The impact of economic growth, trade openness and manufacturing on CO2 emissions in India: an autoregressive distributive lag (ARDL) bounds test approach

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Abstract

Purpose – The purpose of this study is to examine the impact of economic growth, trade openness and manufacturing on CO2 emissions in India.

Design/methodology/approach – The study employed autoregressive distributive lag (ARDL) bounds test approach and uses CO2 emissions, trade, manufacturing and GDP per capita to examine the relationship using an annual time series data from World Development Indicators during 1971 to 2016.

Findings – Results depict that there exists a long-run relationship between CO2 emissions and other variables. Trade openness significantly reduces CO2 emissions, whereas manufacturing and GDP have a significant and positive impact on CO2 in the long run.

Research limitations/implications – The findings of the study contribute to the body of knowledge by providing new evidence on the relationship between developmental metrics and the environment. These findings are critical for policymakers and regulatory bodies to focus on economic development without jeopardizing environmental degradation.

Practical implications – In order to keep its commitment to sustainability, India needs to develop policies that encourage cleaner production methods and establishment of non-polluting industries. Simultaneously, it must disincentivize industries that emit CO2 by policy frameworks such as carbon taxes, pollution taxes or green taxes.

Originality/value – None of studies examine at how these environmental factors interact in India. Kilavuz and Dogan (2020) used the same variables, but their scope was limited to Turkey. As a result, the study is the first to examine this relationship for India, contributing to the body of knowledge on economic growth, manufacturing, trade openness and environmental concerns.

Keywords ARDL, Trade openness, Carbon emissions, EKC hypothesis

Paper type Research paper

1. Introduction

The genesis of globalization was based on the idea of free trade amongst countries as promulgated by Adam Smith in his seminal work – The Wealth of Nations. Historically, production and trade have been our bedrock of economic growth spanning across ancient civilizations to the contemporary world. Climate change as an objective reality has dawned upon our collective conscience in the late 19th century. It is lately that governments have realized the significance of environmental conservation and its perils in case of any further

JEL Classification — F6, F18, O1, Q5

degradation, thus leading to policy formulation around sustainable development (Chowdhury *et al.*, 2021; Dale *et al.*, 2020; Xu *et al.*, 2021). This realization has led to several multilateral initiatives being undertaken by the conscience-stricken international community through the way of globally inclusive platforms such as the Stockholm Conference, Montreal Protocol, Rio Convention, Kyoto Protocol, the recent Paris Agreement, etc. (Wang and Wiser, 2002; Jacquet and Jamieson, 2016).

Modern day consumerism and consumption have imparted substantial momentum to economic growth, which has been largely responsible for the financial upliftment of many countries. Nevertheless, climate change has been a negative externality of this relentless human pursuit. An ample of studies indicates that economic growth often contributes to environmental degradation (Bekun *et al.*, 2019; Song, 2021). The environmental Kuznets curve (EKC) hypothesis proposed by Grossman and Krueger (1995) delineates that during the initial stages of a country's economic development, its environmental degradation increases but gradually subsides at the turning point after attaining a certain level of industrialization. In the context of developing countries, it becomes imperative for policymakers to optimize the trade-off between economic growth and ecological conservation.

Globalization has been an important proponent of trade openness for emerging economies. From a theoretical sense, trade openness has three far-reaching implications on pollution viz. scale effect, composition effect and technology effect (Antweiler *et al.*, 2001). The scale effect implies that an increase in trade leads to an increase in energy consumption, which in turn causes increased environmental degradation. The composition effect revolves around the premise that comparative advantages inherent to a country decide its production composition for the prevalence of either labor or capital-intensive industries. As per the factor endowment hypothesis (FEH), the latter is more polluting, in nature, than the former. Third, the technology effect expounds that increased trade causes greater facilitation of technology transfer amongst trading partners, which results in the adoption of cleaner and more efficient practices.

Developing economies like India tend to have a major share of non-renewable energy sources as a part of their energy consumption mix. Moreover, being amongst the most densely populated country, the scope for raising ecological footprint increases (Sharma *et al.*, 2021). The increased energy demand for powering industrial activity of a developing nation leads to elevated pollution levels. This is in concurrence with several studies that have investigated the nexus between manufacturing and CO2 emissions (Canh *et al.*, 2019; Rahman and Kashem, 2017; Zafar *et al.*, 2020).

