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RESEARCH ARTICLE

Carbon Emission Dynamics in India Due to Financial Development, Renewable Energy Utilization, Technological Innovation, Economic Growth, and Urbanization

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Abstract
Concerns about climate change, emission reduction, and environmental sustainability have become crucial in accomplishing long-term development goals. The present study explored the dynamic effects of financial development, renewable energy utilization, technological innovation, economic growth, and urbanization on carbon dioxide (CO_2) emissions in India. This investigation quantifies short- and long-run dynamics using time series data from 1990 to 2020 and an Autoregressive Distributed Lag (ARDL) model. The outcomes from ARDL short- and long-run analysis revealed a positive and significant effect of financial development, economic growth, and urbanization on CO_2 emissions in India. In contrast, both the short- and long-term coefficients for renewable energy utilization and technological innovation are negative and statistically significant, suggesting that expanding these variables will lead to lower CO_2 emissions. The findings were validated by employing the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegration Regression (CCR) methods. This research provides novel findings that add to the current literature and may be of special relevance to policymakers in the country because of the role that the financial system plays in environmental concerns.

Keywords: Carbon emission; Financial development; Renewable energy; Technological innovation; Environmental sustainability

Introduction

Growing populations, increased urbanization, improved living standards, technological advancements in manufacturing, and increased economic competitiveness all contribute to an increased demand for energy (Raihan et al., 2022a). The increasing usage of fossil fuels sequentially increases atmospheric CO_2 levels and has detrimental effects on the environment, such as climate change (Raihan et al., 2019; Isfat & Raihan, 2022). There has been a rise of 31% in CO_2 emissions over the course of the preceding 200 years, as well as a rise of 0.4-0.8 degree Celsius in the average temperature of the planet during the course of the last century. In recent decades, emissions of carbon dioxide have been the most important contributor to pollution of the environment all around the world (Raihan et al., 2021a; Islam et al., 2022). In recent years, governments have been more cognizant of the issue (Begum et al., 2020; Raihan & Said, 2022). For instance, in 2005, the Kyoto Protocol went into effect to reduce the cumulative emissions of greenhouse gases by developed nations. In addition, the Commission of the European Union (EU) provides funding for a variety of research projects with the objectives of reducing dependency on fossil fuels, increasing energy efficiency, and developing cutting-edge technology, particularly in the field of renewable power.
The use of power derived from renewable sources has the potential to be a substantial contributor to the efforts to achieve the objective of greater energy diversification (Voumik et al., 2022a). By decreasing the dependency on fossil fuels, it is possible to reduce the storms that rage in the energy market (Raihan & Tuspekova, 2022a). The development of renewable energy comes with the extra benefit of possibly lowering the risk of additional damage being done to the natural environment (Raihan et al., 2022b). However, making the transition from producing energy using fossil fuels to producing energy using renewable sources could prove to be difficult. The expense involved in making the transition to renewable sources of energy is one of the most significant barriers. When compared to the costs associated with producing energy

from fossil fuels, the costs associated with developing the necessary infrastructure, operating the business, and initiating operations are all significantly higher. The generation of cash, the promotion of transparent and honest dealings, and the management of capital are all responsibilities that fall under the purview of the financial sector, which is why this sector is critical to the operation of any economic system. Stronger economic growth is the result of a safe and dependable financial system that enables the effective movement of cash and assists firms in operating more smoothly (Ali et al., 2019). This system also contributes to the overall stability of the economy. Both the effectiveness of the economy and the state of the environment are impacted by the activities of the financial sector (Yu & Qayyum, 2021). A robust financial system helps stimulate the economy, and a wealthy economy is typically connected with a stable and safe financial system. A well-developed financial system helps stimulate the economy.

A robust economy also fosters the development of technology that are less polluting and more efficient, which companies can then put to use in their operations. The same is true for India, where an increase in funding for renewable energy is vital since in order to satisfy these obligations by 2022, an expenditure of over 189 billion USD will be required. In spite of this, the Climate Policy Initiative (CPI) anticipates that the actual, realized contribution might fall short of the criteria by a margin of 29% (or USD 17 billion) for stock and by a margin of 27% (or USD 36 billion) for debt. In order to close the funding gap and advance the development of the renewable energy industry, India has initiated a wide range of institutional changes at both the national and state levels. The federal government has provided support in the form of rapid depreciation, generation-based subsidies, and viability gap funding. Policy support at the state level often takes the form of feed-in tariffs, net metering, and tax/duty discounts. When commercial banks are relied on excessively for credit funding, it is inevitable that financial difficulties will occur, regardless of how favorable federal and state regulations may be. The cost of financing projects related to renewable energy in India is often greater than the cost of financing projects of a comparable nature in the United States or Europe. This is a significant obstacle in the way of their general acceptance. When compared to the limited resources that are at the government's disposal, the lofty goals that have been set for renewable energy mean that officials will need to carefully consider whether the advantages of their support outweigh the costs.

A highly developed financial system, on the other hand, encourages economic expansion and urbanization, both of which contribute to an increase in emissions and substantial environmental damage. Even if doing so increases a company's energy consumption and emissions of greenhouse gases, having access to loans with reasonable interest rates from a solid financial system helps firms expand their output, which in turn helps the businesses (Saud et al., 2019a). Despite this, there have been relatively few studies conducted to determine how India's growing GDP and financial system affect the country's carbon footprint. As a result of the growing interest in the topic of financial development's potential adverse effects on the natural world, this study adds financial development to the energy-growth-environmental linkages and examines its significance in India for long-term growth. This is done as a result of the fact that the linkages between energy, growth, and the environment have been studied extensively in recent years. As a result, the primary objective of the study is to analyze the ways in which India's developing middle class, increased access to renewable energy sources, technical breakthroughs, expanding economy, and expanding metropolitan regions all affect the size of the country's carbon footprint.

