Received: 05 January 2024 | Revised: 17 February 2024 | Accepted: 21 February 2024

https://doi.org/10.56946/jeee.v3i1.324

Journal of Environmental and Energy Economics

Research Article

The Influence of Agriculture, Renewable Energy, International Trade, and Economic Growth on India's Environmental Sustainability

Asif Raihan[1*], Tipon Tanchangya[2], Junaid Rahman[2], Mohammad Ridwan[3]

[1]Institute of Climate Change, Universiti Kebangsaan Malaysia, Bangi 43600, Malaysia
[2]Department of Finance, University of Chittagong, Chittagong 4331, Bangladesh
[3]Department of Economics, Noakhali Science and Technology University, Noakhali-3814, Bangladesh
*Corresponding author: Asif Raihan. Email: asifraihan666@gmail.com

Abstract

Agriculture significantly contributes to the economic growth of many developing nations, while energy policies aimed at combating climate change play a crucial role in bolstering this growth. This paper examines the relationship between agriculture, renewable energy, trade openness, and economic growth on carbon dioxide (CO_2) emissions in India from 1965 to 2022. The unit root tests confirmed the stationarity of the data, and the autoregressive distributed lag (ARDL) bound testing confirmed a long-run relationship among variables. The results of the ARDL long-run elasticities indicate that a 1% increase in agriculture productivity and trade openness led to a respective increase in CO_2 emissions of 0.42% and 0.20%, respectively. In addition, a slight increase in usage of renewable energy was found to have a positive impact on reducing CO_2 emissions, while economic growth also contributed to a small decrease in emissions. The findings confirmed the validity of the environment Kuznets curve (EKC) alongside the pollution haven hypothesis in the context of India. The findings suggest that implementing renewable energy usage, low-carbon economy, and trade reforms, along with robust environmental policies that minimize CO_2 emissions, can contribute to the development of the agriculture sector and green economy.

Keywords: Climate change, carbon emissions, agriculture, renewable energy, trade, environmental sustainability

Introduction

Environmental degradation seems a prominent subject of study for researchers in the last century, as a result of the increase in the emission of greenhouse gases (GHGs), particularly CO_2 [1]. In 2022, the world's total emissions of GHGs grew by 1.7 percent, obtaining a new peak of 53.8 billion metric tons of atmospheric carbon dioxide equivalent. Worldwide released greenhouse gases have grown by a factor of over sixty since 1990 [2]. Global warming remains a pressing concern that has garnered focus among nations worldwide [3,4]. The 13th Sustainable Development Goal (SDG) focuses on addressing the effects of global warming. Ever since the UN introduced the SDGs, there has been a global increase in initiatives to address global warming by implementing emission reduction strategies primarily specializing in the factories and power industries [5].

Main energy sources trigger air pollution is caused by the use of oil and gas along with additional resources that are not renewable. These factors have detrimental consequences regarding public welfare and the surroundings [6]. Air pollutants have the ability to enter wetland ecosystems and freshwater sources, causing harm to marine life and contaminating clean water [7]. The expansion regarding the economy within nations that are developing as well as developed is closely linked to air pollution, as various economic activities across different sectors contribute to this issue [8]. Electricity is crucial for driving business growth by contributing to revenue generation, growth, job creation, and production [9]. Moreover, various studies indicate that climate is primarily driven by the factors related to financial expansion and resource utilization [10].

Furthermore, trade openness is having a substantial and favorable consequence for the growth of the economy [11]. Previous studies examined the comparative advantage for resource transfers between nations and debated examining the implications of trade accessibility upon the environment [12]. A theoretical perspective regarding

the influence of trade openness upon environmental effects implies the potential pollutants refuge implications may be better understood through the lens of environmental control laws [13]. Examining the influence of environmental regulation upon establish positioning decisions alongside trade patterns is heavily influenced by the degree of openness [14]. Enforcing environmental regulations in developed countries promotes cleaner production practices. As a result, many large enterprises priorities investing in merchandise with more pollutants in newly industrialized countries that have effective safeguards against pollution [15]. This strategy allows them to generate significant profits in their home countries. On the contrary, this argument lacks persuasiveness as stringent environmental regulations have minimal effect on trade and investment flows. Many academic works explore different countries, but the findings remain inconclusive. Dauda et al. [16] found evidence supporting The Pollution Haven hypothesis. The assumption via demonstrating that CO_2 emissions tend to increase with greater openness to trade. On the other hand, alternative literature argues that trade openness actually reduces CO_2 emissions and supports the reliability of the assumption regarding the existence of halo heaven [17].

In addition, emissions from Activities related to cultivation, including burning hedges, utilizing nutrients, using substances forest destruction, insufficient hunting, alongside converting grasslands towards cultivable land during cultivation, contribute to the rise in GHG emissions [18]. Around 20%-24% of a significant portion of global greenhouse gas emissions come from AFOLU, which refers to farming, forestry, and additional activities involving land [19]. Throughout the final decade of the last century, there came to be a notable rise in global agricultural production, paralleling the increase in population. The rapid growth of the global population delivers a substantial danger to the sustainability of agriculture and the health of the planet is of utmost importance, as it results in a significant increase in the world's need for nutrition [20]. The agriculture sector was officially recognized just like a major source of the release of greenhouse gases since it is inefficient farming methods used to boost productivity and ensure food security [21]. Utilizing fossil fuel-powered farm machinery, implementing irrigation systems, practicing confined animal rearing, and applying nitrogen-rich nutrients contribute to emissions in the agriculture sector [22]. By implementing measures such as preventing deforestation, promoting woodland regeneration, improving plant and animal care, and investing in green energy production, the agricultural sector could potentially achieve a 20% reduction in total emissions by 2050.

