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Economic performance of India amidst high CO_2 emissions

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A B S T R A C T

In recent times, the Indian economy has enjoyed a positive economic trajectory. However, the economy remains vulnerable to domestic and geographical risk as it relates to environmental degradation. The Indian economy is reputed as one of the leading emitters of carbon dioxide (CO_2) emissionsglobally.. In the literature, there is no consensus on the contradiction between decoupling economic growth from CO_2 emission in India and other regions of the globe. By drawing on the Sustainable Development Goals (SDGs) agenda and its 2030 targets, this study examines the relationship between responsible energy consumption (SDGs 7, 12), climate issues (SDGs 13), and economic growth (SDGs 8) for the case of India.

Thus, the present study seeks to investigate the implications of CO_2 emissions on Indian economic growth (GDP) with a focus on the energy intensity in the country's economy. To explore the nexus between economic growth and environmental degradation in a carbon income function, openness to trade and energy use were added as additional variables to circumvent the problem of omitted variable bias. Autoregressive Distributed Lag (ARDL) with the modified Wald test of Toda Yamamoto (T-Y) were applied to annual time series data from 1975-2017. The study reveals a long-term equilibrium association among the described variables over the considered period. Furthermore, a statistically significant negative relationship is observed between CO_2 emissionsand trade openness and economic growth. This study validates the energy-induced economic growth as reported by the ARDL regression. This is also corroborated by the causality analysis results, as a uni-directional relationship was observed running from energy utilization to income (GDP). Thus, the Indian government officials should not adopt conservative energy policies, as this will be detrimental for economic growth given that the economy is dependent on energy. However, based on the growing environmental consciousness around the world, there is a need to shift the energy mix in India to renewables to make uses of cleaner energy sources and create environmentally friendly ecosystems.

1. Introduction

The Indian economic performance in terms of the country's gross domestic product (GDP) growth and per capita growth has proved to be of significant interest to the research community. Ha et al. (2019) asserted that the Indian positive economic trajectory is robust and has placed the economy among the fastest growing economies of the world. Despite the positive economic outlook, the Indian economy remains vulnerable to both domestic and geographical risks with regard to environmental degradation (CO_2 emissions). The good performance of the economy is not free of challenges, specifically the global phenomenon that is climate change. The country's climate is becoming increasingly warm at a very fast rate. Analysis of the temperature trend in the country spanning from the 19thcentury until the present time shows that India has been increasingly getting warmer, at a continuous, consistent and rapid rate (Mahapatra and Ratha 2017). This problem has attracted the interest of the scientific community since it was

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Nomenclature

Y	GDP
$\theta_1,\ \theta_2\ ,\theta_3,\ \theta_4$	are coefficients of parameters to be estimated
ε_t	represents stochastic term of the fitted model
Superscript t	time (which for our case is from 1975-2017)
Σ	summation symbol
ECM_(t-1)	Error correction term for adjustment speed
3.2	List of Abbreviations
ADF	Augmented Dickey–Fuller
PP	Phillips–Perron
ZA	Zivot and Andrews
ARDL	Autoregressive distributive lag
GHG	Greenhouse gas
CO	Carbon monoxide
CO2	Carbon dioxide
GDP	Gross domestic product
OLS	Ordinary Least Square
PLS	Panel Least Squares
UN	United Nations
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
UECM	Unrestricted error correction model
AIC	Akaike information criterion
SIC	Schwarz information criterion
HQ	Hannan Quinn information criterion
FPE	Final prediction error

first discovered that warming of the climate was increasing and it has been determined that this increase is due to the growth in anthropogenic greenhouse gas emissions. It is noticeable and equally reported that the scorching heat impacting many parts of India during the summer periods can reach temperatures as high as 48 degrees Celsius (118.4 degrees Fahrenheit). It is suggested that the continuous increase and severity of these heat waves are caused by changes in global weather systems as a result of climate change due to the emissions of greenhouse gases, which include carbon dioxide, methane and nitrogen oxide, among others. The greenhouse gas emissions are emitted from different sectors of the economy such as the oil and gas, transportation, manufacturing and industries, and agricultural sectors.

Oil and gas are among the primary sources of energy driving Indian economic performance. Oil accounts for about 26% of the total Indian energy consumption, which clearly indicates that the economy relies heavily on oil as a source of energy. India is predicted to overtake China in terms of oil demand growth, and it is obvious that the rate of its demand for the oil is rapidly increasing and is likely to more than double by 2030 (Sheth, 2008). This suggests that carbon dioxide (CO_2) emissions will definitely increase as a result of the growing demand for oil and gas in India. On the other hand, the transportation sector is not left behind in terms of its contributions to greenhouse gas emissions. According to Sheth, (2008), India currently ranks 5thplace in terms of global automobile sales. This is projected to grow further in line with the positive performance of the economy (in terms of rising incomes and swift urbanization) and this has direct implications for global oil demand, which will increase CO_2 emissions. As another source of carbon emissions in India, agriculture is indispensable considering the fact that almost two-thirds of the population rely on farming as their source of livelihood (Gunatilake et al., 2014). Farming accounts for up to 18% of India's gaseous emissions. Livestock (cows and buffalo) farming practice and rice farming are responsible for most (about 80%) of the agricultural emissions of greenhouse gas, which are mainly methane, while inorganic manures (fertilizers) account for about 20%, which largely consist of nitrogen oxide. Coal, which is among the major sources of energy and inducers of CO_2 emissions, is a major player in the manufacturing and industrial sectors of India.