Our research aims at exploring the interplay between economic growth, trade openness and degree of industrialization with carbon emissions in the context of India. We have deployed the autoregressive distributive lag (ARDL) bounds test approach as the statistical methodology for ascertaining empirical relationships amongst the variables under study. There exists a dearth of studies about emerging economies, and our study on one of the largest emerging economies, India, shall prove to be an important source of knowledge for understanding such implications.

2. Literature review
EKC hypothesis is the most popular theory that links the effect of economic growth on the environment; it was the first empirical study of Grossman and Krueger (1995). The theory asserts that there is an inverted relationship between pollution and economic growth. As the economy grows beyond a certain level, it tries to achieve technological advances, which will lead to control the pollution. Shahbaz and Sinha (2019) and Purcel (2020) provide very extensive literature on the EKC hypothesis. Kılavuz and Doğan (2020) modeled economic growth, openness, industry and CO2 emissions during 1961–2018 for Turkey. They observed

industry and economic growth contribute to CO2 emissions positively, while trade openness does not have any effect on CO2 emissions.

Trade openness indicates the degree to which an economy is open to trade across the world economies. It helps countries to increase exports that intend to increase domestic production, by increasing the scale of industries, which leads to increased pollution (Jun *et al.*, 2020). Concerning the relationship between pollution and trade openness, there seems to be no consensus. Across the several countries studied, pollution levels have increased with increased trade openness (Al-Mulali *et al.*, 2016; Jun *et al.*, 2020; Lin, 2017; Wen and Dai, 2020). However, few believe that the increase in trade openness reduces pollution (Ghazouani *et al.*, 2020; Kohler, 2013; Shahbaz *et al.*, 2017). While few observe differences in the relationship based on the economic income. For example, Wang and Zhang (2021) observed that the relationship between pollution and trade openness is positive for low-income countries, while it is negative for high- and middle-income countries. Greater trade openness and FDI are expected to increase emissions in developing economies with fewer environmental regulations (Sajeev and Kaur, 2020). Jayanthakumaran *et al.* (2012) also observed a negative relationship in China and a positive relationship in the case of India.

Manufacturing positively contributes toward pollution levels in industrialized economies (Rauf *et al.*, 2018). The primary reason for pollution from manufacturing is that they heavily rely on fossil fuel energy. Industrial production and energy consumption have significant positive impacts on carbon emissions (Rahman and Kashem, 2017). To achieve higher economic growth, manufacturing activities require higher energy consumption, and in absence of abundant renewable energy sources, these activities rely more on non-renewable sources. Energy consumption and economic growth have a positive and statistically significant association (Esen and Bayrak, 2017). Hence, the use of non-renewable sources leads to environmental degradation. Industrial production is the driving force of CO2 emissions (Hocaoglu and Karanfil, 2011). Zafar *et al.* (2020) examined the role of industrialization in environmental pollution for 46 Asian countries. They observed a significant and positive impact of industrialization on carbon emissions. Most of the researchers have observed a positive relationship between manufacturing activities and pollution (Banerjee and Rahman, 2012; Canh *et al.*, 2019; Lin *et al.*, 2014).

A large number of studies have examined the linkages between economic growth and environment after the most popular EKC theory Grossman and Krueger (1995). Most of the studies found a positive relationship between economic growth and pollution (Alshehry and Belloumi, 2015; Menyah and Wolde-Rufael, 2010; Pao and Tsai, 2011; Park and Hong, 2013; Song, 2021). Rajpurohit and Sharma (2021) observed that moderate economic growth and moderate financial development increase carbon emissions, whereas exponential growth and financial development decrease carbon emissions. Dey and Tareque (2020) observed a negative impact of external debt on GDP growth. Shabbir *et al.* (2020) examined the role of natural resources in economic growth for Pakistan during 1972–2016. They examined the relationship of population density, water renewable resources, CO2 and deforestation on the GDP. They observed a negative and significant relationship of all the variables with GDP. Rasool *et al.* (2020) examined the curvilinear relationship between environmental pollution and economic growth in India during 1971–2014. They identified that energy consumption, economic growth and financial development have negative effects on the environment.