India's economic growth is significantly boosted by the agriculture sector. In 2021, agriculture contributed to approximately 45.5% of the labor force constituted a significant portion and contributed approximately 20% towards India's GDP. Located in India, around 60 percent of the country's land is dedicated to agriculture. India has become a major exporter of agricultural products such as We offer a wide range of products including grain, herbs, fiber, crude oil snack frosting, oil of castor, coffee, the nuts, tea, seasonal produce, and fructose. In 2022, India's agricultural and allied product exports exceeded $50 billion. Nevertheless, the agriculture sector in India holds a major part in contributing to emissions of greenhouse gases, making up 20% of all emissions in the country. India ranks as the third-largest contributor to GHG emissions globally. In 2021, India's CO_2 emissions reached 3.9 billion metric tons, accounting for approximately 7% of the global total.

The agricultural sector performs a critical part within driving the development of a nation's economy alongside progress. Multiple studies have been conducted to analyze CO_2 emission, but only a limited number have considered agricultural variables. Nevertheless, the findings have been varied. There exists a lack regarding research on the investigation examines the correlation among agriculture, trade transparency, renewable energy, and the release of carbon dioxide in India. In addition, India has demonstrated a firm affiliation to decrease its GHG emissions. To 45% of its 2005 level in relation to its GDP through 2030, India’s goal is to attain emissions reductions of net zero in 2070. Many academic studies on Indian emissions have primarily focused on the environmental aspects, often overlooking the country's trade openness and its impact on emissions. India, being a growing economy, is projected to generate emissions due to its robust economic performance and commitment to international trade, the country has experienced significant expansion. It is crucial to analyze the country's emissions with regard to its growth by employing a methodology that emphasizes transparency in trade. This investigation aims to analyze the association among agriculture, renewable energy, exports, as well as economic growth on emissions of carbon dioxide through India.

This investigation adds to the current body of literature on environmental sustainability via examining the association across parameters using a systematic approach. This study investigates the nexus between agriculture and environmental quality in light of the economy, trade, and renewable energy. Since India ranks second in

agricultural productivity and third in GHG emissions, the nation is selected as a sample. Moreover, a wide range of datasets from 1965 to 2022 is utilized for the investigation. The ARDL approach has a virtue regarding capturing each the short-run and long-run relationship simultaneously. Additionally, several unit root tests and diagnostic tests are used to confirm the accuracy of the results. In addition, the paper offers new theoretical and empirical perspectives that are especially valuable for decision makers. This research would assist to the execution of procedures focused on achieving zero hunger (SDG 2), Ensuring access to affordable and clean energy (SDG 7), promoting sustainable economic growth (SDG 8), encouraging responsible consumption and production (SDG 12), and taking action on climate change (SDG 13) This study is notable for employing a pollution-based examine that evolved in accordance with the ecological oasis hypothesis. The study's importance is apparent in India's global position regarding geography, finance, politics, and farming. Nevertheless, the research findings of the investigation have important consequences for other developing countries across different regions.

Literature Review

Extensive research has been conducted in the literature that examines the effects regarding transparency in trade, farming, energy efficiency, as well as CO_2 emissions [23]. The following work explores different countries, with varying strategies alongside observations that are influenced by the financial framework of each country being studied. There are studies that examine the impact of agricultural practices regarding environmental quality, there is a concept known as agriculture-induced environmental Kuznets curve (EKC). There is a limited amount of literature available on the growing phenomenon of agriculture-induced EKC. Ali et al. [24] executed an in-depth study to explore the link between agricultural ecosystem as well as CO_2 emissions across Pakistan compared to 1972 to 2014. By employing the Granger causality test and ARDL model, the researchers were able to identify several factors that assist to the rise through CO_2 emissions. These factors include the expertise lies in the field of cropping equipment transforming farm waste into the plant matter, raising grains, managing animals, and cultivating multiple crops. Balsalobre-Lorente et al. [25] applied the FMOLS and DOLS methods to assess the influence of agriculture on CO_2 emissions within BRICS countries. The study uncovered a clear link between agriculture and the release of CO_2 into the atmosphere. Atasel et al. [26] employed the AMG method and it has been discovered that farming plays a crucial role in the reduction of CO_2 emissions in the highest ten agricultural countries.

In the present day, multiple facets of the financial system contribute to the release of CO_2. Thus, the assessment of examining the link among growth and energy in relation to ecological contamination, and emissions has successfully examined the link within environmental damage and economic prosperity. Increased use of energy and economic growth have found to trigger increased emissions of CO_2 in different countries around the world. Alternative forms of energy are widely acknowledged over their capacity of lowering CO_2 emissions as well as promote a sustainable environment. Countries need to enhance environmental quality and establish environmentally-friendly guidelines that encourage the widespread use of clean energy sources. Multiple studies examined the influence of green electricity on carbon dioxide pollutants in multiple nations. Nevertheless, the outcomes differ based on the percentage of green energy in the total power use of these countries.

There is ongoing debate surrounding the relationship between trade openness as well as CO_2 emissions. It is a notable amount of literature that discusses the consequences of scale, composition, and technique. Expanding the rise in revenue growth is directly linked to a subsequent increase in CO_2 emissions. as a result of openness to trade and the scale effect. As trading expands, the GDP also increases, leading in response to a boost in release of GHG emanating from industrial sector. Through careful analysis of the composition effect, it has been found that commerce has a small but detrimental influence on society. Ultimately, when examining the technique's impact; it becomes evident that the manufacturing sector has an enormous effect upon the environment as a result of the growing demand for more environmentally friendly production methods. The consequences of transparency in trade are actually categorized into three main categories: scale, composition, and technique. The pollution haven hypothesis and pollution halo hypothesis propose two different ways in which trade openness impacts the environment. According to the pollution haven hypothesis, companies that seek refuge in areas with lenient environmental regulations tend to contribute to higher levels of CO_2 emissions. As an illustration, Dauda et al. [16] highlighted the presence associated with the pollutants haven hypothesis within African countries during the

period of 1990-2016. In addition, Mahmood et al. [27] reported the pollution haven hypothesis in Tunisia through the ARDL method.

