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REVIEW ARTICLE

The dynamic relationship between structural change and CO_2 emissions in Malaysia: a cointegrating approach

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Abstract The current study investigates the dynamic relationship between structural changes, real GDP per capita, energy consumption, trade openness, population density, and carbon dioxide (CO_2) emissions within the EKC framework over a period 1971–2013. The study used the autoregressive distributed lagged (ARDL) approach to investigate the long-run relationship between the selected variables. The study also employed the dynamic ordinary least squared (DOLS) technique to obtain the robust long-run estimates. Moreover, the causal relationship between the variables is explored using the VECM Granger causality test. Empirical results reveal a negative relationship between structural change and CO_2 emissions in the long run. The results indicate a positive relationship between energy consumption, trade openness, and CO_2 emissions. The study applied the turning point formula of Itkonen (2012) rather than the conventional formula of the turning point. The empirical estimates of the study do not support the presence of the EKC relationship between income and CO_2 emissions. The Granger causality test indicates the presence of long-run bidirectional causality between energy consumption, structural change, and CO_2 emissions in the long run. Economic growth, openness to trade, and population density unidirectionally cause CO_2 emissions. These results suggest that the government should focus more on information-based services rather than energy-intensive manufacturing activities. The feedback relationship between energy consumption and CO_2 emissions suggests that there is an ominous need to refurbish the energy-related policy reforms to ensure the installations of some energy-efficient modern technologies.

Keywords Structural change · CO_2 · EKC · ARDL · Malaysia

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Introduction

Environmental pollution has become the center of discussions due to the increasing threat of global warming and climate change to the environment and the existence of the human race. These threats to even the existence of human race have turned the attention of scholars, policymakers, and government bodies to pinpoint the main determinants of environmental pollution and the course of their impact (Ghosh 2010; Hatzigeorgiou et al. 2011; Wang et al. 2011). Economic growth has remained one of the target objectives of almost all the countries of the world during the last century under the macroeconomic policies of stabilization. Incompatible policy adoptions for swift growth of the economy, extensive use of natural resources, and environmental degradation are some of the main hurdles the countries face while attaining the rapid goals of development (Apergis and Payne 2010a; Singh 2011). It is reported that out of the total world energy use,

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fossil fuels are the main sources to supply 80% of the energy up to 2040 and will meet more than three fourths of the world energy consumption need by liquid fuels, coal, and natural gas. The world energy-related CO_2 emissions will increase to 36 billion metric tons in 2020 as compared to 31 billion metric tons in 2010. Furthermore, these energy-related CO_2 emissions are projected to reach 45 billion metric tons in 2040 (U.S. Energy Information Agency 2013). These problems may be severe in a highly resource-dependent country such as Malaysia, where environmental sustainability, energy security, and economic growth are concurrently imperative.

The income-pollution relationship has been explained under the theoretical consideration in three ways in the literature: (1) related to the income elasticity of demand for environmental quality, (2) the increasing returns in abatement technology, and (3) the economic growth accompanied by structural changes (Copeland and Taylor 2004a, b; Brock and Taylor 2005; Kijima et al. 2010). The explanation related to structural changes accompanied by economic growth has not been extensively explored, and in the case of Malaysia, it is very naive. The introduction of structural change in the environment growth equation is traced back to the "Lewis's Structural Change Theory" in 1955, and on the environmental side, the hypothesis of the structural change is the base for inclusion of structural change in the income-pollution relationship. Moreover, it is argued that the energy consumption and carbon emissions can be influenced by the population density in the several coming decades (Jorgenson and Clark 2010; Liddle 2015; Sharif Hossain 2011).