Nevertheless, India has not yet fully ratified the Paris Agreement goals into domestic law. The Paris climate agreement is focused on the global objective of combating climatic change through reduced greenhouse gas emissions. This agreement was initiated in a bid to combat the visibly increasing global warming caused by the emission of greenhouse gases. The effect of this agreement was seen in the United Nations (UN) climate summit held in Katowice, Poland where about 200 nations gathered with the goal of achieving the vision of reducing global warming as agreed in Paris in 2015. India is ranked between 3rd and 5th in terms of global CO_2 emissions, even though the country is making significant efforts to diminish the crude energy consumption and shift to an energy conservation strategy involving the consumption of solar energy and wind energy (World Energy Council Statista 2019).

To this effect, given the interesting Indian energy mix, the current study seeks to investigate the impact of CO_2 emissions on the positive growth and development of the Indian economy with a focus on the energy implications via openness and energy use in Indian economic performance. Thus, this study investigates the connection among the selected indexes (*GDP, energy utilization*, *CO_2 emissions, liberalization and urbanization*) to study the impact of CO_2 emissions on the economic performance of India (GDP). The structure of the Indian economy influences the method employed in this study. This is focused on the industrial and productive sectors (*with the intention of accommodating the increasing consumption and investment upsurge*) and prone to high energy consumption. It is interesting to note that as a leading economy in terms of growth, it is pertinent to investigate the economy and make suitable recommendations on the sustainability of the economy based on empirical findings. A thorough study of the sustainability of the Indian economy in the light of the empirical findings will aid us in constructing sustainable policies to address questions such as: (i) Can India diversify its energy mix policies by adopting green energy to enhance its green economy? (ii) Can India consider innovative policies to curtail emissions without damaging the progressive economic development? (iii) It is also important to note that as the Indian economy is growing, the country's position in the global carbon emissions ranking is very sensitive and the levels are increasing at the same pace as other countries that are regarded as the main global emitters of carbon such as China and the US. There has been an inconsistency between the economic growth trajectory and level of emissions in India and the Republic of China, which share the same economic characteristics and demographic structure. This trend has led to CO_2 emission in both regions. However, there has been a serious commitment to mitigating the adverse effect of climate change issues without comprising economic growth in spite of the high population growth rate, particularly in India. This is the motivation for the researchers to explore the covariates highlighted in this study, as we seek to use the results from this study as a policy document for stakeholders and government administrators. Despite this development, there has been minimal focus on investigating the significance of this trend in the light of the positive and significant economic growth of the Indian economy. Bearing this in mind, this study intends to investigate the Indian economic performance amidst carbon dioxide emissions. The present study is differentiated from the extant literature as it accounts for other growth determinants like population (labor force) openness to trade and CO_2 emission. This study extends/complements the debate on the growth-energy and emission nexus in the Indian economy and builds on the study of Emir and Bekun (2019) for the case of Romania. The study is motivated by the Sustainable Development Goals (SDGs-7,8,12 and 13) and addresses pertinent issues related to energy consumption (SDG-7), with a special focus on clean and responsible energy consumption (SDG 7 and 12) in terms of achieving the 2020 Agenda. This is to circumvent for climate issues (SDGs-13) and economic growth (SDGs-8). This type of study is considered particularly timely and worthy of investigation, especially in the current era in which there is an increased focus on responsible energy consumption and environmental sustainability (Sarkodie et al., 2020).

The remainder of this study is structured as follows: Section 2 presents a brief review of the previous literature. Section 3 focuses on the data and model, while the methodologies are presented in Section 4 and the empirical findings are reported in Section 5. The concluding remarks and policy implications are presented in Section 6.

2. Literature Review

2.1. Empirical literature

The review section of this study will discuss the existing literature related to this topic by reviewing the associations that have been found among the selected indexes (income and emissions, income and liberalization and emissions). The studies related to the connection between economic growth and CO_2 emissions are relatively open-ended as the findings indicate that there is no consensus on a definitive conclusion. Consequently, this has made this area more interesting and encouraged more contributions, which will create room for a common ground. Bekun et al. (2019a) confirmed in their work that economic growth increases carbon emissions. Balsalobre-Lorente et al. (2018) reported the existence of an N-shaped relationship between economic growth and CO_2 emissions in the EU-5 countries. Udemba (2019) focused on the Chinese economy and found a positive relationship between economic growth and carbon emissions. Bekun and Emir (2019) found a significant positive relationship between GDP and carbon emissions for the case of Romania. The work of Twerefou et al. (2016) on the Ghanaian economy in terms of the association among income (GDP) and CO_2emissions revealed an a strong connection relationship between GDP and CO_2emission, which implied that efforts to improve environmental quality were impeded. The outcomes of the studies by Umar et al. (2020), and Kalmaz and Kirikkaleli (2019) are in line with the findings of Twerefou et al. (2016). Lee (2013) studied the connection between income (GDP) and C02 emission in the G20 countries and found a negative association among GDP and CO_2 emission Additionally, Kirikkaleli (2020) aimed to capture the time-frequency dependency between GDP and CO_2 emission in China using the wavelet coherence approach. He concluded that GDP causes environmental sustainability in the country. Also, Boopen et al. (2011) detected a negative relationship between GDP and CO_2 emission in his study on the impact of human activities. In the work of Acharya (2009), a positive association was observed between income (GDP) and CO_2emissions. Furthermore, he linked this with the effect of foreign direct investment (FDI) on the environment.

