Exploring the effects of economic growth, population density and international trade on energy consumption and environmental quality in India

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Abstract

Purpose – This paper aims to investigate the effects of economic growth, population density and international trade on energy consumption and environmental quality in India.

Design/methodology/approach – Taking annual data of 1971-2011, autoregressive distributed lag bounds testing technique is applied to explore the long run link between the series. The Granger causality test is used to determine the direction of causality between the variables.

Findings – The obtained results confirm the cointegration of variables, and economic growth and population density are found to have significant positive effects on energy consumption in both the short and long runs. CO_2 emissions are also positively and significantly affected by population density and energy consumption, and negatively affected by economic growth.

Originality/value – The paper is original and valuable in the sense that it has considered two relevant additional explanatory variables, namely, population density and trade openness, which got little attention in the past. This research is an improvement over the previous studies because it has looked at the separate effects of explanatory variables on energy consumption, in addition to the effects on carbon emissions. Therefore, the findings of this research are more reliable because this adopted methodology is better and extensive, and the authors have properly addressed the issue of omitted variable bias.

Keywords CO_2 emission, Energy sector, International trade, Energy consumption, Population density, Economic growth, India

Paper type Research paper

1. Introduction

Energy is a very vital input of an economy. It is, in fact, a foundation stone for modern industrial development. The contribution of energy in socio-economic development is huge all over the globe, as it has essential ingredients required for almost all human activities. In addition to fulfilling the usual needs like cooking, heating, production, storage and transportation, energy also plays a contributory role in abolishing hunger and poverty, improving gender equality and population health and advancing educational outcomes (Rafindadi, 2016). Energy is also considered as a helping factor in increasing material well-being, fighting disease and infection, empowering women and disadvantage groups and

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JEL classification – Q40, Q43, Q56, J11, C22
Data availability statement: Data may be provided upon request.

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maintaining ecological balance (Oyedepo, 2013; Yamusa and Ansari, 2014; Rafindadi, 2015; Rafindadi and Ozturk, 2015).

While the importance of energy and its wider use for achieving various socio-economic objectives are well recognised, the great concern is that it is the main contributory factor for increased carbon dioxide (CO_2) emissions. It is well-known that CO_2 is a greenhouse gas, which is responsible for global warming. Thus, increased CO_2 emissions have serious consequences for human and environment. The empirical studies found the evidence of the direct links between energy consumption and CO_2 emissions (Soytas *et al.*, 2007; Jalil and Mahmud, 2009; Rafindadi, 2016; Rahman, 2017).

Therefore, it is vital to recognise the factors that affect energy consumption and CO_2 emissions in each country. Although a lot of country specific studies that examine the link between CO_2 emissions, economic growth, energy use and international trade (Rahman and Mamun, 2016; Shahbaz *et al.*, 2013; Rafindadi, 2016) exist in the literature, the studies that incorporate population density in the analysis of this relationship are limited. Moreover, the roles of these contributory factors towards energy consumption and CO_2 emissions are not clear, and hence they provide the evidence of debated outcomes (Rahman *et al.*, 2017). Country heterogeneity, *ad hoc* adopted approaches and methodologies, varied data period and sample sizes and omitted variable bias might be the reasons for these inconclusive findings (Rahman *et al.*, 2017; Ozturk, 2010; Zeshan and Ahmed, 2013).

The lack of consensus about the impacts of the explanatory variables on CO_2 emissions and energy consumption and the omitted variable bias have motivated us to conduct the current research to provide the further thoughtful evidence for the policy makers. India has been taken as a case study because India's ranking in the world is the 2nd in terms of population size (UN, 2019), 31st in terms of population density (CIA World Factbook, 2019), 18th in terms of real GDP growth rate (IMF, 2019) and 3rd in terms of energy use and CO_2 emissions production (Global Energy Statistical Yearbook, 2019). By 2040, India's energy and GDP growth will be the highest in the world (ET, 2018), and by population growth, it will be the world's most populous country by 2030 (WPP, 2016), resulting nearly double of current energy consumption (IEA, 2016). Furthermore, in terms of trade GDP ratio, India's position in the world is the 8th in 2014 which is higher than the Japan, the USA and China (WDI, 2015).

Against this backdrop, this research aims to explore the short and long run effects of economic growth, population density and trade openness on energy consumption and the causal relationship among these variables. The study also aims to find out the short and long run effects of economic growth, population density and energy consumption on CO_2 emissions. The rationale for selected explanatory variables is as follows:

- For increased economic growth, additional industrial production is required that demands increased energy use resulting the release of additional CO_2 emissions on earth. However, direction of causality is not always clear.
- India has high population density. High population density means excessive human activities with excessive use of energy that yields unexpected excessive carbon emissions.
- Trade openness, measured by trade-GDP ratio, might also affect energy use and CO_2 emissions via economic growth process.

To ensure desired growth level, increased production of tradeable goods is essential that demands more energy use in a country like India. However, the direction of effects between trade openness and energy use is mixed in the literature.

The core contributions of this study to the existing literature are: this study is certainly an improvement over the past studies (Tiwari, 2011 and Vidyarthi, 2013) in India considering the fact that we have added two relevant additional explanatory variables: population density and trade openness. This is also an improvement over the study of Ohlan (2015) in the sense that we have looked at the separate effects of explanatory variables on energy consumption, in addition to the effects on carbon emissions. Therefore, the findings of this research are more reliable because our adopted methodology is better and extensive, and we have properly addressed the issue of omitted variable bias by exploring the effects of two variables, population density and trade openness, on energy consumption and CO_2 emissions, which got relatively less attention in the past. Hence, our findings will help policy makers of India and other countries to revisit its current energy, population and growth policies for sustainable economic development.

The remaining part of the paper is structured as follows: Section 2 offers literature review; Section 3 describes the methodology and data; Section 4 shows and explains estimated results, and finally Section 5 draws conclusion with policy implications.

2. Literature review

Although many studies explaining the relationship between energy consumption, economic growth and CO_2 emissions exist in the literature, very few studies are available regarding the effect of population density on CO_2 emissions and energy consumption. This is particularly true for India (Ohlan, 2015). In the context of objectives of this paper, we will review the past studies under the following strands.