India is one of the fastest-growing economies of the world and it is also the third-largest carbon emitter. With the ambitions of high economic and industrial growth, the emissions are going to increase substantially because of the reliance on carbon emissive fuels. Due to this, along with India, the world is also vulnerable to climate change and faces threats from rising sea levels, floods, droughts and health hazards. Therefore, our research aims to find the cointegration relationship of carbon emissions in the Indian context.

Our research is the most recent and is closely linked to the literature on environmental variables that are responsible in India. None of these studies investigates how these environmental factors interact in India. Kılavuz and Doğan (2020) used the same variables, but their reach was limited to Turkey. As a result, our research is the first to look into this relationship for India, adding to the body of knowledge on economic development, manufacturing, trade openness and environmental issues. Table 1 summarized the empirical evidence on the relationship of the variables with CO2 emissions.

3. Method

3.1 Data and variables
The current research examines the relationship between carbon dioxide emissions, trade openness, manufacturing and economic growth. The variables in this study are time series data from 1971 to 2016, with data sources and descriptions mentioned in Table 2.

Hence, Eq (1) represents the functional relationship.

$$\ln CO2_t = f(\ln TO_t, \ln MFG_t, \ln GDP_t) \tag{1}$$

3.2 Model
For the study, we employed the ARDL bounds test approach by Pesaran *et al.* (2001). The ECM representation of ARDL is formulated with reference to CO2 in Eq (2) in order to examine cointegration among the variables defined in Eq (1):

$$\Delta \ln CO2 = \alpha_0 + \beta_1 \ln CO2_{t-1} + \beta_2 \ln TO_{t-1} + \beta_3 \ln MFG_{t-1} + \beta_4 \ln GDP_{t-1}$$
$$+ \sum_{i=1}^{n} \varnothing_1 \Delta \ln CO2_{t-i} + \sum_{i=1}^{n} \varnothing_2 \Delta \ln TO_{t-i} + \sum_{i=1}^{n} \varnothing_3 \Delta \ln MFG_{t-i}$$
$$+ \sum_{i=1}^{n} \varnothing_4 \Delta \ln GDP_{t-i} + \varepsilon_t \tag{2}$$

Here Δ represents the change; β and $\varnothing$ represent in long run and short run, respectively; ε_t represents the white noise terms.

The null hypothesis of no cointegration among the variables is rejected if the F-statistics obtained is above the upper bound values, and the null hypothesis is not rejected if the F-statistics is below the lower bound critical values. The presence of a long-run relationship is considered inconclusive if the F-statistics is between the upper and lower bound values.

3.3 Procedure
As a first step, the stationarity of the data is tested using the unit root tests to ensure that none of the variables are of order I(2). Later, the ARDL model is performed on the selected variables with AIC as lag length criteria. The bounds test is performed to check the existence of a long-term relationship between the variables. After confirming the cointegration relationship amongst the variables, the long-run and short-run elasticities of the variables are estimated. Finally, model stability is tested by performing various diagnostic and stability tests.

4. Results
The primary condition of ARDL states that the series should not be integrated at the order I(2) to prevent spurious results. As a result, the null hypothesis of unit roots is validated using two unit root tests namely, ADF and PP. We have assessed the order of integration at a 1% significance level from both tests. The results of unit root tests are shown in Table 3.