Openness can have either a positive or negative effect on the economic growth of a given country. This was justified by the following empirical investigations of different scholars. Studies such as (Keho 2017; Nowbutsing 2014; Zarra-Nezhad, Hosseinpour, and Arman 2014) found a positive link between income (GDP) and liberalization. Kwame Asiedu (2013) researched the association between the trade openness and economic growth of Ghana and found a positive relationship between the two variables. Nduka et al. (2013) found that trade openness impacted the economic growth of Nigeria significantly positively. Using the Autoregressive Distributed Lag (ARDL) technique, Keho (2017) detected that openness has a positive effect on the income (GDP) of Cote d'Ivoire. The study of Topalova (2004) found evidence of a positive association between trade openness and economic growth in India. He suggested that trade openness influences the productivity of firms positively, which via spillover effects improves the economic performance and welfare of India. The association between trade openness and industrial sector performance in India was researched by Barua and Lange (2006) and a positive link was identified between liberalization and economic growth. They referenced the effects of openness on the price margins, which reduced the overconcentration in the industrial sector and positively impacted the consumer surplus. The study by Vedpal et al. (2007) revealed a bi-directional causality among economic growth and openness, which supported their assertion that a higher level of trade openness impacts economic growth positively. The studies on India by Dash (2009) reported findings indicating the existence of a long-run relationship among exports and output as well as a uni-directional causality running from exports to economic growth. He maintained that trade openness enhances economic growth. Using the Two-Stage Least Squares method, Marelli et al. (2011) found that trade openness has a positively impact on the economic growth of China and India. Hye (2012) employed the ARDL technique in their studies and found a negative relationship between trade openness and economic growth. Also using the ARDL method, Sakyi, (2010) found a positive relationship between trade openness and economic growth in the case of Ghana. Table 1 presents a summary of the literature review on the nexus between energy consumption, economic growth and CO_2 emission.

2.2. Theoretical background

The theoretical background of this study is anchored on the Environmental Kuznets Curve (EKC). This theory was propounded by Simon Kuznets (1955) based on this studying of income inequality and is called the Kuznets curve. He studied the incremental pattern of per capita income and inequality. A turning point exists along the curve, which indicates where the per capita income of rural farmers who abandon their farming activities to take up white collar jobs in urban cities eventually increases and this closes the wide gap that exists between the poor and the rich. At this point, it is expected that the income inequality gap is reduced, thus improving the per capita income of the poor farmers. After the successful application of this hypothesis by Simon Kuznets (1965), environmental economists (Grossman and Krueger, 1991: Shafik and Bandyopadhyay, 1992 and Panayotou, 1997) applied the Kuznets curve to investigate the relationship between environmental sustainability and economic growth. According to them, economic growth occurs in 3 stages: scale, structural and composite effects. In the initial stage of growth, the environment suffers until a certain point is reached (turning point); at this point, the economic growth will impact the environment positively because of the development innovations and increased environmental awareness that occurs at this stage. The initial stage is called the scale effect stage, while the turning point and the time after the turning point are called structural and composite effect stages, respectively. The scale effect stage is associated with developing economies where productive activities and economic performance are supported by non-renewable energy sources, while the last two stages are associated with developed countries where service and technological innovations dominate the economic performance. In this, study, it is expected that Indian economic growth will be achieved to the detriment of the environment and will suggest policies that will encourage the sustainable and balanced development of economic growth and the environment.