2.1 Energy consumption – economic growth nexus

According to neoclassical growth theory, output depends on capital and labour under given technology. However, later on natural scientists and some ecological economists have recognised the important role of energy in the economic production and growth processes (Hall *et al.*, 2001, 2003). In the literature, energy growth nexus is analysed under four hypotheses (Ozturk and Aslan, 2010; Rahman and Mamun, 2016). The *growth hypothesis* is the first one, which considers that energy is an important input for production, and increase of energy use increases economic growth. Empirically, this hypothesis is confirmed by Mbarek *et al.* (2017) for Tunisia, Vidyarthi (2013) for India, Bowden and Payne (2009) for the USA, Apergis and Payne (2010) for South America, and Narayan and Smyth (2008) for G7 countries. The *conservative hypothesis* is the second one, which states that a unidirectional causality runs from economic growth to energy consumption, and therefore, the policy for reduction of energy use may be adopted without affecting economic growth. This hypothesis is empirically validated by the studies of Rahman and Velayutham (2020) for South Asia, Lise and Van Montford (2007) for Turkey and Huang *et al.* (2008) for 82 countries. The *feedback hypothesis* is the third one, which views that energy use and economic growth are interdependent, and a bidirectional causality exists between them. The evidence of the *feedback hypothesis* is proved by Saidi *et al.* (2017) for 53 countries, Shahbaz *et al.* (2015) for India, Fuinhas and Marques (2012) for 5 European countries, Eggoh *et al.* (2011) for 21 African countries and Belke *et al.* (2011) for 25 OECD countries. The co-existence of combined hypotheses was also revealed by several researchers. For example, for G-7 countries and ten emerging markets, Soytas and Sari (2003, 2006) found the validity of the existence of *growth, feedback* and *conservative hypotheses* in their studies. Belloumi (2009) also confirmed the coexistence of *growth* and *feedback hypotheses* for Tunisia. The *neutrality hypothesis* is the fourth one, which states that there is no causality between energy use and economic growth, and any action on one variable will not affect the other

(Rahman and Mamun, 2016; Belke *et al.*, 2011). Lee (2006) and Akinlo (2008) found the validity of *neutrality hypotheses* in their studies on 11 major industrial and 11 Sub-Sahara African countries, respectively, along with *feedback* and *conservation* hypotheses.

2.2 CO_2 emissions – economic growth nexus

The link between CO_2 emissions and economic growth mainly tests the theoretical framework of the environmental Kuznets curve (EKC) hypothesis. EKC postulates an inverted U-shaped link between economic growth and CO_2 emissions implying that CO_2 emissions increases with an increase of income initially and then declines after achieving fixed level of income growth. The implication of this hypothesis is that economic growth brings positive effect for environment in the long run (Alam *et al.*, 2016). The empirical evidence about the existence of this hypothesis is inconclusive across countries/regions. For example, recent studies of Rahman and Velayutham (2020), Acheampong *et al.* (2019), Shahbaz *et al.* (2018), Zoundi (2017) and Ertugrul *et al.* (2016) revealed the evidence of the existence of EKC hypothesis. In contrast, some studies found no concrete evidence for this hypothesis (Acheampong, 2019; Rahman, 2017; Khadaroo and Sultan, 2013; Arouri *et al.*, 2012; Musolesi *et al.*, 2010; He and Richard, 2010). Rahman (2017) and Musolesi *et al.* (2010) found the evidence of U-shaped link; on the other hand, Kashem and Rahman (2019), Arouri *et al.* (2012) and Musolesi *et al.* (2010) revealed an increasing long-run linear link between these two variables,

2.3 CO_2 emissions, economic growth and energy consumption nexus

There are some studies which examined the dynamic link between energy use, CO_2 emissions and economic growth together (Rahman and Kashem, 2017), but the relationship among these variables is also not uniform. For example, Appiah (2018), Pao and Tsai (2010) and Alam *et al.* (2011, 2012) found a bidirectional causal link between CO_2 emissions and energy consumption for Ghana, BRIC countries, India and Bangladesh, respectively. However, no causal link between CO_2 emissions and economic growth was found in India though a unidirectional causality was revealed from CO_2 emissions to economic growth in Bangladesh along with the bidirectional link between output and energy in BRIC countries. In contrast, some empirical studies found the unidirectional causality from economic growth to energy use and CO_2 emissions [see Khan *et al.* (2020) for Pakistan, Rahman and Kashem (2017) for Bangladesh, Uddin *et al.* (2016) for Sri Lanka, Ghosh (2010) for India, Kasman and Duman (2015) for the EU members and candidate countries, Shahbaz *et al.* (2013) for Indonesia and Hossain (2012) for Japan]. Furthermore, the studies of Balsalobre-Lorente *et al.* (2018), Ahmed *et al.* (2017) and Alam *et al.* (2016) confirmed the positive effects of economic growth and energy consumption on CO_2 emissions for EU-5 countries, ASEAN-8 countries and for other four countries, respectively. Mbarek *et al.* (2017) and Acheampong (2018) also found a causal nexus between energy consumption and CO_2 emissions in Tunisia and 116 countries, respectively. In contrast, Ghosh (2010) found no causal link between economic growth and CO_2 emissions in India; Soytas *et al.* (2007) also revealed no link between CO_2 emissions and economic growth and between energy and economic growth in the USA.

2.4 Energy consumption – international trade nexus

Theoretically, international trade can affect energy consumption. For an increase in exports, an increased number of machineries and equipment are essential to load and carry the exportable goods to the seaports and airports to facilitate the offloading of the exports and re-loading for foreign destinations. These machineries and equipment need energy to operate. More exports mean more production activities that should demand for more energy consumption (Sadorsky, 2011). Imports, on the other hand, can influence energy consumption in two opposite ways. If imports are substitutes for domestic production, energy consumption might decrease, other things remaining the same. If imported goods are mostly durable goods like automobiles and air conditioners, the demand for energy consumption would be higher (Najarzadeh *et al.*, 2015). Empirical results on the relationship between energy use and trade is mixed. For example, in two similar papers on Malaysia, Lean and Smyth (2010a, 2010b) found the evidence of one way causality from electricity consumption to exports and no evidence of relationship between these two variables, respectively. The study of Sadorsky (2011) on eight Middle East countries over the period of 1980-2007 reveals that there is a Granger causality from exports to energy use and a bidirectional causal link between imports and energy use; both exports and imports have statistically significant positive effect on energy consumption in the long run. In a separate study on seven South American countries over the period of 1980-2007, Sadorsky (2012) also found a short-run bidirectional linkage between energy use and exports and evidence of unidirectional causal link from energy use to imports. Najarzadeh *et al.* (2015) also found a significant link between trade and energy use in the OPEC countries where imports and exports have negative and positive effects on energy use, respectively. The study of Rafindadi (2016) revealed that trade openness increased energy use and decreased CO_2 emissions in Nigeria. Rahman *et al.* (2017) found a unidirectional causality running from trade openness to CO_2 emissions in three developed countries.

2.5 CO_2 emissions – international trade nexus

From theoretical point of view, the net effect of international trade on CO_2 emissions can either be positive or negative (Rahman, 2017). The negative effect is argued that because of free trade, countries have greater access to broader international markets that increase competition power and efficiency of countries which facilitates the import of cleaner technologies for lowering carbon emissions (Shahbaz *et al.*, 2013). On the other hand, positive effect is justified as increased exports result in increased industrial production which ultimately increases CO_2 emissions that damage environmental quality (Schmalensee *et al.*, 1998). The studies of Jebli *et al.* (2019), Adams and Acheampong (2019), Gasimli *et al.* (2019), Mahmood *et al.* (2019) and Balsalobre-Lorente *et al.* (2018), and exhibited the positive effects of trade on CO_2 emissions in 22 Central and South American countries, 46 sub-Saharan African countries, Sri Lanka, Tunisia and 5 EU countries, respectively. In contrast, Shahbaz *et al.* (2012) and Haq *et al.* (2016) found the evidence of negative effect of trade on CO_2 emissions in Pakistan and Morocco, respectively, though Haug and Ucal (2019) and Hasanov *et al.* (2018) found no effects of trade on CO_2 emissions in Turkey and oil exporting countries, respectively. Developing a theoretical model, Antweiler *et al.* (2001) showed that free trade is beneficial for the environment.

