intensifying CO_2 emissions in India, whereas enhanced renewable energy use, agricultural productivity, and forest area contribute to improved environmental quality by lowering CO_2 emissions. The projected outcomes are vigorous to FMOLS and CCR model. The results provided insights into the possibility of renewable energy utilization, agricultural output, and forest areas to accomplish environmental sustainability in India. Furthermore, the findings made recommendations regarding sustainable development in India by building strong governing policy tools to minimize environmental deterioration.

5.2 Policy Implications

The outcomes of the current investigation recommended that India's authorities develop an environmental management system that minimizes CO_2 emissions while maintaining economic progress. In India, the best option for mitigating climate change is a low-carbon economy. To minimize pollution at its source, the "pollute first, then treat" policy and economic growth at the price of the environment might be modified. In this context, the study recommended that the government assist markets by establishing robust regulation that improves long-term emission reduction targets and continuously supports carbon-reducing technologies. India's government can implement laws such as high carbon taxes, carbon capture and storage, and emission trading programs to limit CO_2 emissions through fossil fuel use across electricity production and industries. Sectoral decoupling necessitates considerable changes in centralized government policy, behavioral patterns, and scientific and technical development. India may move its emphasis from extensive to intensive growth, altering its economic developmental trajectory by concentrating not only on productive capacity but also on sustainable economic improvement. Furthermore, promoting the economic switch to renewables is crucial for mitigating the environmental shocks of economic expansion. Policymakers should also support and promote renewable energy technologies. These steps would stimulate economic growth and increase the share of renewable energy usage in final energy utilization by substituting CO_2-intensive traditional energy sources. Furthermore, organizational coordination is essential to promote renewable energy use across all economic operations to ensure long-term growth in the economy. Finally, strict attention to environmental regulations is essential. These policies will assure that the nation's goal of accelerated economic expansion and change does not jeopardize environmental quality.

Long-term development in India might be increased by adopting and executing efficient rules to manage the nation's industrial sector practices. The current analysis proposed that more clean energy or renewable energy be employed to optimize the energy utilization structure. India's energy consumption is primarily reliant on conventional high-carbon power sources such as coal, oil, and natural gas. Increased use of renewable energy might have long-term effects on CO_2 emissions and industrialization. India could implement measures to decrease the price of renewable energy while discouraging the consumption of fossil fuels in industry, businesses, and families. Governmental policies to encourage renewable energy, and sustainable development may be implemented. The government would also encourage the use of energy-efficient residential equipment and more inexpensive renewable energies in the domestic sector. The government might formulate and maintain appropriate policies to encourage investment in the development of renewable energy technology, resulting in increased renewable energy usage. The government, for example, would finance renewable energy projects through public–private partnerships. Furthermore, India could be successful in establishing technical cooperation partnerships with Latin American countries whilst still researching renewable energy technology proactively. Furthermore, local authorities and non-governmental groups can help to increase environmental awareness amongst persons of different ages by disseminating information about green energy technology, and energy efficiency. This can be achieved via training and instructional programs at schools and universities. Fiscal methods that the authorities may employ to motivate people to convert to cleaner energy include tax breaks, monetary assistance, and government contracts. The government may use media to spread its green living idea including low-carbon lifestyles and consumer behavior.

Furthermore, authorities should set legislation to design and provide environmentally friendly urban and smart building technology. It is crucial for India's government to concentrate its attention on the development, enhancement, and support of green and sustainable urbanization, which will help to improve the performance and sustainability of economic growth while avoiding environmental mortification. Rapid urbanization degrades the ecosystem, necessitating urban development plans through improving energy efficiency, the implementation of technology innovation, and the promotion of sustainable lifestyles. Consequently, authorities may promote sustainable and green urbanization to reduce the possibility of environmental degradation, so increasing the role of renewables in following urbanization, such as the use of electric vehicles, solar lights, ethanol for cars, and so on. In urban regions, using renewable energy and energy-efficient devices and office machinery can help to minimize energy use and CO_2 emissions. Furthermore, due to its ability to absorb almost 1000 kg of CO_2 for each tree, green foliage in the manner of planting trees is yet another procedure for lowering CO_2 emissions and cooling the urban environment. However, precautions are needed to preserve harmony between rural and urban populations in order to avoid migration to metropolitan areas and overburdening urban infrastructure. As a result, the government may inspire people to avoid megacities like Delhi, Mumbai, and Kolkata in favor of mid-sized and small cities (MSCs). Additionally, the government may stimulate industry development and job creation in rural areas. Such measures can increase overall economic growth in cities, alleviate the load on megacities, and boost the competitiveness of MSCs. Lastly, policymakers in India may suggest carbon taxes, emissions trading strategies, carbon capture and storage, and other measures for various urban activities.