India was selected despite the fact that it has one of the most rapidly expanding economies because of the significance of the financial industry to the total economy of the country. The commercial banks, non-banking financial institutions, rural banks, pension funds, mutual funds, and insurance companies that make up the pillars of India's financial sector are its most important institutions. Since the beginning of the Financial Sector Assessment Program (FSAP) in 2011, both the economy of India and the variety of financial instruments that it uses have expanded at a rapid rate. This expansion has been made possible by significant structural shifts as well as improvements to the country's overall trade balance. The expansion of the financial industry has been helped along by an increase in the sector's diversification, commercial focus, and integration driven by technology, in addition to sufficient governance, legislative, and disciplinary procedures. However, the banking sector is beset with issues, and the expansion of the economy has slowed down. The slow deflation and the rebuilding of corporate balance sheets, together with high levels of nonperforming assets, are putting a burden on the soundness of the financial system, which in turn is constraining growth. Therefore, it is essential for the decision-makers in India to have an awareness of the connection between the expansion of the economy, the development of new technologies, and the emission of carbon dioxide. In order to carry out econometric research, the most recent time series data are applied to the econometric method that is considered to be the most suited for time series (the ARDL model). In addition, FMOLS, DOLS, and CCR methodologies are utilized in order to conduct an investigation into the reliability of the results obtained from this study. On the basis of the findings, this article presents key policy implications that should be considered by the government and policymakers.

The rest of the article is structured as follows. The Introduction is followed by the section Literature Review, where relevant research studies have been discussed. The third section is the Methodology section, followed by the

Results and Discussion section. Subsequently, the last section presents the Conclusion, policy recommendations, limitations of the study, and future research directions.

Literature Review

The environmental growth-energy model has recently been updated to account for numerous aspects related to financial development. Researchers have examined the financial growth nexus for many samples of countries and regions, employing a wide variety of proxies and approaches, with conflicting results (Bibi & Sumaira, 2022). Dogan and Seker (2016) state that attempts to include the measurements of financial development are not unrealistic in the discussion on the relationship between environmental concerns, economic development, and energy use. Foreign direct investment, specialized knowledge and research, and new ideas can all contribute to a reduction in energy use and a general improvement in the economy. In turn, this improves environmental quality. Saud et al. (2019b) analyzed the effects of CO_2 emissions on the economies, financial growth, energy use, and international commerce from 1980 to 2016, and reported that increasing energy consumption and economic growth are detrimental to the environment, whereas more trade and financial development are good for the environment since they minimize pollution. In a similar vein, Zafar et al. (2019) examined the results of financial development and globalization on carbon emissions and reached the same conclusion: these two factors significantly enhance environmental performance by decreasing pollution. Using data collected between 1995 and 2015, Kahouli (2017) found a correlation between economic growth, energy efficiency, and financial development in six nations in the South Mediterranean. Kahouli (2017) exposed the long-term cointegration of variables and proposed that financial development is the crucial factor in enhancing energy use. However, several studies argued that the demand for energy brought on by economic development has negatively impacted the atmosphere due to rising carbon emissions. To investigate how financial development affects carbon emissions, Guo et al. (2019) analyzed province data from China between 1997 and 2015. Guo et al. (2019) came to the conclusion that the level of carbon emissions grew due to the volume of stock trading and the stability of financial development. Moghadam and Dehbashi (2018) investigated the connections between Iran's economic growth, exports, and ecological footprint and concluded that economic growth has hastened the contamination of natural areas.

Renewable energy sources including wind, hydro, solar, and many others have gained appeal as an eco-friendly alternative to traditional fuels like coal, gasoline, and oil. It is clear that these forms of energy have the potential to deliver non-carbon clean energy at levels comparable to those given by carbon-based energy while simultaneously reducing atmospheric concentrations of greenhouse gases. Over the past few years, numerous research have been conducted to understand how and to what extent the use of renewable energy can reduce carbon dioxide emissions. For instance, Zoundi (2017) analyzed the relationship between CO_2 emissions and the utilization of renewable energy in 25 African economies from 1980 to 2012. According to Cherni and Essaber Jouini (2017), renewable energy use reduced CO_2 emissions as Tunisia's economy grew, while the use of fossil fuels increased emissions. Between 1980 and 2014, Chen et al. (2019) examined the connection between China's CO_2 emissions, economic growth, renewable energy utilization, and foreign trade. Chen et al. (2019) reported that the use of renewable energy sources is inversely related to carbon dioxide emissions. Charfeddine and Kahia (2019) examined the impact of renewable energy consumption and financial development on CO_2 emissions in the Middle East and North Africa (MENA) from 1980 to 2015, and found that the two factors had a negligible impact on CO_2 levels. By using an advanced panel quantile regression model, Azam et al. (2022) reported a positive relationship between economic growth and CO_2 emissions, and a negative relationship between renewable energy and CO_2 emissions in the top-five emitter countries, covering the data from the period from 1995–2017. Raihan and Tuspekova (2022a) reported a positive relationship between economic growth and CO_2 emissions while a negative relationship between renewable energy use and CO_2 emissions in Peru utilizing the data over 1990-2018. Liu et al. (2017a) utilized time data over 1992-2013 to establish a negative association between renewable energy use and CO_2 emissions in the BRICS countries. Furthermore, by using time data over 1970-2013, Liu et al. (2017b) revealed a positive association between economic growth and CO_2 emissions while a negative association between renewable energy use and CO_2 emissions in Indonesia, Malaysia, the Philippines, and Thailand.

Moreover, the relationship between technological innovation and CO_2 emissions has been examined comprehensively in recent years as increased research and development (R&D) spending can enhance economic production efficiency and resource usage efficiency. Technological advancements are expected to have a major effect on pollution reduction. With the help of environmental protection programs, new technologies have reduced CO_2 emissions and improved environmental performance in many countries. Previous research shows that a lot of focus has been placed on the potentially positive effect of technological innovations on CO_2 emissions. The majority of academics choose patents as a measure for technological innovation because they protect company and intellectual property rights that help create technologies to address environmental problems. According to Chen and Lee (2020), technical innovation in high-income nations efficiently decreases CO_2 emissions and is thus considered environmentally beneficial green technology innovation.