2.6 CO_2 emissions – energy consumption – population density nexus

Very few studies, to the best of our knowledge, are available in the literature that examine the impact of population density/growth on carbon emissions and energy consumption though population growth has an impact on environmental quality via increased pressure on scarce resources like energy. O'Neill *et al.* (2005) opine that population growth is one of the main contributory factors for carbon emissions in all countries, irrespective of level of development. Empirically, Mamun *et al.* (2014) explored the link between CO_2 emissions and population growth for a total of 136 countries, and found that in the long run, population size increased the CO_2 emissions. The similar effect is also observed by Acheampong *et al.* (2019)

for 46 sub-Saharan African countries. Ohlan (2015) also found a statistically significant positive impact of population density on the CO_2 emissions in India in the short and long runs; however, this study has not explored the impact of explanatory variables on energy consumption. Furthermore, the study of Shi (2001) on 93 countries over the period of 1975-1995 revealed that 1.28% of CO_2 emissions is associated with 1% of population growth, and the extent of impact of population pressure on emissions is more in developing countries than the developed countries (A summary of empirical findings of earlier studies is shown in Appendix).

Clearly, the literature discussed above showed that the nexus among the chosen variables of interest is not only inconclusive but also provides uncertain and debatable results. This might be due to country-specific characteristics, use of different approaches and methodologies, different data periods, variable selections, stage of economic development, etc. (Vidyarthi, 2013). Therefore, a continuation of research on this issue will grow which is justified. Country-specific studies focusing on appropriate variables such as population density and trade are important to mitigate the current debate.

3. Data and methodology

3.1 Data description

Data used in this research are collected from the World Development Indicators WDI (2018), World Bank. All observations are annual. We have used the data period of 1971-2011. We could not use the data after 2011, as the required data for all variables are not available. The variables are energy use (kg of oil equivalent per capita), CO_2 emissions (metric ton per capita), international trade (percentage of GDP), population density (people per sq. km of land area) and GDP per capita (constant 2005 US$), a proxy of economic growth. Environmental quality is represented by CO_2 emissions.

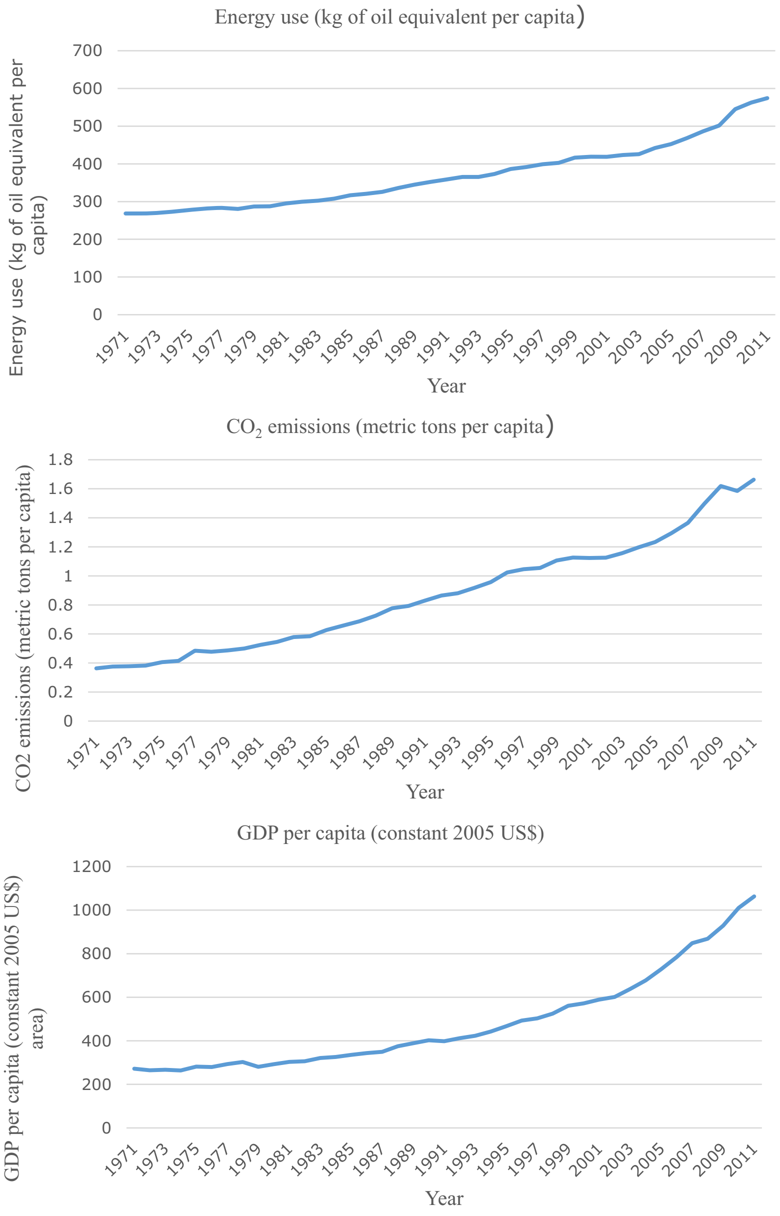
Figure 1 shows the trend lines of all variables used in the paper. The trend of energy use in India is increasing right from 1971. Per capita energy use (kg of oil equivalent) was 269 in 1971. It has increased to 574 in 2011 implying that energy use has increased more than double. A sharp increase is noticed from 2003 onward. During 2008-2009, the rate of increase of energy use is the highest, jumping from 501 to 545 kg per capita.

The increase of carbon emissions is very noticeable. It has increased more than five times in 2011 compared to 1971. While carbon emission was 0.36 metric tons per capita in 1971, it has increased to 1.66 metric ton per capita in 2011. A sharp increase of carbon emissions is evident after 2007.

Per capita GDP has also increased over the years. However, from 1971 to 1991 the GDP growth rate was just moderate. In 1971, per capita GDP was US$272; it has increased to just US$398 in in 1991. A rapid growth in GDP was observed after 1991, and it continued till 2011. In 2011, per capita GDP in India was US$1063 implying four times GDP growth in 2011 compared to 1971.

Population density provides a solid increasing trend line during 1971-2011. In 1971, population density (people per square kilo metre) was 190. It has increased to 420 in 2011 in India. It is an increase of 2.21 times over the study period.