The study of Itkonen (2012) argued about the three main problems in the current literature. The first problem is the lack of proper econometric methods such as Vector Autoregressive (VAR) and Vector Error Correction Mechanism (VECM) due to the creation of binding constraint for the model, thus, the integrity of the estimators is compromised. The second and third problem may arise even in the presence of a proper econometric technique as the recent literature has included energy consumption in the model as an explanatory variable. Since CO_2 emissions are linearly derived from different fuel commodities, in the recent datasets the carbon emissions are measured indirectly from energy use. Thus, controlling the energy consumption level means that only the intensity of the carbon in the fuel mix can vary. Thus, the parameters' meaning is inaccurate and the environmental Kuznets curve (EKC) relationship is not what it was conventionally. The third problem arises due to the energy-output nexus as it can lead to bias results by exaggerating the shape of EKC. Thus, the current study looks into the EKC relationship between income and pollution by considering the arguments of Itkonen (2012) and incorporated the role of structural changes in the economy along with international trade (Halicioglu 2009) as international trade might be one of the causes of structural change in the economy because it may affect the composition of the industries directly (Ederington et al. 2004; Pezzey 1992). The study further incorporated the role of international trade as trade is considered as one of the main driving forces behind the structural shifts in the economy. The study further incorporated the role of population density in the equation to bridge the gap of the omitted variable bias.

The current study has for the first time focused on the role of structural change in Malaysian economy in the environmental perspective and is the first of its kind to investigate the combination of all these variables over a period 1971–2013. The 10th Malaysia Plan (2011–2015) of the government has targeted the growth of the services sector up to 7.2% on an annual basis until 2015, which will increase the contribution of the services sector to GDP to 61% by 2015. Recently, the services sector in Malaysian economy is dominating the manufacturing sector as services sector accounts for more than 51% of total GDP relative to a share of 22% by the manufacturing sector in 2013 (WDI 2016). According to the Malaysian Institute of Economic Research, the growth of the domestic-oriented services sector of Malaysia has almost surpassed the growth of the real GDP as is becoming the fast and critical economic sector in the country. On the other hand, due to the uncertainties in the export-oriented market, the growth of the manufacturing sector at 4.5% per year in 2011 was lower than the growth rate of real GDP.

Literature review

There has been a vital empirical investigation regarding the relationship between carbon dioxide emissions and its determinants over the years. The literature can be divided into four strands. In the first strand of literature, we discuss the studies related to EKC. The second strand of literature emphasized on the introduction of energy consumption in the income-pollution nexus. Third, we introduced the literature on the impact of openness to international trade on the environmental quality. Lastly, the study focused on the relationship between structural changes in the economy and its impact on the environmental quality.

The relationship between economic growth and environmental quality is a burning issue under discussion in the economic and environmental literature globally. This environment has evolved from the philosophy of the EKC theory. The EKC theory for the first time was empirically tested by Grossman and Krueger (1991, 1995) in analyzing the relationship between environmental pollution and income per capita. The EKC has been presented with four main explanations to create the preferred shape of the income-pollution relation and to show the emphasis of income by depicting the equilibrium pollution as a function of income by restricting the technology and preferences (Copeland and Taylor 2004a, b). The key feature of all the four mechanisms, namely (1) sources of growth, (2) income effects, (3) threshold effects, and (4) increasing returns to abatement, has been isolated (Copeland and Taylor 2004a, b; Smulders 2004). In the late 1990s, Shafik (1994) and Grossman and Krueger (1995) found an N-shaped relationship between per capita income and CO_2 emissions.

In a different way, Holtz-Eakin and Selden (1995) among others observed a monotonic relationship between income and pollution. Agras and Chapman (1999) included other variables such as energy price and trade in the income-pollution nexus and concluded that there is no EKC relationship between income and pollution. Similarly, Richmond and Kaufmann (2006) claimed that there is no significant relationship between environmental pollution and economic growth. Some recent studies including Apergis and Payne (2009), Lean and Smyth (2010), Pao and Tsai (2010), Baek and Kim (2013), Lau et al. (2014), and Ali et al. (2016), among others, also evidenced the presence of EKC relationship between income and pollution. In contrast, there are other studies who negated the presence of EKC relationship between per capita income and carbon emissions (Govindaraju and Tang 2013; Mugableh 2013; Saboori and Sulaiman 2013b; Begum et al. 2015). Begum et al. (2015) observed a U-shaped relationship between per capita income and environmental pollution in Malaysia. Last but not the least, applying the quantile regression methods, You et al. (2015) found a monotonic relationship between income and pollution in world economies.