Several studies have shown that technological innovation reduces CO_2 emissions. According to Shahbaz et al. (2020), China's technological innovation efficiency have a significant positive impact on environmental performance. Rahman et al. (2019) reported that the adoption of clean technology by international businesses might enhance environmental quality in Pakistan by lowering carbon emissions. Ahmed et al. (2016) reported that technological innovation improves environmental quality by reducing CO_2 emissions in 24 European nations. Raihan et al. (2022b) utilized time data over 1990-2019 to establish a positive association between economic growth and CO_2 emissions while a negative association of renewable energy use and technological innovation with CO_2 emissions in Malaysia. Furthermore, Raihan and Tuspekova (2022b) revealed the positive effects of economic growth on CO_2 emissions, and the negative effects of renewable energy use and technological innovation on CO_2 emissions in Kazakhstan utilizing the data over 1996-2018. It is now commonly acknowledged that technical advancements play a significant role in lowering emissions while maintaining economic growth; as a result, any improved understanding of the process of technological innovation is likely to expand our knowledge of mitigation options (Raihan et al., 2022b).
Furthermore, there has been a lot of research done recently on the connection between urbanization, economic growth, and CO_2 emissions. Zhang et al. (2021) reported that economic growth and urbanization have positive influences on CO_2 emissions in Malaysia. Adebayo and Kalmaz (2021) exposed a positive contact of economic growth and urbanization on CO_2 emissions in Egypt by using the data from 1971 to 2014. Nondo and Kahsai (2020) uncovered positive impacts of economic growth and urbanization on CO_2 emissions in South Africa from 1970 to 2016. Kirikkaleli and Kalmaz (2020) found positive influences of economic growth, and urbanization on CO_2 emissions in Turkey during 1960-2016. Liu and Bae (2018) revealed the positive impacts of economic growth and urbanization on CO_2 emissions in China from 1970 to 2015. By utilizing yearly data between 1971 and 2014, Ahmed et al. (2019) reported that economic growth and urbanization trigger CO_2 emissions in Indonesia. Al-Mulali et al. (2013) utilized time-series data from 1980 to 2009 and found a positive association between urbanization and CO_2 emission in MENA countries. By using time series data over 1985-2013 for 20 African countries, Raheem and Ogebe (2017) found that economic growth and urbanization increase CO_2 emissions. By utilizing a nonparametric additive model for South Asian countries over 1978-2011, Irfan and Shaw (2017) found that urbanization positively influence CO_2 emissions. Sehrawat et al. (2015) found that economic growth and urbanization increase CO_2 emissions in India. Rehman et al. (2022) demonstrated that urban population growth has an adverse influence on CO_2 emissions.
Despite the hopeful economic and financial development in India, the mechanisms of knowledge accumulation remain a mystery, and the true potential of renewable energy use and technological innovation to reduce CO_2 emissions is yet unknown. Therefore, the present study intends to fill up the existing literature gap in the case of India by examining the dynamic impacts of financial development, renewable energy consumption, technological advancement, economic expansion, and urbanization on CO_2 emissions using several econometric approaches.

Methodology

Data

The goal of this study was to apply the ARDL method to analyze the interplay between India's financial growth, renewable energy consumption, technological advancement, economic expansion, and urbanization on the country's CO_2 emissions. This analysis makes use of data from the years 1990 all the way through the year 2020. The data for all the variables were obtained from the World Development Indicators (WDI) (World Bank, 2022). The variable names and their measurement unit are presented in Table 1. All the variables were logged to ensure conformity to normality. Moreover, the annual trend of the study variables is presented in Figure 1.

Table 1. Variables with description

Variables	Description	Logarithmic structures	Measurement	Sources
CO_2	CO_2 emissions	LCO2	Kilotons	WDI
FD	Financial development	LFD	Domestic credit to private sector (% of GDP)	WDI
RE	Renewable energy use	LRE	Percentage of total final energy use	WDI
TI	Technological innovation	LTI	Number of patent applications	WDI
GDP	Economic growth	LGDP	Constant Indian rupee	WDI
U	Urbanization	LU	Number of urban populations	WDI