International trade of India has also increased over the years. Although an increasing trend line is noticed during the study period, there are ups and downs in certain years. A huge increase of international trade was observed during 2003-2006 (increased from 30 to 45% of GDP). There was a little drop in 2007; in 2008, it has increased a lot (52% in 2008). In 2009, a severe drop is evident mainly because of global financial crisis. In 2011, the trade GDP ratio was more than 55% in India.



(*continued*)

Figure 1.
Trend lines of variables of interest

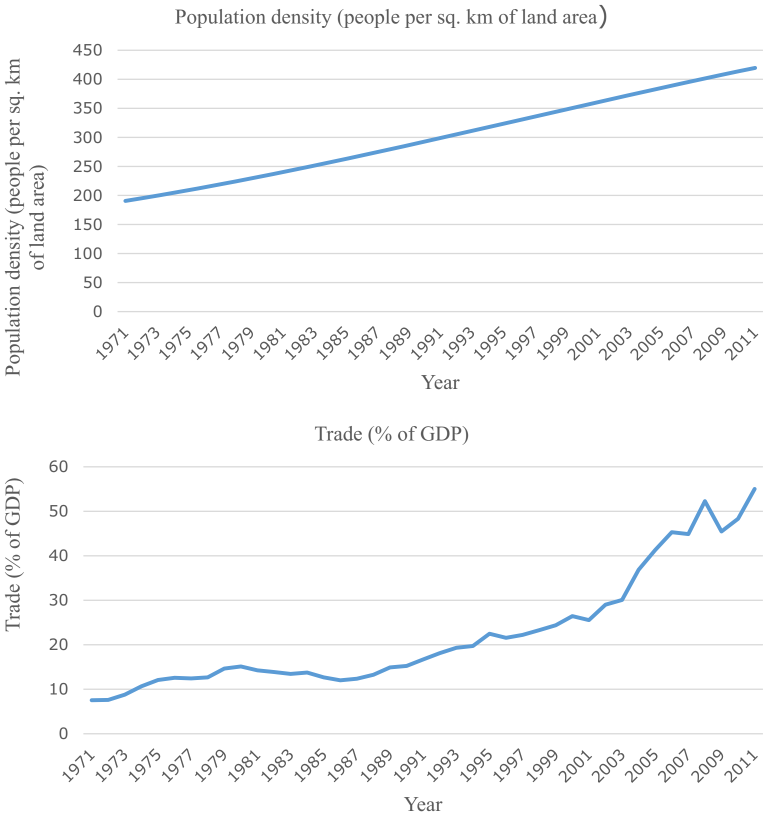


Figure 1.
Trend lines of variables of interest

3.2 The models

Following the empirical study of Rafindadi (2016), we have set the following two models to understand the long run relationships of energy consumption and CO_2 emissions with economic growth, population density and foreign trade:

$$EC_t = f\,(TR_t,\ PD_t,\ Y_t) \tag{1}$$

$$CO_{2t} = f\,(PD_t,\ Y_t,\ EC_t) \tag{2}$$

All the variables were transformed into logarithm to attain more uniform and dependable estimates. After transformation the model specifications are:

$$\ln EC_t = \beta_0 + \beta_1 \ln TR_t + \beta_2 \ln PD_t + \beta_3 \ln Y_t + \mu_i \tag{3}$$

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln PD_t + \alpha_2 \ln Y_t + \sigma_3 \ln EC_t\, \mu_i \tag{4}$$

In equations (3) and (4), ln EC_t and ln CO_{2t} represent the natural log for energy consumption and CO_2 emissions, respectively. ln TR_t, ln PD_t and ln Y_t are the natural log of foreign trade, population density and per capita GDP, and μ_i is the white noise. Due to the existence of breakpoint and model's goodness of fit, trade openness variable was not included in the model of CO_2 emissions [equations (2) and (4)].

3.3 Estimation strategy

We have used autoregressive distributed lag (ARDL) model, initiated by Pesaran, and Shin (1998), and Pesaran *et al.* (2001), in this study to investigate the long run nexus among energy consumption, CO_2 emissions, foreign trade, population density and GDP growth. The ARDL cointegration approach was chosen rather than other cointegration methods such as Engle and Granger (1987), Johansen (1988) and Johansen and Juselius (1990) procedures due to its flexibility in order of integration and prescribed efficiency even for small samples (Narayan and Smyth, 2005). Further advantages of using ARDL approach are:

- the long run and short-run parameters of the model can be estimated at a time with simple modification; and
- ARDL approach does not contain any endogeneity problem (Rahman *et al.*, 2015; Rahman and Shahbaz, 2013; Shahbaz and Rahman, 2012).

To apply the ARDL model, the order of integration can only be $I(0)$ or $I(1)$. To confirm that, we have applied ADF (augmented Dickey–Fuller) test to verify the unit roots of the variables. The test confirms the underlying assumptions of ARDL model. The unrestricted error correction model (UECM) version of the ARDL model can be expressed as follows:

$$\begin{aligned}\Delta \ln EC_t = c_0 &+ \sum_{i=0}^{p} \pi_i \Delta \ln EC_{t-1}\\ &+ \sum_{j=0}^{q} \pi_j \Delta \ln TR_{t-1}\\ &+ \sum_{k=0}^{r} \pi_r \Delta \ln PD_{t-1} + \sum_{m=0}^{s} \pi_m \Delta\, ln\, Y_{t-1} + \delta_1 \ln EC_{t-1}\\ &+ \delta_2 \ln TR_{t-1} + \delta_3 \ln PD_{t-1} + \delta_4 \ln Y_{t-1} + \varepsilon_{1t}\end{aligned} \tag{5}$$

$$\begin{aligned}\Delta \ln CO_{2t} = c_0 &+ \sum_{i=0}^{p} \pi_i \Delta \ln CO_{2t-1}\\ &+ \sum_{j=0}^{q} \pi_r \Delta \ln PD_{t-1}\\ &+ \sum_{k=0}^{r} \pi_m \Delta\, ln Y_{t-1} + \sum_{j=0}^{s} \pi_j\, \Delta \ln EC_{t-1} + \delta_1 \ln CO_{2t-1}\\ &+ \delta_2 \ln PD_{t-1} + \delta_3 \ln Y_{t-1} + \delta_4 \ln EC_{t-1} + \varepsilon_{2t}\end{aligned} \tag{6}$$

where ε_{it} and Δ are the white noise term and the first difference operator, respectively. An appropriate lag is selected based on a criterion named Akaike Information Criterion (AIC). The ARDL procedure is based on the joint F-statistic or Wald statistic that tested the null hypothesis of no cointegration, H_0: $\pi_1 = \pi_2 = \pi_3 = \pi_4 = 0$ against the alternative of H_a: $\pi_1 \neq \pi_2 \neq \pi_3 \neq \pi_4 \neq 0$. Pesaran *et al.* (2001) provide two sets of critical value bounds: upper and lower. The null hypothesis is rejected, if the calculated F-statistic lies above the upper level of the band; this indicates the existence of cointegration. The null hypothesis of no cointegration is not rejected if the calculated F-statistic is below the upper critical value. Finally, a conclusive inference cannot be made, without knowing the order of integration of the underlying regressors, if it lies between the bounds, Acaravci and Ozturk (2010). The next stage involves approximation of the long run and the short run parameters by using the error correction term (ECT_{t-1}). To ensure that there exists a long-term relationship, the sign for the coefficient of the lagged error correction term (ECT_{t-1}) should be negative.

