

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

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Exploring the
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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. CO₂ 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 CO₂ 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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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 (CO₂) emissions. It is well-known that CO₂ is a greenhouse gas, which is responsible for global warming. Thus, increased CO₂ emissions have serious consequences for human and environment. The empirical studies found the evidence of the direct links between energy consumption and CO₂ 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 CO₂ emissions in each country. Although a lot of country specific studies that examine the link between CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions exist in the literature, very few studies are available regarding the effect of population density on CO₂ 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, Soytaş 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 CO₂ emissions – economic growth nexus

The link between CO₂ 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 CO₂ emissions implying that CO₂ 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 CO₂ emissions, economic growth and energy consumption nexus

There are some studies which examined the dynamic link between energy use, CO₂ 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 CO₂ emissions and energy consumption for Ghana, BRIC countries, India and Bangladesh, respectively. However, no causal link between CO₂ emissions and economic growth was found in India though a unidirectional causality was revealed from CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions in Tunisia and 116 countries, respectively. In contrast, Ghosh (2010) found no causal link between economic growth and CO₂ emissions in India; Soytas *et al.* (2007) also revealed no link between CO₂ 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 CO₂ emissions in Nigeria. Rahman *et al.* (2017) found a unidirectional causality running from trade openness to CO₂ emissions in three developed countries.

2.5 CO₂ emissions – international trade nexus

From theoretical point of view, the net effect of international trade on CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions in Pakistan and Morocco, respectively, though Haug and Ucal (2019) and Hasanov *et al.* (2018) found no effects of trade on CO₂ 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 CO₂ 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 CO₂ emissions and population growth for a total of 136 countries, and found that in the long run, population size increased the CO₂ 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 CO₂ 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 CO₂ 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), CO₂ 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 CO₂ 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 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.

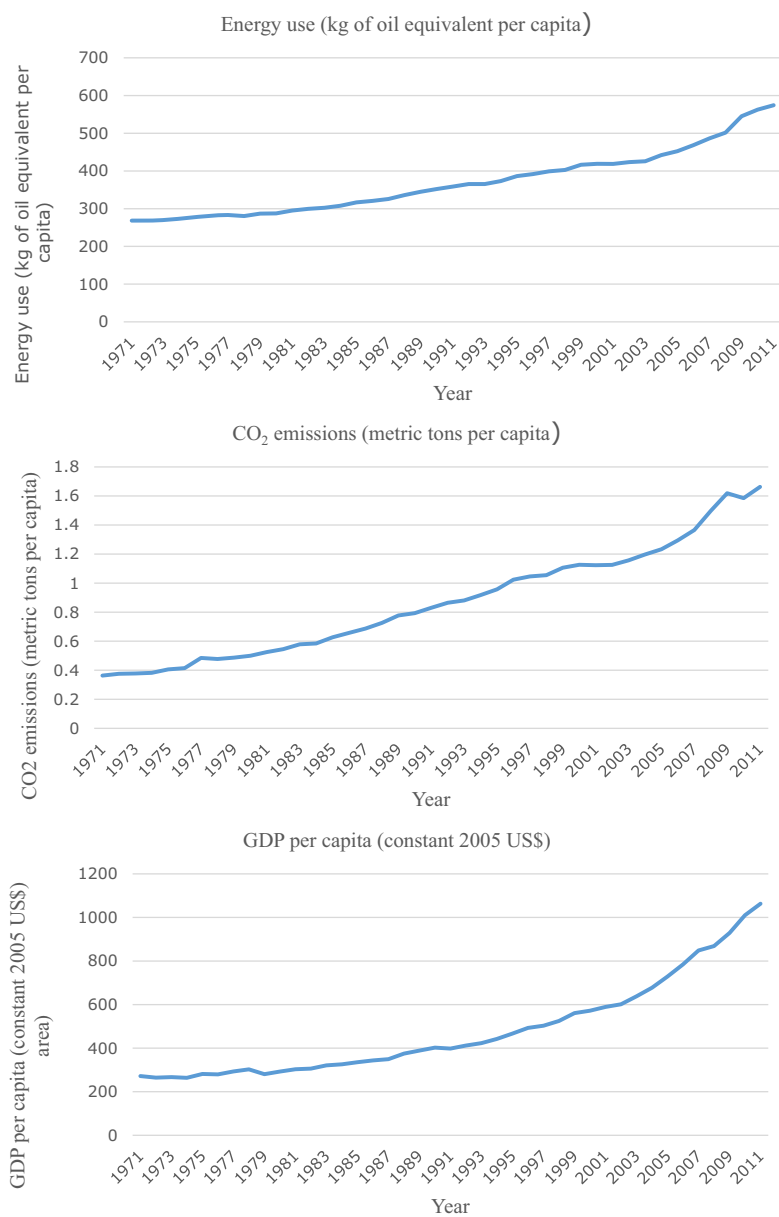


Figure 1. Trend lines of variables of interest (continued)