Sr. No	Relation	Authors	Countries	Data	Period	Methodology	Variables	Findings	Relation with CO2
1	Pollution and trade	Kohler (2013)	South Africa	Time series	1960–2009	J&J Coint. test and ARDL	CO2, EU, Inc and TO	CO2 decrease as the country's levels of foreign trade levels	Negative
2	Pollution and trade	Wang and Zhang (2021)	182 countries	Panel	1990–2015	DIM	CO2, Crude, REC, GDP, Pop and TO	Negative for high- and middle-income countries and positive for low-income countries	Negative for high- and middle-income countries and positive for low-income countries
3	Pollution and trade	Shahbaz et al. (2017)	105 countries	Panel	1980–2014	Pedroni and Wester	CO2, Exp, Imp, GDP	Trade openness reduces CO2 in most of the countries	Negative
4	Pollution and trade	Ghazouani et al. (2020)	Australia, Indonesia, Japan, Malaysia, Pakistan, South Korea and Thailand	Panel	1980–2017	B-ARDL	GDP, TO, REC, RC	When attempting to implement comprehensive fiscal, trade and energy policies that can both maintain long-term economic growth and reduce CO2 emissions	Negative
5	Pollution and trade	Jayanthakumaran et al. (2012)	India and China	Time series	1971–2007	ARDL	CO2, EC, TO, GDP and Ind	Negative for China and positive for India	Negative for China and positive for India
6	Pollution and Trade	Lin (2017)	China	Time series	2004–2011	OLS, 2SLS, GMM	TO, GDP, Ind, Pop, FDI, HD	Trade affects harmfully to some measures of air quality	Positive
7	Pollution and trade	Jun et al. (2020)	China	Time series	1982–2016	WCA	CO2 and TD	Trade openness has increased pollution in China	Positive
8	Pollution and trade	Wen and Dai (2020)	China	Time series	1990–2016	ARDL	GDP to CO2, TO and HC	Trade openness contributes positive to the CO2	Positive
9	Pollution and trade	Al-Mulali et al. (2016)	Kenya	Time series	1980–2012	ARDL	CO2, GDP, REG, FFC, FD, TO and Urb	In the long- and short-run, trade openness increases air pollution	Positive
10	Pollution and trade openness	Sajeev and Kaur (2020)	India	Time series	1980–2012	ARDL	CO2, GDP, Ind, FDI and TO	Trade openness has been shown to reduce emissions	Negative
11	Pollution and manufacturing	Rauf et al. (2018)	China	Time series	1968–2018	ARDL	CO2, GDP, EC, FD, Ind, Agri, Serv, TO and Urb	CO2 is impacted positively and significantly by trade openness	Positive

(continued)

Table 1.
Summary of literature review

Sr. No	Relation	Authors	Countries	Data	Period	Methodology	Variables	Findings	Relation with CO2
12	Pollution and manufacturing	Rahman and Kashem (2017)	Bangladesh	Time series	1972–2011	ARDL	CO2, EC and Ind	The industrial production has significant positive impact on the CO2	Positive
13	Pollution and manufacturing	Banerjee and Rahman (2012)	Bangladesh	Time series	1972–2008	ARDL	CO2, Ind, FDI and Pop	Growth in industrial production, population, and FDI have a positive impact on CO2	Positive
14	Pollution and manufacturing	Hocaoglu and Karanfil (2011)	G7 countries	Panel	1970–2008	HMM	CO2, Ind and Pop	In the G-7 nations, industrial production is the primary source of CO2	Positive
15	Pollution and manufacturing	Lin et al (2014)	China	Time series	1980–2012	ARDL	CO2, EP, EC and Ind	From industrial growth to CO2, there is a one-way causality	Positive
16	Pollution and manufacturing	Canh et al. (2019)	106 countries	Panel	1995–2012	GMM	CO2, CH4, N2O, Inc, Urb, Ind, EI, PE, TO and FDI	Manufacturing growth raises CH4 emissions across the income group	Positive
17	Pollution and Manufacturing, value added (% of GDP)	Zafar et al. (2020)	46 countries	Panel	1991–2017	FMOLS	CO2, Ind, GDP, EC and Urb	CO2 is impacted positively by industrialization	Positive
18	Pollution and growth	Song (2021)	China	Panel data	2001–2016	T-regression	CO2, GDP, Worker, REC, SOC, FOC, Urb, Ind, TO, EII and R&D	GDP per capita and CO2 in China are positively associated	Positive
19	Pollution and growth	Pao and Tsai (2011)	BRIC	Panel data	1980–2007	Pedroni, GC	CO2, EU, FDI and GDP	GDP and pollution has strong positive causality	Positive
20	Pollution and growth	Park and Hong (2013)	South Korea	Time series	1991QI–2011Q4	MSM	CO2, GDP, FFC	Economic growth and CO2 emissions are coincidental and fossil fuels, which emit CO2	Positive
21	Pollution and growth	Alshehry and Belloumi (2015)	Saudi Arabia	Time series	1971–2010	JCT	CO2, EU, GDP and OP	CO2 and economic growth have a bidirectional causal relationship	Positive

(continued)

Table 1.