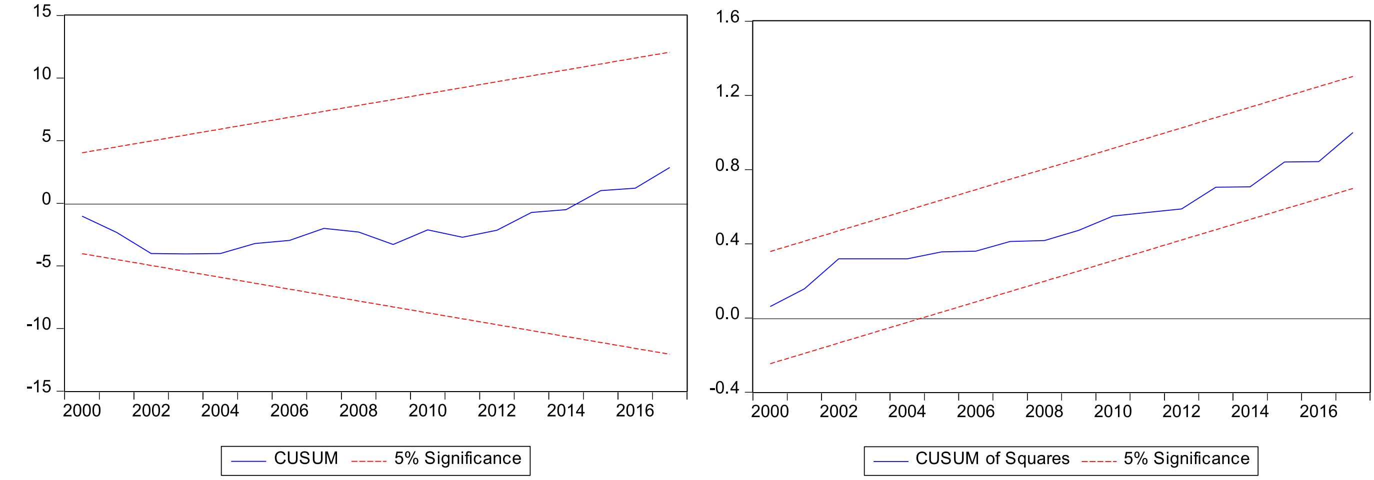

Figure 1. Graphical plot of CUSUM and CUSUMsq

Table 1
Summary of literature review

Sources	Periods	Countries	Estimators	Findings
Acharya (2009)	1980-2003	India	OLS	Economic growth effects CO_2 emissions
Balsalobre et al. (2018)	1985–2016	EU-5 countries	Panel Least Squares	Economic growth affects CO_2 emissions
Bekun and Emir (2019)	1990-2014	Romania	ARDL	Positive relationship between economic growth and CO_2 emissions
Bekun et al., 2019b	1960-2016	South Africa	ARDL	Economic growth increases CO_2 emissions
Boopen and Vinesh (2011)	1975-2009	Mauritius	Ordinary Lest Squares	Negative linkage between GDP and CO2 emission
Dash (2009)	1992–2007	India	Two-stage Least Squares	Trade openness impacts economic growth positively
Hye (2012)	1971-2009	Pakistan	DOLS and ARDL	Negative relationship between trade openness and economic growth
Kirikkaleli (2020)	1950–2016	China	Wavelet coherence	Economic growth causes CO_2 emissions
Kalmaz and Kirikkaleli (2019)	1960- 2015	Turkey	ARDL	Economic growth affects CO_2 emissions
Keho (2017)	1965–2014	Cote d'Ivoire	ARDL	Trade openness has positive effects on economic growth
Kwame (2013)	1986–2010	Ghana	ARDL	Positive linkage between trade openness and economic growth
Lee (2013)	1971-2009	G20 countries	Panel Regression	Economic growth has a negative relationship with CO2 emissions
Nowbutsing 2014)	1997-2011	Indian Ocean Rim Countries	FMOLS	Trade openness positively affects economic growth
Sakyi, (2010)	1984-2007	Ghana	ARDL	Positive relationship between trade openness and economic growth
Topalova (2004)	1989-2002	India	-	Positive relationship between trade openness and economic growth
Twerefou et al. (2015)	1970-2010	Ghana	ARDL	Negative relationship between GDP and CO_2 emission
Udemba (2019)	1995–2016	China	ARDL	A positive relationship between economic growth and carbon emissions
Umar et al. (2020)	1971-2018	China	Wavelet Coherence	Negative correlation between CO2 emissions and development
Zarra-Nezhad, Hosseinpour, and Arman 2014	1990-2010	94 countries	Extreme bounds analysis approach	A positive relationship between economic growth and trade openness

Source: Authors compilation

3. Data and Model

The current study employed annual data for India covering the period of 1975 to 2017 to investigate and capture the underlying association between economic growth and environmental quality with other controlled variables such as energy use and trade openness. The selected variables for this work are Gross Domestic Product GDP per capita, Carbon emissions (metric tons per capita), Energy consumption (kg of oil equivalent per capita), openness (import+export/GDP) and population (Urban population). The data and variables are retrieved from the World Development Indicators of the World Bank (WDI, 2020) and the British Petroleum database (2020) for the case of carbon dioxide emission (CO_2) with all series later transformed into logarithm values. The variables are summarized and presented in Table 2 below.

Table 2
Definition of variables

Full Detail of the series	Short form	Measurement
GDP per capita	GDP	Constant local currency
Carbon dioxide	CO_2	Metric tons per capita
Energy use	EU	kg of oil equivalent per capita
Trade Openness	OPEN	Export+Import/GDP
Urban population	POP	Urban population(logpop)

Source: Compiled by authors

Table 3
Summary of Statistics

Variables	GDP	CO_2	EU	OPEN	POP
Mean	10.4716	-0.1756	5.9917	19.2184	20.6770
Median	10.3882	-0.1038	5.9682	19.2173	20.7019
Maximum	11.4840	0.6043	6.4745	20.3788	21.0153
Minimum	9.8216	-0.9015	5.6229	17.9610	20.2473
Std. Dev.	0.5163	0.4607	0.2695	0.7894	0.2336
Skewness	0.4644	-0.0011	0.3881	0.0917	-0.2559
Kurtosis	1.9508	1.8552	1.9953	1.5298	1.8260
Jarque-Bera	3.5181	2.3477	2.8883	3.9327	2.9389
Probability	0.1722	0.309174	0.2359	0.1399	0.2300
Observations	43	43	43	43	43

Source: Author's own computation

In addition to the basic analyses, the descriptive statistics are presented in Table 3, which shows the minimum, median and maximum, as well as the standard deviation. The descriptive statistics reports the results of Jarque Bera and Kurtosis. The variables with the maximum and minimum statistics are the population and the carbon emissions, respectively. This is not surprising, particularly with regard to population considering the explosive nature of Indian population growth. The Kurtosis values of all variables are less than 3, which depicts light tails. All the variables are well distributed as indicated by the Jarque Bera results with its probability.