ARDL cointegration method examines whether there exists a long-run relationship between variables. It does not indicate the direction of causality (Acaravci and Ozturk, 2010). The direction of causality is evaluated by applying the Vector Error Correction Model (VECM) Granger causality test after confirming the presence of cointegration between the variables. Granger (1969) showed that VECM is more correct to investigate such causality between any series provided the variables are integrated at I(1). This paper has also applied VECM Granger causality test among the variables to understand the directions. Thus, the following model has been applied to explore the causal relationships between energy consumption and other covariates:

$$\begin{bmatrix} \Delta \ln EC_t \\ \Delta \ln TR_t \\ \Delta \ln PD_t \\ \Delta \ln Y_t \end{bmatrix} = \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} + \begin{bmatrix} \pi_{11,1} & \pi_{12,1} & \pi_{13,1} & \pi_{14,1} \\ \pi_{21,1} & \pi_{22,1} & \pi_{23,1} & \pi_{24,1} \\ \pi_{31,1} & \pi_{32,1} & \pi_{33,1} & \pi_{34,1} \\ \pi_{41,1} & \pi_{42,1} & \pi_{43,1} & \pi_{44,1} \end{bmatrix} x \begin{bmatrix} \Delta \ln EC_{t-1} \\ \Delta \ln TR_{t-1} \\ \Delta \ln PD_{t-1} \\ \Delta \ln Y_{t-1} \end{bmatrix} + \cdots + \begin{bmatrix} \pi_{11,k} & \pi_{12,k} & \pi_{13,k} & \pi_{14,k} \\ \pi_{21,k} & \pi_{22,k} & \pi_{23,k} & \pi_{24,k} \\ \pi_{31,k} & \pi_{32,k} & \pi_{33,k} & \pi_{34,k} \\ \pi_{41,k} & \pi_{42,k} & \pi_{43,k} & \pi_{44,k} \end{bmatrix} x \begin{bmatrix} \Delta \ln EC_{t-k} \\ \Delta \ln TR_{t-k} \\ \Delta \ln PD_{t-k} \\ \Delta \ln Y_{t-k} \end{bmatrix} + \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \end{bmatrix} xECT_{t-1} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{bmatrix} \tag{7}$$

where the residual terms ε_1, ε_2, ε_3 and ε_4 are assumed to be independently and normally distributed with zero mean and constant variance. Using equation (7), short-run or weak Granger causalities are identified through the F-statistic or Wald test examining the significance of the relevant π coefficients on the first differenced series. Whereas, the long run causality is investigated by the significance of the coefficient for the $ECT_{t-1}(\varphi_i)$ by using the t-test statistics. Similar model was re-created for the CO_2 emissions variable.

4. Results and analysis

The descriptive statistics and pair-wise correlation of all the series are shown in Table 1. Jarque–Bura test statistics show that each series is white noised. There seems to exist very storng correlations among the variables.

The next stage is to evaluate whether the integration is of order 0 or 1. To investigate that, we have used augmented Dickey–Fuller (ADF) test, and the results are displayed in Table 2. Our null hypothesis is unit root; the alternative hypothesis is level stationary. In the

Variable	ln EC_t	ln CO_{2t}	ln TR_t	ln PD_t	ln Y_t
Mean	5.888	−0.245	2.959	5.679	6.088
Median	5.881	−0.186	2.815	5.699	5.997
Maximum	6.353	0.509	4.008	6.039	6.969
Minimum	5.593	−1.012	2.019	5.250	5.575
Std. Dev.	0.221	0.459	0.542	0.241	0.418
Skewness	0.389	−0.135	0.404	−0.192	0.559
Kurtosis	2.133	1.823	2.222	1.796	2.138
Jarque-Bura	2.321	2.492	2.148	2.728	3.402
Probability	0.313	0.288	0.342	0.256	0.182
Correlation					
ln EC_t	1.00				
ln CO_{2t}	0.98	1.00			
ln TR_t	0.96	0.93	1.00		
ln PD_t	0.97	0.99	0.94	1.00	
ln Y_t	0.99	0.96	0.97	0.96	1.00

Table 1. Descriptive statistics and correlation matrix

	ADF test (T-statistic)							
	At level (lag)				At first difference (lag)			
Variables	Intercept T-statistic (lags)	Time break	Trend and intercept T-statistic (lags)	Time break	Intercept T-statistic (lags)	Time break	Trend and intercept T-statistic (lags)	Time break
ln CO_{2t}	−1.141(0)	2006	−4.574(0)	2000	−7.499(0)*	2009	−7.382(0)*	2009
ln EC_t	0.449 (0)	2004	−3.609(0)	2008	−6.769(0)*	2003	−6.751(0)*	2003
ln Y_t	1.345(0)	1993	−2.559(0)	2004	−7.313(0)*	2002	−8.118(0)*	2002
ln PD_t	−10.349(3)*	1993	−0.443(7)	1992	−0.043(7)	1995	−6.506(2)*	1992
ln TR_t	−1.769(0)	2002	−3.345(0)	1983	−5.725(0)*	1986	−5.776(0)*	1986

Notes: * and ** show significant at 1 and 5% level of significance, respectively

Table 2. Unit root test

levels, the Dickey–Fuller regressions include an intercept and a linear trend, and in the first differences, it includes an intercept. The results in Table 2 show that each of the series is nonstationary at level, except for ln PD_t, with the presence of structural breakpoint that originates within the series. Each of the variables is observed to be stationary at first difference implying that each of the variables is integrated at $I(1)$.

This concludes that the variables are stationary at first difference and the series could be further examined for the long run relationship. The correct lag order of the variables to compute the suitable ARDL F-statistic is required before applying the ARDL bounds testing approach and to test whether there exists cointegration between the variables. As the *F*-test result is very sensitive to the selection of lag length (Shahbaz *et al.*, 2013). We have considered AIC, Bayesian Information Criterion (BIC), Schwarz Information Criterion (SC) and Hannan–Quinn (HQ) Information Criterion for the lag length selection (Tables 3 and 4). Lag 6 was chosen for ln EC_t and lag 1 for ln CO_t following the AIC, as the AIC has superior power properties and provides reliable results that help in capturing the dynamic relationship between the series (Lütkepohl, 2006).

The bounds *F*-test for cointegration provides the evidence of a long-run link for both dependent variables with foreign trade, population density and GDP per capita at 2.5% significance level (Table 5).

The ARDL model is fitted for both models. The short and long run estimated results are shown in Table 6.