Sr. No	Relation	Authors	Countries	Data	Period	Methodology	Variables	Findings	Relation with CO2
22	Pollution and growth	Menyah and Wolde-Rufael (2010)	South Africa	Time series	1965–2006	ARDL	CO_2, GDP, EU and GFC	Pollutant emissions and economic growth have a positive and significant relationship	Positive
23	Pollution and economic development	Rajpurohit and Sharma (2021)	India, Pakistan, Bangladesh, Sri Lanka and Malaysia	Panel data	1980–2014	PMG	CO_2, GDP, EU and FD	Moderate economic growth and moderate financial development increase CO_2, whereas exponential growth decreases CO_2	Positive
24	Pollution and Economic Development	Shabbir et al. (2020)	Pakistan	Time series	1972–2016	JCT	Pop, WRR, CO_2, Deforestation	Negative and significant relationship of all the variables with GDP	Negative
25	Pollution and economic development	Rasool et al. (2020)	India	Time series	1971–2014	ARDL	EC, GDP, FD and CO_2	Energy consumption, economic growth and financial development have negative effects on the environment	Positive
26	Pollution and economic growth, openness and industry	Kilavuz and Doğan (2020)	Turkey	Time series	1961–2018	ARDL	GDP, TO, Ind and CO_2	Industry and economic growth contribute positively to CO_2, while trade openness has no effect on CO_2	Positive

Note(s): *Abbreviation used: CO2* (Carbon Emissions); *TO* (Openness ratio/total trade/exports and imports/trade intensity); *GDP* to *CO2* (GDP to CO2); *EU* (Commercial energy use or Consumption/Transport energy consumption/Energy Consumption); *Exp* (Exports); *EC* (Electricity Consumption); *TD* (Trade); *Ind* (Industry value added/industrialisation); *Urb* (Urbanization); *EP* (energy price); *Inc* (Income); *REC* (Renewable energy consumption); *Imp* (Imports); *HC* (Human Capital); *REG* (Renewable Energy Generation); *FDI* (Foreign Direct Investment); *Pop* (Population); *N2O* (Nitrous oxide emissions); *Worker* (Worker); *FFC* (Fossil fuel/Non-Renewable energy consumption or generation); *RC* (Real capital per capita); *FD* (financial development); *GFC* (Real gross fixed capital); *SOC* (state-owned capital); *HD* (Highway density); *Agri* (agricultural value added share); *FOC* (foreign-owned capital); *Serv* (Service Value Added); *EI* (Energy imports); *EII* (environmental improvement investment); *R&D* (Research and Development/R&D intensity); *WRR* (Water Renewable Resources); *2SLS* (Two-stage least squares); *ARDL* (AutoRegressive Distributive Lag); *B-ARDL* (Bootstrap ARDL approach); *DIM* (Decoupling index model); *FMOLS* (Fully Modified Ordinary Least Squares); *GMM* (Generalized Method of Moments (GMM)); *GC* (Granger causality); *HMM* (Hidden Markov model); *J & J Coint* (Johansen and Juselius Cointegration); *JCT* (Johansen Cointegration Test); *MSM* (Markov Switching Model); *OLS* (Ordinary Least Square); *Pedroni* (Pedroni panel cointegration test); *PMG* (Pooled Mean Group); *T-Regression* (Threshold regression model); *WCA* (Wavelet-Coherence Analysis); *Wester* (Westerlund panel cointegration tests)
Source(s): Own elaboration

Table 1.

The results of the unit root tests in Table 3 show that none of the variables are stationary at the 1% level, but they become stationary at their first difference. This ensures that none of the variables are integrated at I(2).

