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Re-examining the Environmental Kuznets Curve Hypothesis in India: The Role of Coal Consumption, Financial Development and Trade Openness

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ABSTRACT

The objective of this study is to evaluate the effect of GDP growth, coal consumption, financial advancement, and trade openness on CO_2 *discharges in India for the time span 1971-2017. The present research employs the ARDL bounds test to inspect the long-run cointegrating linkage followed by Granger causality test structured on vector error correction modelling (VECM) techniques to analyse the causal relationship between the variables. The results obtained from the bounds F-statistics confirm the presence of a long-run stable relationship between the variables. The results further demonstrate that GDP growth and coal consumption raise carbon emissions substantially while the financial development and trade openness boost the environmental quality in India. Besides, the findings confirm an inverse quadratic link between economic growth and* CO_2 *discharges, supporting the validity of EKC hypothesis for India. The Granger causality analysis shows bidirectional causality between coal consumption and economic growth, economic growth and* CO_2 *emissions and between coal consumption and* CO_2 *emissions.*

Keywords: CO_2 emissions, GDP, coal consumption, financial development, trade openness, Environmental Kuznets curve, ARDL, VECM, India.

JEL Classification: C32, Q43, Q53, Q56.

1. INTRODUCTION

Global warming and climate change are the two most debated and alarmed environmental issues in our times. Indeed, there is a wide-ranging agreement among environmental researchers that amassed CO_2 discharged through the combustion of fossil fuels alongside contributions from other human-activated ozone-depleting gases are heating the air and oceans of our planet. The world-wide impacts of climate change are now evident in escalating the occurrence of harsh weather situations, changing pattern of rainfall, heightening storm intensity, turning around of ocean flows and rising sea level (Boutabba, 2014). These alterations can affect the working of eco-system, the sustainability of wild-

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life, and prosperity of human being. International organizations such as the United Nations have been endeavouring to lessen the unfriendly effects of global warming with the aid of intergovernmental and official understandings. The Kyoto Protocol is this kind of an arrangement which was signed in 1997 following heavy dialogs. It is a convention towards the United Nations model on climate change with the goal of decreasing climate change-causing greenhouse gases (GHG) in a time-bound manner. The Paris Agreement of UNFCC was enacted by accord with 195 nations (which accounts for more than 95 percent of global emissions) as the successor of the Kyoto Protocol in December, 2015 (S. Zhang, Liu, & Bae, 2017). This agreement is wider and more effective which brings almost all nations, including developing and major emitting nations such as China and India, into a common cause to undertake an ambitious effort to combat climate change. India endorsed the second commitment period (or Doha Amendment) of the Kyoto Protocol, which mandated the nations to limit the greenhouse gas emissions. With this, India became the 80^{th} nation to acknowledge the second commitment period (2013-2020) of the Kyoto Protocol.

India is one of the World's largest transitional and growing economies, with growth averaging about 7 percent over the last five years. According to International Monetary Fund, India is the World's sixth largest economy by nominal GDP (with 2.611 trillion dollar) and third largest by purchasing power parity (PPP) with 9.459 trillion dollar in 2017-18. Naturally, this quick economic growth is linked to higher energy consumption and increased emissions. India was the World's third largest energy consumer after China and the United States in 2013, and it is projected that the country's energy consumption continues to rise in future because of its prioritization to economic development including modernization, urbanization, and poverty alleviation drive (U.S. Energy Information Administration, 2016).

Because of the availability of large coal reserves, more than 56 percent of India's power supply emanates from coal (Kanjilal & Ghosh, 2013). Different domestic and global agencies' projections indicate that coal is anticipated to further lead its share in India's energy supply because of its accessibility and cost-effectiveness. But coal is a filthy fuel, which is held responsible for the largest share of CO_2 emissions. Though India's per capita emissions are well below the global average (40 percent of the global average), India emitted 2299 million tons of CO_2 in 2018- a 4.8 percent increase from the previous year (IEA, 2018). Most notably, this growth was higher than that of the USA and China, the first and the second largest emitter in the world. India contributed 7 percent to the global CO_2 burden, while the United States was responsible for 14 percent of total CO_2 emissions (IEA, 2018). Being cognizant of its growth trajectory in an ecologically viable manner and in conformity with its commitments to United Nations Framework Convention on climate change, India has pledged a 33-35 percent decrease in its economy's emission intensity by 2030, compared to 2005 levels. Additionally, it has committed to get 40 percent of its energy supply from clean (renewable) sources by 2030. Therefore, India faces the problems of formulating such a policy-mix, which help to achieve its economic development without doing much harm to the environment.

While lowering energy consumption appears to be a feasible alternative for lessening CO_2 emissions, its effect on economic growth may be negative. Thus, there is a pressing prerequisite to comprehend the dynamic connections among coal consumption, CO_2 emissions, and economic growth in India. Although environment-energy-income nexus has been assessed intensively by researchers globally, only a few studies have been conducted to investigate the dynamic link among these variables in the case of India (Boutabba, 2014; Chandran Govindaraju & Tang, 2013; Ghosh, 2010; Jayanthakumaran, Verma, & Liu, 2012; Tiwari, Shahbaz, & Adnan Hye, 2013).

In the light of this backdrop, the present study is an endeavour to make a contribution to the existing literature by exploring the causal links between per capita CO_2 emissions, per capita real GDP, coal consumption, financial development, and trade openness for India over the period 1971-2017. Additionally, this study includes the square term of per capita GDP in the modelling framework in order to investigate the validity of EKC hypothesis in India.

The remainder of the paper is structured as follows. Section 2 presents a brief review of the relevant literature on energy-income-pollution nexus and EKC hypothesis. Section 3 discusses the data sources, variables, econometric models and estimation techniques used in the study, while section 4 presents the empirical results and discussion. Finally, conclusion and policy implications emanated from the present study are given in section 5.

2. LITERATURE REVIEW

There are primarily three groups of studies in the literature on the linkages between economic growth (income) and CO_2 emissions. The first group of studies focuses on only the economic growth and carbon emission links, which is closely related to examining the EKC (Environmental Kuznets Curve) hypothesis. After the initial work of Grossman and Kruger (1991) concerning the validity of EKC hypothesis, a growing body of literature has investigated the economic growth-emissions nexus (Coondoo & Dinda, 2008; Dinda & Coondoo, 2006; Friedl & Getzner, 2003; Heil & Selden, 1999; Managi & Jena, 2008; Romero-Ávila, 2008; Shafik, 2012; Taskin & Zaim, 2000). The findings of these studies, however, have been inconclusive.