In the second strand of literature, researchers emphasized on the inclusion of energy consumption in the income-pollution nexus and argued that there is a strong relationship between energy consumption and environmental pollution, as consuming more energy not only increases the production which leads to economic development but also is one of the main reasons of increasing pollutant gases (Ang 2007; Apergis and Payne 2009, 2010b; Lean and Smyth 2010; Arouri et al. 2012) among others. The inclusion of energy consumption in the income-pollution nexus for the first time by Ang (2007) to avoid the omitted variable problem pioneered the role of energy consumption in the EKC relationship between income and pollution. In a study for China, Zhang and Cheng (2009) investigated the multivariate causality relationship between CO_2 emissions, GDP, and energy consumption and concluded that in the long run, energy consumption granger causes CO_2 emissions granger, while economic growth granger causes energy consumption. On the other hand, in a study for Turkey, Soytas and Sari (2009) concluded that carbon emissions can granger cause energy consumption, but there is no causality found from energy consumption toward CO_2 emissions. Later, Apergis and Payne (2009, 2010b) extended the work of Ang (2007) and concluded that energy consumption has a positive and significant impact on CO_2 emissions. The study also found a bidirectional relationship between energy consumption and CO_2 emissions in the long run. More recently, Al-Mulali et al. (2013) found a bidirectional causality relationship between urbanization, energy consumption, and CO_2 emissions, while Omri (2013) found unidirectional causality from energy consumption toward CO_2 emissions in the case of MENA countries. In contrast, Kivyiro and Arminen (2014) in the case of six Sub-Saharan African countries found neutrality hypothesis between CO_2 emissions, energy consumption, and GDP both in the short and long run.

International trade is considered as an important factor in driving the economic growth of the country to higher altitudes. In this course of action, trade also can influence the quality of the environment. Most of the previous literature discussing the nexus between trade and environment has focused on the "Pollution Haven" hypothesis (Copeland and Taylor 1994; Chichilnisky 1994; Pethig 1976). The pollution haven hypothesis states that polluting industries will be displaced to the countries or areas having laxer strict environmental protection. Another main theoretical base for the inclusion of trade in the income-pollution nexus is the Hickscher-Ohlin model which argues that the abundance of input factors of a good is the base for the regional export of goods. It is argued that environmental quality can be influenced by trade via three main factors, including scale, composition, and technique effect (Antweiler et al. 2001). The empirical literature on trade and environment is composed of these three effects of trade. Some researchers have argued that trade can harm the environment by increasing economic growth via scale effect (Ali et al. 2017; Ling et al. 2015; Shahzad et al. 2017). Another strand of literature have arrived at a conclusion that trade can be harmful to environment via the composition effect as the change in the composition of the exports and imports of goods to more manufacturing based goods can increase the CO_2 emissions (Ang 2009; Ling et al. 2015; Panayotou 2003; Shahzad et al. 2017). On the other hand, a group of studies concluded that openness to international trade can improve the environmental quality via technique effect as the exports and imports involve the transfer and utilization of modern technology in the exporting products (Ali et al. 2016; Charfeddine and Ben Khediri 2016; Márquez-Ramos 2015; Sbia et al. 2014; Shahbaz 2013; Shahbaz et al. 2013a, b).