However, when the host nation benefits from trade-related innovations that promote environmental sustainability, it encourages a positive impact on our planet. This phenomenon is known as the pollution halo effect. Essandoh et al. [28] verified the validity of the pollution halo effect in 52 developed and developing countries from 1991 to 2014. It revealed openness to trade encompasses a negative impact upon CO_2 emissions through developed countries. It was revealed that sharing trade-related knowledge encounters a beneficial effect on reducing the release of CO_2 across countries. By leveraging human capital and other resources, countries can maximize the benefits of economic spillover.

Nevertheless, a bit of a dearth of research investigating pollution haven hypothesis in relation to India, specifically focusing on agriculture and renewable energy. This study seeks to address the current void in scholarly research; this study investigates the influence regarding agriculture, clean energy, trade, as well as economic growth on India's CO_2 emissions.

Methodology

Data

This study analyzed the effects of green energy, agriculture, and trade openness on CO_2 emissions in India. The research utilized the ARDL method and covered the time span from 1965 to 2022. Variables were chosen based on prior research. Data on CO_2 emissions and renewable energy were collected from the Our World in Data (OWD) database, while data on agricultural value added, trade, and GDP were retrieved from the World Development Indicators (WDI) database. Figure 1 illustrates the visual representation of the yearly patterns of the variables. Variables were transformed into natural logarithms to ensure data normality.

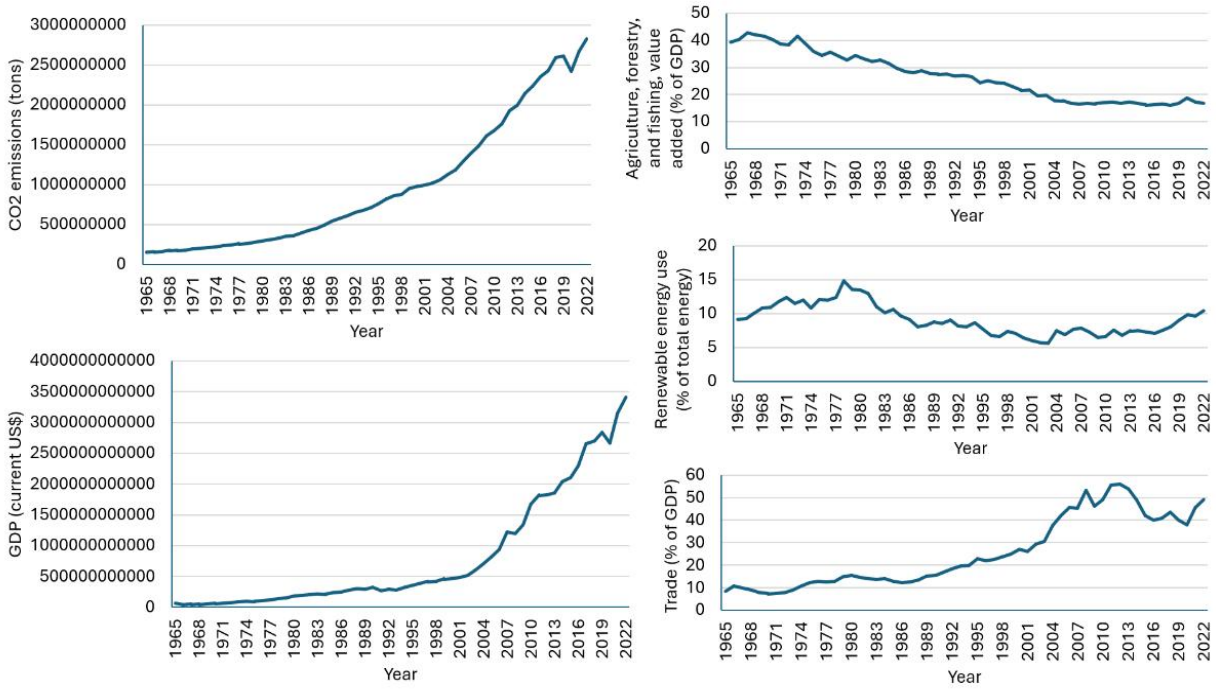

Figure 1. Annual trends of the variables.

Empirical model and analysis procedures

The framework analyses the consequences of farming, openness to trade, and renewable energy on CO_2 emissions in India. We have derived from the following formula:

$$C_t = f(A_t; R_t; Y_t; T_t) \quad (1)$$

where, C_t, A_t, R_t, Y_t, and T_t are CO_2 emissions, agricultural value-added, renewable energy, economic growth, and trade at time t.
Once the variables are assumed to have a relationship and a logarithmic form. A proposed empirical model is as follows:

$$LC_t = \tau_0 + \tau_1 LA_t + \tau_2 LR_t + \tau_3 LY_t + \tau_4 LT_t + \varepsilon_t \quad (2)$$