The second group of researches mainly centre around the relationship between economic growth (income) and energy consumption as emissions stems from the combustion of non-renewable energy. Since the seminal research of Kraft and Kraft (1978), a growing number of studies explored the causal connections between energy consumption and economic growth. Most of the earlier researchers

(Akarca & Thomas, 1980; Erol & Yu, 1987; Glasure & Lee, 1998; Hwang & Gum, 1991; Yu & Choi, 1985; Yu & Hwang, 1984) used bivariate models which produced misleading results. They were severely criticized later, especially by Stern (1993) for model specification bias due to the omissions of relevant variables. Following the work of Stern (1993), a large number of studies have explored the income (output) and energy nexus in multivariate framework (Asafu-Adjaye, 2000; Belloumi, 2009; Ghali & El-Sakka, 2004; Jamil & Ahmad, 2010; Lee, 2005; Masih & Masih, 1998; Narayan & Smyth, 2005; Oh & Lee, 2004; Sanu & Ahmad, 2017; Stern, 2000; Wang, Wang, Zhou, Zhu, & Lu, 2011; Wolde-Rufael, 2005, 2009). These studies also provided conflicting results.

Lastly, a third group of studies has appeared, which merged the previous two practices and examined the soundness of both the nexuses within the same model (Ang, 2007; Apergis & Payne, 2009; Arouri, Ben Youssef, M'henni, & Rault, 2012; Lean & Smyth, 2010; Ozturk & Acaravci, 2010) This group of studies explored the dynamic linkages among economic growth, carbon emissions, and energy consumption altogether. The most recent literature has extended the third approach by controlling for additional variables like trade openness, urbanization, financial development, etc. There have been a few studies which looked into the connections between income, energy consumption, and environmental pollution for India, using different time series methodologies.

Ghosh (2010) re-visited the causal connection between economic growth and CO_2 discharges for India employing ARDL bounds testing approach supplemented by Johansen-Juselius (1990) maximum likelihood procedure within a multivariate framework including energy supply, investment, and employment. The results indicated that there was no prolonged linkage between economic growth and carbon emissions in India; nonetheless, a short-run bi-directional causality between the two was found. Alam, Begum, Buysse, Rahman, & Van Huylenbroeck (2011) used the Toda-Yamamoto Granger causality to probe the causal links among income, CO_2 discharges, labour, and gross fixed capital formation for India. Their research revealed that there was a long-run feedback causality between energy consumption and carbon emission. However, neither energy consumption nor CO_2 emissions caused income. Jayanthakumaran et al. (2012) made a comparative analysis of China and India using four variables- energy consumption, economic growth, trade openness, and CO_2 emissions and applied ARDL bounds testing approach and endogenously determined structural breaks. Their research has found proof in favour of the presence of EKC hypothesis both for China and India. Nevertheless, they did not come up with any crystal clear picture concerning the links of structural change and carbon emission in the case of India. Kanjilal & Ghosh (2013) examined the cointegrating links among carbon emissions, energy consumption, economic activity, and trade openness for India using 'threshold cointegration test' over the period 1971-2008. Their study established the presence of 'regime shift' or threshold cointegration among the variables as well as found confirmation for the presence of an EKC in India. Boutabba (2014) investigated the causal links between economic growth, energy consumption, trade openness and financial development for India using ARDL bounds tests followed by VEC model. The contribution of this study to the literature lies in the fact that it included financial development variable for India in its analysis. The study found evidence in favour of long-run causal linkage between energy consumption, income, trade openness, and financial development. The study also indicated that financial development has a long-run positive effect on CO_2 emissions, which suggests that financial development degrade the environment in India.

The results of the above studies are conflicting and thus may create doubts in the minds of policy makers while formulating comprehensive economic, energy, financial, trade, and environmental policies. Therefore, further empirical research is necessary in India in order to provide a conclusive result. Hence, the objective of this research is to explore further the links between energy consumption, GDP, square of GDP, coal consumption, financial development, and trade openness in a more robust manner in the case of India.

3. DATA, VARIABLES, MODELLING FRAMEWORK AND ESTIMATION TECHNIQUES

3.1. Data and variables

The present study uses annual time series data of coal consumption, GDP per capita, CO_2 emissions, financial development, and trade openness in the case of India over the period 197-2017. The data on CO_2 emissions, GDP per capita, financial development and trade openness are obtained from the World Bank's 'World Development Indicators' (*World Development Indicators*, 2019), whereas the data on coal consumption is extracted from 'BP Statistical Review of World Energy, 2018'. The brief definitions of the series are as follows:

lCO_2= CO_2 emissions are measured by metric tons per capita.

$lGDP$= GDP per capita (constant 2010 US$) is used as a proxy for income.

$lCOAL$= Coal consumption is measured in terms of million tons of oil equivalents.

lFD= Financial development is proxied by domestic credit to the private sector as percentage of GDP.

lTR= Trade openness is the sum of exports and imports of goods and services as a share of GDP.

Each of the variables is changed into their natural log to eliminate the issue of heteroscedasticity and also to have the growth rate of the applicable variables by their differenced log.

The results of the descriptive statistics and correlation matrix are provided in table 1. It can be seen from Table 1 that all the series are normally distributed as indicated by the Jarque-Bera statistics. The correlation analysis shows that per capita GDP, coal consumption, financial development, and trade openness are positively associated with carbon emission. Similarly, coal consumption, financial development, and trade openness have a positive correlation with per capita GDP. Financial development and trade openness are also positively correlated with coal consumption. Finally, a positive correlation also exists between trade openness and financial development.

Table 1. Descriptive statistics and correlation matrix

	lCO_{2t}	$lGDP_t$	$lCOAL_{2t}$	lFD_t	lTR_t
Mean	-0.2975	6.5113	4.8278	3.3294	3.0955
Median	-0.2518	6.3796	4.8841	3.2289	3.0104
Maximum	0.5481	7.5830	6.0496	3.9586	4.0216
Minimum	-1.0117	5.8628	3.6396	2.5386	2.0480
Std. Dev.	0.4654	0.5310	0.7235	0.4188	0.5832
Skewness	0.0638	0.5307	0.0201	0.0475	0.1476
Kurtosis	1.8245	2.0149	1.8511	2.1954	1.8005
Jarque-Bera	2.5627	4.1073	2.5880	1.2854	2.9881
Probability	0.2776	0.1282	0.2741	0.5258	0.2244
lCO_{2t}	1.0000				
$lGDP_t$	0.9774	1.0000			
$lCOAL_t$	0.9983	0.9752	1.0000		
lFD_t	0.9186	0.9327	0.9291	1.0000	
lTR_t	0.9525	0.9699	0.9576	0.9375	1.0000