The bounds test was used to evaluate the long-run relationship between the variables, as shown in Table 4. The null hypothesis states that there is no cointegration relationship between the variables. If the calculated F-statistic is greater than critical [I(1)], there exists a cointegration relationship in the model. If the F-statistic is less than the critical value [I(0)], there is no cointegration. However, if the F-statistic falls between the critical limits, it is concluded as inconclusive.

The results reveal that the F-statistic is greater than the critical values of the upper bound at a 1% significance level. Therefore, we can reject the null hypothesis of no long-run relationship between CO2 emissions and other variables. This concludes that there exists a cointegration among CO2 emissions, trade openness, manufacturing and economic growth. Once the cointegration relationship is established, we then estimated the long-run coefficient of the model.

Table 5 presents the long-run elasticity of CO2 emissions regarding the independent variables. Trade openness has a significant negative impact on CO2 emissions, whereas manufacturing and GDP have a significant and positive impact on CO2 emissions in the long run. Our results are consistent with that of Khan *et al.* (2019), Munir and Riaz (2019), Abumunshar *et al.* (2020), Ali *et al.* (2020), Sajeev and Kaur (2020) and Sharma and Kautish (2020).

The coefficient of −1.194 for trade indicates that a 1% increase in trade results in a decrease of 1.19% in CO2. With increased global trades, there will be a faster and larger inflow of information, resources and cleaner technology, which will aid in the reduction of environmental burdens. Our results are consistent with that of Ghazouani *et al.* (2020), Kohler (2013) and Shahbaz *et al.* (2017).

Variable	Variable representation	Description	Source
CO2 emissions	CO2	India's carbon dioxide emissions per capita in metric tonnes	WDI
Trade openness	TO	Percentage of India's GDP, reflected by overall trade performed (both imports and exports)	WDI
Manufacturing	MFG	Represents India's manufacturing production as a percentage of GDP	WDI
Economic growth	GDP	GDP per capita	WDI
Source(s): World Development Indicators (WDI)			

Table 2.
Data description and sources

	Level		First difference		
Variables	ADF	PP	ADF	PP	Order of integration
lnCO2	0.805	0.777	−6.472*	−6.491*	I(1) at 1%
lnTO	−1.597	−1.491	−4.966*	−4.949*	I(1) at 1%
lnMFG	−2.930**	−3.076**	−6.654*	−6.799*	I(0) at 5% I(1) at 1%
lnGDP	3.839	6.594	−6.193	−6.216*	I(1) at 1%

Note(s): * and ** indicates 1% and 5% statistical significance, respectively. The critical values of ADF test are: 1% level (−3.585), 5% level (−2.928) and 10% level (−2.602)
Source(s): Authors' calculations from Eviews

Table 3.
Results of unit root tests

Manufacturing has a significant positive long-run relationship with CO2. The coefficient of manufacturing indicates that a 1% increase in manufacturing leads to a 6% increase in CO2 emissions. This means that manufacturing activities positively lead to CO2 emissions as the industrial sector is highly reliant on energy input generated from carbon emitting fossil fuels. Our study is consistent with Hocaoglu and Karanfil (2011), Banerjee and Rahman (2012), Lin *et al.* (2014), Rahman and Kashem (2017), Rauf *et al.* (2018), Canh *et al.* (2019) and a more recent study of Zafar *et al.* (2020).

In India, economic growth has a significant and positive impact on CO2 emissions. Every 1% increase in GDP leads to a 2.56% increase in CO2 emissions. As India is an emerging country, its growing economic activity necessitates a higher energy demand that is more reliant on fossil fuels, resulting in a rise in CO2 emissions. This result is consistent with Menyah and Wolde-Rufael (2010), Pao and Tsai (2011), Park and Hong (2013), Alshehry and Belloumi (2015), Rasool *et al.* (2020), Rajpurohit and Sharma (2021) and Song (2021).

Once the long-run relationship is established, it is now required to check the adjustments (error correction model) toward the long-run equilibrium relationship. Table 6 displays the short-run relationship.