Nevertheless, using non-stationary variables in regression can lead to inaccurate outcomes. Therefore, subsequently ought to verify that all factors are stationary before making any adjustments. Three unit root tests were used to evaluate the stationary of the data set in this investigation. These tests consist of the Augmented Dickey-Fuller (ADF) test [29], the Dickey-Fuller generalized least squares (DF-GLS) test [30], and the Phillips-Perron (P-P) test [31].
This research utilized the ARDL model [32] to analyse the relationship across each of the variables. The ARDL model was chosen for its many advantages. One of its key benefits is the capacity to assess both short-run and long-run parameters simultaneously. Additionally, this framework is able to apply whatever that these time series variables tend to be frictionally integrated, I (0), or I (1). Using proper variables is essential to ensure accurate regression or ARDL procedure results.
A bounds test was used to evaluate whether there is a long-term relationship between the variables. According to Pesaran et al. [32] critical value table, if the F test result exceeds the maximum essential cherish limit, the null hypothesis of no co-integration between research variables is rejected. If the F test value falls within the range of the critical boundaries, it indicates a biased result. The analysis suggests that the null hypothesis is supported, indicating that there is no cooperation within the variables. Fortunately, the estimated result of the F test falls below the lower critical limit. Furthermore, the long-term coefficient is established when there exists a long-run relationship between the variables under investigation. Here is the formula for the long-run estimation model:

$$\Delta LC_t = \tau_0 + \tau_1 LC_{t-1} + \tau_2 LA_t + \tau_3 LR_t + \tau_4 LY_t + \tau_5 LT_t + \sum_{i=1}^{q} \alpha_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LA_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LR_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LY_{t-i} + \sum_{i=1}^{q} \alpha_5 \Delta LT_{t-i} + \varepsilon_t \quad (3)$$

Once a long-term association among the research a parameter has been recognized, a prediction for the short-term model can be made. Equation (4) represents the short-run model, also known as the error correction model (ECM).

$$\Delta LC_t = \tau_0 + \tau_1 LC_{t-1} + \tau_2 LA_t + \tau_3 LR_t + \tau_4 LY_t + \tau_5 LT_t + \sum_{i=1}^{q} \alpha_1 \Delta LC_{t-i} + \sum_{i=1}^{q} \alpha_2 \Delta LA_{t-i} + \sum_{i=1}^{q} \alpha_3 \Delta LR_{t-i} + \sum_{i=1}^{q} \alpha_4 \Delta LY_{t-i} + \sum_{i=1}^{q} \alpha_5 \Delta LT_{t-i} + \theta ECM_{t-1} + \varepsilon_t \quad (4)$$

Where, θ the error correction coefficient is an essential aspect in the model being estimated. The given value illustrates the parameter for adjustment speed, indicating the velocity at which the series converges to a long-term equilibrium.

Results and Discussion

The initial Table 1 which displays the descriptive and correlation statistical results of variables within our study. The results indicate that the CO_2 emission exhibits a negative skewness, whereas the remaining variables demonstrate a positive skewness. The sleekness values, which are near zero, indicate most of those factors adhere

to a normal distribution. All the series demonstrate platykurtic characteristics, with kurtosis values that are less than 3. According to the Jarque-Bera probability, it can ensure that each of the variables adhere to a normal distribution. The correlation matrix shows that trade openness and GDP are positively and significantly correlated with CO_2 emissions. On the other hand, agriculture and green energy have an adverse association with CO_2 emissions.

Table 1. Descriptive and correlation statistics

Variables	LC	LA	LR	LY	LT
Mean	20.310	3.2280	2.1759	26.686	3.0509
Median	20.360	3.2850	2.1523	26.504	2.9889
Maximum	21.763	3.7554	2.6959	28.860	4.0217
Minimum	18.851	2.7746	1.7271	24.549	2.0362
Skewness	-0.0169	0.0311	0.2155	0.1041	0.0548
Kurtosis	1.6913	1.5436	2.1292	1.9272	1.6529
Jarque-Bera	2.1419	3.1352	2.2816	2.8864	2.4143
Probability	0.2161	0.1767	0.3196	0.2362	0.1111
Observations	58	58	58	58	58
Correlation between the variables					
	LC	LA	LR	LY	LT
LC	1.0000				
LA	-0.9789	1.0000			
LR	-0.6734	0.7159	1.0000		
LY	0.9876	-0.9679	-0.5892	1.0000	
LT	0.9560	-0.9757	-0.6621	0.9507	1.0000

The results of unit root testing using ADF, DF-GLS, and P-P tests are displayed in Table 2. The results indicate that the variables were not stationary in their original form but became stationary when their first differences were considered in all three unit root tests. The results of the unit root tests proceed us to conduct the analysis within the ARDL framework.

Table 2. Results of unit root testing

Variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LC	-0.1611	-7.6776***	-0.7176	-7.3295***	-0.1624	-7.6752***
LA	-0.6015	-8.1213***	-0.7708	-4.2033***	-0.6015	-8.1213***
LR	-1.2927	-7.7088***	-1.3187	-7.6031***	-1.3395	-7.7076***
LY	-0.5072	-8.5875***	-0.8952	-7.1057***	-0.5063	-8.5106***
LT	-0.6676	-6.1753***	-0.6964	-5.2563***	-0.7140	-6.2548***

***P<0.01

The study utilized the ARDL-bound testing procedure for a comprehensive and concise long-run cointegration within the variables (Table 3). The result indicates the presence of co-integration, which signifies a long-term association with variables. This is supported by the F statistic (26.14) for this model, which exceeds the upper critical values.