3.2. The model

Following the empirical literature especially the works of Hossain (2011), Sharma (2011), Boutabba (2014) and, Farhani and Ozturk (2015), we have formulated the following empirical model to analyse the long-run relationship between CO_2 emissions, GDP growth, coal consumption, financial development and trade openness for India:

$$CO_2 = A.GDP^{\beta_{gdp}}COAL^{\beta_{coal}}FD^{\beta_{fd}}TR^{\beta_{tr}} \quad (1)$$

Applying the natural logarithm of eq. (1), we have obtained the succeeding log-linear model:

Model A

$$lCO_{2t} = \alpha_0 + \beta_{GDP}lGDP_t + \beta_{COAL}COAL_t + \beta_{FD}lFD_t + \beta_{TR}TR_t + \varepsilon_t \quad (2)$$

In order to verify if the EKC hypothesis is present in India when coal consumption, financial development, and trade openness are incorporated in energy-income nexus, the above model can be extended by including the squared term of GDP.

Model B

$$lCO_{2t} = \alpha_0 + \beta_{GDP} lGDP_t + \beta_{GDP^2} GDP_t^2 + \beta_{COAL} COAL_t + \beta_{FD} lFD_t + \beta_{TR} TR_t + \varepsilon_t \quad (3)$$

Where α_0, t and ε denote fixed country effect (constant term), time period and white noise stochastic error term respectively. The parameters β_{GDP}, β_{GDP^2}, β_{COAL}, β_{FD} and β_{TR} are the long-run elasticity estimators of per capita GDP, squared of GDP, coal consumption, financial development, and trade openness respectively. As for the expected sign of the parameters in eq. (2) and eq. (3), it is likely that the β_{GDP} and β_{GDP^2} would be positive and negative, respectively for the EKC hypothesis to hold (Farhani & Ozturk, 2015; Kanjilal & Ghosh, 2013). The positive sign of β_{GDP} indicates the phenomenon where the increase in income is accompanied by increased CO_2 emissions; however once the income reaches the threshold level, the CO_2 emissions start declining with the increase in income level as revealed by the negative sign of β_{GDP^2}. The anticipated sign of β_{COAL} is positive as an increased level of coal utilization may accelerate economic activity and trigger CO_2 emissions (Farhani & Ozturk, 2015; Halicioglu, 2009). The likely sign of β_{FD} is varied corresponding to the level of economic development in a country. The financial development may reduce carbon emission ($\beta_{FD} < 0$) through promoting research and development. Tamazian et al. (2009) found that financial development aids listed enterprises to encourage technological innovation and adopt new technologies in order to increase energy efficiency and spread low-carbon economic development. Additionally, Claessens & Feijen (2007) observed that enterprises with more forward-looking governance often are enthusiastic to consider low-carbon development. On the other hand, financial development may degrade environmental quality ($\beta_{FD} > 0$) as an efficient and well-developed financial system is conducive to consumers' loan activities which encourage customers to buy big items like automobiles, houses, refrigerators, air conditioners, washing machine etc. leading to more carbon emission (Y. J. Zhang, 2011). Besides, financial development may attract foreign direct investment (FDI), which increases the industrial activities and economic growth in the host country leading to more carbon emissions (Frankel & Romer, 1999).

The expected sign of β_{TR} is also mixed. For most of the developed nations, β_{TR} is expected to be negative as countries march towards development, they stop producing certain pollution-intensive goods and import these goods from other countries with less restrictive environmental protection laws (Halicioglu, 2009). On the other hand, for developing nations β_{TR} is expected to be positive because they have a tendency to produce without any environmental protection laws and technology, and thus become the heaven for dirty industries with a heavy share of pollutants (Grossman & Kruger, 1995).

3.3. ESTIMATION TECHNIQUES

3.3.1. ARDL bounds cointegration

To establish the long-run link among the series- $lCO2$, $lGDP$, $lCOAL$, lFD and lTR, the present paper has employed the ARDL bound testing approach developed by Pesaran et al. (2001). The

ARDL technique possesses many positive aspects over other methods of cointegration, like Engle and Granger (1987) and Johansen & Juselius (1990). The first and the foremost merit lies in the fact that the ARDL model can be used irrespective of the order of the integration of the series, i.e. I(0), I(1) or mixture of both. Second, it generally offers more robust results even when some of the regressors are endogenous (Harris & Sollis, 2003; Shahzad, Kumar, Zakaria, & Hurr, 2017). Third, the ARDL procedure is more useful in determining the cointegrating relation in case of small sample sizes (Odhiambo, 2009; Pesaran et al., 2001). Fourth, the dynamic error correction model (ECM) can be derived from the ARDL specification through a simple linear transformation, which clubs together short-run adjustment and long-run equilibrium relationship without losing long-run information (Boutabba, 2014; Pesaran & Shin, 1999). As a first step, the present study has estimated the succeeding unrestricted error correction model (UECM):

$$\begin{aligned} \Delta lCO_{2t} = a_0 + a_{dum}DUM + \sum_{i=1}^{p} b_{1i}\,\Delta lCO_{2,t-i} + \sum_{i=0}^{q} b_{2i}\,\Delta lGDP_{t-i} + \sum_{i=0}^{q} b_{3i}\,\Delta lCOAL_{t-i} \\ + \sum_{i=0}^{q} b_{3i}\,\Delta llFD_{t-i} + \sum_{i=0}^{q} b_{4i}\,\Delta lTR_{t-i} + \delta_1 CO_{2,t-1} + \delta_2 lGDP_{t-1} \\ + \delta_3 lCOAL_{t-1} + \delta_4 lFD_{t-1} + \delta_5 lTR_{t-1} + \mu_t \end{aligned} \tag{4}$$

In eq. (4), a_0 is the drift component, Δ is the first difference operator, $b_i s$ are the short-run parameters, δs are the long-run parameters, and all the variables are as defined previously (in section 3.1). The null-hypothesis of no-cointegration among the variables in eq. (4) is $H_0\colon \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$ against the alternative hypothesis of the presence of a long-run cointegrating relationship,$(H_1\colon \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5)$, which is conventionally expressed as $F_{lCO_2}(lCO_2/lGDP\,, lCOAL, lFD, lTR)$.