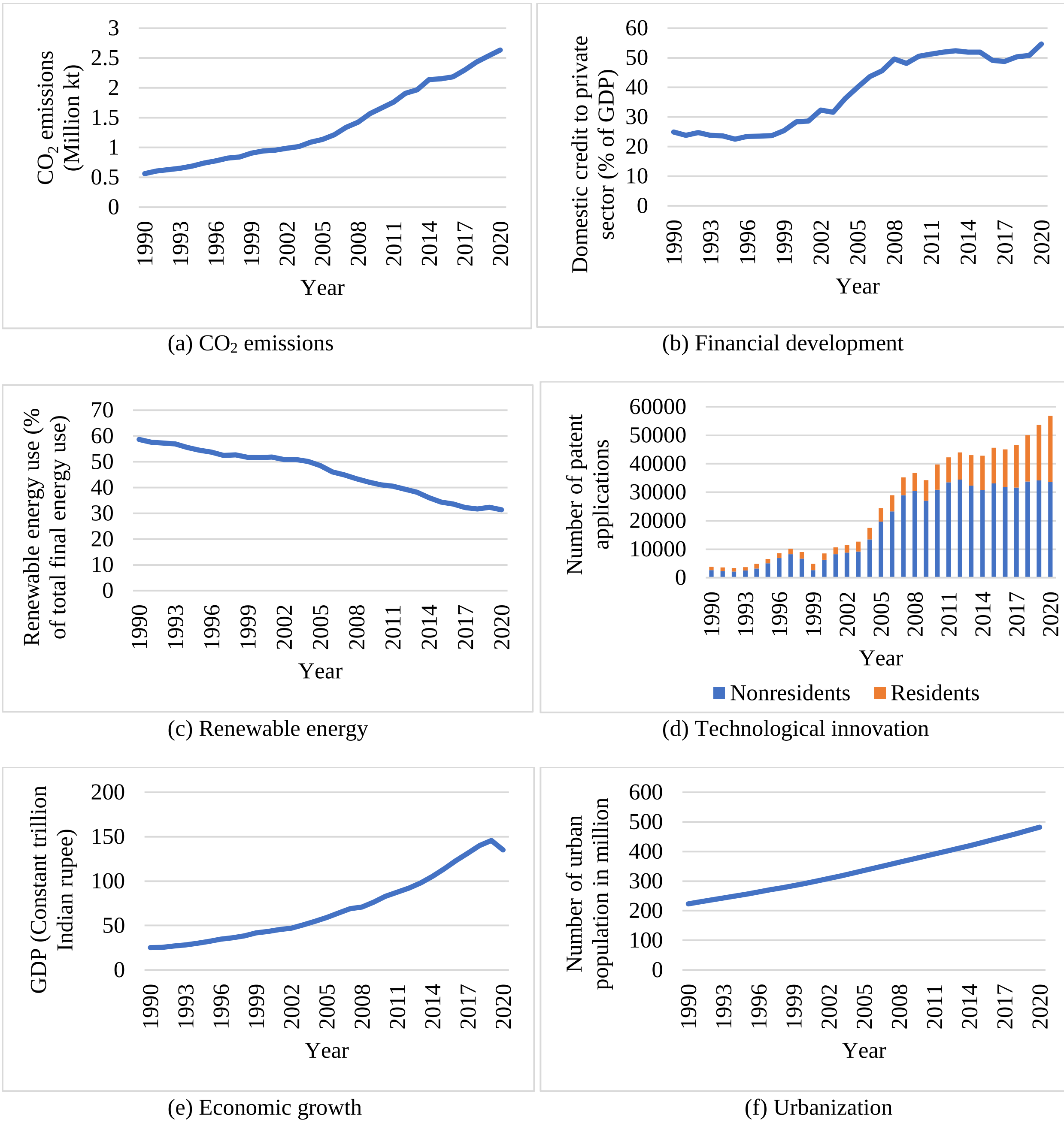

Figure 1. Annual trends of the study variables

Theoretical framework and model specification

This study investigated the relationship between urbanization, economic expansion, the development of new technologies, and the use of alternative energy sources and their impact on CO_2 emissions. Even while financial development is necessary for both economic progress and a healthy climate, the two are inexorably intertwined (Voumik et al. 2022b). In addition, developed and robust financial sectors improve environmental performance in a number of ways, including but not limited to: providing businesses with access to clean technology; making low-cost credit available for environmentally friendly initiatives and technological advancements; and rewarding businesses for adhering to environmental standards and guidelines (Raihan & Tuspekova, 2022b). If expansion plans involve the use of energy-efficient equipment and if the use of renewable energy sources is emphasized, then the use of renewable energy sources may have an effect on environmental performance (Raihan et al., 2022c). One area in which advancements in technology could potentially have an effect on environmental consequences is the efficacy and efficiency of energy production. Because it requires a significant amount of energy use, economic development is also a key contributor to increasing CO_2 emissions (Raihan & Tuspekova, 2022c). This, in turn, has a detrimental impact on the efficiency with which natural resources are utilized. The previously noted connection between urbanization and economic growth influenced an investigation of the correlation between urbanization and higher standards of environmental protection. The following criteria were employed according to these statements in order to build the detailed CO_2 emissions model that was used in this investigation:

$$CO_{2t} = f\,(FD_t, RE_t, TI_t, GDP_t, U_t) \tag{1}$$

The empirical model with the logarithmic form of the variables is represented by the following equation:

$$LCO2_t = \tau_0 + \tau_1 LFDt + \tau_2 LREt + \tau_3 LTIt + \tau_4 LGDPt + \tau_5 LUt + \varepsilon_t \tag{2}$$

where τ_1, τ_2, τ_3, and τ_4 represent the coefficients of the regressors. Moreover, ε_t represents an error term.

Strategies for estimation

A number of cutting-edge econometric techniques were applied to the defined empirical model to produce trustworthy findings for use in policymaking. Because of this, the stationarity property of the time series data by employing ADF, DF-GLS, and P-P unit root tests was the initial focus of the inquiry. When the integration order of the series was defined, the study confirmed the stated model's long-term relationship. The analysis followed the method proposed by Pesaran et al. (2001), known as the ARDL model, as an effective estimating methodology to expose both short- and long-term relationships among the parameters of the specified model. This method has many advantages over the previous cointegration methods. The integration property of a series needed to be discovered before employing other cointegration procedures, whereas this method did not necessitate any such preliminary testing. By considering the lag length of the variable, the ARDL model can be utilized to account for endogeneity. Second, it is applicable in any investigational series integration scenario. Finally, the ARDL model maintains validity even with a little number of observations. As indicated in Equation (3), the ARDL bound testing strategy can be written using the econometric model given in Equation (2).