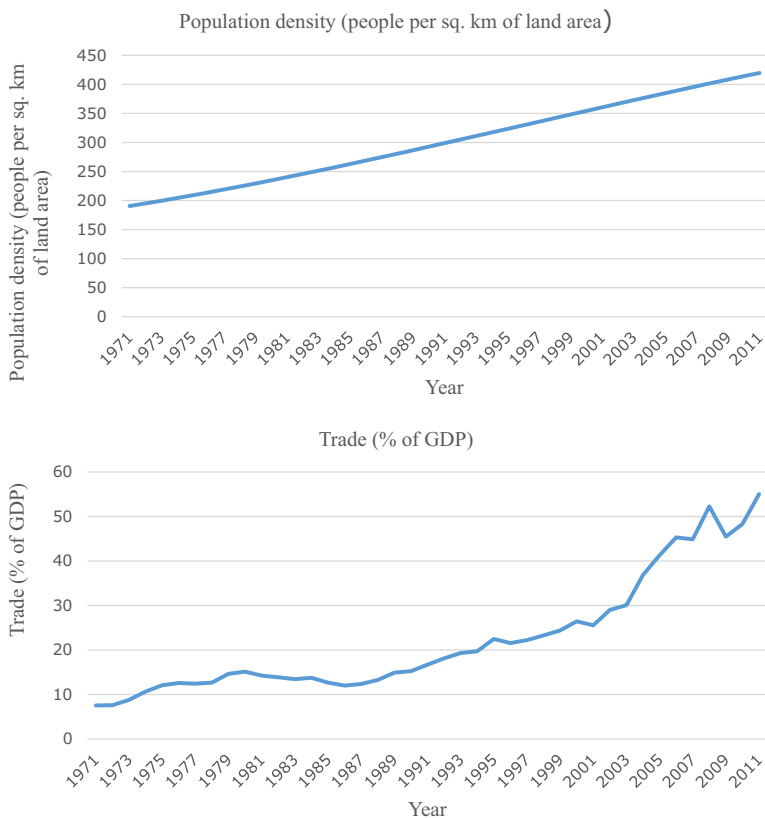


Figure 1.
Trend lines of
variables of interest

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 CO₂ emissions with economic growth, population density and foreign trade:

$$EC_t = f(TR_t, PD_t, Y_t) \quad (1)$$

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

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

$$\ln EC_t = \beta_0 + \beta_1 \ln TR_t + \beta_2 \ln PD_t + \beta_3 \ln Y_t + \mu_i \quad (3)$$

$$\ln CO_{2t} = \alpha_0 + \alpha_1 \ln PD_t + \alpha_2 \ln Y_t + \sigma_3 \ln EC_t + \mu_i \quad (4)$$

In equations (3) and (4), $\ln EC_t$ and $\ln CO_{2t}$ represent the natural log for energy consumption and CO₂ 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 CO₂ 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, CO₂ 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:

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

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

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:

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

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 CO₂ 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 strong 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
<i>Correlation</i>					
$\ln EC_t$	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

Variables	ADF test (T -statistic)							
	At level (lag)				At first difference (lag)			
	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: ^aLag order selected 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: ^aLag order selected 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

Variables	Dependent variable $\ln EC_t$		Dependent variable $\ln CO_{2t}$	
	Coefficient	T-statistics	Coefficient	T-statistics
<i>Long run analysis</i>				
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*	-
<i>Short run analysis</i>				
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
<i>Diagnostic tests</i>				
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

Table 6.
Results of ARDL
cointegration test

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 CO₂ emissions were also revealed by this study in India. An increase of 1% in population density and energy consumption results in an increase of CO₂ 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%, CO₂ 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 CO₂ 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. CO₂ 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 CO₂ 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 CO₂ 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 CO₂ 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 CO₂ emissions by 0.32% over the study period. Our long run results of growth variable on CO₂ 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 CO₂ 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.

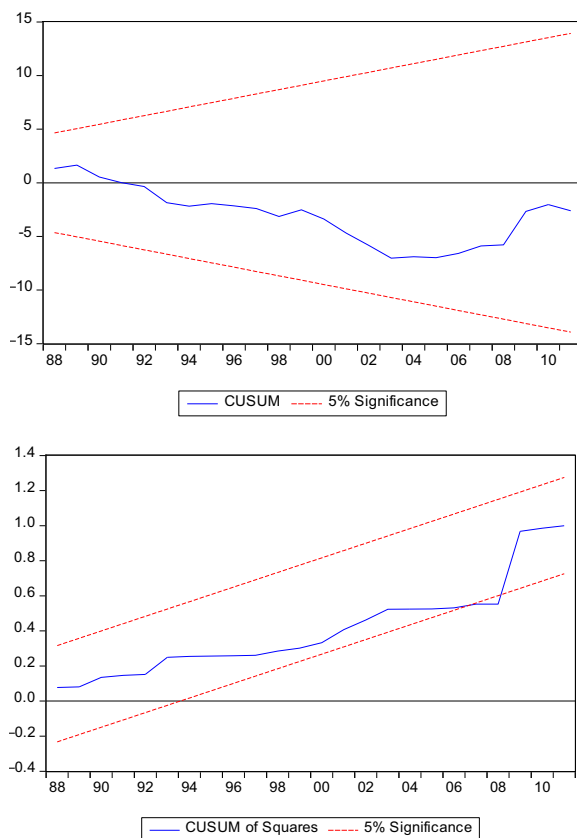


Figure 2. Cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) of energy consumption series

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 CO₂ 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 CO₂ emissions and between population density and CO₂ 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 CO₂ emissions is also consistent with the findings of [Ohlan \(2015\)](#). We have also found a unidirectional causal link running from energy consumption to CO₂ emissions for India over the period of 1971-2011 that supports the findings of [Rahman and Kashem \(2017\)](#) and [Alam et al. \(2016\)](#).