The decision about cointegration under bound test is based on the joint F-Statistics. Pesaran et al. (2001) and Narayan (2005) reported two sets (upper bound and lower bound) of critical values; in which the lower bound critical values assume that all series incorporated in the ARDL model is I(0), whereas the upper bound critical values assume that all the series are I(1). If the calculated F-statistics exceeds the upper bound critical value, the H_0 i.e., the null hypothesis of no cointegration is rejected, and it is concluded that there is a long-run relationship among the variables. Conversely, if the calculated F-statistics is lower than the lower bound critical values, we cannot reject the null-hypothesis of no cointegration. And, if the calculated F-Statistic falls between the bounds, then the decision regarding the cointegration is inconclusive.

Having found the existence of a long-run equilibrium connection among the variables, the subsequent stage is to estimate the short-run dynamic coefficient through the succeeding error correction model:

$$\Delta lCO_{2t} = a_0 + a_{dum}DUM + \sum_{i=1}^{p} b_{1i}\,\Delta lCO_{2,t-i} + \sum_{i=0}^{q} b_{2i}\,\Delta lGDP_{t-i} + \sum_{i=0}^{q} b_{3i}\,\Delta lCOAL_{t-i} + \sum_{i=0}^{q} b_{3i}\,\Delta llFD_{t-i} + \sum_{i=0}^{q} b_{4i}\,\Delta lTR_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (5)$$

Where λ is the error correction coefficient, which measures the velocity of adjustment to obtain the long-run equilibrium after shock(s) and ECT_{t-1} is the one period lagged residuals which are derived from the calculated long-run cointegration model, i.e. eq. (1).

3.3.2. Causality Analysis

The ARDL method discussed above only establishes the absence or existence of cointegration among variables; however not the direction of causality. As a standard practice, whenever we do not observe any indication for cointegration between the series, the Granger causality is tested with a vector auto-regression (VAR) in the first difference form. Nonetheless, in the presence of any cointegrating relationship, Engle and Granger (1987) suggested augmenting the Granger-style causality test with a one-period lagged error correction term (ECT_{t-1}) in order to circumvent the possibility of misleading results. To this end, after finding the evidence of cointegration in our ARDL model, we have formulated an enhanced form of Granger causality test including the error correction term in a multivariate q^{th} order vector error correction model (VECM).

$$(1-B)\begin{bmatrix} CO_{2t} \\ lGDP_t \\ lCOAL_t \\ lFD_t \\ lTR_t \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} + \sum_{i=1}^{q}(1-B)\begin{bmatrix} c_{11i} & c_{12i} & c_{13i} & c_{14i} & c_{15i} \\ c_{21i} & c_{22i} & c_{23i} & c_{24i} & c_{25i} \\ c_{31i} & c_{32i} & c_{33i} & c_{34i} & c_{35i} \\ c_{41i} & c_{42i} & c_{43i} & c_{44i} & c_{45i} \\ c_{51i} & c_{52i} & c_{53i} & c_{54i} & c_{55i} \end{bmatrix} + \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \end{bmatrix}\left[ECT_{t-1}\right] + \begin{bmatrix} \gamma_{1t} \\ \gamma_{2t} \\ \gamma_{3t} \\ \gamma_{4t} \\ \gamma_{5t} \end{bmatrix} \quad (6)$$

Where $(1 - B)$ is the lag operator and ECM is the error correction term obtained from the long-run cointegration equation. $b_i's(i = 1 \ldots .5)$ are the time-invariant constant, $c_i's(1 \ldots ..5)$ are the coefficient of error correction terms and $\gamma_i's(i = 1 \ldots .5)$ are the disturbance terms which are assumed to be serially uncorrelated with zero mean.

4. EMPIRICAL RESULTS AND DISCUSSION

Before proceed to test the long-run cointegrating relationship through the ARDL bounds testing approach, the order of integration of the series is inspected. As discussed above, the ARDL bounds test is centred on the assumption that series are integrated of order I(0) or I(1) or a mix of both. However, the computed F-statistic given by Pesaran et al. (2001) becomes unacceptable in the presence of any I(2) series (Ghosh, 2010). Therefore, it is imperative to examine the unit root characteristics of the variables to ascertain that none of the variables is integrated of order I(2) or beyond this. For this specific intention, the present study applies the traditional Augmented Dickey-Fuller (ADF) and Phillips and Perron (PP) unit root tests. Table 2 provides the results of ADF and PP with the only intercept and with both intercept and trend. The results reveal that lCO_2, $lGDP$, $lCOAL$, lFD and lTR are non-stationary at their level form; however they become stationary after taking first differences indicating that all the series are I(1), integrated of order one.

Table 2. Conventional unit root test

Variables	Intercept		Intercept and Trend	
	At Level	At First Diff.	At level	At First Diff.
Augmented Dickey-Fuller (ADF)				
lCO_{2t}	1.0567[0]	-6.1421[0]*	-1.8143[0]	-6.3011[0]*
$lGDP_t$	4.1126[0]	-5.8879[0]*	-1.4839[0]	-8.1983[0]*
$lCOAL_t$	0.1170[0]	-7.0471[0]*	-2.0809[0]	-6.9799[0]*
lFD_t	-1.5819[2]	-3.1761[1]**	-3.1693[4]	-3.2678[1]***
lTR_t	-1.6430[0]	-5.0896[0]*	-2.2336[2]	-5.2557[0]*
Phillips and Perron (PP)				
lCO_{2t}	1.0191[3]	-6.1891[3]*	-2.0078[3]	-6.3295[3]*
$lGDP_t$	5.5259[4]	-5.9499[4]*	-1.5546[4]	-9.7962[6]*
$lCOAL_t$	0.1334[1]	-7.0471[0]*	-2.2128[2]	-6.9799[0]*
lFD_t	-1.3376[4]	-5.8645[4]*	-1.8426[4]	-5.9142[4]*
lTR_t	-1.5261[3]	-5.0716[1]*	-1.6397[3]	-5.2491[1]*

Optimal lag length is given in parentheses, *, ** and *** denote the level of significance at 1%, 5% and 10% respectively.

The ordinary unit root tests commonly do not consider the structural breaks of the series, which may cause spurious results by falsely accepting or rejecting the null hypothesis of 'no unit root'. Therefore, the study also applies the single break unit root tests of Perron (1997) and Zivot & Andrews (1992). Results of these tests are presented in Table 3. The results of Perron (1997) unit root test show that in the presence of unknown structural break, all the variables have unit roots at level, but they become stationary after taking the first difference. The results received from ZA unit root test indicate that only $lGDP$ has a unit root at level but it is stationary in first difference while all other variables are stationary at levels as well as in first differences. As it is confirm that none of the series is I(2), integrated of order two or beyond, we can advance to the ARDL bounds testing for cointegration.