Table 3.
Lag length selection criteria for ln EC_t

Model	LogL	AIC	BIC	SC	HQ
ARDL (6, 1, 0, 0)	111.508	−5.7433[a]	−5.2544	−5.254	−5.5746[a]
ARDL (6, 0, 3, 0)	113.339	−5.7337	−5.1559	−5.156	−5.5342
ARDL (6, 0, 2, 0)	112.244	−5.7282	−5.1949	−5.195	−5.5441
ARDL (6, 0, 0, 0)	110.061	−5.7178	−5.2734[a]	−5.273[a]	−5.5643

Note: [a]Lag order selcted by the criterion

Table 4.
Lag length selection criteria for ln CO_t

Model	LogL	AIC	BIC	SC	HQ
ARDL (1,0,4,0)	92.134	−4.494[a]	−4.102	−4.494[a]	−4.356
ARDL (1,0,3,0)	90.957	−4.484	−4.136[a]	−4.484	−4.361[a]
ARDL (1,3,4,0)	94.858	−4.479	−3.956	−4.479	−4.295
ARDL (4,3,4,0)	97.713	−4.471	−3.818	−4.471	−4.241

Note: [a]Lag order selcted by the criterion

Table 5.
Estimated ARDL models and bounds *F*-test for cointegration

Dependent variable	Model	*F*-statistic	Upper bound (2.5%)	Lower bound (2.5%)
ln EC_t	ARDL (6, 1, 0, 0)	4.318688	4.08	3.15
ln CO_{2t}	ARDL (1,0,4,0)	4.797417	3.15	4.08

Table 6. Results of ARDL cointegration test

Variables	Dependent variable ln EC_t		Dependent variable ln CO_{2t}	
	Coefficient	*T*-statistics	Coefficient	*T*-statistics
Long run analysis				
Constant	2.151342*	11.074404	−13.208952*	−21.689858
ln TR_t	0.057279	1.531867	–	–
ln PD_t	0.379950*	4.913395	1.294096*	9.976320
ln Y_t	0.222451*	2.876297	−0.523190*	−4.194819
ln EC_t	–	–	1.486523*	5.400247
R^2	0.997540		0.997534	
Adjusted - R^2	0.996514		0.996829	
F-statistic	973.449*		1415.633*	
Short run analysis				
Constant	1.466253	0.429335	7.937474*	−2.799234
ln TR_t	0.040459	1.326246	–	–
ln PD_t	0.277138**	2.420978	0.732558**	2.212307
ln Y_t	0.144846**	2.188672	−0.323427*	−2.698964
ln EC_t	–	–	0.946701*	3.065565
ECM_{t-1}	−0.333311**	−2.043961	−0.434626**	−2.079220
Diagnostic tests				
Test	*F*-statistic	Prob. value	*F*-statistic	Prob. value
χ^2 *SERIAL*	1.32756	0.2855	2.534978	0.0987
χ^2 *ARCH*	2.166477	0.1508	0.798839	0.3777
χ^2 *WHITE*	1.918831	0.0927	–	–
χ^2 *RAMSAY*	1.295445	0.2668	1.199627	0.2831
χ^2 *NORMAL*	0.655333	0.720603	5.440630	0.065854

Notes: * and ** show significant at 1 and 5% level of significance, respectively

The results show that population density and per capita GDP have significant (1% level) positive effects on energy consumption in the long run. If population density is increased by 1%, energy consumption is increased by 0.38% in India over the study period. Similarly 1% increase in GDP per capita pushes 0.22% rise of energy consumption. Furthermore, positive long run effects of population density and energy consumption on CO_2 emissions were also revealed by this study in India. An increase of 1% in population density and energy consumption results in an increase of CO_2 emissions by 1.29 and 1.49%, respectively. However, economic growth negatively affects carbon emissions in India. If GDP per capita is increased by 1%, CO_2 emissions is reduced by 0. 52% in India. Because people can afford green technologies and energy efficient devices with increased income. All these long run results are statistically significant at 1% level. The results of lagged error term (ECM_{t-1}) are found significant and negative implying that long run relationships exist among the variables.

The short run effects of economic growth and population density on energy consumption are also similar to the long run effects. Both explanatory variables have positive and statistically significant effects on energy consumption. A 1% increase in population density and per capita GDP result in an increase of 0.28 and 0.14%, increase in energy consumption, respectively. Our findings of positive effects of economic growth on energy consumption are in line with the findings of Rahman and Velayutham (2020) and Huang *et al.* (2008) but contradictory to the findings of Rahman and Mamun (2016) and Belke *et al.* (2011). The implication of these findings are that conservative hypothesis holds in India meaning that reduction of energy use may be adopted without compromising economic growth. The short run effects of population density, energy consumption and economic growth on CO_2 emissions are also similar to the long run effects; former two variables have positive and statistically significant effects and the later variable has negative significant effect on carbon emissions. CO_2 emissions are increased by 0.73 and 0.95%, respectively, by 1% increase of population density and energy consumption. The obtained short and long run effects of energy consumption on CO_2 emissions are consistent with the results of Balsalobre-Lorente *et al.* (2018), Ahmed *et al.* (2017) and Alam *et al.* (2016) among others, but opposite of the results of Ghosh (2010) and Soytas *et al.* (2007). The positive effects of energy use on CO_2 emissions imply that India needs to develop the alternative energy sources such as renewable energy; green and clean technology are to be used to reduce emissions; energy efficiency needs to be improved; subsidies for use of renewable energy is to be provided and taxes on coal and petroleum consumption can be imposed. Our findings of population density on CO_2 emissions reinforce the findings of Mamun *et al.* (2014), Acheampong *et al.* (2019) and Ohlan (2015). The results imply that excessive growth of population needs to be controlled through appropriate measures because increased number of people creates extra pressure on natural resource exploitation that contributes to environmental degradation. However, an increase of 1% per capita GDP reduces per capita CO_2 emissions by 0.32% over the study period. Our long run results of growth variable on CO_2 emissions substantiate the findings of Rahman and Velayutham (2020), Acheampong *et al.* (2019) and Shahbaz *et al.* (2018) and many others, though short run results are contradictory. However, the short-run results are similar to the findings of Rahman (2017) and Musolesi *et al.* (2010). Our findings of growth variable imply that economic growth brings desirable effect to protect environmental quality in India. Interestingly, no short or long run effect of international trade was found on energy consumption. This result is contradictory with the findings of Ohlan (2015) for India where trade openness was found to have an effect on energy consumption.

The diagnostic tests show that both models passed all the tests. No problem is detected in case of heteroscedasticity as well as normality assumption. Ramsey reset test results are also satisfactory along with serial correlation. Figures 2 and 3 display the results of cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq). It is important to note that a breakpoint is evident during 2007/2008. We can assume that it is linked to global financial crisis during that time. However, the pattern got back to conventional normal shape after 2008 suggesting not much diversion in estimation.

We have applied the VECM Granger causality test following the presence of cointegration between energy consumption, foreign trade, population density and per capita GDP, and between CO_2 emissions, population density, per capita GDP and energy consumption. The VECM Granger causality test shows both short run and long run causality results. The results are displayed in Tables 7 and 8.