Table 3. The outcome of the ARDL bounds test

Test statistic	Value	Significance	I(0)	I(1)
F-statistic	26.141	At 10%	1.99	2.94
K	4	At 5%	2.27	3.28
		At 2.5%	2.55	3.61

At 1%	2.88	3.99

Table 4 displays the estimated findings of the long- and short-run results obtained through the ARDL approach. The outcome suggests that over time, there is a notable increase in CO_2 emissions due to agriculture and trade openness, whereas energy efficiency and GDP have the opposite effect, leading to a decrease in CO_2 emissions. Utilizing renewable energy sources in the immediate future has been shown to lower emissions, while factors such as GDP, agriculture, Trade openness and professional expertise play a crucial role in the rise of CO_2 emissions. The estimated coefficients for agriculture show a clear positive relationship with CO_2 emissions. This implies that a 1% increase in agriculture productivity culminates in a 0.42% rise in CO_2 emissions in the long run, and a 0.15% increase in the short run. One possible reason for this could be the continued dependence on fossil fuel energy in India's agricultural sector. The agricultural sector heavily relies on fossil fuels for various processes such includes thawing, watering, warmth, wrapping, water delivery, along with conveyance of crop-related merchandise. Unfortunately, The transportation of petroleum and gas leads to the increased emissions of CO_2. It appears that the promotion of the agricultural sector in India does not lead to improvements in the field of energy optimization or the implementation of sources of clean energy. Considering the significant magnitude of the farming industry and the widespread use of fossil fuels in India, it can reasonably conclude that the expansion of farming processes brings about a rapid increase in CO_2 emissions. Preceding empirical results support the foregoing conclusion [33,34]. It has been stated that farming leads to an upsurge in CO_2 emissions. On the other hand, these findings challenge other scientific evidence that argue farming diminishes CO_2 emissions [35,36].

Table 4. ARDL long and short-run results

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LA	0.4192**	3.3508	0.0232	0.1509**	3.6397	0.0342
LR	-1.7613***	-5.1815	0.0001	-1.036***	-5.8351	0.0000
LY	-0.0236*	-1.8467	0.0693	1.9819***	3.6085	0.0002
LT	0.1984**	2.5014	0.0176	0.6061***	4.9516	0.0009
C	15.720	1.8319	0.1047	-	-	-
ECM (-1)	-	-	-	-0.5417***	-3.3119	0.0000
R^2	0.9883					
Adjusted R^2	0.9821					

***P<0.01, **p<0.05, *p<0.1

The findings indicate that a 1% increase in renewable power consumption decreases CO_2 emission by 1.76% in the long run whereas 1.04% in the short-run. In this context, it is imperative to prioritize the embrace of renewable power sources in order to effectively reduce CO_2 emissions in India. Prior results from experiments further support this outcome [37-41]. The shift from fossil fuels to clean energy uses aids in reducing the negative impact on the environment in the context of India. Renewable energy uses improve environmental quality through the mitigation of CO_2 emissions [42-46]. The Indian government established specific objectives aimed at mitigating its overall anticipated carbon emissions by 1 billion metric tons by the year 2030. India aims through the year 2030; the goal is to generate 50% of the total electricity from non-fossil fuel sources. India has adopted wind, solar, bio, and hydro energy in its total electricity production. As it is gradually adopting clean energy in the national energy production, the consequences are working in accordance. National-wide adoption of clean energy is aiding India in the achievement of sustainability in the environment and development.

The estimated coefficient of GDP shows that in the short-run, a 1% rise in GDP boosts CO_2 emissions by 1.98%. However, in the long run, the negative coefficient indicates that a 1% increase in GDP would decrease CO_2 emissions by 0.02%. Our research discovered an association among economic growth and CO_2 emissions, following an inverse U shape pattern. This indicates that the association among revenue growth and CO_2 emissions in India can be reversed as the country's GDP continues to rise. The outcomes support the EKC hypothesis within the Indian context. This result was reinforced by previous empirical findings [47-53] that revealed an inverse U shape relationship between economic growth and CO_2 emission in India. Economic growth

is measured by the GDP. Increase in the GDP, or economic growth, assessments in a spike in emissions of CO_2 in India. As economic growth increases, several demands related to economic growth also increase. To meet the direct and indirect increasing demand of people, waste and garbage are produced more. Fossil fuel burning also increases in the industry, including manufacturing and transportation, to support the increasing economic growth. This suggests that environmental risk should be minimized by adopting environmentally friendly technology in the Indian industry as well as shifting from fossil fuel energy production to renewable energy in India. Indian expanded economic growth should be supported through environmentally friendly activities that will assure the mitigation of CO_2 and lead to sustainable development. Through sustainable economic development, Indian competitive capacity will increase globally.

In terms of trade openness, the positively significant coefficients indicate that a 1% increase in trade openness increases CO_2 emission by 0.20% (long-run) and 0.61% (short run). The results confirmed the pollution haven hypothesis in the context of India. Prior findings from experiments further supported this outcome [34,38,39,54]. When the degree of trade increases in a nation, it means production as well as consumption increases, which is supported by the higher use of natural resources and enhanced pollution. Industries usually stress their priority on production efficiency over environmental sustainability. When industries prioritize production, it results in environmental degradation through air pollution, water pollution, deforestation, and habitual destruction in India. Moreover, expanded trade resulted in an upsurge in the utilization of transportation that required the use of fossil fuels, thereby increasing CO_2 emissions. Trade openness in India may provide economic benefits, but in the long run, to achieve sustainable development, it is required to adopt environmentally friendly activities through the use of new technology.

The ECM estimate of the significance threshold at the 1% level, along with the negative trend, suggests that the departure from long-run equilibrium in the current year is corrected at a speed of 54% through various channels such as the farming industry, openness to trade, economic expansion, and green power. Moreover, the R^2 and adjusted R^2 values for long-run estimation are 0.9883 as well as 0.9821, respectively, indicating a high level of accuracy for the calculated regression model. It is evident that the independent factors account for 98% of the discrepancy in the change of the variable that is dependent.