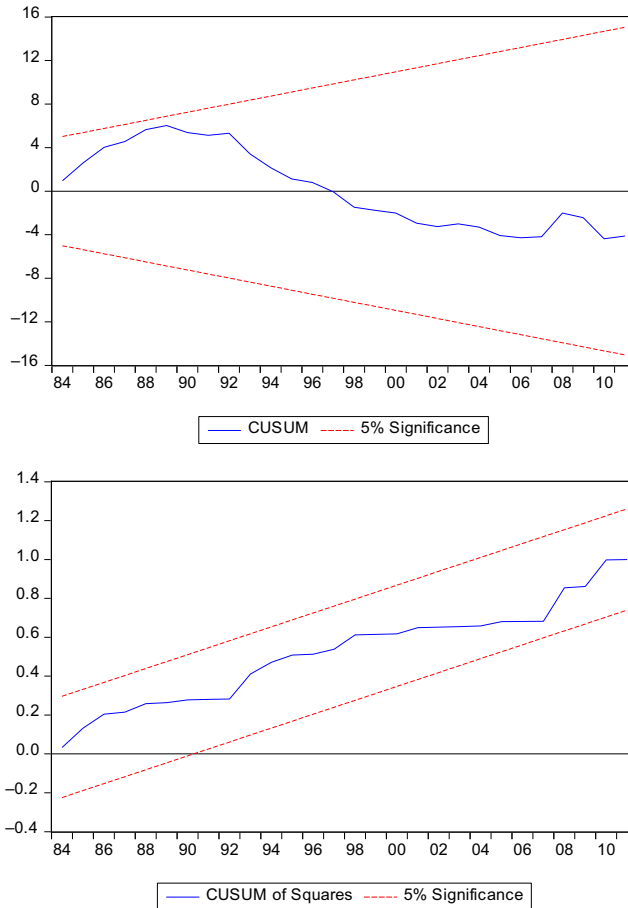


Figure 3.
Cumulative sum
(CUSUM) and
cumulative sum of
squares (CUSUMsq)
of CO₂ emissions
series

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 CO₂ 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

Dependent variable	Direction of causality			Long run ECT _{t-1}
	Short run (Chi-square statistic)	Direction of causality		
	$\Delta \ln EC_{t-1}$	$\Delta \ln TR_{t-1}$	$\Delta \ln PD_{t-1}$	$\Delta \ln Y_{t-1}$
$\Delta \ln EC_t$...	6.2396 [0.2836]	12.1822** [0.0324]	4.3456 [0.5008]
$\Delta \ln TR_t$	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]	...
				-1.1748** [-2.0727]
				...
				...
				-1.3557** [-2.0590]

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

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

Table 8.
The VECM granger
causality test results
for CO₂ emissions

Dependent variable	Direction of causality		
	Short run (Chi-square statistic)	Long run	
	$\Delta \ln PD_{t-1}$	$\Delta \ln Y_{t-1}$	ECT_{t-1}
$\Delta \ln CO_{2t}$			
$\Delta \ln PD_t$	20.309* [0.0004]	18.009* [0.0012]	-2.621* [-3.711]
$\Delta \ln Y_t$	9.062** [0.0596]	...	4.322 [0.3641]
$\Delta \ln EC_{t-1}$	12.752* [0.0126]	...	-0.790 [-2.862]
	4.668 [0.3230]	6.767 [0.1487]	...
		10.051** [0.0396]	
		0.609 [0.9621]	
		5.129 [0.2743]	
		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 CO₂ emissions and between population density and CO₂ 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 CO₂ emissions, and energy consumption also affects CO₂ 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 CO₂ 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 CO₂ emissions and to guarantee the sustainable economic development in the long run.

References

- Acaravci, A. and Ozturk, I. (2010), "On the relationship between energy consumption, CO₂ emissions and economic growth in", *Energy*, Vol. 35 No. 12, pp. 5412-5420.
- Acheampong, A.O. (2018), "Economic growth, CO₂ emissions and energy consumption: what causes what and where?", *Energy Economics*, Vol. 74, pp. 677-692.
- Acheampong, A.O. (2019), "Modelling for insight: does financial development improve environmental quality?", *Energy Economics*, Vol. 83, pp. 156-179.
- Acheampong, A.O., Adams, S. and Boateng, E. (2019), "Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa?", *Science of the Total Environment*, Vol. 677, pp. 436-446.
- Adams, S. and Acheampong, A.O. (2019), "Reducing carbon emissions: the role of renewable energy and democracy", *Journal of Cleaner Production*, Vol. 240, p. 118245.
- Ahmed, K., Bhattacharya, M., Shaikh, Z., Ramzan, M. and Ozturk, I. (2017), "Emission intensive growth and trade in the era of the Association of Southeast Asian Nations (ASEAN) integration: an empirical investigation from ASEAN-8", *Journal of Cleaner Production*, Vol. 154, pp. 530-540.
- Akinlo, A.E. (2008), "Energy consumption and economic growth: evidence from 11 African countries", *Energy Economics*, Vol. 30, pp. 2391-2400.
- Alam, M.J., Begum, I.A., Buysse, J. and Van Huylenbroeck, G. (2012), "Energy consumption, carbon emissions and economic growth nexus in Bangladesh: cointegration and dynamic causality analysis", *Energy Policy*, Vol. 45, pp. 217-225.