Economic growth accompanied by structural change can have effects on the quality of environment when there occur variations in the composition of economic activities, and a shift occurs from lower to higher pollution intensity or higher to lower. When the income levels are low, there is a tendency to move from agriculture sector to industrial sector, which is more polluting and will increase pollution. While on the other hand, when the income levels are higher, a significant shift will be from industrial sector to the service industry which is less polluting and will lead to a decrease in the intensity of pollution. Therefore, this change in the industry share of GDP can be considered as the structural change (Panayotou 2000). A strand of authors is of the view that structural change and technological advancement can play a vital role in attaining the pattern of EKC (Shafik and Bandyopadhyay 1992; De Bruyn et al. 1998; Hettige et al. 2000; Dinda 2004). Smulders and Bretschger (2000) focused the structural change in achieving sustainable development and concluded that rather than worsening the economy, structural change may be helpful in promoting the innovation and investments. It is argued that a transition (structural change) from pollution intensive to the information-based less pollutive economy can reduce the environmental degradation in the long run (Panayotou 2003). Moreover, in a study, López et al. (2007) analyzed the relationship between environmental quality and structural change and concluded that even if there is no environmental policy, a movement of the structural change toward the non-resource sector will lead to sustainable growth. It is argued that the difference in the productivity performance of Latin America, Africa, and Asia is due to the pattern of structural change caused by a movement of labor toward high productivity from low-productive sectors in Asia. Similarly, the movement in Africa and Latin America from high-productive activities to low-productive sectors of the economy can lead to changes in the environmental quality (McMillan and Rodrik 2011).

Furthermore, in a study of China and India, Jayanthakumaran et al. (2012) investigated the relationship between economic growth, energy use, structural changes, the openness of trade, and CO_2 emissions and concluded that there is no clear picture of the relationship between CO_2 emissions and structural changes in the economy. The study also confirmed the existence of EKC hypothesis for India. In a recent study discussing the EKC evolution, Kaika and Zervas (2013) claimed that income distribution, technical progress, the openness of trade, structural changes, energy efficiency, quality of institutions, good governance, and consumer preferences could be the possible causes of the inverted U shape of EKC between income and environmental pollution. Similarly, Luukkanen et al. (2015) investigated the relationship between structural change, carbon emissions, and energy use in China and concluded that turning away from energy-intensive industries, development of services sector, changing the emission-intensive growth, and higher investments in renewable energy capacity can lower the carbon emissions by 27% until 2030 relative to the current scenario of 2013.

Data and methodology

Model specification

The current study investigates the long-run relationship between carbon dioxide emissions and its determinants, namely economic growth, energy consumption, structural change, trade openness, and population density, using secondary time series annual data over a period 1971–2013. The current study followed the work of Itkonen (2012), where he targeted the previous work of Ang (2007) to present the energy-emissions-output (EEO) model, where Ang (2007) introduced the role of energy consumption for the first time in the income-pollution nexus.

$$CO_{2t} = \beta_0 + \beta_1 EC_t + \beta_2 GDP_t + \beta_3 GDP_t^2 + U_t \quad (3.1)$$

Itkonen (2012) has highlighted some problems by comparing the EKC (emissions-output nexus) model and emissions-energy-output (EEO) model where researchers have included the energy consumption as an explanatory variable in the income-pollution relationship which can lead to the problem of endogeneity. This equation included the energy consumption in the income-pollution relationship to bridge the gap of omitted variable bias but did not look for the problem of endogeneity. The recent trend of researchers has followed this equation for a long while neglecting the direct link between output and energy while considering the relationship between income, energy consumption, and CO_2 emissions in the long run. Instead of following this equation, Itkonen (2012) presented a system of equations to justify the EEO model as follows:

$$CO_{2t} = \beta_0 + \beta_1 EC_t + \beta_2 GDP_t + \beta_3 GDP_t^2 + U_t \quad (3.2)$$

$$EC_t = \beta_e y_t + V_t \quad (3.3)$$

where Eq. (3.3) is supplementing the EEO model Eq. (3.2) by linking the energy and output, where β_e is positive as output directly and positively affects the consumption of energy and V_t is the error term, covering the effect of other factors affecting the relationship (see Itkonen 2012). The inclusion of the squared term of GDP following the work of Grossman and

Krueger (1995) is showing a non-linear relationship between economic growth and carbon emissions and is used to investigate the EKC relationship.