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LFD_{t-1} + \tau_3 LRE_{t-1} \\ & + \tau_4 LTI_{t-1} + \tau_5 LGDP_{t-1} + \tau_6 LU_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2\, \Delta LFD_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3\, \Delta LRE_{t-i} + \sum_{i=1}^{q} \gamma_4\, \Delta LTI_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_6\, \Delta LU_{t-i} + \varepsilon_t\end{aligned}$$

The short-run coefficient needs to be captured once the long-term relationship between series has been established. So, as indicated in Equation (4), this investigation assessed the error-correction model and glean the short-run coefficients.

$$\begin{aligned}\Delta LCO2_t = {} & \tau_0 + \tau_1 LCO2_{t-1} + \tau_2 LFD_{t-1} + \tau_3 LRE_{t-1} \\ & + \tau_4 LTI_{t-1} + \tau_5 LGDP_{t-1} + \tau_6 LU_{t-1} \\ & + \sum_{i=1}^{q} \gamma_1\, \Delta LCO2_{t-i} + \sum_{i=1}^{q} \gamma_2\, \Delta LFD_{t-i} \\ & + \sum_{i=1}^{q} \gamma_3\, \Delta LRE_{t-i} + \sum_{i=1}^{q} \gamma_4\, \Delta LTI_{t-i} \\ & + \sum_{i=1}^{q} \gamma_5\, \Delta LGDP_{t-i} + \sum_{i=1}^{q} \gamma_6\, \Delta LU_{t-i} \\ & + \theta ECT_{t-1} + \varepsilon_t\end{aligned}$$

The error-correction dynamics and long-term linkages between the series are displayed in the aforementioned equation. The lag length of the series is denoted by q in Equations (3) and (4), and Δ stands for the first difference operator. In addition, ECT stands for the error correction term, and θ is the ECT's coefficient.

As a robustness evaluation, this investigation employed the FMOLS, DOLS, and CCR on the stated model to look at how different factors throughout time affected the CO_2 output. There were two main factors that prompted the need to employ these methods. To begin, the cointegration condition among the I(1) parameters must be satisfied before the FMOLS, DOLS, or CCR may be used. Second, these methods deal with endogeneity and serial correlation biases that arise from the cointegration relationship (Raihan & Tuspekova, 2022d). As a result, it yields outcomes with asymptotic efficiency. The analysis flowchart is shown in Figure 2.

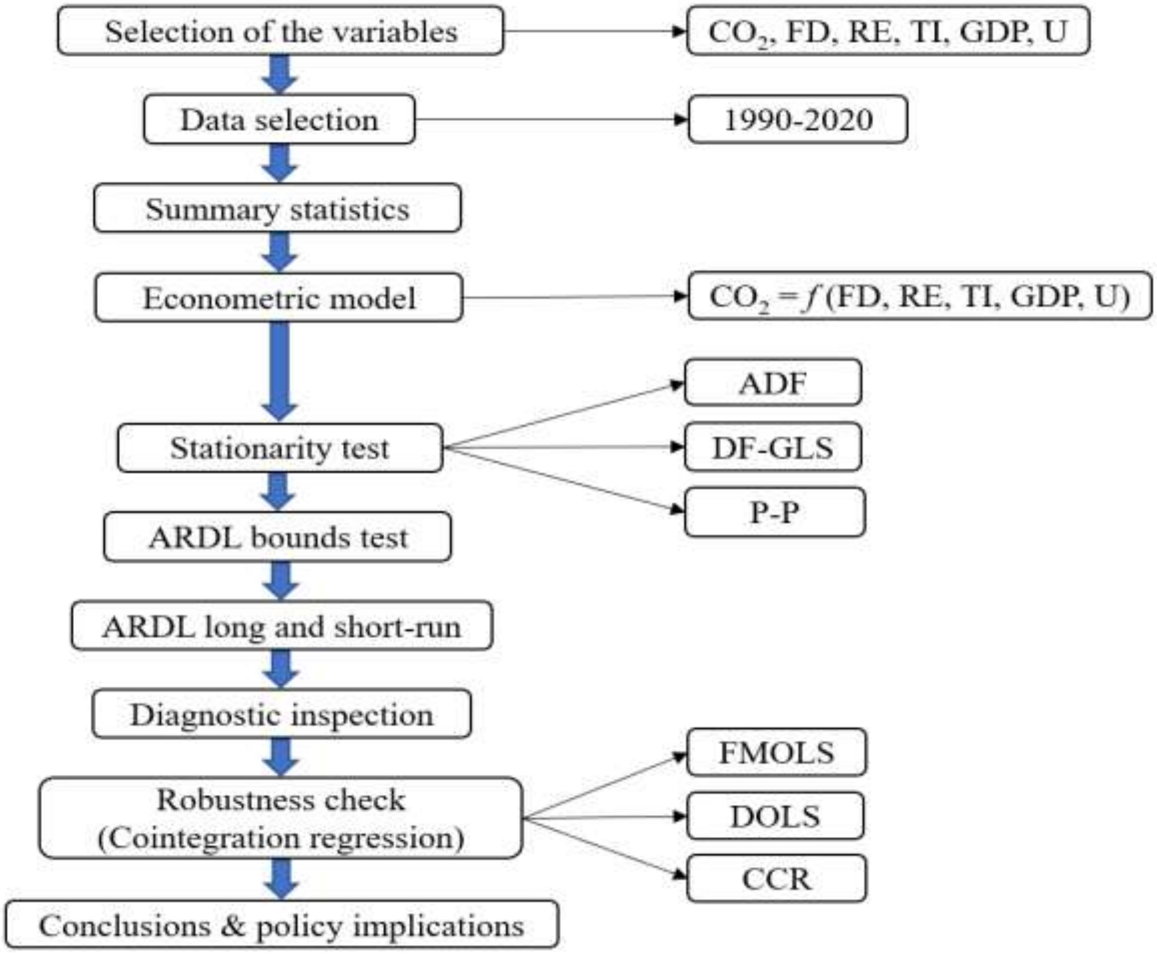

Figure 2. The analysis flowchart

Results and Discussion

The results of multiple normality tests are shown alongside a description of the data in Table 2. It was clear that the dataset was normal because the skewness values were near to zero. In addition, kurtosis values below 3 were indicative of platykurtic variables. All the variables are normally distributed, as shown by the Jarque-Bera and probability values.