The present study was conceived with the mindset of analyzing the associations that exist among economic growth, CO_2emissions, energy utilization (use) and liberalization (openness) for the case of India. The empirical modelling is centered on the ARDL approach. This study draws on the study of Emir and Bekun (2019), by accounting for more growth catalysts that have been ignored in the literature such as urban population–induced growth theory. This is also reflected in the Solow growth model in terms of the contribution of labor and capital. In our study case, urban population and openness to trade (i.e., economic liberation) are included for the cases of India and China, which share the same economic characteristics. The initial equation used to build and examine the direct link that exists among the selected indexes is presented as:

$$Y = ACO_2{}^{\theta 1} EU^{\theta 2} OPEN^{\theta 3}\ POP^{\theta 4} \tag{1}$$

Where Y denotes Income (GDP), A denotes the technological utilization in India that is assumed to be constant, CO_2denotes CO_2 emission, EU denotes energy consumption (use), OPEN represents trade openness and POP denotes population. All series are in logarithmic form (Shahbaz and Feridun 2012). Non-linear models can incorporate a level of bias and unreliability, which hampers the policy-making process. To address this, we present the equation in a more linearized form as follows:

$$GDP_t = A + \theta_1 C0_{2t} + \theta_2 EU_t + \theta_3 OPEN_t \theta_4 POP_t \varepsilon_t \tag{2}$$

From Eq. (2), the association between income (GDP) and CO_2 emission is tested keeping the technology (A) constant. The association between income (GDP) and the CO_2 emission is further expressed in a direct model after holding A constant as:

$$GDP_t = \theta_0 + \theta_1 C0_{2t} + \theta_2 EU_t + \theta_3 OPEN_t \theta_4 POP_t \varepsilon_t \tag{3}$$

Where GDP represents income, CO_2represents CO_2emission, EU denotes energy consumption, OPEN represents liberalization and POP stands for population, and ε and t represent residual and time, respectively.

4. Methodology

It is generally believed that time series data are mostly not stable, and for this reason, it is essential to test for the stationarity of the data. This is done by performing a unit root test with any of the recognized estimation approaches such as ADF, PP and KPSS tests to ascertain whether the series are stable as well as the order of integration. Also, to enable accurate modelling and to minimize the possibility of a misleading or spurious estimation, it is important to test the time series properties of the data by checking for co-integration.

Furthermore, we considered the ARDL technique appropriate for this estimation as this approach is suitable when there is a limited number of observations (Pesaran et al. 2001). Another reason or employing ARDL in the current study is due to its benefit of showing its deduced output in lag pattern/order, which gives an insight into the relationship history of the series. This is always the case when the variables may display a negative relationship in one lag, but a positive relationship in the next lag. This always gives credence to good policy formulation in the research. The ARDL approach is considered the most appropriate in the case of a mixed order of integration and stationarity test (see Pesaran and Shin, 1998; Pesaran and Shin, 2001; Afonso, 2015). Thus, the ARDL-bounds testing method is adopted in this study, as presented in Table 5.

The modelling of the ARDL equation is as follows:

$$LnGDP = \theta_0 + \theta_1 LnC0_2 + \theta_2 LnEU + \theta_3 LnOPEN + \theta_4 LnPOP_t \varepsilon \tag{4}$$

Where GDP denotes the log of income (GDP), $C0_2$is the log of CO_2emission, EU is the log of energy consumption, OPEN is the log of trade openness, POP is urban population and εdenotes the residual. The $\theta_i = i = 1, 2, 3 \ldots etc$represent the parameters of the series in the equation. Eq. (4) is formulated into a linear ARDL equation. The model is further expanded to have both the ARDL long path and short path models. The two equations are represented in Eqs. (5) & (6). Thus:

$$GDP_t = \theta_0 + \theta_1 Y_{t-1} \theta_2 C0_{2t-1} + \theta_3 EU_{t-1} + \theta_4 OPEN_{t-1} + \theta_5 POP_{t-1} \varepsilon_t \tag{5}$$

$$\begin{aligned} \Delta GDP_t = {} & \theta_0 + \theta_i \sum_{i=1}^{n} Y_{t-i} \theta_j \sum_{j=1}^{n} C0_{2t-j} + \theta_k \sum_{k=1}^{n} EU_{t-k} \\ & + \theta_{n \sum_{n=1}^{n}} OPEN_{t-n} \theta_{m \sum_{n=1}^{n}} POP_{t-m} + \mathrm{ECM}_{t-1} \varepsilon_t \end{aligned} \tag{6}$$

Note that the parameters in Eq. (5); $\theta_0, \theta_1, \theta_2, \theta_3$and $\theta_4$are the parameters of long run in Eq. (6); $\theta_0, \theta_I, \theta_J, \theta_K$, $\theta_N and$ θ_m are parameters of short path. Δ and $\mathrm{EC}M_{t-1}$denote the 1st Diff of the selected series and the speed of correction over a certain period of time. The next step is to test for cointegration to determine the long-run relationship among the selected series. For this purpose, we employed the ARDL–bounds testing approach. The hypotheses for the cointegration testing are as follows. The null hypothesis refutes the existence of cointegration in the model and is specified as:

$$\mathrm{Ho}: \theta_0 = \theta_I = \theta_J = \theta_K = \ \theta_N = 0$$

while the alternate hypothesis opposing the view of no co-integration is stated as:

$$\mathrm{H1}: \ \theta_0 = \theta_I = \theta_J = \theta_K = \ \theta_N \neq 0.$$

This process is tested by comparing the calculated values of the F and T-statistics with the critical values of both bounds (lower I (0) and upper I (0) bound). The Wald or F-test is applied in estimating the bounds test.

The traditional linear regression only depicts the linear relationship that exists among the selected variables, which could be either positive or negative. This does not portray the direction of the relationship among the selected variables; in other words, it does not indicate which of the variables is responsible for the reaction of the other variables. It could be possible that the link that exists between GDP and energy use is caused by the transmission from energy utilization to economic growth or vice versa. This kind of inference cannot be obtained purely from a linear regression. We further applied Granger causality as a robustness check to confirm both the causation and the direction of the causation amongst the selected variables. To this end, we employed the Toda and Yamamoto causality method for the estimation of the Granger causality.