The model's reliability was implemented using the cumulative sum (CUSUM) and cumulative sum of the square (CUSUMSQ) analyses, based on the recursive regression residuals (Figure 2). The estimated coefficients of the ARDL model are considered stable as the statistical line falls within the critical boundaries with a significance level of 5%.

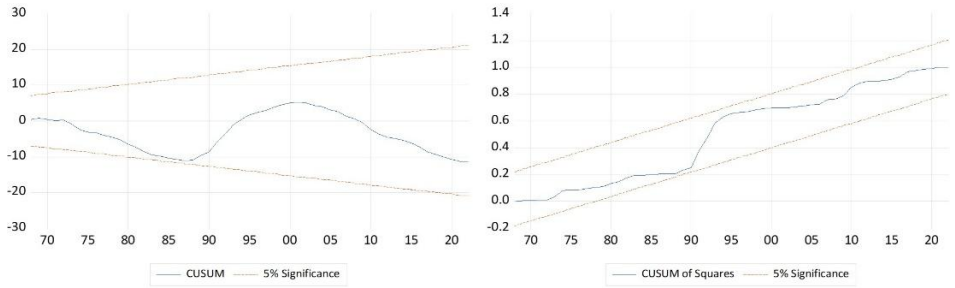

Figure 2. The results of CUSUM and CUSUMSQ tests

In addition, we performed extra diagnostic tests to verify the reliability of the ARDL model used in this study. The diagnostic tests in Table 5 include the serial correlation test alongside the heteroscedasticity test. The diagnostic inspection indicates that the residuals follow a normal distribution, and the model is correctly specified. In addition, there is no evidence of serial correlation or heteroscedasticity.

Table 5. The results of diagnostic tests

Diagnostic tests	Coefficient	p-value	Decision
Jarque-Bera test	2.2346	0.3271	Normal residual distribution
Ramsey RESET test	0.9833	0.3461	The model is properly specified
Breusch-Godfrey LM test	1.8445	0.1738	No serial correlation exists

Breusch-Pagan-Godfrey test	0.7687	0.2783	No heteroscedasticity exists

Conclusions

India's economy is significantly driven by the agriculture and trade sectors, which play a crucial role to encourage the expansion of the marketplace. On the other hand, there is a dearth of scientific and philosophical information about the influence that farming, the utilization of clean energy and trade accessibility has on carbon dioxide emissions. Additionally, the association among independent variables and CO_2 emissions has yielded mixed theoretical and empirical findings. This study addresses to what extent carbon emissions are affected by agricultural practices, renewable energy sources, economic expansion, and trade liberalization from 1965 to 2022. This study is built upon a strong analytical framework that is provided by the scientific basis underlying pollutant haven and environment Kuznets curves. We utilized ARDL as our chosen method of analysis. The co-integration tests confirm the presence of a co-integrating relationship among the variables in India. In addition, when examining the long-term data, it becomes evident that both the GDP and the utilization of renewable energy are associated with a reduction within CO_2 emissions. Conversely, the agricultural sector and international trade show there has been rising in CO_2 emissions. On the other hand, the analysis of the short-term reveals that GDP, agriculture, and international trade contribute to a rise in CO_2 emissions, but renewable energy is effective in lowering them. The adverse influence of agriculture, trade across borders, and economic expansion upon environmental sustainability suggests a lack of sufficient environmental regulations and the role of trade improvements in contributing to environmental degradation.

Fossil fuel usage in the agricultural sector results in a significant spike in CO_2 emissions. Renewable energy is crucial for the agriculture industry. Implementing it is highly recommended to incorporate rooftop solar power mechanisms, offshore wind electricity, effectiveness watering techniques, training programmers, and financial support in the agriculture sector to promote environmental sustainability. Policymakers should prioritize emphasizing the success of transitioning from fossil fuel energy to clean energy. This can be achieved through increased Securing financing for advancement and research initiatives, while also enhancing regulations and legislation. In order to mitigate the effects of trade openness and the impact of economic expansion on ecological sustainability, it is essential to promote the development of environmentally friendly industries that can facilitate the transfer of clean technology knowledge across all sectors of the economy. In order to facilitate an effective and streamlined method for knowledge transfer, it is crucial for receiving countries to enhance their capacity for absorbing new information.

Funding: Not applicable.
Acknowledgement: Not applicable.
Conflict of interest: The author declares no conflict of interest.
Authors contributions: Asif Raihan contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Asif Raihan, Junaid Rahman, and Tipon Tanchangya. The first draft of the manuscript was written by Asif Raihan, and Mohammad Ridwan commented on previous versions of the manuscript. All authors read and approved the final manuscript.
Data availability statement: Data on CO_2 emissions and renewable energy were collected from the Our World in Data (OWD) database, while data on agricultural value added, trade, and GDP were retrieved from the World Development Indicators (WDI) database (https://databank.worldbank.org/source/world-development-indicators).

References

1. Chen, R., & Kong, Y. (2023). A comprehensive review of greenhouse gas based on subject categories. Science of The Total Environment, 866, 161314.
2. Chen, X. H., Tee, K., Elnahass, M., & Ahmed, R. (2023). Assessing the environmental impacts of renewable energy sources: A case study on air pollution and carbon emissions in China. Journal of environmental management, 345, 118525.
3. Kumar, P., Sahani, J., Rawat, N., Debele, S., Tiwari, A., Emygdio, A. P. M., ... & Pfautsch, S. (2023). Using empirical science education in schools to improve climate change literacy. Renewable and Sustainable Energy Reviews, 178, 113232.