The fundamental goal of this study was to investigate the development of a lasting connection between the series under consideration. The evaluation of the unit root test provides crucial information on the integration characteristic of the parameters, which is necessary for employing the approaches in the creation of a long-term interrelationship. Therefore, the integration qualities of the series were investigated using a battery of conventional root tests, including the ADF, DF-GLS, and PP tests. The findings of the stationarity test are summarized in Table 3.

According to the canonical tests of unit root output, all variables exhibited the unit root problem at level before becoming stationary after the first difference.

Based on the unit root observations, this study found that the series under examination is an I(1) series. Therefore, the current investigation used the ARDL-based bounds test technique to evaluate the long- and short-term connections between the series under investigation. The model's consistent results from each alternative's information criterion led to settling on the Akaike information criterion (AIC) as the lag specification. Table 4 shows that the calculated F-statistic (7.762475) for the cointegration analysis is higher than the upper critical threshold. This investigation, therefore, concludes that the independent variable and the regressors are cointegrated.

Table 2. Statistical summaries of the variables

Variables	LCO2	LFD	LRE	LTI	LGDP	LU
Mean	14.01616	3.591260	3.759587	9.765203	31.72137	3.382792
Median	13.94344	3.690578	3.787819	10.10160	31.71103	3.375367
Maximum	14.71417	4.000980	4.071636	10.94678	32.60885	3.553232
Minimum	13.24206	3.113994	3.471636	8.138565	30.85570	3.240520
Std. Dev.	0.480383	0.340624	0.210310	0.979248	0.564657	0.095557
Skewness	0.040435	-0.199575	0.036449	-0.370346	0.039371	0.205197
Kurtosis	1.638421	1.280313	1.491181	1.605142	1.727702	1.790822
Jarque-Bera	2.403065	4.025664	2.947388	3.221742	2.098885	2.106106
Probability	0.300733	0.133610	0.229078	0.199714	0.350133	0.348871

Table 3. Unit Root test results

Logarithmic form of the variables	ADF		DF-GLS		PP	
	Log levels	Log first difference	Log levels	Log first difference	Log levels	Log first difference
LCO2	-1.2152	-3.7061***	-1.0469	-3.7390***	-1.0734	-3.7924***
LFD	-0.2630	-2.9146**	-0.6055	-2.6553**	-0.4754	-4.8820***
LRE	-0.9464	-4.5273***	-0.0627	-4.5768***	-0.9160	-4.5550***
LTI	-1.0002	-4.9207***	-0.0981	-4.7089***	-1.0233	-4.9930***
LGDP	-1.6294	-3.0137**	-1.8257*	-3.5403**	-0.5945	-3.0137**
LU	1.8904	-2.3462*	0.4129	-2.5908**	-0.3462	-3.6701***

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

Table 4. ARDL bounds test results

F-bounds test		Null hypothesis: No degrees of relationship		
Test statistic	Estimate	Significance	I(0)	I(1)
F-statistic	7.762475	At 10%	2.57	3.86
K	6	At 5%	2.86	4.19
		At 2.5%	3.13	4.46
		At 1%	3.43	4.79

Table 5. ARDL long and short-run results

Variables	Long-run			Short-run		
	Coefficient	t-Statistic	p-value	Coefficient	t-Statistic	p-value
LFD	0.6132**	2.7639	0.0274	0.2921**	2.0173	0.0419
LRE	-0.8889***	-3.2173	0.0005	-0.4416***	-3.5623	0.0071
LTI	-0.4445**	-2.1634	0.0265	-0.0136**	-2.6731	0.0392
LGDP	1.3174***	6.6731	0.0002	0.7620***	4.9468	0.0008
LU	1.8629***	7.1191	0.0004	0.8294***	5.7823	0.0061
C	32.4764	8.1076	0.1012	-	-	-
ECT (-1)	-	-	-	-0.5219	-0.1332	0.0029
R^2	0.9912			0.9925		
Adjusted R^2	0.9864			0.9871		

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

Table 5 displays the findings of the ARDL long- and short-run estimation. The empirical findings provide some encouraging evidence that there is a connection between India's economic expansion and increases in carbon dioxide emissions. Both in the long run and the near term, there is a significant and favorable correlation between rising financial growth and rising emissions of carbon dioxide.

Therefore, the effects of environmental deterioration are made worse by the expansion of the economy (Raihan & Tuspekova, 2022e). The coefficient of LFD indicates that a one percentage point increase in economic development has a negative impact on environmental performance by increasing CO_2 emissions by 0.61 percent in the long run and 0.29 percent in the short run. This is the case even when all other factors are held constant. These findings are consistent with those discovered by Saud et al. (2019b) for countries in Central and Eastern Europe as well as those discovered by Zakaria and Bibi (2019) for South Asian countries. The results of this study provide some insight into the way in which India's rising standard of living is affecting the country's ability to maintain its natural resources. It's possible that the easy access to financial resources was a contributing factor in this outcome, as it enabled polluting enterprises and investors to thrive. This is another evidence that India's banks are not supporting environmentally friendly projects. It is not out of the question that financial institutions are looking to improve their earnings by providing start-up capital to new businesses. The advantages of manufacturing on a small scale, which include lower service costs and less pollution, attract more investors who are prepared to put up more money in exchange for those advantages. Consequently, the scale of the manufacturing operation can increase. As a direct consequence of these actions, there will be a greater demand for energy, which will in turn lead to an increase in carbon emissions, which will have a detrimental impact on the natural environment (Raihan et al., 2022d).