The current study's findings imply that industrialization is a major issue that should be prioritized when developing sustainability initiatives. The industrial framework must be properly altered and optimized to sustain economic growth while minimizing CO_2 emissions. Established industrial operations in India that are liable for emissions and public health dangers must take adequate measures to prevent pollution. Moreover, foreign investors must comply with regulations and constraints in order to implement green industrialization plans. Energy usage and production must be sustainable for green industrialization, particularly renewable energy use increasing. Improving the share of renewable energy in overall energy consumption will have a long-term influence on green industrialization. Furthermore, the authority might use administrative means to strengthen the reformation of heavy- and high-emissions businesses while still encouraging zero- and low-emissions industries by supporting industrial diversification. The use of ecologically friendly techniques must be made compulsory for the entire industry sector, and the use of obsolete, polluting technologies must be forbidden. Furthermore, the government may assist firms in acquiring machinery to reduce emissions. If any industry does not adopt inclusive technologies, policymakers may consider imposing environmental levies. Additionally, governmental and non-governmental research and development institutes are necessary to limit pollution through revolutionary technologies, whilst encouraging the use of recycled industrial garbage as a supplier of power, resulting in lower emissions.

Furthermore, India's government should create a framework that makes locals, tourists, and other parties responsible for their behavior in regard to the natural ecosystem of India's tourist attractions. Tourists would have not only a considerably better trip but would still be better educated if all tourism businesses went green and embraced sustainability in their activities. In addition to information booklets and leaflets, government service disclosures with clear graphs and charts could be dispersed to the wider populace as regularly as needed, together with the latest update on the governments' continuous green attempts and improvement, inspiring people to be aware of the value of saving energy, environmental protection, and to adopt green practices even while being on holiday. Moreover, transportation technological progress, including the use of energy-efficient airplanes and high-speed trains, must be encouraged. CO_2 emissions can be lowered by modernizing the public transport system and financing energy efficiency and waste disposal as a result of increasing tourism. Additionally, in order to conserve the ecosystem in tourist hotspots, the authorities may levy and implement environmental charges. Furthermore, the government could make it simpler for businesses to employ green and low-carbon technology and alternative energies for transport systems, logistics, accommodation, and other tourism-related activities, decreasing CO_2 emissions and minimizing resource overexploitation. India may enhance its current sustainability initiatives and shine a light on other nations where the tourist industry is degrading the environment.

This research recommends that India's authorities develop effective strategies to enhance the conditions of the environment through enhancing agricultural productivity. High-yielding and disease-resistant crop types, combined with encouraging farmers to reject conventional cultivation practices in favor of more efficient agrarian practices, are among the necessary measures to increase agricultural production. Furthermore, with the application of new agricultural techniques and the supply of good seeds as well as other agricultural implements, agricultural growth and value-added aspects can be boosted to a higher extent. By building organic and low-carbon agricultural practices, sustainable agriculture can cut emissions and improve carbon storage. To attain long-term agricultural output, the administration may promote a more efficient power infrastructure and facilitate the transition to cleaner, more intensive agricultural energy sources. The authority might encourage the usage of clean renewable energy such as wind, solar, hydro, and biofuel, as it increases agricultural output while simultaneously aiding in the fight against global warming and climate change. Incentives for the use of renewable energy in farming would develop the firm compete in global markets while releasing fewer pollutants. Irrigation technologies can be shifted from non-renewable to renewable supplies of energy to achieve a carbon–neutral environment. Other significant agricultural improvements include encouraging farmers for using solar tube wells for irrigation, tunnel farming, transitioning from traditional tillage to no-till farming, organic farming, and minimizing fertilizer use to reduce the environmental effect. These modern agricultural technologies can assist huge farms in reducing personnel, increasing output, and lowering emissions. Additionally, intensive farming investments in India through increased international collaboration will help to reduce emissions from India's agricultural sector whilst enhancing agricultural productivity.