- Alam, M.M., Murad, M.W., Noman, A.H.M. and Ozturk, I. (2016), "Relationships among carbon emissions, economic growth, energy consumption and population growth: testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia", *Ecological Indicators*, Vol. 70, pp. 466-479.
- Alam, M.J., Begum, I.A., Buysse, J., Rahman, S. and Van Huylbroeck, G. (2011), "Dynamic modeling of causal relationship between energy consumption, CO2 emissions and economic growth in India", *Renewable and Sustainable Energy Reviews*, Vol. 15 No. 6, pp. 3243-3251.
- Antweiler, W., Copeland, B.R. and Taylor, M.S. (2001), "Is free trade good for the environment?", *American Economic Review*, Vol. 91 No. 4, pp. 877-908.
- Apergis, N. and Payne, J.E. (2010), "Energy consumption and growth in South America: evidence from a panel error correction model", *Energy Economics*, Vol. 32 No. 6, pp. 1421-1426.
- Appiah, M.O. (2018), "Investigating the multivariate granger causality between energy consumption, economic growth and CO2 emissions in Ghana", *Energy Policy*, Vol. 112, pp. 198-208.
- Arouri, M.E.H., Youssef, A.B., M'henni, H. and Rault, C. (2012), "Energy consumption, economic growth and CO2 emissions in Middle East and North African countries", *Energy Policy*, Vol. 45, pp. 342-349.
- Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D. and Farhani, S. (2018), "How economic growth, renewable electricity and natural resources contribute to CO2 emissions?", *Energy Policy*, Vol. 113, pp. 356-367.
- Belke, A., Dobnik, F. and Dreger, C. (2011), "Energy consumption and economic growth: new insights into the cointegration relationship", *Energy Economics*, Vol. 33 No. 5, pp. 782-789.
- Belloumi, M. (2009), "Energy consumption and GDP in Tunisia: cointegration and causality analysis", *Energy Policy*, Vol. 37 No. 7, pp. 2745-2753.
- Bowden, N. and Payne, J.E. (2009), "The causal relationship between U.S. energy consumption and real output: a disaggregated analysis", *Journal of Policy Modeling*, Vol. 31 No. 2, pp. 180-188.
- CIA World Factbook (2019), *The World Factbook: India*, Central Intelligence Agency.
- Eggoh, J.C., Bangaké, C. and Christophe, R. (2011), "Energy consumption and economic growth revisited in African countries", *Energy Policy*, Vol. 39 No. 11, pp. 7408-7421.
- Engle, R.F. and Granger, C.W. (1987), "Co-integration and error correction: representation, estimation, and testing", *Econometrica*, Vol. 55 No. 2, pp. 251-276.
- Ertugrul, H.M., Cetin, M., Seker, F. and Dogan, E. (2016), "The impact of trade openness on global carbon dioxide emissions: evidence from the top ten emitters among developing countries", *Ecological Indicators*, Vol. 67, pp. 543-555.
- ET (2018), "The economic times", Energyworld.com, available at: <https://energy.economicstimes.indiatimes.com/news/oil-and-gas/india-will-register-highest-gdp-energy-demand-among-all-nations-through-2040-opec-world-oil-outlook-2040/65924579>
- Fuinhas, J.A. and Marques, A.C. (2012), "Energy consumption and economic growth nexus in Portugal, Italy, Greece, Spain and Turkey: an ardl bounds test approach (1965–2009)", *Energy Economics*, Vol. 34 No. 2, pp. 511-517.
- Gasimli, O., Gamage, S.K.N., Shihadeh, F., Rajapakshe, P.S.K. and Shafiq, M. (2019), "Energy, trade, urbanization and environmental degradation nexus in Sri Lanka: bounds testing approach", *Energies*, Vol. 12, p. 1655.
- Ghosh, S. (2010), "Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach", *Energy Policy*, Vol. 38 No. 6, pp. 3008-3014.
- Global Energy Statistical Yearbook (2019), "World energy statistics", available at: <https://energydata.info/dataset/key-world-energy-statistics-enerdata>
- Granger, C.W. (1969), "Investigating causal relations by econometric models and cross-spectral methods", *Econometrica*, Vol. 37 No. 3, pp. 424-438.
- Hall, C.A.S., Tharakan, P., Hallock, J., Cleveland, C. and Jefferson, M. (2003), "Hydrocarbons and the evolution of human culture", *Nature*, Vol. 426 No. 6964, pp. 318-322.