The change in manufacturing is having a significant and positive impact on CO2 emissions. In the short run, increased trade openness lowers CO2 emission levels. This negative relationship may mean that trade is an environmental quality improver. In the short run, for every 1% increase in trade openness, there will be a 0.11% decrease in CO2 emissions. On the other hand, an increase in manufacturing output by 1% leads to an increase of 0.26% in CO2 emissions. As expected, the error correction term ECM (−1) is negative and significant, which indicates how quickly the dependent variable adjusts to the long-run equilibrium point. Any disequilibrium in the dependent variable is returned to equilibrium in one period at a speed of 8.80%. Different diagnostic measures, such as normality, heteroscedasticity and serial correlation, are used to determine the model's stability. The Jarque-Bera test is used to verify the model's normality assumption. The null hypothesis of normally distributed residuals is accepted. The null hypothesis of homoscedastic disturbance terms is accepted using the Breusch-Pagan test. The Ramsey RESET test indicates that the

Model $\ln CO2_t = f(\ln TO_t,\ \ln MFG_t,\ \ln GDP_t)$	99% critical values		F-stat
	Lower bound	Upper bound	
Null hypothesis	3.65	4.66	7.988*
No long-run relationship $\beta_1 = \beta_2 = \beta_3 = \beta_4$			
No short-run relationship $\varnothing_1 = \varnothing_2 = \varnothing_3 = \varnothing_4$			
Note(s): * indicates 1% statistical significance level			
Source(s): Authors' calculations from Eviews			

Table 4.
ARDL bound test results

	CO2	
Independent variables	Coefficient [std. error]	T-stat [prob.]
lnTO	−1.194 [0.679]	−1.756 [0.088***]
lnMFG	6.019 [3.169]	1.899 [0.066***]
lnGDP	2.563 [0.892]	2.874 [0.007*]
C	−29.794 [12.173]	−2.447 [0.020**]
Note(s): *, **, *** indicate 1%, 5% and 10% statistical significance, respectively		
Source(s): Authors' calculations from Eviews		

Table 5.
Long-run coefficient estimates

Independent variables	Coefficient [std. error]	CO2	T-stat [prob.]
D(lnCO2(−1))	−0.180 [0.131]		−1.379 [0.1767]
D(lnMFG)	0.264 [0.106]		2.481 [0.018**]
D((−1))	−0.338 [0.103]		−3.285 [0.002*]
D(TO)	−0.111 [0.046]		−2.475 [0.019**]
D(TO(−1))	0.223 [0.042]		5.269 [0.000*]
ECM(−1)	−0.088 [0.013]		−6.681 [0.000*]

Diagnostic tests

R-squared	0.442
Adjusted R-squared	0.3687
Durbin–Watson stat	2.017
Normality [Jarque-Bera (p-value)]	0.207 (0.902)
Serial correlation [LM Test F-statistic (p-value)]	0.075 (0.928)
Heteroscedasticity [Breusch-Pagan-Godfrey (p-value)]	1.307 (0.269)
Ramsey RESET test [F-statistic (p-value)]	2.787 (0.106)

Note(s): *, ** indicates 1% and 5% statistical significance respectively
Source(s): Authors' calculations from Eviews

Table 6.
Short-run coefficient
estimates

CO2 model is a good fit. Finally, to validate the estimated ARDL model stability of the long-run coefficients with the short-run dynamics, we used the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares (CUSUMSQ). Figure 1 plots the CUSUM and CUSUMSQ.

5. Discussion

The economic growth in India has been largely driven by consumption, urbanization and industrialization. The energy requirements to supplement this growing demand has been largely met through non-renewable energy sources. Hence, economic growth and CO2 emissions in India have grown in tandem. Improving the existing skewed energy mix of India and increasing the share of cleaner alternative energy sources must take precedence in any policy planning considerations.

The negative relationship between trade openness and carbon emissions can be justified by technology effects. As trade opens up a gateway for spillover effects, cleaner and efficient technological practices become mainstream across partner nations. Hence, India should encourage preferential trade policies, with a particular emphasis on technological value addition, which can be cultivated through reciprocal trade liberalization and the removal of trade barriers. Ultimately, trade openness persuades a virtuous cycle that benefits the economy by increasing employment opportunities, softening capital flows and fostering a competitive environment.