Table 3. Unit root test with single structural break

Test	Perron				Zivot-Andrews			
$Var(X)$	Level		First Diff.		Level		First Diff.	
	T_{Stat}	TB_X	T_{Stat}	TB_X	T_{Stat}	TB_X	T_{Stat}	TB_X
lCO_{2t}	-2.48[0]	1999	-6.90[0]*	1992	-2.50[0]**	1998	-7.01[0]**	1997
$lGDP_t$	-2.99[4]	2005	-6.10[1]*	2002	-2.87[0]	1979	-5.07[3]***	2005
$lCOAL_t$	-3.14[2]	1997	-7.51[0]*	1992	-3.15[2]**	1998	-7.58[0]**	1993
lFD_t	-5.44[3]	2003	-5.45[1]*	1998	-5.12[4]*	2004	-4.22[4]*	1999
lTR_t	-1.81[0]	2001	-5.95[0]*	1998	-3.31[2]***	2002	-6.01[0]**	1988

Figures in parentheses show the lag order, *, ** and *** indicate the level of significance at 1%, 5% and 10% respectively.

As the value of the F-statistics in bounds test is very responsive to the number of lags added, we should select the lag length very carefully. Pesaran et al. (2001) suggested that the optimal lag should be determined using AIC and SBC criterion. Lütkepohl (2006) proved that AIC lag length criterion produces efficient and consistent results, and it also lowers the loss of degrees of freedom. In this study, using both AIC and SBC criteria, the optimal lag length is found to be one.

Table 4. Bounds test for cointegration

	Estimated Model	Lag	F-Statistics	Decision
Model A	$F_{lCO_2}(lCO_2 \mid lGDP, lCOAL, lFD, lT)$	1	4.71	Cointegration
Model B	$F_{lCO_2}(lCO_2 \mid lGDP, lGDP^2, lCOAL, lFD, lT)$	1	4.54	Cointegration

Critical values are taken from Narayan (2005)

Table 4 presents the results of the ARDL bounds test along with F-statistics. The results show that F-statistics is larger than the upper bound critical value at 5 percent significance level in both estimated models, i.e., Model A: $F_{lCO_2}(lCO_2 \mid lGDP, lCOAL, lFD, lT)$ and Model B: $F_{lCO_2}(lCO_2 \mid lGDP, lGDP^2, lCOAL, lFD, lT)$ in which CO_2 emissions is used as predicted variable while in Model A, GDP, coal consumption, financial development, and trade openness are the explanatory variables, and in Model B apart from these explanatory variables square of GDP is used as an explanatory variable. This indicates the presence of cointegration and thus the long-run relationship among lCO_2, $lGDP$, $lGDP^2$ $lCOAL$, lFD, and lTR.

Soon after we found the presence of a long-run cointegrating connection in our Model A and Model B, the long-run and short-run elasticities (here the estimated coefficients are mathematically equivalent to the elasticity of CO_2 with respect to lCO_2, $lGDP$, $lGDP^2$ $lCOAL$, lFD and lTR respectively as all the series are converted to their natural logarithmic forms) are determined utilizing the connected ARDL and error correction model (ECM).

Table 5. Estimated long-run coefficients (dependent variable lCO_{2t})

Regressor	Model A			Model B		
	Coefficient	t-ratio	Prob.	Coefficient	t-ratio	Prob.
$lGDP_t$	0.1923	3.0178*	0.0047	1.6744	2.9554*	0.0058
$lGDP_t^2$	-	-	-	-0.0924	-2.4819**	0.0185
$lCOAL_t$	0.6609	19.5463*	0.0000	0.4971	8.8081*	0.0000
lFD_t	-0.0647	-1.7881***	0.0822	-0.0575	-2.0719**	0.0464
lTR_t	-0.0647	-1.7384***	0.0907	-0.0412	-1.4545	0.1555
Dum	-0.0183	-0.8440	0.4042	-0.0564	-3.0005*	0.0052
$Constant$	-4.2392	-17.8599*	0.0000	-9.2178	-4.9240*	0.0000

*, ** and *** show the level of significance at 1%, 5% and 10% respectively.

The long-run elasticities obtained by normalizing CO_2 in model A and model B are presented in table 5. The results reveal that the linear and squared term of GDP per capita are positive and negative respectively and significant at 1 percent and 5 percent levels (see Model B), which lends support in favour of an inverted-U association between economic growth and CO_2 emissions for India. Other things being the same, a 1 percent growth in per capita GDP leads to 1.67 percent increase in per capita CO_2 emissions while a 1 percent increase in the squared term of per capita GDP lowers the CO_2 emissions by 0.092 percent in the long-run. These outcomes patronize the 'EKC hypothesis' for India indicating that economic growth results in increase in CO_2 emissions at the initial level, but after a threshold point of income CO_2 emissions start declining. These findings are consistent with some important previous Indian studies such as Jayanthakumaran et al. (2012), Kanjilal & Ghosh (2013), Tiwari et al. (2013) and Boutabba (2014) and also in line with the many other studies which investigates the EKC hypothesis such as Song et al. (2008), Halicioglu (2009), Lean & Smyth (2010), Jalil & Feridun (2011), Saboori, Sulaiman, & Mohd (2012) and Ozturk & Acaravci (2013).

The results reported in Table 5 also demonstrates that the long-run elasticity of CO_2 emissions with regard to coal consumption is 0.66 in Model A and 0.49 in Model B and significant at 1 percent level, suggesting that a 1 percent increase in coal consumption results in 0.66 percent rise in CO_2 emissions for Model A while the corresponding figure for Model B is 0.49 percent. This outcome supports the study of Tiwari et al. (2013), who found that coal consumption is the second highest emitter of CO_2 emissions in India only behind the GDP growth. These results are also fortified by IEA report (2018) which states that India's recent high economic growth has created strong coal demand (one of the major contributors of CO_2 emission) especially for electricity generation and steel production as India surpassed Japan to become the world's second largest steel producer only after China.

The long-run influence of financial development on CO_2 emission is negative and significant at 10 percent and 5 percent levels in Model A and Model B, respectively. In Model A, a 1 percent increase in domestic credit to private sector depresses CO_2 emissions by 0.064 percent, and the corresponding figure for Model B is 0.057 percent. These findings are consistent with the studies of Tamazian et al. (2009), Jalil & Feridun (2011) and Shahbaz, Solarin, Mahmood, & Arouri (2013) among others; but these results are in contrast with Boutabba (2014) who found that financial development deteriorates the environment quality in India.