It is argued that various human activities are responsible for the carbon emission where the population of the area can be a key factor determining the dynamics of carbon emissions (Bongaarts 1992). Moreover, it is argued that the energy consumption and carbon emissions can be influenced by the population density in the several coming decades (Jorgenson and Clark 2010; Liddle 2015; Hossain 2011).

$$CO_{2t} = \beta_0 + \beta_1 EC_t + \beta_2 GDP_t + \beta_3 GDP_t^2 + \beta_4 Pop_t + \varepsilon_t \tag{3.4}$$

There is a greater concern that different human activities including structural changes in the economy in the shape of shifts from the basic agriculture economy to a modern industrial economy (manufacturing) and then further to a more information-based services sector can alter the concentrations of carbon dioxide in the atmosphere. Since Malaysia is a fast-developing country passing through the transition stage from developing to a fully developed economy, the share of the services sector to GDP of the country has crossed the share of the manufacturing sector to GDP. Based on the previous literature, the current study focuses on investigating the role of structural changes in the economy on the environmental quality (Kaivo-oja et al. 2014; Marsiglio et al. 2016; McMillan and Rodrick 2011; Shahbaz et al. 2014). Similarly, there is a strand of literature which focus on the role of international trade in determining the carbon emissions in an economy (Acaravci and Ozturk 2010; Ali et al. 2016; Halicioglu 2009; Menyah and Wolde-Rufael 2010; Saboori and Sulaiman 2013a). All the variables are converted into the logarithmic form and the model in the logarithmic form can be written as follows:

$$\begin{aligned} lnCO_{2t} = {} & \beta_0 + \beta_1 \ln EC_t + \beta_2 \ln GDP_t + \beta_3 \ln GDP_t^2 + \beta_4 \ln Pop_t \\ & + \beta_5 \ln \mathrm{INDVA}_t + \beta_6 \ln \mathrm{Trade}_t + \varepsilon_t \end{aligned} \tag{3.5}$$

where environmental pollution is measured by CO_2 emissions metric tons per capita, economic growth is represented by real GDP per capita, GDP^2 is included to check the validity of the EKC, and energy consumption is shown by EC in kilograms of oil equivalent per capita (Azam 2016; Azam et al. 2015; Shahbaz et al. 2013a, b). The population density is represented by Pop in terms of people per square kilometer in land area, structural change is represented by INDVA in terms of industry value added percent of GDP, and Trade measures the international trade in terms of imports plus exports as a share of GDP.

According to Itkonen (2012), the link between output and energy creates the bias in parameters and the causal effect of his system of equations by Itkonen (2012) as follows:

$$\frac{\partial c_t}{\partial y_t} = (\beta_2 + 2\beta_3) + \beta_e \beta_1 \tag{3.6}$$

While the causal effect of the EEO model is

$$\frac{\partial c_t}{\partial y_t} = (\beta_2 + 2\beta_3) \tag{3.7}$$

Thus, there is a bias of $-\beta_e\beta_1$, where the sign of β_e is positive as more output leads to more energy use. The sign of $\beta_1$is also positive as energy consumption has an increasing impact on the carbon emissions. There are two possible implications of the negative bias for the EKC shape, first the turning point and second is the behavior of the pollution before and after the turning point. Based on the negative bias, the turning point will occur at a higher output and will arrive at a point later than estimated. Secondly, the unbiased EKC shape grows faster and fall more slowly than the biased one. This is because that after the turning point, there is still a slow growth in carbon emissions for a while and then falls slowly (see Itkonen 2012). The turning point can be calculated in the biased version as follows:

$$y* = \frac{-\beta_2 - \beta_e \beta_1}{2\beta_3} \tag{3.8}$$

Rather than the conventional turning point based on the unbiased case:

$$y = \frac{-\beta_2}{2\beta_3} \tag{3.9}$$

Estimation techniques

The study employed the unit root tests of Augmented Dickey-Fuller (ADF), Phillips-Peron (PP), and Dickey-Fuller GLS (DF-GLS) to investigate the order of integration of the variables. The study applied the autoregressive distributed lag (ARDL) bounds test by Pesaran et al. (2001) to investigate the long-run cointegration between the variables of the study. The ARDL bound testing approach is preferred over other techniques because this technique (1) uses the OLS technique to estimate the long-run cointegration between the variables based on the proper selection of the lag length for the model; (2) can be applied to the model regardless of the order of the integration (i.e., variables are $I(0)$, $I(1)$, or a mixture of $I(0)$ and