- Hall, C.A.S., Lindenberger, D., Kümmel, R., Kroeger, T. and Eichhorn, W. (2001), "The need to reintegrate the natural sciences and economics", *BioScience*, Vol. 51 No. 8, pp. 663-673.
- Haq, I., Zhu, S. and Shafiq, M. (2016), "Empirical investigation of environmental kuznets curve for carbon emission in Morocco", *Ecological Indicators*, Vol. 67, pp. 491-496.
- Hasanov, F.J., Liddle, B. and Mikayilov, J.I. (2018), "The impact of international trade on CO2 emissions in oil exporting countries: territory vs consumption emissions accounting", *Energy Economics*, Vol. 74, pp. 343-350.
- Haug, A.A. and Ucal, M. (2019), "The role of trade and FDI for CO2 emissions in Turkey: nonlinear relationships", *Energy Economics*, Vol. 81, pp. 297-307.
- He, J. and Richard, P. (2010), "Environmental kuznets curve for CO2 in Canada", *Ecological Economics*, Vol. 69 No. 5, pp. 1083-1093.
- Hossain, S. (2012), "An econometric analysis for CO2 emissions, energy consumption, economic growth, foreign trade and urbanization of Japan", *Low Carbon Economy*, Vol. 3 No. 3, pp. 92-105.
- Huang, B.N., Hwang, M.J. and Yang, C.W. (2008), "The causal relationship between energy consumption and GDP growth revisited: a dynamic panel data approach", *Ecological Economics*, Vol. 67 No. 1, pp. 41-54.
- IEA (2016), "International energy Agency-India".
- IMF (2019), "IMF world economic outlook database", Washington D.C.
- Jalil, A. and Mahmud, S. (2009), "Environment kuznets curve for CO2 emissions: a cointegration analysis for China", *Energy Policy*, Vol. 37 No. 12, pp. 5167-5172.
- Jebli, M.B., Youssef, S.B. and Apergis, N. (2019), "The dynamic linkage between renewable energy, tourism, CO₂ emissions, economic growth, foreign direct investment, and trade", *Latin American Economic Review*, Vol. 28 No. 2.
- Johansen, S. (1988), "Statistical analysis of cointegration vectors", *Journal of Economic Dynamics and Control*, Vol. 12 Nos 2/3, pp. 231-254.
- Johansen, S. and Juselius, K. (1990), "Maximum likelihood estimation and inference on cointegration – with applications to the demand for money", *Oxford Bulletin of Economics and Statistics*, Vol. 52 No. 2, pp. 169-210.
- Kashem, M.A. and Rahman, M.M. (2019), "CO₂ emissions and development indicators: a causality analysis for Bangladesh", *Environmental Processes*, pp. 1-23.
- Kasman, A. and Duman, Y. (2015), "CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis", *Economic Modelling*, Vol. 44, pp. 97-103.
- Khadaroo, A.J. and Sultan, R. (2013), "Economic growth and carbon emission in Mauritius: an econometric analysis in the context of the maurice ile durable project", *African J. Of Economic and Sustainable Development*, Vol. 2 No. 3, pp. 266-278.
- Khan, M.K., Khan, M.I. and Rehan, M. (2020), "The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan", *Financial Innovation*, Vol. 6 No. 1, p. 13.
- Lean, H.H. and Smyth, R. (2010a), "Multivariate granger causality between electricity generation, exports, prices and GDP in Malaysia", *Energy*, Vol. 35 No. 9, pp. 3640-3648.
- Lean, H.H. and Smyth, R. (2010b), "On the dynamics of aggregate output, electricity consumption and exports in Malaysia: evidence from multivariate granger causality tests", *Applied Energy*, Vol. 87 No. 6, pp. 1963-1971.
- Lee, C.C. (2006), "The causality relationship between energy consumption and GDP in G-11 countries revisited", *Energy Policy*, Vol. 34 No. 9, pp. 1086-1093.
- Lise, W. and Van Montford, K. (2007), "Montfort. Energy consumption and GDP in Turkey: is there a cointegration relationship?", *Energy Economics*, Vol. 29 No. 6, pp. 1166-1178.