Industrialization in India has witnessed enormous momentum in recent decades. Manufacturing has been a substantial contributor to the GDP of India. Nonetheless, it has also been a precursor for rising CO2 emissions. To uphold its commitment toward environmental conservation, India must formulate policies around incentivizing cleaner methods of production or setting up the so-called non-polluting industries. Parallelly, it must disincentivize CO2 emissions by manufacturing industries through policy mechanisms such as carbon tax, pollution tax or green tax.
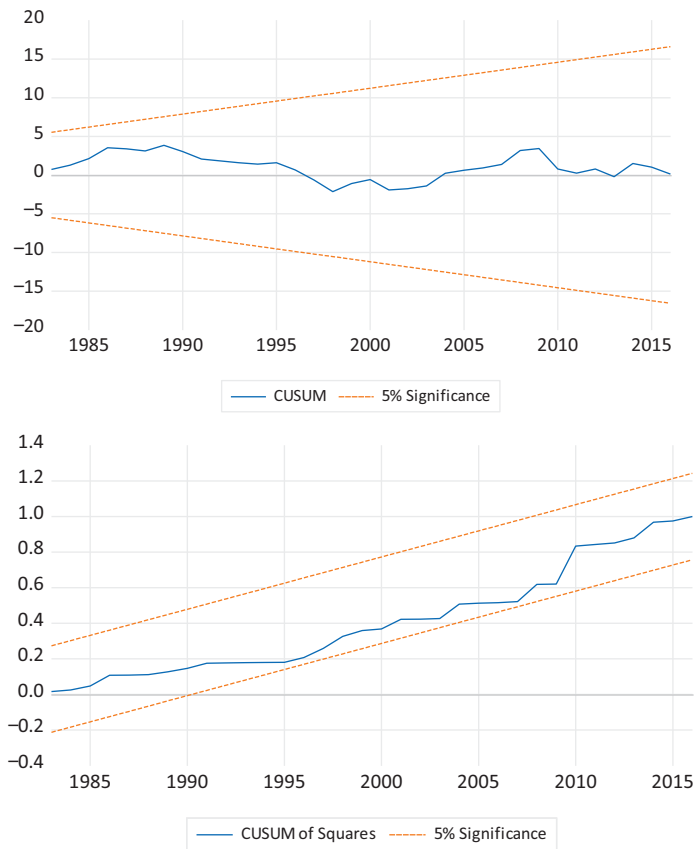
Figure 1.
Plots of CUSUM and
CUSUM of squares

Source(s): Authors' calculations from Eviews

The scope of the study can be extended by considering urbanization and renewable energy generation, which are considered important proxies for economic growth and reduction of CO_2 emissions, respectively. Fossil fuels are the primary source of energy for most of the emerging economies; hence, the study can also be extended by considering this relationship for a panel of emerging economies.

6. Conclusions

The present study explores the long-run and short-run relationship between economic growth, trade openness and manufacturing with CO_2 emissions in the Indian context. The ARDL bound test approach is employed to establish this relationship. For this study, annual time series data from 1971 to 2016 were used. Empirical findings reveal that the variables under research have a long-term relationship.

The results of the long-run relationship are congruent with the empirical research. Trade openness has a considerable negative association with CO_2 emissions. With expanded global trades, there will be a faster and larger inflow of information, resources and cleaner technologies, which will contribute to the reduction of environmental burdens.

Manufacturing and GDP have a significant and positive relationship with CO2 emissions in the long run. As the industrial sector is heavily reliant on energy input generated from carbon emitting fossil fuels, this means that manufacturing operations have a positive impact on CO2 emissions. Because India is a developing country, its increasing economic activity needs a higher energy demand, which is more reliant on fossil fuels, increasing CO2 emissions.

In order to keep its commitment to sustainability, India needs to implement regulations that encourage cleaner manufacturing methods and the establishment of non-polluting industries. Simultaneously, it must disincentivize industries that emit CO2 by policy frameworks such as carbon taxes, pollution taxes or green taxes.

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