Granger causality analysis reveals that in the long run, ECT terms for energy consumption and GDP per capita are negative and statistically significant (Table 7). This confirms that there is a long run relationship between these variables. These results are in line with the energy literature such as Rafindadi (2016), Shahbaz *et al.* (2015, 2013) and Paul and Bhattacharya (2004). However, no causal relationship was detected between trade and energy consumption, which supports the results of Shahbaz *et al.* (2015) for India but opposes the findings of Ohlan (2015). The difference in results may be due to the differences in measuring the trade openness variable.

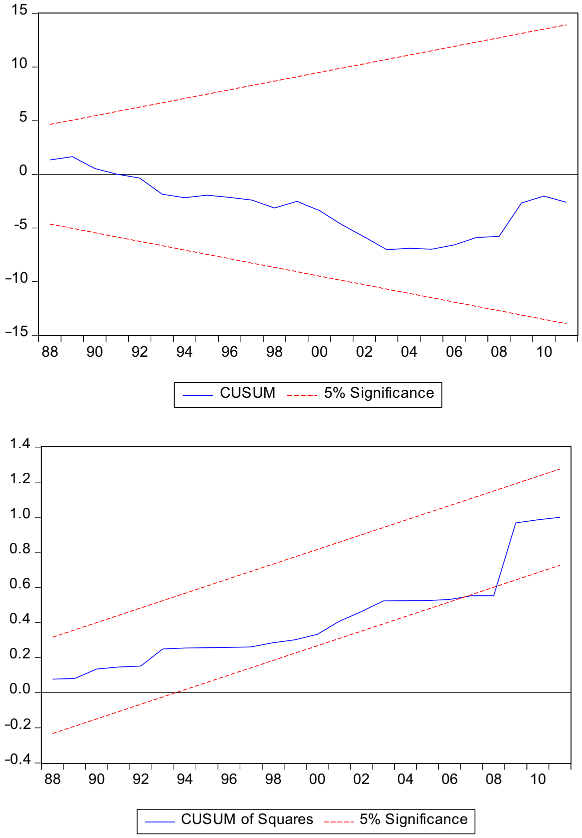


Figure 2. Cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) of energy consumption series

In the short run, there is a unidirectional Granger causality from population density and economic growth (GDP) to energy consumption. This causality result between economic growth and energy consumption supports the study of Lise and Van Montford (2007) and Rahman and Velayutham (2020) but contradicts the results of Narayan and Singh (2007) and Squalli (2007).

Table 8 exhibits that there exists a long run significant relationship between CO_2 emissions and other variables. This supports the findings of some literature such as Shahbaz *et al.* (2013) and Ohlan (2015).

In the short run, bidirectional Granger causality has been revealed between per capita GDP and CO_2 emissions and between population density and CO_2 emissions. This causality result between income and carbon emissions is contradictory to the findings of Soytas *et al.* (2007) and Ghosh (2010) but supports the findings of Khan *et al.* (2020) for Pakistan, Rahman and Kashem (2017) for Bangladesh and Uddin *et al.* (2016) for Sri Lanka. The causality result between population density and CO_2 emissions is also consistent with the findings of Ohlan (2015). We have also found a unidirectional causal link running from energy consumption to CO_2 emissions for India over the period of 1971-2011 that supports the findings of Rahman and Kashem (2017) and Alam *et al.* (2016).

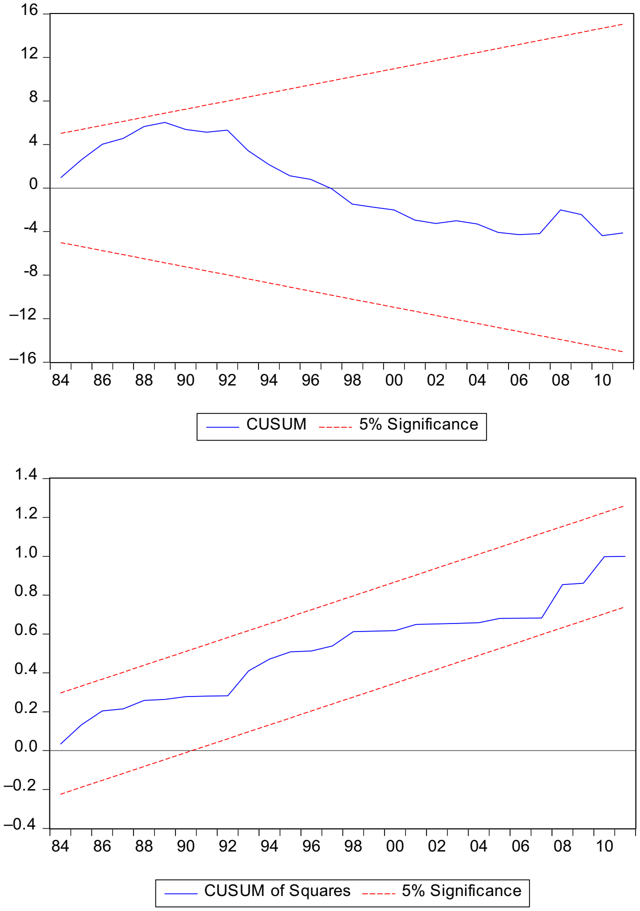


Figure 3.
Cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) of CO_2 emissions series

5. Conclusion and policy implications

This study investigates the short and long run effects of economic growth, population density and international trade on energy consumption and carbon emissions for the largest economy of South Asia, India, over the period of 1971-2011. As a methodological approach, the ARDL bounds testing approach has been applied to examine the cointegration among the variables. The VECM causality test is applied to detect the direction of causality between the variables of interest, and different diagnostic tests are performed for the validity of the obtained results.

The research findings show the evidence of the cointegration of the long run relationship among the variables. We have also found that population density and economic growth positively affect the energy consumption both in the short and long runs. That is, energy consumption increases with the increase of economic growth and population density in India. Furthermore, our results detect positive effects of population density and energy consumption and a negative effect of economic growth on the CO_2 emissions in India in the short run and long run. That is, carbon emission increases with the increase of population density and energy consumption and decreases with the increase of economic growth. The

Table 7.
The VECM granger causality test results for energy consumption

	Direction of causality				
	Short run (Chi-square statistic)				Long run
Dependen variable	$\Delta \ln EC_{t-1}$	$\Delta \ln TR_{t-1}$	$\Delta \ln PD_{t-1}$	$\Delta \ln Y_{t-1}$	ECT_{t-1}
$\Delta \ln EC_t$	. . .	6.2396 [0.2836]	12.1822** [0.0324]	4.3456 [0.5008]	−1.1748** [−2.0727]
$\Delta \ln TR_t$	1.2728 [0.9377]	. . .	5.4865 [0.3594]	2.3231 [0.8029]	. . .
$\Delta \ln PD_t$	6.2943 [0.2786]	4.0809 [0.5378]	. . .	2.1893 [0.8224]	. . .
$\Delta \ln Y_t$	11.1520** [0.0484]	8.0518 [0.1534]	7.2099 [0.2055]	. . .	−1.3557** [−2.0590]

Notes: * and ** show significant at 1 and 5% level of significance, respectively.