$I(1)$); (3) valid for small and finite data set thus is superior to Johansen and Juselius approach; (4) can integrate the short-run adjustments with the long-run equilibrium via deriving the error correction mechanism (ECM) by simple linear transformation without spreading the long-run information; (5) is free from the residual correlation, thus, there is no danger of endogeneity problem as the lags are selected automatically by this technique; and (6) can distinguish the dependent and independent variables. However, the computed F-statistics table of Pesaran et al. (2001) will be invalid for the $I(2)$ variables (Ouattara 2004). The unit root tests confirmed that there is no $I(2)$ variable in the model. The presence of the long-run relationship is detected by applying the ARDL approach and the OLS technique is applied to estimate Eq. (3.5) as follows:

$$\begin{aligned}\Delta\ln CO_2 = \beta_0 &+ \sum_{i=1}^{p}\beta_1\Delta\ln CO_{2\ t-i} + \sum_{i=1}^{p}\beta_2\Delta\ln EC_{t-i} + \sum_{i=1}^{p}\beta_3\Delta\ln GDP_{t-i} + \sum_{i=1}^{p}\beta_4\Delta\ln(GDP_{t-i})^2 \\ &+ \sum_{i=1}^{p}\beta_5\Delta\ln\mathrm{INDVA}_{t-i} + \sum_{i=1}^{p}\beta_6\Delta\ln TO_{t-i} + \sum_{i=1}^{p}\beta_7\Delta\ln Pop_{t-1} + \lambda_1\ln CO_{2\ t-i} + \lambda_2\ln EC_{t-i} + \lambda_3\ln GDP_{t-i} + \lambda_4\ln(\ GDP_{t-i})^2 \\ &+ \lambda_5\ln\mathrm{INDVA}_{t-i} + \lambda_6\ln TO_{t-i} + \lambda_7\ln Pop_{t-i} + \varepsilon_t\end{aligned} \tag{3.10}$$

where β_0 represents the drift component and the error term is represented by ε_t. The summation signs in the first half of the equation represent the dynamics of the short-run error correction mechanism while the next half of the equation carrying the λ represents the long-run relationship. The joint F-statistics or Wald statistics test are employed to find out the existence of the long-run relationship between the variables, counting for the null hypothesis of no cointegration; $H_0 = \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = \lambda_6 = \lambda_7 = 0$ and the alternative hypothesis is $H_1 = \lambda_1 \neq \lambda_2 \neq \lambda_3 \neq \lambda_4 \neq \lambda_5 \neq \lambda_6 \neq \lambda_7 \neq 0$. There are two critical values to compare the calculated F-statistics, either the variables will be stationary at level, $I(0)$, or the variables will be stationary at first difference, $I(1)$ (Pesaran et al. 2001). The null hypothesis of the no cointegration will be rejected if the calculated F-statistics value is greater than the upper bound critical value regardless if the variables are $I(0)$ or $I(1)$. There will be no long-run relationship between the variables if the F-statistics calculated value is less than the critical value of the lower bound and the test will be inconclusive if the calculated F-statistics value falls between the critical values of upper and lower bounds (Pesaran and Pesaran 1997). This technique can select the optimum lag length by either Schwartz-Bayesian Criteria (SBC) for smallest possible lag length or Akaike information Criteria (AIC) for the maximum lag length of the variables. After the lag length selection and model estimation, the error correction model can be represented as follows if the bounds test detects the presence of the long-run relationship.