The elasticity of CO_2 emissions with regard to trade openness is negative in both the models, but it is significant only in Model A at 10 percent level, suggesting that CO_2 emissions are inversely related to trade openness. Keeping all else the same, a 1 percent increase in trade openness results in declining the CO_2 emissions minimally by 0.064 percent. These empirical findings support the study of Shahbaz et al. (2013), whose research provides a similar conclusion for Indonesia. Shahbaz et al. (2013) argued that trade openness assists the developing countries to access to sophisticated technologies which reduce carbon emissions substantially.

Table 6. Short-run estimation results (dependent variable ΔlCO_{2t})

Regressor	Model A			Model B		
	Coefficient	t-ratio	Prob.	Coefficient	t-ratio	Prob.
$\Delta lGDP_t$	0.1293	2.8314*	0.0075	4.6648	2.7232**	0.0104
$\Delta lGDP_t^2$	-	-	-	-0.3669	-2.6979**	0.0110
$\Delta lCOAL_t$	0.4446	5.7794*	0.0000	0.4197	5.9576*	0.0000
ΔlFD_t	-0.0435	-1.5963	0.1191	-0.0486	-1.8765***	0.0697
ΔlTR_t	-0.0435	-1.6948***	0.0987	-0.1032	-2.6020**	0.0139
ΔDUM	-0.0123	-0.8806	0.3844	-0.0476	-2.9701*	0.0056
ECT_{t-1}	-0.6727	-6.1575*	0.0000	-0.8444	-7.7481*	0.0000
R-Squared	0.600070			0.99895		
$\bar{R}$-Squared	0.53415			0.99862		
F-Statistic	9.02(.0000)			3042.4(0.000)		
DW-Statistics	2.0851			2.0615		

Note: *, ** and *** denote the level of significance at 1%, 5% and 10% respectively.

After reporting the results of long-run elasticities, the short-run dynamic results are provided in Table 6. The estimated coefficient of the lagged ECT is negative and significant at 1 percent level, providing additional evidence for the long-run cointegration relationship detected through bounds F-statistics between CO_2 emissions, per capita GDP, per capita GDP^2, financial development and trade openness. The coefficient of ECT_{t-1} is -0.6727 in Model A and -0.8444 in Model B, implying that when per capita CO_2 emissions are higher or lower than its equilibrium level in the current period due to any shock, it adjusts by 67.27 percent and 84.44 percent in the next year in Model A and Model B respectively. This indicates that the velocity of adjustment is markedly fast for the Indian economy in the event of any shock to CO_2 emission models.

It can be seen from Table 6 that the linear and the squared terms of real GDP per capita are positive and negative, respectively, and highly significant, implying the presence of EKC in the short-run. The short-run results also depict that coal consumption has a positive impact on CO_2 emissions in the short-run. It is found that economic growth is the major contributor to CO_2 emissions followed by coal consumption (see Model B). The short-run elasticity of CO_2 emissions with respect to financial development is negative and significant at 10 percent level in Model B, signifying that financial development controls the CO_2 emissions even in the short-run. An inverse relationship is observed between trade openness and CO_2 emissions.

Table 7. Results of diagnostic tests

Test	Model A		Model B	
	Statistics	Prob. Value	Statistics	Prob. Value
$\chi^2 NORM$	1.0964	0.577	0.9948	0.608
$\chi^2 SERIAL$	0.1366	0.711	0.0638	0.800
$\chi^2 HETRO$	2.0914	0.148	0.2804	0.596
$\chi^2 RAMSEY$	0.3688	0.544	2.3455	0.126

The results of the diagnostic tests for Model A and Model B are summarized in Table 7. For diagnostic tests, we have applied LM test for residual serial correlation, Ramsey's RESET test for correct functional form, heteroscedasticity test based on the regression of squared residuals on squared fitted values and normality test based on Skewness and Kurtosis of residuals. The results indicate that the estimated models are adequate and robust as they pass all the diagnostic tests. Finally, the stability of our estimated Model A and Model B are examined through CUSUM, and CUSUMSQ tests and the results are provided in Fig. 1, and Fig. 2. As can be seen from Fig. 1 and Fig. 2 that the plots are well inside the 5 percent critical bounds, suggesting that the estimated models are stable over the sample period.

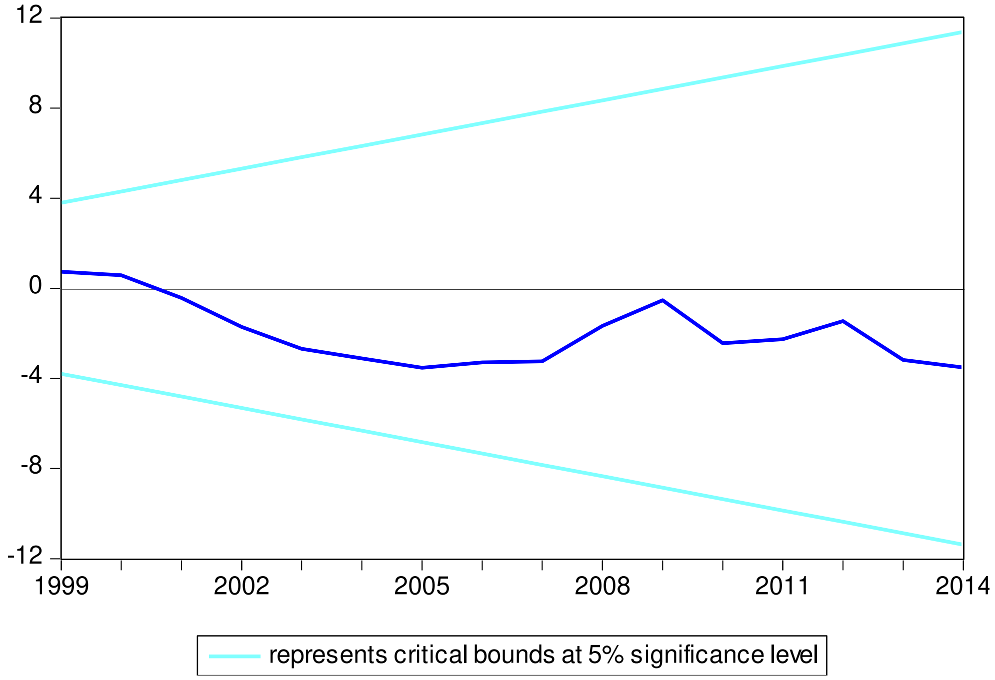

Fig. 1(a) Plot of cumulative sum of recursive residuals [Model A]