5. Empirical Findings

The present work employed all the above stated techniques to test for the unit root and the results show that all the series have a mixed order of one I (1) and I(0), as reported in Table 4.

The stationarity tests confirm that all the variables have a mixed order of integration. Subsequently, the ARDL model is applied and the results are reported in Table 5. The results are compared in such a way that if the calculated value of the F-test is higher than the values of both bounds (upper and lower), this confirms the existence of a long-run relationship amongst the variables. In this case, the null hypothesis of no cointegration will not be accepted. Again, the alternative hypothesis of the existence of cointegration is rejected when the F-statistics is lesser than the lower bound critical value. However, the outcome is considered inconclusive if the F-stats falls between the critical values of the two bounds.

The results of the linear-ARDL test are displayed in Table 5 for both the long-run and ECT short-run testing with the optimum lag of 4 as specified by the Akaike information criterion (AIC) Akaike, 1987. The Akaike information criterion is mostly preferred for lag selection due to its superior features (Shahbaz and Rahman 2012). The values of R^2 (0.9871) and adjusted R^2 (0.9861) represent the goodness of fit. From the R^2, it is shown that 98.7% of the dependent variable (GDP) is explained by the explanatory variables (CO_2emission, energy utilization, liberalization and population), and the remaining variation or part of the dependent variable is explained by the residual (error term). The speed of adjustment is found to permit convergence among the variables in the long run with negative and significant coefficient of the error correction model (ECM) (See Bannerjee et al. 1998). The finding that the ECT is 0.62 indicates that there is cointegration among the variables, and this shows the ability of the model to experience a speed of adjustment at the rate of 62 percent to ascertain alignment to long run equilibrium on GDP due to impact from the explanatory variables (CO_2emission, energy utilization, liberalization and population). The findings from the linear ARDL testing revealed varied types of relationships amongst the selected variables and income (GDP). The results show a negative and significant relationship between CO_2emissions, trade openness and GDP in the short-run (as expected). In other words, both CO_2emissions and trade openness are impacting the economic growth of the India in a significantly negative manner. Hence, a one percent increase or decrease in CO_2emissions leads to a -0.26 percent decrease or increase in Indian economic growth in the short run at a significance level of 5 percent. This is in agreement with the findings reported by Twerefou et al. (2015) on the Ghanaian economy and Lee's (2013) study on the G20 countries. Also, in the short run, a one percent increase in trade openness leads to a -0.09 percent decrease in Indian economic growth, and this equally supports the findings of Hye (2012, 2016) for the case of Pakistan. This is like a true representation of India considering the level of the trade deficit and the increase in imports over exports in the country. Free trade (openness) is not favorable in India due to the overreliance in the importation of primary goods and less capital and technological products. The result equally shows a positive connection among energy utilization, population and income (GDP), which suggests that energy use and population are impacting the economic growth of India. Hence, a one percent point upsurge in energy utilization and population causes the income (GDP) to upsurge by 1.24 and 0.16 percent, respectively, in the short run. This is a clear indication that energy intensity and population are significant factors in the growth of the India economy. As one of the major contributors and drivers of the Indian economy, the manufacturing sector consumes a significant amount of energy, which in turn affects the income (GDP) favorably. This finding affirms the discoveries of Haseeb and Azam (2015) for the case of Pakistan. This should help the policy makers in formulating effective policies for sustaining the economy and its performance, but with a monitoring influence on the population growth for the avoidance of its negative impact.

Similarly, in the long run, the results of the test depict a combined trend of association among the selected independent variables (carbon emissions, energy use, openness and population)

Table 4
Stationarity Test

Variables	@ Level With intercept	Intercept trend	@ First Difference With intercept	Intercept trend	Remark
ADF					
GDP	3.720	-1.403	-5.432	-7.259***	I(1)
CO_2	0.114	-3.017*	-3.443**	-3.342*	Mix Order
EU	1.491	-1.707	-5.041***	-5.304***	I(1)
OPEN	-1.220	-0.732	-5.415***	-5.433***	I(1)
POP	4.1012	0.691	-6.7017***	-6.8174***	I(1)
PP					
GDP	4.650	-1.447	-5.476***	-10.029***	I(1)
CO_2	0.201	-2.747	-6.930***	-6.819***	I(1)
EU	1.183	-1.832	-5.226***	-5.495***	I(1)
OPEN	-1.137	-1.237	-5.479***	-5.499***	I(1)
POP	-11.737***	5.383	-1.902	-6.8405***	Mix Order
KPSS					
GDP	0.807***	0.217**	0.770	0.088	I(1)
CO_2	0.815***	0.069	0.072	0.060	Mix Order
EU	0.804***	0.1689**	0.0255	0.0676	I(1)
OPEN	0.798***	0.098	0.178	0.136*	Mix Order
POP	0.822***	0.218***	0.177	0.134*	I(1)

Source: Compiled by the authors
Notes: a: (*, **, ***) represent significance at the 10%, 5% and 1% levels, respectively:
(2): Probability based on MacKinnon (1996) one-sided p-values

Table 5
ARDL Dynamic estimates (ARDL (4,1,3,1,2))