Furthermore, the coefficient of LRE was negative and statistically significant, indicating that a 1% increase in the usage of renewable energy might lead to a 0.89% (long-term) and 0.44% (short-term) reduction in CO_2 emissions. Inferences about renewable energy being beneficial to environmental sustainability were drawn from the outcome. The findings of this study, which suggest that increasing the usage of renewable energy enhances environmental efficacy, are consistent with those of other research that have been done on the topic (Raihan & Tuspekova, 2022f). Based on these findings, higher utilization of renewable energy sources should be considered as a possible policy instrument for enhancing India's environmental performance. In addition, the coefficient of LTI was negative and statistically significant, suggesting that a 1% increase in LTI contributes to the reduction of CO_2 emissions by 0.44% (long-term) and 0.01% (short-term). This exemplifies how the progression of technology is beneficial to the environment by lowering the amount of carbon dioxide emissions. The results of this experiment are consistent with those obtained from earlier experiments (Raihan et al., 2022e; Raihan et al., 2022f). The implementation of novel technology, as discovered by the researchers, resulted in a lower overall level of pollution (Raihan et al., 2022g). As a result, the results of this study suggest that encouraging technological innovation can be an efficient policy instrument for lowering environmental pollution in India. The result indicates that if India invests more in technical innovation, it may be able to slow the rate of environmental deterioration.

The empirical results demonstrated a positive and statistically significant coefficient of LGDP, which means that a 1% increase in GDP leads to a 1.32% (long-term) and 0.76% (short-term) increase in CO_2 emissions, respectively. In assertion, India's rapid economic development has negative effects on the environment both immediately and over the long term. Previous research (Raihan & Tuspekova, 2022f; Raihan et al., 2022h) found that there is a positive link between GDP and CO_2 emissions. It should come as no surprise that India's energy consumption has increased in tandem with the country's growing gross domestic product. This is a significant factor that contributes to the emission of greenhouse gases in India. According to the LU coefficient, an increase of one percent in urbanization results in an increase of 1.86 and 0.83 percent in CO_2 emissions over the long and short terms, respectively. The findings are in agreement with what Irfan and Shaw (2017), Raihan and Tuspekova (2022f), and Sehrawat et al. (2015) have discovered in their research. According to this conclusion, the rapid urbanization that took place in India led to a rise in energy consumption, which was driven by sources of fossil fuel, which in turn led to an increase in CO_2 emissions.

The increasing number of urban residents in India is driving up the demand for automobiles and other kinds of personal mobility. The rise in popularity of automobiles has resulted in an increase in the consumption of fossil fuels, which in turn has led to a worsening of the environment's conditions (Raihan & Tuspekova, 2022g). In India, where the standard of public transportation is generally low, there has been a rise in the number of people purchasing private automobiles. The growth in urban density has been attributed, in part, to the rapid development of housing and factories. There has been an increase in the utilization of products that have a high demand for energy in both the industrial and domestic settings (Raihan & Tuspekova, 2022h). The residential sector has overtaken the commercial sector as the primary consumer of energy in recent years as a direct result of increasing urbanization (Raihan & Tuspekova, 2022i). As urbanization has spread throughout the region, increases in waste output, forest loss, and alterations in land use have all occurred concurrently (Raihan et al., 2018; Jaafar et al., 2020; Raihan et al., 2021b). This has resulted in a significant rise in the levels of pollutants, as well as traffic congestion and electrical consumption, in metropolitan areas (Raihan & Tuspekova, 2022j). Even in India, the rate of industrialization is accelerating, which means that urbanization implicitly contributes to a decline in air quality as a result of the industrial revolution (Raihan & Tuspekova, 2022k).

The ECT was also found to have very detrimental results. This estimate of 0.464 showed how the short-run equilibrium evolved as it moved toward a stable long-run equilibrium, with annual adjustments of 46%. It demonstrated the value of the feedback system in maintaining stable CO_2 emissions in India. Finally, there was no evidence of serial correlation or heteroskedasticity in the residuals, and the residuals followed a normal distribution without any signs of misspecification, as shown in Table 6 of the diagnostic test findings. Figure 3 further displays the results of the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) stability tests, which demonstrated the model's stability at the 5% significance level.

Table 6. Diagnostic tests results

Diagnostic tests	Coefficient	p-value	Decision
Serial Correlation	1.8495	0.147	No serial correlation exits
Heteroskedasticity Test	1.1787	0.198	No heteroscedasticity exists
Normality Test	1.1489	0.563	Residuals are normally distributed