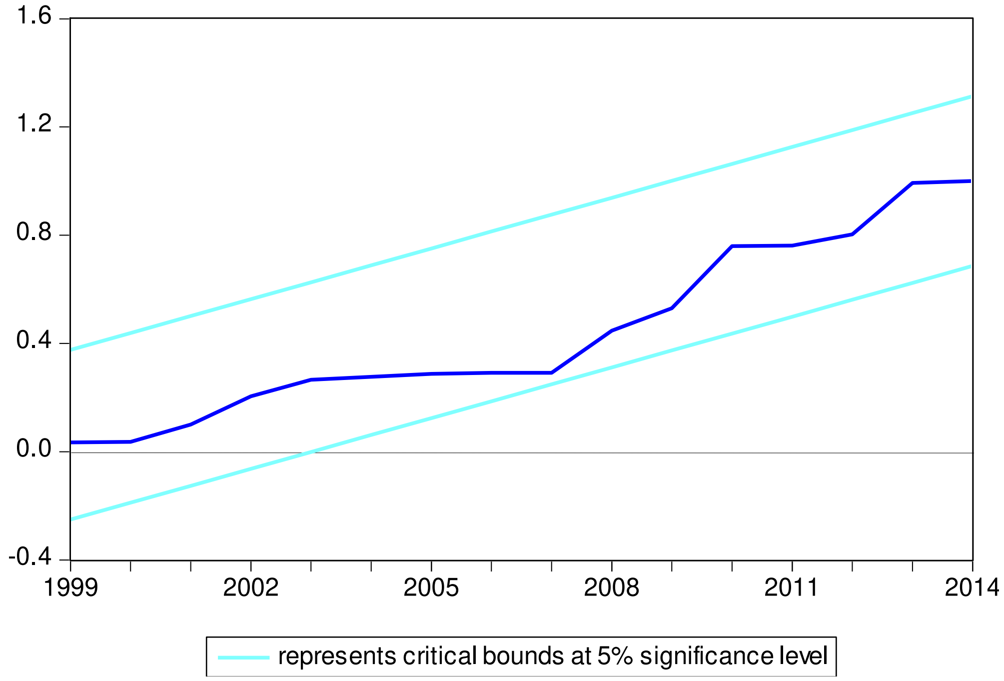

Fig. 1(b) Plot of CUSUMSQ of recursive residuals [Model A]

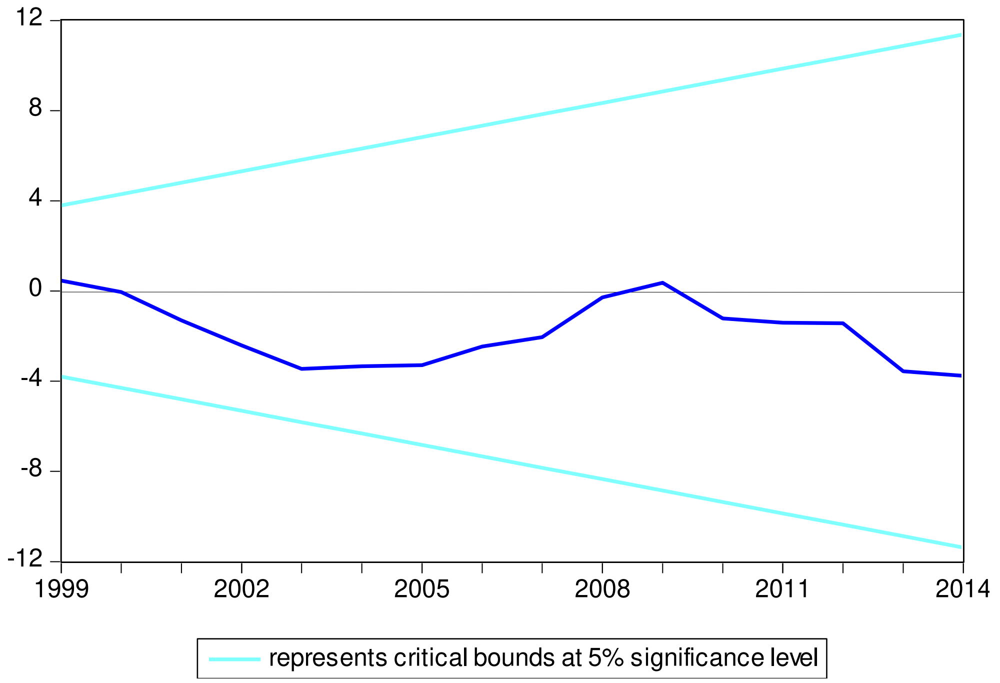

Fig. 2(a) Plot of cumulative sum of recursive residuals [Model B]

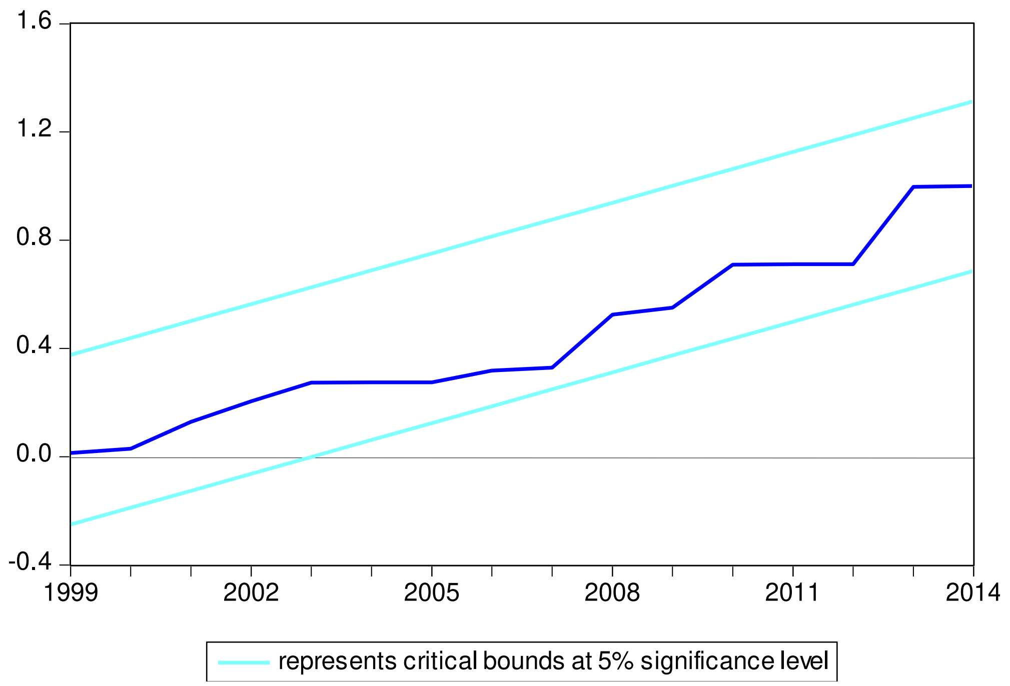

Fig. 2(b) Plot of CUSUMSQ of recursive residuals [Model B]

The presence of cointegrating link between per capita CO_2 emissions, per capita GDP, square of per capita GDP, coal consumption, financial development, and trade openness indicates that there should be Granger causality at a minimum in one direction; however, it does not tell about the direction of causality. Therefore, the study performs the VECM Granger causality test to assist the policy-making authorities in formulating apposite economic, energy, trade, and environmental policies by understanding the directions of causality among the variables. The results obtained from VECM Granger causality are presented in Table 8.