Variables	Coefficients	Std. Error	t-Stats	Prob.
Short-run				
D(CO_2)	-0.263***	0.0837	-3.1369	0.0046
D(EU)	1.244***	0.2310	5.3849	0.0000
D(EU (-1))	0.740***	0.1947	3.7996	0.0009
D(EU (-2))	0.283	0.1930	1.4675	0.1558
D(OPEN)	-0.089**	0.0386	-2.2971	0.0310
D(POP)	0.162***	0.0310	5.0620	0.0000
D(POP(-1))	-0.160***	0.0290	-5.2678	0.0000
ECT(-1)	-0.619***	0.0522	-11.8322	0.0000
Long-run				
GDP(-1)	0.619***	0.1544	4.0054	0.0006
CO_2	-1.496***	0.2386	-6.2674	0.0000
CO_2(-1)	-0.925***	0.1472	-6.2842	0.0000
OPEN	-0.063	0.0401	-1.5697	0.1301
OPEN(-1)	-0.039	0.0236	-1.6473	0.1131
EU	2.620***	0.3627	7.2242	0.0000
EU(-1)	1.621***	0.3069	5.2814	0.0000
POP	2.541***	0.5586	4.5492	0.0001
POP(-1)	1.572***	0.2005	7.8400	0.0000
Constant	-56.79***	13.258	-4.2832	0.0003
R^2 = 0.9871				
Adj-R^2 =0.9861				
Bound test(Long-path)				
F-stats	19.16***	K=4,@ 1%	Lower bound=3.74	Upper bound=5.06
T-stats	-9.4***	K=4,@1%	Lower bound= -3.4	Upper bound= -4.6
Wald test(Short-path)				
F-statistics	45.956***			
P-value	0.0000			
Serial Correlation test				
F-statistics	0.622			
R-square	2.181			
P-value	0.546			
Heteroskedasticity Test				
F-statistics	0.796			
R-square	11.425			
P-value	0.657			
Normality Test				
(Jarque-Bera/Joint)	4.686			
P-value	0.096			

Sources: Authors computation
Note: *, **, *** denotes rejection of the null hypothesis at the 1%, 5% and 10% levels, respectively

and the dependent variable (GDP). Hence, CO_2emissions and trade openness have a negative relationship with economic growth, but it is noticeable from lag-1 of the estimation that CO_2emissions and trade openness remain in a negative relation with the economic growth of India. In the same manner, as reported in the ECT short run, energy use and population displayed a positive relationship with economic growth. The ARDL results reveal a long-run positive and negative relationship exist between economic growth and the explanatory variables (CO_2emission, trade openness, energy use and population). In clarity with the dynamics of coefficients, a one percentage point rise or decrease in CO_2emissions causes a 1.50 percent decrease or rise in the economic growth of India. The negative relationship that exists between economic growth and CO_2emissions can be viewed in two different perspectives in terms of the interpretation of the coefficient (*either an increase in CO_2emissions causes a decrease in economic growth or a decrease in the CO_2emissions induces economic growth positively*). However, due to the current performance of the Indian economy, which could be regarded as among the fastest growing economies in the world, coupled with the fact that the growth is manufacturing and investment oriented, this leads to increased energy consumption, and energy consumption is seen as a source of CO_2emissions; therefore, we conclude that a decrease in CO_2emissions will impact economic growth positively. Hence, India has achieved some success in moving away from a high CO_2emissions energy intensity to a lower CO_2emissions energy intensity. This could justify the current economic growth amidst CO_2emissions in India. Again, a one percent increase in trade openness will lead to a -0.06 decrease in the economic growth of India. This is as expected as the trade openness is found to be significantly negatively correlated with the economic growth of India and is unsurprising given the fact that India is only practicing a partial openness to trade policy. Also, in attempt to have a total non-trade barrier, the trade openness is still more import-oriented towards non-technological goods, which adds nothing to the development of the economy as it is targeted at satisfying consumers to the detriment of the local producers. This characterizes the economy as having a persistent trade deficit as well as being a net importer of primary products, which is unhealthy for a developing economy like India. This outcome conforms with the results of Muhammod and Wee-Yeap (2016), Hye (2012), and Prabirjit and Brototi (2006), who all found a negative relationship between the economic growth and trade openness in India. Interestingly we found a positive relationship between economic growth and energy use and population as expected. In other words, a one percent point rise in energy utilization and population will lead to 2.6 and 2.54 percent increases in economic growth, respectively. This is good news and a success for the authorities in India, as it serves as a pointer for meeting the 2020/2030 vision of renewable energy target, which will reduce the Indian CO_2emissions. Hence, our study confirms that practitioners and stakeholder should shift to renewable energy sources (solar, wind and hydro) and intensify the push to diversify the

Table 6
Toda Yamamoto Causality

Null Hypothesis	MWALT	Prob	Causality	Direction
$CO_2 \rightarrow GDP$	12.882**	0.0313	YES	BI-DIRECTION
$GDP \rightarrow CO_2$	16.432**	0.0116		
EU→ GDP	4.202**	0.0404	YES	UNI-
GDP→EU	1.471	0.2251		DIRECTION
OPEN→GDP	2.098*	0.0881	YES	UNI-
GDP→OPEN	1.0196	0.3126		DIRECTION
POP→ GDP	0.4228	0.8094	YES	UNI-
GDP→POP	18.317**	0.0001		DIRECTION

Sources: Authors computation
Note: *, **, *** Denotes rejection of the null hypothesis at the 10%, 5% and 1% respectively

energy sources of the country. This is not surprising considering the fact that Indian economy is largely manufacturing and investment oriented economy, which are heavily reliant on intensive energy use; however, a positive aspect of this is the ability to reduce the CO_2emissions by changing the energy mix to incorporate more green energy(renewables) sources like solar and wind. This affirms the findings of Shahbaz et al. (2013), Acelean et al. (2017), Quanxiliang and Yang (2011), and Cui (2016).