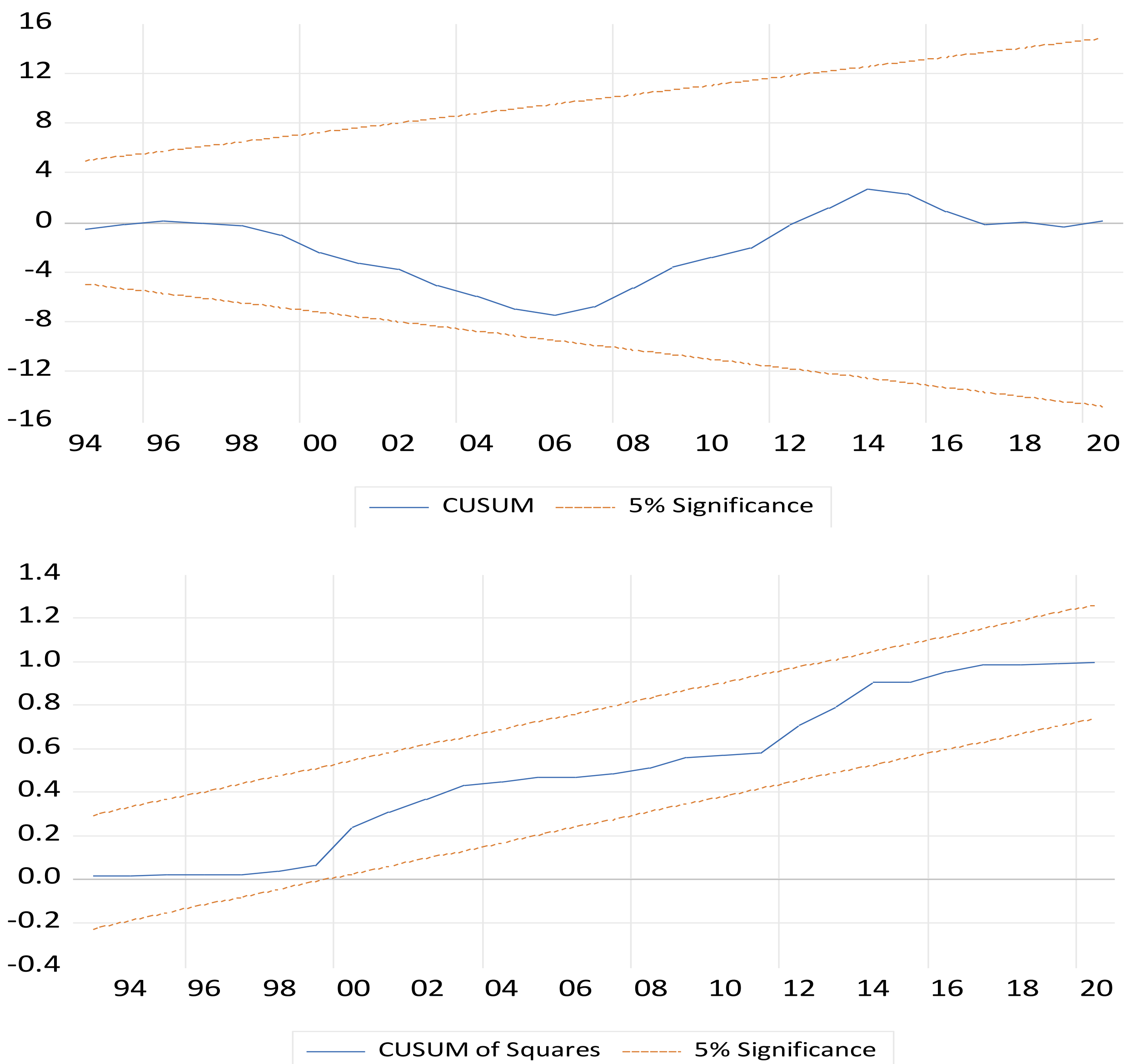

Figure 3. Results of the CUSUM and CUSUMQ tests

The findings of the ARDL framework were also tested over the long term with the help of the FMOLS, DOLS, and CCR tests. Table 7 displays the projected results from the use of FMOLS, DOLS, and CCR. The sign and reliability of the FMOLS, DOLS, and CCR results were all shown to be consistent and dependable. This causes them to produce the same results as the ARDL simulations in the long term. Specifically, the data showed that increasing financial development, GDP, and urbanization increases CO_2 while increasing renewable energy and technical innovation decreases CO_2 emissions. As a result, decisions can be made with an element of certainty based on the findings.

Table 7. Robustness results

Variables	FMOLS		DOLS		CCR	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
LFD	0.5873**	2.1523	0.5982**	1.8685	0.5984**	2.4756
LRE	-0.8735***	-5.2477	-0.8756***	-3.6467	-0.9271***	-4.8804
LTI	-0.4425**	-1.9368	-0.4513**	-1.9631	-0.4605**	-1.5534
LGDP	1.2391***	4.8117	1.3574***	6.2697	1.2554***	5.0928
LU	1.4957***	3.9167	1.8934***	6.0289	1.8595***	7.1996
C	16.277	3.6867	14.0281	5.0667	19.932	4.9906
R^2	0.9967		0.9969		0.9955	
Adjusted R^2	0.9960		0.9962		0.9945	

The significance levels depicted by *, **, and *** are 1%, 5%, and 10% respectively.

Conclusions and Policy Implications

This article covers India's CO_2 emissions from 1990 to 2020 from the perspectives of financial growth, use of renewable energy, technological advancement, economic expansion, and urbanization. The time period covered is from 1990 through 2020. In this investigation, the evaluation of the long-term correlations that exist between parameters was accomplished by the utilization of the ARDL cointegration approach. It was discovered that financial development, economic growth, and urbanization each had a positive and significantly favorable effect on CO_2 emissions. However, there is a negative link between the consumption of renewable energy and technological innovation, and this association is statistically significant. This suggests that increasing these measures will reduce CO_2 emissions both in the short term and in the long run. In this research, an examination of the reliability of the ARDL outcomes was carried out by employing FMOLS, DOLS, and CCR techniques.

The empirical findings of the study have the potential to have significant repercussions for the direction that India's economic policies will take in the future. The findings of the study also indicate that the current strategies of India to grow financial institutions are potentially damaging to the environment and ought to be rethought as a result of these findings. In addition, India has to improve the state of its financial infrastructure so that businesses can use cutting-edge technologies, reduce the amount of energy they use, and contribute to the preservation of the environment. It is possible to improve environmental performance by utilizing the financial system as a tool, and legislators can propose reforms that encourage and compensate enterprises that utilize environmentally friendly technologies. This will push enterprises to employ environmentally sustainable technologies so that they can save money, minimize costs related to energy, and reduce emissions of greenhouse gases. This study also discovered that making use of current technology and renewable forms of energy leads to a reduction in the amount of carbon dioxide that is released into the environment. It is strongly suggested that India put these policies into effect in order to significantly enhance the quality of the environment. In a similar line, rising urbanization has resulted in the residential sector becoming the primary consumer of energy. This is due to the rise in the number of people living in urban areas. As a consequence of this, it has been suggested that homes limit the amount of energy they use by installing solar panels and switching to more energy-efficient electrical appliances.

This study has some limitations, despite the fact that the present study's outcomes have important consequences for public policy. The unavailability of data beyond the study period restricted the econometric methodologies used by the study. Furthermore, it may be possible to add to the existing body of knowledge by doing research into the link between environmentally responsible finance and consumption-based carbon emissions. It is possible to conduct additional research on India's economic growth and CO_2 emissions by including factors such as the country's political unpredictability, the volume of remittances received, the quality of its institutions, the degree to which the economy fluctuates, and data relating to the social dimension, such as employment rates.

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