4. Sahoo, S. K., Das, A. K., Samanta, S., & Goswami, S. S. (2023). Assessing the Role of Sustainable Development in Mitigating the Issue of Global Warming. Journal of process management and new technologies, 11(1-2), 1-21.
5. Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A. I., Fawzy, S., ... & Yap, P. S. (2023). Circular economy strategies for combating climate change and other environmental issues. Environmental Chemistry Letters, 21(1), 55-80.
6. Bukhari, W. A. A., Pervaiz, A., Zafar, M., Sadiq, M., & Bashir, M. F. (2023). Role of renewable and non-renewable energy consumption in environmental quality and their subsequent effects on average temperature: an assessment of sustainable development goals in South Korea. Environmental Science and Pollution Research, 30(54), 115360-115372.
7. Muruganandam, M., Rajamanickam, S., Sivarethinamohan, S., Reddy, M. K., Velusamy, P., Gomathi, R., ... & Munisamy, S. K. (2023). Impact of climate change and anthropogenic activities on aquatic ecosystem–A review. Environmental Research, 238, 117233.
8. Balsalobre-Lorente, D., Abbas, J., He, C., Pilař, L., & Shah, S. A. R. (2023). Tourism, urbanization and natural resources rents matter for environmental sustainability: The leading role of AI and ICT on sustainable development goals in the digital era. Resources Policy, 82, 103445.
9. Madaleno, M., & Nogueira, M. C. (2023). How renewable energy and CO_2 Emissions Contribute to Economic Growth, and Sustainability—An Extensive Analysis. Sustainability, 15(5), 4089.
10. Hussain, M. N., Li, Z., Sattar, A., & Ilyas, M. (2023). Evaluating the impact of energy and environment on economic growth in BRI countries. Energy & Environment, 34(3), 586-601.
11. Kumari, R., Shabbir, M. S., Saleem, S., Yahya Khan, G., Abbasi, B. A., & Lopez, L. B. (2023). An empirical analysis among foreign direct investment, trade openness and economic growth: evidence from the Indian economy. South Asian Journal of Business Studies, 12(1), 127-149.
12. Wang, J., Yang, J., & Yang, L. (2023). Do natural resources play a role in economic development? Role of institutional quality, trade openness, and FDI. Resources Policy, 81, 103294.
13. Ozturk, I., Farooq, S., Majeed, M. T., & Skare, M. (2023). An empirical investigation of financial development and ecological footprint in South Asia: Bridging the EKC and pollution haven hypotheses. Geoscience Frontiers, 101588.
14. Song, G., & Feng, W. (2023). Analysis of the spatial layout and influencing factors of pollution-intensive industries based on enterprise dynamics. Ecological Indicators, 152, 110378.
15. Balcilar, M., Usman, O., & Ike, G. N. (2023). Operational behaviours of multinational corporations, renewable energy transition, and environmental sustainability in Africa: Does the level of natural resource rents matter?. Resources Policy, 81, 103344.
16. Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Ampon-Wireko, S., & Dogbe, C. S. K. (2021). Innovation, trade openness and CO_2 emissions in selected countries in Africa. Journal of Cleaner Production, 281, 125143.
17. Zheng, H., Zhang, L., Song, W., & Mu, H. (2023). Pollution heaven or pollution halo? Assessing the role of heterogeneous environmental regulation in the impact of foreign direct investment on green economic efficiency. Environmental Science and Pollution Research, 30(8), 21619-21637.
18. Bhattacharyya, R., Bhatia, A., Ghosh, B. N., Santra, P., Mandal, D., Kumar, G., ... & Chaudhari, S. K. (2023). Soil degradation and mitigation in agricultural lands in the Indian Anthropocene. European Journal of Soil Science, 74(4), e13388.
19. Anyanwu, C. N., Ojike, O., Emodi, N. V., Ekwe, E. B., Okereke, C., Diemuodeke, E. O., ... & Nnamani, U. A. (2023). Deep decarbonization options for the agriculture, forestry, and other land use (AFOLU) sector in Africa: a systematic literature review. Environmental monitoring and assessment, 195(5), 565.
20. Albahri, G., Alyamani, A. A., Badran, A., Hijazi, A., Nasser, M., Maresca, M., & Baydoun, E. (2023). Enhancing essential grains yield for sustainable food security and bio-safe agriculture through latest innovative approaches. Agronomy, 13(7), 1709.
21. Balasundram, S. K., Shamshiri, R. R., Sridhara, S., & Rizan, N. (2023). The Role of Digital Agriculture in Mitigating Climate Change and Ensuring Food Security: An Overview. Sustainability, 15(6), 5325.