- Lütkepohl, H. (2006), "Structural vector autoregressive analysis for cointegrated variables", *Modern Econometric Analysis*, Springer, Berlin Heidelberg, pp. 73-86.
- Mahmood, H., Maalel, N. and Zarrad, O. (2019), "Trade openness and CO2 emissions: evidence from Tunisia", *Sustainability*, Vol. 11 No. 12, p. 3295.
- Mamun, M.D., Sohag, K., Mia, M.A.H., Uddin, G.S. and Ozturk, I. (2014), "Regional differences in the dynamic linkage between CO2 emissions, sectoral output and economic growth", *Renewable and Sustainable Energy Reviews*, Vol. 38, pp. 1-11.
- Mbarek, M.B., Saidi, K. and Rahman, M.M. (2017), "Renewable and non-renewable energy consumption, environmental degradation and economic growth in Tunisia", *Qual and Quant*, doi: [10.1 007/s11135-017-0506-7](https://doi.org/10.1007/s11135-017-0506-7).
- Musolesi, A., Mazzanti, M. and Zoboli, R. (2010), "A panel data heterogeneous Bayesian estimation of environmental kuznets curves for CO2 emissions", *Applied Economics*, Vol. 42 No. 18, pp. 2275-2287.
- Najarzadeh, R., Reed, M., Khoshkhoo, A. and Gallavani, A. (2015), "Trade and energy consumption in the OPEC countries", *Journal of Economic Cooperation and Development*, Vol. 36 No. 1, pp. 89-102.
- Narayan, P. and Singh, B. (2007), "The electricity consumption and GDP nexus for the Fiji islands", *Energy Economics*, Vol. 29 No. 6, pp. 1141-1150.
- Narayan, P.K. and Smyth, R. (2005), "Electricity consumption, employment and real income in Australia: evidence from multivariate granger causality tests", *Energy Policy*, Vol. 33 No. 9, pp. 1109-1116.
- Narayan, P.K. and Smyth, R. (2008), "Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks", *Energy Economics*, Vol. 30 No. 5, pp. 2331-2341.
- O'neill, B.C., Mackellar, F.L. and Lutz, W. (2005), *Population and Climate Change*, Cambridge University Press.
- Ohlan, R. (2015), "The impact of population density, energy consumption, economic growth and trade openness on CO2 emissions in India", *Natural Hazards*, Vol. 79 No. 2, pp. 1409-1428, doi: [10.1007/s11069-015-1898-0](https://doi.org/10.1007/s11069-015-1898-0).
- Oyedepo, S.O. (2013), "Energy in perspective of sustainable development in Nigeria", *Sustainable Energy*, Vol. 1, pp. 14-25.
- Ozturk, I. (2010), "A literature survey on energy-growth nexus", *Energy Policy*, Vol. 38 No. 1, pp. 340-349.
- Ozturk, A. and Aslan, H. (2010), "Kalyoncu, energy consumption and economic growth relationship: evidence from panel data for low and Middle-income countries", *Energy Policy*, Vol. 38 No. 8, pp. 4422-4428.
- Pao, H.T. and Tsai, C.M. (2010), "CO2 emissions, energy consumption and economic growth in BRIC countries", *Energy Policy*, Vol. 38 No. 12, pp. 7850-7860.
- Paul, S. and Bhattacharya, R.N. (2004), "Causality between energy consumption and economic growth in India: a note on conflicting results", *Energy Economics*, Vol. 26 No. 6, pp. 977-983.
- Pesaran, M.H. and Shin, Y. (1998), "An autoregressive distributed-lag modelling approach to cointegration analysis", *Econometric Society Monographs*, Vol. 31, pp. 371-413.
- Pesaran, M.H., Shin, Y. and Smith, R.J. (2001), "Bounds testing approaches to the analysis of level relationships", *Journal of Applied Econometrics*, Vol. 16 No. 3, pp. 289-326.
- Rafindadi, A.A. (2015), "Econometric prediction on the effects of financial development and trade openness on the German energy consumption: a startling new revelation from the data set", *International Journal of Energy Economics and Policy*, Vol. 5, pp. 182-196.
- Rafindadi, A.A. (2016), "Does the need for economic growth influence energy consumption and CO2 emissions in Nigeria? Evidence from the innovation accounting test", *Renewable and Sustainable Energy Reviews*, Vol. 62, pp. 1209-1225.

- Rafindadi, A.A. and Ozturk, I. (2015), "Natural gas consumption and economic growth nexus: is the 10th Malaysian plan attainable within the limits of its resource?", *Renewable and Sustainable Energy Reviews*, Vol. 49, pp. 1221-1232.
- Rahman, M.M. (2017), "Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries?", *Renewable and Sustainable Energy Reviews*, Vol. 77, pp. 506-514.
- Rahman, M.M. and Kashem, M.A. (2017), "Carbon emissions, energy consumption and industrial growth in Bangladesh: empirical evidence from ARDL cointegration and granger causality analysis", *Energy Policy*, Vol. 110, pp. 600-608.
- Rahman, M.M. and Mamun, S. (2016), "Energy use, international trade and economic growth nexus in Australia: new evidence from an extended growth model", *Renewable and Sustainable Energy Reviews*, Vol. 64, pp. 806-816.
- Rahman, M.M. and Shahbaz, M. (2013), "Do imports and foreign Capital inflows lead economic growth? Cointegration and causality analysis in Pakistan", *South Asia Economic Journal*, Vol. 14 No. 1.
- Rahman, M.M. and Velayutham, E. (2020), "Renewable and non-renewable energy consumption-economic growth nexus: new evidence from South Asia", *Renewable Energy*, Vol. 147 No. 1, pp. 399-408.
- Rahman, M.M., Saidi, K. and Mbarek, M.B. (2017), "The effects of population growth, environmental quality and trade openness on economic growth: a panel data application", *Journal of Economic Studies*, Vol. 44 No. 3, pp. 456-474.
- Rahman, M.M., Shahbaz, M. and Farooq, A. (2015), "Financial development, international trade and economic growth in Australia: new evidence from multivariate framework analysis", *Journal of Asia-Pacific Business*, Vol. 16 No. 1.
- Sadorsky, P. (2011), "Trade and energy consumption in the Middle east", *Energy Economics*, Vol. 33 No. 5, pp. 739-749.
- Sadorsky, P. (2012), "Energy consumption, output and trade in South America", *Energy Economics*, Vol. 34 No. 2, pp. 476-488.
- Saidi, K., Rahman, M.M. and Amamri, M. (2017), "The causal nexus between economic growth and energy consumption: new evidence from global panel of 53 countries", *Sustainable Cities and Society*, Vol. 33.
- Schmalensee, R., Stoker, T.M. and Judson, R.A. (1998), "World carbon dioxide emissions: 1950-2050", *Review of Economics and Statistics*, Vol. 80 No. 1, pp. 15-27.
- Shahbaz, M. and Rahman, M.M. (2012), "The dynamic of financial development, imports, foreign direct investment and economic growth: cointegration and causality analysis in Pakistan", *Global Business Review*, Vol. 13 No. 2.
- Shahbaz, M., Lean, H.H. and Shabbir, M.S. (2012), "Environmental kuznets curve hypothesis in Pakistan: cointegration and granger causality", *Renewable and Sustainable Energy Reviews*, Vol. 16 No. 5, pp. 2947-2953.
- Shahbaz, M., Nasir, M.A. and Roubaud, D. (2018), "Environmental degradation in France: the effects of FDI, financial development, and energy innovations", *Energy Economics*, Vol. 74, pp. 843-857.
- Shahbaz, M., Mallick, H., Mahalik, M.K. and Loganathand, N. (2015), "Does globalization impede environmental quality in India?", *Ecological Indicators*, Vol. 52, pp. 379-393.
- Shahbaz, M., Hye, Q.M.A., Tiwari, A.K. and Leitão, N.C. (2013), "Economic growth, energy consumption, financial development, international trade and CO₂ emissions in Indonesia", *Renewable and Sustainable Energy Reviews*, Vol. 25, pp. 109-121.
- Shi, A. (2001), "Population growth and global carbon dioxide emissions", *Paper presented at IUSSP Conference in Brazil/session-s09, Development Research Group, The World Bank.*
- Soytas, U. and Sari, R. (2003), "Energy consumption and GDP: causality relationship in G-7 countries and emerging markets", *Energy Economics*, Vol. 25 No. 1, pp. 33-37.