Table 8.
The VECM granger causality test results for CO_2 emissions

	Direction of casuality				
	Short run (Chi-square statistic)				Long run
Dependent variable	$\Delta \ln CO_{2t-1}$	$\Delta \ln PD_{t-1}$	$\Delta \ln Y_{t-1}$	$\Delta \ln EC_{t-1}$	ECT_{t-1}
$\Delta \ln CO_{2t}$	...	20.309* [0.0004]	18.009* [0.0012]	10.051** [0.0396]	−2.621* [−3.711]
$\Delta \ln PD_t$	9.062** [0.0596]		...	0.609 [0.9621]	4.322 [0.3641]
$\Delta \ln Y_t$	12.752* [0.0126]	8.071 [0.0890]	...	5.129 [0.2743]	−0.790 [−2.862]
$\Delta \ln EC_{t-1}$	4.668 [0.3230]		6.767 [0.1487]	1.132 [0.8892]	...

Notes: * and ** show significant at 1 and 5% level of significance, respectively

Granger causality analysis reveals the long run bidirectional causality between energy consumption and economic growth. In addition, there exists a short run unidirectional Granger causality from population density and economic growth (GDP) to energy consumption. A long run relationship between carbon emissions and other variables is found, and a short run bidirectional Granger causality has been detected between economic growth and CO_2 emissions and between population density and CO_2 emissions. However, the study has found no effect of trade openness on energy consumption in India.

Based on the study results, the following policy implications may be drawn:

- Since population density affects energy consumption and CO_2 emissions, and energy consumption also affects CO_2 emissions, Indian Government should design and implement such a population policy that will stabilize the population growth and population density to limit the carbon emissions for achieving sustainable economic growth in India.
- As carbon emission is negatively affected by economic growth, and trade has no effect on energy consumption, further economic growth can be achieved with no cost to environment especially in the long run, perhaps by producing more tradeable goods and increasing trade openness. Increased growth will enable the economy to use more environment friendly devices and technologies that will further curtail carbon emissions.
- Since a long run positive relationship between economic growth and energy consumption exists and increased energy consumption increases CO_2 emissions, the Indian government should not take energy conservation policy straightway, as it will decrease the much needed economic growth; rather, the government should adopt a policy that will look for alternative energy sources like renewable energy and for clean and green technologies.

A concerted effort through public and private partnership must be pursued to increase the efficiency of energy use to reduce the CO_2 emissions and to guarantee the sustainable economic development in the long run.

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Appendix

Authors	Countries of study*	Findings
Energy consumption and economic growth nexus		
Mbarek *et al.* (2017), Vidyarthi (2013), Bowden and Payne (2009), Apergis and Payne (2010), Narayan and Smyth (2008)	Tunisia; India; the USA; South Amerca; G7 countries	Existence of growth hypothesis
Rahman and Velayutham (2020), Lise and Van Montford (2007), Huang *et al.* (2008)	South Asia; Turkey;82 countries	Existence of conservative hypothesis
Saidi *et al.* (2017), Shahbaz *et al.* (2015), Fuinhas and Marques (2012), Eggoh *et al.* (2011), Belke *et al.* (2011)	53 countries; India; 5 European countries; 21 African countries; 25 OECD countries	Existence of feedback hypothesis
Lee (2006), Akinlo (2008)	11 major industrial countries; 11 Sub S-Saharan African countries	Existence of neutrality hypothesis
Economic growth and CO_2 emissions nexus		
Rahman and Velayutham (2020), Acheampong *et al.* (2019), Zoundi (2017), Shahbaz *et al.* (2018), Tiwari *et al.* (2013), Ertugrul *et al.* (2016)	South Asia; Sub-Sahara Africa; 25 selected African countries; France; India; 10 developing countries	Existence of EKC
Acheampong, 2019; Rahman, 2017; Khadaroo and Sultan, 2013; Arouri *et al.*, 2012; Musolesi *et al.*, 2010; He and Richard (2010), Zoundi (2017)	116 countries; Asian populous countries; Mauritius; MENA countries; 109 countries; Canada; 25 African countries	Non-existence of EKC
Economic growth, energy consumption and CO_2 emissions nexus		
Appiah (2018), Pao and Tsai (2010), Alam *et al.* (2011, 2012)	Ghana; BRIC countries; India; Bangladesh	Bidirectional causal link between CO_2 emissions and energy consumption; no causal link between CO_2 emissions and economic growth in India; a unidirectional causality from CO_2 emissions to economic growth in Bangladesh; bidirectional link between output and energy in BRIC countries
Khan *et al.* (2020), Rahman and Kashem (2017), Uddin *et al.* (2016), Ghosh (2010), Kasman and Duman (2015), Shahbaz *et al.* (2013), Hossain (2012)	Pakistan; Bangladesh; Sri Lanka; India; EU members and candidate countries; Indonesia; Japan	Unidirectional causality from economic growth to energy use and CO_2 emissions
Mbarek *et al.* (2017), Acheampong (2018)	Tunisia; 116 countries	Causal nexus between energy consumption and CO_2 emissions
Ghosh (2010), Soytas *et al.* (2007)	India; USA	No link between CO_2 emissions and economic growth, and between energy use and economic growth

(*continued*)

Table A1.
Summary of empirical findings of earlier studies

Authors	Countries of study*	Findings
Energy consumption and international trade nexus		
Lean and Smyth (2010a)	Malaysia	One way causality from electricity consumption to exports; no causality
Sadorsky (2011), Sadorsky (2012), Najarzadeh *et al.* (2015), Rafindadi (2016), Rahman *et al.* (2017)	8 Middle East countries; seven South American countries; OPEC countries; Nigeria; three developed countries	Granger causality from exports to energy use and a bidirectional causal link between imports and energy use; short-run bidirectional link between energy use and exports and unidirectional causality from energy use to imports; significant link between trade and energy use; trade openness increased energy use and decreased CO_2 emissions; unidirectional causality from trade openness to CO_2 emissions
CO_2 emissions and international trade nexus		
Jebli *et al.* (2019), Adams and Acheampong (2019), Gasimli *et al.* (2019), Mahmood *et al.* (2019), Balsalobre-Lorente *et al.* (2018)	22 Central and South American countries; 46 sub-Saharan African countries; Sri Lanka; Tunisia; 5 EU countries	Positive impact of trade on CO_2 emissions
Shahbaz *et al.* (2012)	Pakistan	Negative impact of trade on CO_2 emissions
Hasanov *et al.* (2018)	Oil exporting countries	No effects of trade on CO_2 emissions
Haug and Ucal (2019)	Turkey	Inconclusive results
CO_2 emissions, energy consumption and population density nexus		
Mamun *et al.* (2014) ;Acheampong *et al.* (2019), Ohlan (2015) ; Shi (2001)	136 countries; 46 sub-Saharan African countries; India; 93 countries	Population growth/size/density has positive impact CO_2 emissions

Note: *Countries of studies are shown respectively following the authors

Table A1.

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