22. Kabange, N. R., Kwon, Y., Lee, S. M., Kang, J. W., Cha, J. K., Park, H., ... & Lee, J. H. (2023). Mitigating Greenhouse Gas Emissions from Crop Production and Management Practices, and Livestock: A Review. Sustainability, 15(22), 15889.
23. Koshta, N., Bashir, H. A., & Samad, T. A. (2021). Foreign trade, financial development, agriculture, energy consumption and CO_2 emission: testing EKC among emerging economies. Indian Growth and Development Review, 14(1), 50-80.
24. Ali, B., Ullah, A., & Khan, D. (2021). Does the prevailing Indian agricultural ecosystem cause carbon dioxide emission? A consent towards risk reduction. Environmental Science and Pollution Research, 28, 4691-4703.
25. Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., & Farhani, S. (2018). How economic growth, renewable electricity and natural resources contribute to CO_2 emissions?. Energy policy, 113, 356-367.
26. Atasel, O. Y., Guneysu, Y., & Pata, U. K. (2022). Testing the agricultural induced EKC hypothesis: fresh empirical evidence from the top ten agricultural countries. AGRIS on-line Papers in Economics and Informatics, 14(1), 19-31.
27. Mahmood, H., Maalel, N., & Zarrad, O. (2019). Trade openness and CO_2 emissions: Evidence from Tunisia. Sustainability, 11(12), 3295.
28. Essandoh, O. K., Islam, M., & Kakinaka, M. (2020). Linking international trade and foreign direct investment to CO_2 emissions: any differences between developed and developing countries?. Science of the Total Environment, 712, 136437.
29. Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. Journal of the American statistical association, 74(366a), 427-431.
30. Elliott, G., Rothenberg, T. J., & Stock, J. H. (1992). Efficient tests for an autoregressive unit root. National Bureau of Economic Research.
31. Phillips, P. C., & Perron, P. (1988). Testing for a unit root in time series regression. Biometrika, 75(2), 335-346.
32. Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of applied econometrics, 16(3), 289-326.
33. Mohan, R. R. (2018). Time series GHG emission estimates for residential, commercial, agriculture and fisheries sectors in India. Atmospheric Environment, 178, 73-79.
34. Emir, F., Udemba, E. N., & Philip, L. D. (2023). Determinants of carbon emissions: nexus among carbon emissions, coal, agriculture, trade and innovations. Environment, Development and Sustainability, 1-15.
35. Raza, M. Y., Khan, A. N., Khan, N. A., & Kakar, A. (2021). The role of food crop production, agriculture value added, electricity consumption, forest covered area, and forest production on CO_2 emissions: Insights from a developing economy. Environmental Monitoring and Assessment, 193, 1-16.
36. Wang, L., Vo, X. V., Shahbaz, M., & Ak, A. (2020). Globalization and carbon emissions: is there any role of agriculture value-added, financial development, and natural resource rent in the aftermath of COP21?. Journal of Environmental Management, 268, 110712.
37. Raihan, A., & Tuspekova, A. (2022). Nexus between emission reduction factors and anthropogenic carbon emissions in India. Anthropocene Science, 1(2), 295-310.
38. Li, B., & Haneklaus, N. (2022). The potential of India's net-zero carbon emissions: Analyzing the effect of clean energy, coal, urbanization, and trade openness. Energy Reports, 8, 724-733.
39. Zafar, M. W., Mirza, F. M., Zaidi, S. A. H., & Hou, F. (2019). The nexus of renewable and nonrenewable energy consumption, trade openness, and CO_2 emissions in the framework of EKC: evidence from emerging economies. Environmental Science and Pollution Research, 26, 15162-15173.
40. Qayyum, M., Ali, M., Nizamani, M. M., 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.
41. Akadiri, S. S., & Adebayo, T. S. (2022). Asymmetric nexus among financial globalization, non-renewable energy, renewable energy use, economic growth, and carbon emissions: impact on environmental sustainability targets in India. Environmental Science and Pollution Research, 29(11), 16311-16323.

42. Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096.
43. Raihan, A., Muhtasim, D. A., Farhana, S., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. Energy and Climate Change, 3, 100080.
44. Raihan, A., Pavel, M. I., Muhtasim, D. A., Farhana, S., Faruk, O., & Paul, A. (2023). The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia. Innovation and Green Development, 2(1), 100035.
45. Raihan, A. (2023). The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. Energy Nexus, 9, 100180.
46. Raihan, A., & Tuspekova, A. (2022). Dynamic impacts of economic growth, energy use, urbanization, tourism, agricultural value-added, and forested area on carbon dioxide emissions in Brazil. Journal of Environmental Studies and Sciences, 12(4), 794-814.
47. Rasool, H., Malik, M. A., & Tarique, M. (2020). The curvilinear relationship between environmental pollution and economic growth: Evidence from India. International Journal of Energy Sector Management, 14(5), 891-910.
48. Mahmood, T., Shireen, S., & Mumtaz, M. (2021). Testing the Role of Financial Development and Urbanization in the Conventional EKC: Evidence from China and India. International Journal of Sustainable Development & Planning, 16(3), 445-455.
49. Jena, P. K., Mujtaba, A., Joshi, D. P. P., Satrovic, E., & Adeleye, B. N. (2022). Exploring the nature of EKC hypothesis in Asia's top emitters: role of human capital, renewable and non-renewable energy consumption. Environmental Science and Pollution Research, 29(59), 88557-88576.
50. Murshed, M., & Dao, N. T. T. (2022). Revisiting the CO_2 emission-induced EKC hypothesis in South Asia: the role of Export Quality Improvement. GeoJournal, 87(2), 535-563.
51. Mehmood, U., Tariq, S., Ul Haq, Z., Azhar, A., & Mariam, A. (2022). The role of tourism and renewable energy towards EKC in South Asian countries: fresh insights from the ARDL approach. Cogent Social Sciences, 8(1), 2073669.
52. Adebayo, T. S., Ozturk, I., Ağa, M., Uhunamure, S. E., Kirikkaleli, D., & Shale, K. (2023). Role of natural gas and nuclear energy consumption in fostering environmental sustainability in India. Scientific Reports, 13(1), 11030.
53. Uche, E., Das, N., & Bera, P. (2023). Re-examining the environmental Kuznets curve (EKC) for India via the multiple threshold NARDL procedure. Environmental Science and Pollution Research, 30(5), 11913-11925.
54. Adebayo, T. S., Akadiri, S. S., Riti, J. S., & Tony Odu, A. (2023). Interaction among geopolitical risk, trade openness, economic growth, carbon emissions and Its implication on climate change in india. Energy & Environment, 34(5), 1305-1326.