- Soytas, U. and Sari, R. (2006), "Energy consumption and income in G-7 countries", *Journal of Policy Modeling*, Vol. 28 No. 7, pp. 739-750.
- Soytas, U., Sari, R. and Ewing, B.T. (2007), "Energy consumption, income, and carbon emissions in the United States", *Ecological Economics*, Vol. 62 Nos 3/4, pp. 482-489.
- Squalli, J. (2007), "Electricity consumption and economic growth: bounds and causality analyses of OPEC countries", *Energy Economics*, Vol. 29 No. 6, pp. 1192-1205.
- Tiwari, A.K. (2011), "Energy consumption, CO₂ emissions and economic growth: a revisit of the evidence from India", *Applied Econometrics and International Development*, Vols 11/2.
- Tiwari, A.K., Shahbaz, M. and Hye, Q.M.A. (2013), "The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy", *Renewable and Sustainable Energy Reviews*, Vol. 18, pp. 519-527.
- Uddin, M.G.S., Bidisha, S.H. and Ozturk, I. (2016), "Carbon emissions, energy consumption, and economic growth relationship in Sri Lanka", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 11 No. 3, pp. 282-287.
- UN (2019), "United nations statistics division", 17 June 2019. Retrieved 30 July 2019.
- Vidyarthi, H. (2013), "Energy consumption, carbon emissions and economic growth in India", *World Journal of Science, Technology and Sustainable Development*, Vol. 10 No. 4, pp. 278-287.
- WDI (2015), *World Development Indicators*, World Bank, Washington, DC.
- WDI (2018), *World Development Indicators*, World Bank, Washington, DC.
- WPP (2016), "World population prospects", United Nations Department of Economic and Social Affairs, Population Division.
- Yamusa, S.U. and Ansari, A.H. (2014), "Law and policy on renewable energy sources in Nigeria: a critical appraisal", Seminar paper.
- Zeshan, M. and Ahmed, V. (2013), "Energy, environment and growth nexus in South Asia", *Environment, Development and Sustainability*, Vol. 15 No. 6, pp. 1465-1475.
- Zoundi, Z. (2017), "CO₂ emissions, renewable energy and the environmental kuznets curve, a panel cointegration approach", *Renewable and Sustainable Energy Reviews*, Vol. 72, pp. 1067-1075.

Further reading

- Akarca, A.E., and Long, T.V.I. (1998), "On the relationship between energy and GNP: a re-examination", *Journal of Energy and Development*, Vol. 5, pp. 326-331.
- Apergis, N. and Payne, J.E. (2009), "Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model", *Energy Economics*, Vol. 31 No. 2, pp. 211-216.
- Apergis, N. and Payne, J.E. (2012), "The electricity consumption-growth nexus: renewable versus non-renewable electricity in Central America", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 7 No. 4, pp. 423-431.
- Asafu-Adjaye, J. (2000), "The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries", *Energy Economics*, Vol. 22 No. 6, pp. 615-625.
- Baranzini, A., Weber, S., Bareit, M. and Mathys, N.A. (2013), "The causal relationship between energy use and economic growth in Switzerland", *Energy Economics*, Vol. 36, pp. 464-470.
- Begum, R.A., Sohag, K., Abdullah, S.M.S. and Jaafar, M. (2015), "CO₂ emissions, energy consumption, economic and population growth in Malaysia", *Renewable and Sustainable Energy Reviews*, Vol. 41, pp. 594-601.
- Birdsall, N. (1992), "Another look at population and global warming", World Bank Country Economics Department Working Paper No. 1020. November.