Moreover, the results of this study recommended that India's policymakers formulate appropriate environmental and climate-resilient strategies, with a special focus on lowering emissions via forest development. The objective of achieving sustainable development with sustainable forest management particularly helping preserve the quality of the environment along with socio-economic benefits from forests might be included in India's forest policy. As a result, proper forest management strategy and significant policy execution may be considered. A special emphasis on greening India could be provided in collaboration with the local administrations by enhancing forest conservation including replanting and rehabilitation of degraded forest areas. India's government may increase investments while establishing strict forest rules aimed at reducing CO_2 emissions by enhancing forest biomass through forest protection and conservation. Additionally, the government may encourage private sector participation in sustainable forest management by developing commercial forest plantation sections. India may potentially collaborate with international organizations to attract more investment in GHG emission reduction initiatives through forestry sector development. India can potentially increase its ability to mitigate climate change by adopting a diverse range of forestry-based mitigation measures. As a result, forest carbon sinks will continue to grow as a result of more suitable and cost-effective forest management practices such as afforestation, reforestation, forest conservation, agroforestry, increased natural regeneration, and urban forestry. Finally, effective forest policy-making might help India improve its national carbon sink thereby assuring national green growth and sustainable management of the forests.

5.3 Limitations and Future Research Opportunities

This research showed some major pragmatic results in the instance of India, although the methodology had some shortcomings that might be conducted in future investigations. The scarcity of data on renewable energy consumption, tourism, and forest area outside its study period limited the analytical capacity of the econometric methodologies applied. Additional potential factors for reducing emissions and ecological sustainability, including recycling commodities, lowering water and electricity consumption, and switching to organic food, could be studied in future research. Furthermore, CO_2 was utilized as a measure of environmental pollution in this investigation. More exploration on consumption-based carbon pollution, as well as other emission measures such as methane (CH_4), nitrous oxide (N_2O), sulphur dioxide (SO_2), and short-lived climate forces (SLCF), is required. Although carbon emissions have been used as a proxy for environmental damage, it is not the only source of deteriorating environmental quality. Additional pollution measurements, such as water and land pollution, may be examined in the future.

Data Availability All data generated or analyzed during this study are available here: https://databank.worldbank.org/source/world-development-indicators#.

Declarations

Conflict of interest All the authors associated with this work declare that there is no conflict of interest.

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

References

Appiah M, Li F, Korankye B (2021) Modeling the linkages among CO_2 emission, energy consumption, and industrialization in sub-Saharan African (SSA) countries. Environ Sci Pollut Res 28(29):38506–38521. https://doi.org/10.1007/s11356-021-12412-z

Begum RA, Raihan A, Said MNM (2020) Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. Sustainability 12(22):9375. https://doi.org/10.3390/su12229375

Chaturvedi RK, Jose K, Shruthi BVR, Kariya KP, Garg A (2022) Suitability assessment and carbon mitigation potential of plantations on India's railway land. Anthropocene Sci 1(1):145–163. https://doi.org/10.1007/s44177-022-00015-3

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74:427–431. https://doi.org/10.1080/01621459.1979.10482531

Elliott G, Rothenberg TJ, Stock JH (1992) Efficient tests for an autoregressive unit root (No. t0130). National Bureau of Economic Research

Friedman M (1949) The Marshallian demand curve. J Polit Econ 57(6):463–495

Hansen B, Phillips PCB (1990) Estimation and inference in models of cointegration: a simulation study. Adv Econ 8:225–248

IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change. IPCC, Geneva, Switzerland, p 151

IPCC (2018) Summary for policymakers. In: Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, p 32

Jaafar WSWM, Maulud KNA, Kamarulzaman AMM, Raihan A, Sah SM, Ahmad A, Saad SNM, Azmi ATM, Syukri NKAJ, Khan WR (2020) The influence of forest degradation on land surface temperature—a case study of Perak and Kedah, Malaysia. Forests 11(6):670. https://doi.org/10.3390/f11060670

Jayasinghe M, Selvanathan EA (2021) Energy consumption, tourism, economic growth and CO2 emissions nexus in India. J Asia Pacific Econ 26(2):361–380. https://doi.org/10.1080/13547860.2021.1923240

Lenzen M, Sun YY, Faturay F, Ting YP, Geschke A, Malik A (2018) The carbon footprint of global tourism. Nat Clim Chang 8(6):522–528. https://doi.org/10.1038/s41558-018-0141-x

Li K, Lin B (2015) Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: does the level of development matter? Renew Sustain Energy Rev 52:1107–1122. https://doi.org/10.1016/j.rser.2015.07.185

Park JY (1992) Canonical cointegrating regressions. Econometrica 60(1):119–143. https://doi.org/10.2307/2951679