$$\begin{aligned}\Delta\ln CO_2 = \beta_0 &+ \sum_{i=1}^{p}\beta_1\Delta\ln CO_{2\ t-i} + \sum_{i=1}^{p}\beta_2\Delta\ln EC_{t-i} + \sum_{i=1}^{p}\beta_3\Delta\ln GDP_{t-i} \\ &+ \sum_{i=1}^{p}\beta_4\Delta\ln(GDP_{t-i})^2 + \sum_{i=1}^{p}\beta_5\Delta\ln\mathrm{INDVA}_{t-i} + \sum_{i=1}^{p}\beta_6\Delta\ln TO_{t-i} \\ &+ \sum_{i=1}^{p}\beta_7\Delta\ln Pop_{t-1} + \theta ECT_{t-i} + \varepsilon_t\end{aligned} \tag{3.11}$$

where the speed of adjustment toward the long-run equilibrium after a shock in the short-run is shown by ECT_{t-1}. The goodness of fit of the model is investigated by applying the diagnostic tests of serial correlation, functional form, non-normality, and heteroscedasticity. The stability of model is tested by applying the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ) tests which are introduced for model stability (Brown et al. 1975).

Empirical results

The empirical analysis of the time series data requires the level of the data stationarity for the application of appropriate cointegration test. The unit root test decides the level of stationarity of the variables and there are two cointegration tests, the ARDL bounds test and the Johansen and Juselius (1990) test, to be applied accordingly to the integration level of the variables. The ARDL bounds testing is applicable irrespective of the integration order of the variables if they are $I(0)$, $I(1)$, or a mixture of $I(0)$ and $I(1)$. The Johansen test of cointegration, on the other hand, is applicable when all the variables of the model are integrated of order $I(1)$. The study applied unit root tests, namely the Augmented Dickey-Fuller (ADF), the Phillips-Peron (PP), and the Dickey-Fuller GLS (DF-GLS) unit root tests, to the natural logarithms of the variables to investigate the order of integration. The unit root test indicates that all the variables except the population density are stationary at first differences $I(1)$ while the population density is stationary in the levels $I(0)$. The study thus supported the application of ARDL bound testing approach for cointegration and not the Johansen cointegration approach (Table 1).

Table 1 ADF, PP, and DF-GLS unit root test

Variables	ADF level		PP level		DF-GLS level	
	Intercept	Trend and intercept	Intercept	Trend and intercept	Intercept	Trend and intercept
$lnCO_2$	−1.004255	−1.856897	−1.004255	−1.856897	0.253214	−2.059868
lnEC	−1.156357	−1.862791	−1.753222	−1.899010	0.816072	−2.090009
lnGDP	−1.563286	−2.216848	−1.520098	−2.333951	0.811148	−1.906875
$lnGDP^2$	−1.153897	−2.279667	−1.130119	−2.423458	0.890705	−2.129062
lnInvad	−1.483102	−0.854397	−1.702818	−0.746050	0.673736	−1.173208
lnTrade	−2.341868	−0.185181	−1.805025	−0.039223	−0.915675	−1.215360
lnPop	−2.805169*	−3.444305*	−2.323680*	−3.523623*	−2.502512*	−5.575525**
1st Difference	Intercept	Trend and intercept	Intercept	Trend and intercept	Intercept	Trend and intercept
$lnCO_2$	−7.11470***	−7.07335***	−7.10115***	−7.07335***	−7.13439***	−7.05759***
lnEC	−6.68603***	−6.82444***	−6.87478***	−9.57090***	−5.99978***	−6.62568***
lnGDP	−5.50140***	−5.57545***	−5.46772***	−5.57588***	−5.15847***	−5.68466
$lnGDP^2$	−5.62559***	−5.62021***	−5.62477***	−5.62137***	−5.41894***	−5.7436***
lnInvad	−5.90424***	−6.08675***	−5.8913***	−6.21771***	−5.90110***	−6.2450***
lnTrade	−5.19992***	−5.88268***	−5.22389***	−5.91827***	−3.98254***	-5.0484***

Note: *, **, and *** represent the significance level at 10%, 5%, and 1%, respectively