To capture the causal linkage among the time series variables, the Toda Yamamoto causality approach is implemented and the outcomes of this approach are reported in Table 6.

Table 6 shows the results from the Yamamoto Granger causality test. The outcomes support the findings of the linear regression and ECT (short path) shown above. From the results, it can be deduced that there is a one-way causality running from economic growth to carbon emissions at 1%, and a uni-directional relationship flowing to economic growth from energy consumption at 5%, from trade openness to economic growth at 10%, and from economic growth to population at 1%. This confirms the results of the linear regression estimate that energy use causes the economic growth of India. This causality running energy to the economic growth of India is in line with the findings of Udemba (2019), Fan and Hossain (2018), and Ramakrishna and Rena (2013). Thus, this indicates that Indian economic performance is not free from fossil-fuel induced growth. This is due to the fact that the economy is highly dependent on productivity and industrial activities. This finding equally establishes the links or a connecting relationship between the selected variables and CO_2emission intensity; hence, growth is caused by energy, trade openness causes growth, while growth in turn causes population and carbon emissions. This is also an indication that India is trading off environmental quality for economic growth. This is the perception of the current situation of the Indian economy, which is one of the most populous countries in the world, and the primary sources of energy utilization and CO_2emissions are economic growth and population. This also has implications for the economic performance of India with regard to the rapid population growth, where expenditures will be primarily channeled towards the population that that is comprised of the poor masses with the assurance of welfare improvement. Indian policy-makers should develop policies in this regard in line with the diversification of the energy portfolio in the country.

To affirm the stability and fitness of the model additional diagnostics tests were employed in this study, including tests of normality, serial correlation, heteroscedasticity and cumulative sum and square (CUSUM) tests. These findings confirm the absence of serial correlation, heteroscedasticity and the stability of the model which can be seen from the output of CUSUM. The findings of this approach are shown in Table 6 following the bound test. The CUSUM tests confirm the stability and reliability of model. This is shown where the red line is bounded with the two blue lines, which the shows critical bounds at 5% significance level (Brown et al. 1975).

The policy framing and implementation should be focused on how energy utilization and economic growth should be moderated to maintain the economic momentum while curtailing the high levels of CO_2emissions in India. Government administrators should consider energy security and diversification as good options which entails avenues that would be better ways of enhancing the energy competence and curtailing the negative energy impact. Furthermore, population and energy use have significant cost implications as India has been identified as one of the most populous nations in the world. Given the Indian demographic dynamics, stakeholders and the advocates of safeguarding the environment, proper energy conservation policies are needed to consolidate the renewable energy in India without disrupting the positive economic growth of the country.

Nevertheless, India as a country has established the target of installing 175 gigawatts of renewable energy capacity by 2022. According to the recent performance track of India towards achieving its target as shown by its report indicating that 72 gigawatts has been achieved, it appears that the goal set by the country is attainable (Jocelyn, 2019) as India has installed 23 gigawatts of solar and is working towards building the world's biggest solar environment. With this progress and a better policy formulation towards diversification of the energy portfolio, the Indian economy is well positioned to maintain the growth trend amidst environmental challenges.

6. Conclusion and Policy Implications

The present study complements the already existing body of knowledge in the energy literature by exploring the connection between economic performance, energy utilization, CO_2 emission, liberalization and urban populace to mitigate the impact of CO_2 emissions on India economic performance (GDP). To achieve the objective, Pesaran's ARDL bounds testing to cointegration and Toda Yamamoto Granger causality estimation techniques are used. The findings indicate a mix (positive and negative) of relationships amongst the explanatory variables and the explained variable (GDP). It is revealed that there are positive and negative relationships between income (GDP) and all the explanatory variables and they are all significant except for the case of trade openness, which is insignificant in the long run. Table 4. shows the results on the established link among economic performance and the selected variables. The findings of the Granger causality displayed in Table 5 give insight and credence to the link among the selected variables, namely CO_2emission, energy utilization, liberalization (openness) and population.

The findings of this study have helped us come to the terms with the advocates of diversification of the energy intensity of India. This could be achieved by adopting a more aggressive measure into renewable energy sources which will sustain the economic momentum of the country. The formulation and implementation of good policies to moderate the activities in the Indian energy sector and manufacturing sector will enhance the sustainable development of the country. If the government places emission limits on the manufacturing companies and industries, this will assist with controlling the CO_2 emission rate in the country. The option of imposing fines or heavy taxation on violators of this policy will discourage the degradation of the environment. Conservative energy use should be adopted through the introduction of alternative (renewable) energy sources such as wind, hydropower and oceanic energy sources. The implementation of the above-mentioned policies will aid in sustaining the positive economic growth and improved environmental performance of India.

The implications and limitations of this study include the benefits for neighboring counties and time period covered by this study. The findings in this study will have positive effects on the neighboring countries, who can adopt the measures suggested by this study to enhance their own sustainable development. The time period of this study only covers the years from 1975 to 2017 and this limits the ability to observe the current performance of India with regard to economic growth and environment. This will be an opportunity for a future research on a similar topic, which can include data from recent years. Also, other indexes such as FDI can be utilized in future research.

Ethical Statement

We confirm that this manuscript has not been published elsewhere and is not under consideration by another journal. In addition, we also confirm that this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. We have no conflicts of interest to disclose. Ethical approval and informed consent are not applicable for this study.

Compliance with Ethical Standards

The author wishes to disclose here that there are no potential conflicts of interest at any level of this study.

Declaration of Competing Interest

No.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2020.10.024.

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