Table 8. VECM Granger causality results

Dependent Variable	Sources of Causation					
	Short-run					Long-run
	ΔlCO_{2t}	$\Delta lGDP_t$	$\Delta lCOAL_t$	ΔlFD_t	ΔlTR_t	ECM_{t-1}
	F-statistics [p-values]					t-statistics
ΔlCO_{2t}	–	0.4465 [0.5084]	0.7316 [0.3982]	0.6655 [0.4201]	9.2833* [0.0044]	-3.9514* [0.0004]
$\Delta lGDP_t$	0.0112 [0.9160]	–	1.2191 [0.2768]	0.1059 [0.7467]	1.8773 [0.1791]	-2.1450** [0.0388]
$\Delta lCOAL_t$	2.9810*** [0.0928]	0.1970 [0.6598]	–	0.6230 [4351]	7.1412** [0.0112]	-2.1254** [0.0405]
ΔlFD_t	3.3949*** [0.0736]	13.6591* [0.0007]	5.0344** [0.0311]	–	0.1095 [0.7426]	3.1481* [0.0033]
ΔlTR_t	2.3939 [0.1306]	1.8984 [0.1768]	0.0468 [0.8299]	1.8132 [0.1865]	–	1.2480 [0.2201]

Note: *, ** and *** denote the level of significance at 1%, 5% and 10% respectively.

In the long-run, there is an indication of three causal linkages as recorded by a significant t-test on the negative coefficient of ECM_{t-1}: (i) from per capita GDP, coal consumption, financial development and trade openness to CO_2 emissions; (ii) from CO_2 emissions, coal consumption, financial development and trade openness to per capita GDP; and (iii) from CO_2 emissions, per capita GDP, financial development and trade openness to coal consumption. In the short-run, there seem to be three cases of unidirectional causal relationships: (i) from trade openness to per capita CO_2 emissions; (ii) from CO_2 emissions and trade openness to coal consumption; and (iii) from CO_2 emissions, per capita GDP and coal consumption to financial development.

The long-run bidirectional causality between per capita GDP and coal consumption signifies that India is an energy-reliant economy and any cutting down on energy consumption, especially coal consumption, may negatively affect the GDP growth of India. The feedback hypothesis also exists between coal consumption and CO_2 emissions, implying that India can lower CO_2 emissions by curtailing coal consumption. This suggests that at the present arrangement, it is very difficult for the Indian economy to dissociate its mounting CO_2 emissions. Therefore, to reduce CO_2 emissions without hampering the economic growth of the country, the Indian policy designers have to explore alternative energy policies which focus on boosting energy efficiency and maximizing the utilization of carbon-free energy sources. As expected, we have found a bidirectional causal linkage between CO_2 emissions and economic growth. This outcome further supports the presence of the Environmental Kuznets Curve (EKC) in India. The long-run causal flow from financial development to CO_2 emissions implies that India's efforts to bring down CO_2 emissions should not only consider the economic growth and energy-related initiatives, but also financial development. In effect, it is necessary to adopt an integrated strategy in such a manner that financial development policies are intertwined with energy policies and economic growth policies in India.

5. CONCLUSION AND POLICY IMPLICATIONS

This study analyses the dynamic links between CO_2 emissions and its possible determinants (as dictated by the existing literature) viz., per capita GDP, squared term of per capita GDP, coal consumption, financial development, and trade openness for India over the period 1971-2017. The study has applied unit root tests with and without structural breaks to explore the stationary properties of the data followed by the ARDL bounds F-statistics to detect the existence of any long-run cointegrating relationship between the variables. The study also uses VECM Granger causality analysis to test the direction of long-run and short-run causal connections among the variables.

The results obtained from the ARDL bounds F-statistics shows that there exists a long-run cointegrating linkage between the variables. The findings of the research reveal that coal consumption stimulates CO_2 emissions significantly, and economic growth is the primary contributing factor to emissions in India. Furthermore, the elasticity of CO_2 emissions with regard to GDP and square term of GDP confirm the presence of EKC in the long-run as well as in the short-run in India. More notably, financial development is recognized to boost environmental quality in India. An inverse relationship is also found between trade openness and CO_2 emissions. The VECM Granger causality results unfold bi-directional causal links between CO_2 emissions and economic growth. Similarly, a feedback causal relationship exists between coal consumption and economic growth. Also, evidence of bidirectional causality is found between coal consumption and CO_2 emissions.

This evidence manifests that Indian economy is highly dependent on energy consumption, predominantly on coal, which has the highest carbon emission coefficient. Various agencies' projections indicate that India's energy demand continues to climb up because of its high economic growth coupled with various developmental initiatives like urbanization, poverty alleviation, universal electrification, etc. Therefore, to achieve the maximum economic growth with minimum carbon emissions, Indian policy-makers have to restructure the energy policies which aim at increasing energy efficiency on the one hand and enhance the utilization of clean sources of energy on the other. NITI Aayog's draft paper on 'National Energy Policy' states that improved energy efficiency alone can lower the energy demand in the country over BAU (business as usual) by 17 percent in 20240 (NITI Aayog, 2017). As India is a tropical country, it is richly endowed with solar and wind energies which can be harnessed with appropriate technologies in order to solve the energy problem to a great extent. The importance of other clean energy sources like nuclear power, large-hydro and bio-mass are also well-recognized in India. The large hydropower can play a vital role in electricity generation as the country is very rich in water resources.

The long-run causal flow from financial development to CO_2 emissions suggests that India should not only consider the economic growth and energy-related initiatives, but also financial development in its bid to bring down the CO2 emissions. In short, the policy designers should adopt an integrated strategy in such a fashion that financial sector development policies are inter-weaved with economic growth, energy, and environmental policies in India.

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