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econometr 16(3):289–326. https://doi.org/10.1002/jae.616

Phillips PC, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346

Qayyum M, Ali M, Nizamani MM, Li S, Yu Y, Jahanger A (2021) Nexus between financial development, renewable energy consumption, technological innovations and CO_2 emissions: the case of India. Energies 14(15):4505. https://doi.org/10.3390/en14154505

Raihan A, Said MNM (2021) Cost-benefit analysis of climate change mitigation measures in the forestry sector of peninsular Malaysia. Earth Syst Environ 6:1–15. https://doi.org/10.1007/s41748-021-00241-6

Raihan A, Tuspekova A (2022a) The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: new insights from Peru. Energy Nexus 6:100067. https://doi.org/10.1016/j.nexus.2022.100067

Raihan A, Tuspekova A (2022b) Role of economic growth, renewable energy, and technological innovation to achieve environmental sustainability in Kazakhstan. Curr Res Environ Sustain 4:100165. https://doi.org/10.1016/j.crsust.2022.100165

Raihan A, Tuspekova A (2022c) Toward a sustainable environment: nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resour Conserv Recycl Adv 15:200096. https://doi.org/10.1016/j.rcradv.2022.200096

Raihan A, Tuspekova A (2022d) Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: new insights from Kazakhstan. World Dev Sustain 1:100019. https://doi.org/10.1016/j.wds.2022.100019

Raihan A, Tuspekova A (2022e) Nexus between economic growth, energy use, agricultural productivity, and carbon emissions: new insights from Nepal. Energy Nexus 7(2022):100113. https://doi.org/10.1016/j.nexus.2022.100113

Raihan A, Begum RA, Said MNM, Abdullah SMS (2018) Climate change mitigation options in the forestry sector of Malaysia. J Kejuruteraan 1(6):89–98. https://doi.org/10.17576/jkukm-2018-si1(6)-11

Raihan A, Begum RA, Said MNM, Abdullah SMS (2019) A Review of emission reduction potential and cost savings through forest carbon sequestration. Asian J Water Environ Pollut 16(3):1–7. https://doi.org/10.3233/AJW190027

Raihan A, Begum RA, Said MNM (2021a) A meta-analysis of the economic value of forest carbon stock. Geogr Malaysian J Soc Space 17(4):321–338

Raihan A, Begum RA, Said MNM, Pereira JJ (2021b) Assessment of carbon stock in forest biomass and emission reduction potential in Malaysia. Forests 12(10):1294. https://doi.org/10.3390/f12101294

Raihan A, Begum RA, Said MNM, Pereira JJ (2022a) Dynamic impacts of energy use, agricultural land expansion, and deforestation on CO_2 emissions in Malaysia. Environ Ecol Stat. https://doi.org/10.1007/s10651-022-00532-9

Raihan A, Begum RA, Said MNM, Pereira JJ (2022b) Relationship between economic growth, renewable energy use, technological innovation, and carbon emission towards achieving Malaysia's Paris Agreement. Environ Syst Decis. https://doi.org/10.1007/s10669-022-09848-0

Raihan A, Muhtasim DA, Pavel MI, Faruk O, Rahman M (2022c) Dynamic impacts of economic growth, renewable energy use, urbanization, and tourism on carbon dioxide emissions in Argentina. Environ Process 9:38. https://doi.org/10.1007/s40710-022-00590-y

Raihan A, Muhtasim DA, Pavel MI, Faruk O, Rahman M (2022d) An econometric analysis of the potential emission reduction components in Indonesia. Clean Prod Lett 3:100008. https://doi.org/10.1016/j.clpl.2022.100008

Sharif A, Meo MS, Chowdhury MAF, Sohag K (2021) Role of solar energy in reducing ecological footprints: an empirical analysis. J Clean Prod 292:126028. https://doi.org/10.1016/j.jclepro.2021.126028

Sohag K, Taşkın FD, Malik MN (2019) Green economic growth, cleaner energy and militarization: evidence from Turkey. Resour Policy 63:101407. https://doi.org/10.1016/j.resourpol.2019.101407

Sohag K, Chukavina K, Samargandi N (2021) Renewable energy and total factor productivity in OECD member countries. J Clean Prod 296:126499. https://doi.org/10.1016/j.jclepro.2021.126499

World Bank (2022) World development indicators (WDI). Data series by The World Bank Group. The World Bank, Washington, DC, USA. Retrieved from https://databank.worldbank.org/source/world-development-indicators#