- Chang, J. and Wong, J.F. (2001), "Poverty, energy and economic growth in Singapore", Working Paper, Department of Economics, National University of Singapore.
- Cheng, B.S. and Lai, T.W. (1997), "An investigation of co-integration and causality between energy consumption and economic activity in Taiwan", *Energy Economics*, Vol. 19 No. 4, pp. 435-444, doi: [10.1016/S0140-9883\(97\)01023-2](https://doi.org/10.1016/S0140-9883(97)01023-2).
- Dhakal, S. (2009), "Urban energy use and carbon emissions from cities in China and policy implications", *Energy Policy*, Vol. 37 No. 11, pp. 4208-4219.
- Erol, U. and Yu, E.S.H. (1987), "Time-series analysis of the causal relationships between US energy and employment", *Resources and Energy*, Vol. 9 No. 1, pp. 75-89.
- Glasure, Y.U. (2002), "Energy and national income in Korea: further evidence on the role of omitted variables", *Energy Economics*, Vol. 24 No. 4, pp. 355-365.
- Govindaraju, C.V.G.R. and Tang, C.F. (2013), "The dynamic links between CO2 emissions, economic growth and coal consumption in China and India", *Applied Energy*, Vol. 104, pp. 310-318.
- Grossman, G. and Krueger, A. (1995), "Economic environment and the economic growth", *The Quarterly Journal of Economics*, Vol. 110 No. 2, pp. 353-377.
- Hettige, H., Lucas, R.E.B. and Wheeler, D. (1992), "The toxic intensity of industrial production: global patterns, trends, and trade policy", *American Economic Review*, Vol. 82, pp. 478-481.
- Lee, C.C. (2005), "Energy consumption and GDP in developing countries: a cointegrated panel analysis", *Energy Economics*, Vol. 27 No. 3, pp. 415-427.
- Martinez-Zarzoso, I. and Bengochea-Morancho, A. (2004), "Pooled mean group estimation for an environmental kuznets curve for CO2", *Economics Letters*, Vol. 82 No. 1, pp. 121-126.
- Oh, W. and Lee, K. (2004), "Causal relationship between energy consumption and GDP revisited: the case of Korea 1970-1999", *Energy Economics*, Vol. 26 No. 1, pp. 51-59.
- Pao, H.-T., Yu, H.-C. and Yang, Y.-H. (2011), "Modeling the CO2 emissions, energy use, and economic growth in Russia", *Energy*, Vol. 36 No. 8, pp. 5094-5100.
- Sanjari, F. and Delongizan, S. (2010), "Carbon emissions and economic growth: the Iranian experience", Working Paper.
- Tang, C.F. and Tan, E.C. (2013), "Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia", *Applied Energy*, Vol. 104, pp. 297-305.
- Tiwari, A.K. (2012), "On the dynamics of energy consumption, CO2 emissions, and economics growth: evidence from India", *Indian Economic Review*, Vol. 47 No. 1, pp. 57-87.
- Tunç, G.I., Türüt-Aşık, S. and Akbostancı, E. (2009), "A decomposition analysis of CO2 emissions from energy use: Turkish case", *Energy Policy*, Vol. 37 No. 11, pp. 4689-4699.
- UN (2015), List of Countries by Population Density, United Nations Department of Economic and Social Affairs.
- Wolde-Rufael, Y. (2009), "Energy consumption and economic growth: the African experience revisited", *Energy Economics*, Vol. 31 No. 2, pp. 217-224.
- Yu, E.S.H. and Hwang, B.K. (1984), "The relationship between energy and GNP: further results", *Energy Economics*, Vol. 6 No. 3, pp. 186-190, doi: [10.1016/0140-9883\(84\)90015-X](https://doi.org/10.1016/0140-9883(84)90015-X).
- Yu, E.S.H. and Choi, J.Y. (1985), "The causal relationship between energy and GNP: an international comparison", *Journal of Energy and Development*, Vol. 10 No. 2, pp. 249-272.

Authors	Countries of study*	Findings
<i>Energy consumption and economic growth nexus</i>		
Mbarek <i>et al.</i> (2017), Vidyarthi (2013), Bowden and Payne (2009), Apergis and Payne (2010), Narayan and Smyth (2008)	Tunisia; India; the USA; South America; G7 countries	Existence of growth hypothesis
Rahman and Velayutham (2020), Lise and Van Montford (2007), Huang <i>et al.</i> (2008)	South Asia; Turkey; 82 countries	Existence of conservative hypothesis
Saidi <i>et al.</i> (2017), Shahbaz <i>et al.</i> (2015), Fuinhas and Marques (2012), Eggoh <i>et al.</i> (2011), Belke <i>et al.</i> (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
<i>Economic growth and CO₂ emissions nexus</i>		
Rahman and Velayutham (2020), Acheampong <i>et al.</i> (2019), Zoundi (2017), Shahbaz <i>et al.</i> (2018), Tiwari <i>et al.</i> (2013), Ertugrul <i>et al.</i> (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 <i>et al.</i> , 2012; Musolesi <i>et al.</i> , 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
<i>Economic growth, energy consumption and CO₂ emissions nexus</i>		
Appiah (2018), Pao and Tsai (2010), Alam <i>et al.</i> (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 <i>et al.</i> (2020), Rahman and Kashem (2017), Uddin <i>et al.</i> (2016), Ghosh (2010), Kasman and Duman (2015), Shahbaz <i>et al.</i> (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 <i>et al.</i> (2017), Acheampong (2018)	Tunisia; 116 countries	Causal nexus between energy consumption and CO ₂ emissions
Ghosh (2010), Soyatas <i>et al.</i> (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
<i>Energy consumption and international trade nexus</i>		
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
<i>CO₂ emissions and international trade nexus</i>		
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
<i>CO₂ emissions, energy consumption and population density nexus</i>		
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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