The study applied the ARDL bound testing and carried out the Joint F-significance test of Eq. (3.5) to compare the critical values of the lagged level of variables given by Pesaran et al. (2001). The number of lags play a key role in the F-test of cointegration results for the first-differenced variables, and the optimal lags are selected based on AIC and SBC criteria. The calculated F-statistics value of the bounds test for the Eq. (3) shows the presence of the long-run relationship between the variables of the model as is shown in Table 2. The results concluded that the calculated F-statistics values of the variables under constant and no trend are higher than the critical values of the upper bound of Narayan's (2005) table. An alternate way to detect the presence of the association between the variables in the long run is to observe the value of the lagged error correction term (ECT_{t-1}) of the cointegrating equation. It is claimed that if the value of ECT_{t-1} (the lagged error correction term) is negative and statistically significant, it is an indication of the presence of the long-run association between the variables (Pesaran et al. 2001). An alternate way to check the presence of long-run association is the value of the cointegrating equation (ECT_{t-1}). It is argued that if the value of the lagged error correction term (ECT_{t-1}) is statistically significant and bears a negative sign, it confirms the existence of the long-run relationship (Banerjee et al. 1998).

ARDL long-run results

The long-run results of the study under the ARDL approach are presented in Table 3 of the study. The long-run results of the study reveal that energy use in the country has a positive and significant relationship with the carbon emissions, meaning that an increase in the consumption of energy resources will further give rise to the carbon dioxide concentrations in the

Table 2 ARDL cointegration results

Model	ARDL (AIC 2 lags)	F-statistics	ECT_{t-1} (t-statistics)	Conclusion
$FlnCO_2$ ($lnCO_2$/lnEC lnGDPpc $lnGDP^2$ lnInvad lnTrade lnPop)	(1 0 2 2 1 1 1)	5.92***	−0.76 (−6.574)***	Cointegration
FlnEC (lnEC/$lnCO_2$ lnGDPpc $lnGDP^2$ lnInvad lnTrade lnPop)	(2 2 0 0 1 1 0)	5.29***	−0.92 (−15.08)***	Cointegration
FlnGDPPc (lnGDPpc/$lnCO_2$ lnEC $lnGDP^2$ lnInvad lnTrade lnPop)	(1 0 1 1 2 1 2)	14.08***	−0.32 (−6.968)***	Cointegration
$FlnGDP^2$ ($lnGDP^2$/$lnCO_2$ lnEC lnGDPpc lnInvad lnTrade lnPop)	(1 0 1 1 2 1 2)	14.16***	−0.33 (−6.704)***	Cointegration
FlnInvad (lnInvad/$lnCO_2$ lnEC lnGDPpc $lnGDP^2$ lnTrade lnPop	(1 1 2 0 2 0 2)	2.65	−0.55 (−3.356)***	Cointegration
FlnTrade (lnTrade/$lnCO_2$ lnEC lnGDPpc $lnGDP^2$ lnInvad lnPop	(2 2 1 2 1 1 0)	3.62**	−0.34 (−3.666)***	Cointegration
FlnPop (lnPop/$lnCO_2$ lnEC lnGDPpc $lnGDP^2$ lnInvad lnTrade	(2 1 2 2 2 2 2)	12.77***	−0.01 (−4.452)***	Cointegration
Critical values	Lower bound $I(0)$	Upper bound $I(1)$		
10%	2.12	3.23		
5%	2.45	3.61		
1%	3.15	4.43		

Table 3 ARDL long-run results

Variables	Coefficient	Standard error		Probability
lnEC	0.658657	0.168130		0.0006***
lnGDPpc	6.401551	2.939526		0.0387**
$\ln GDP^2$	−0.364537	0.172784		0.0447**
lnInvad	−2.219285	0.102225		0.0000***
lnTrade	0.771216	0.063626		0.0000***
lnPop	−0.181786	0.210441		0.3956
C	−25.660157	12.118362		0.0439**
EKC proof	$-\beta_2 – \beta_1\beta_e/2\beta_3$	Value	GDP highest value	Conclusion
Turning point (Itkonen 2012)	$E\,(-6.4015 - (0.620^{*}\ 0.658))/2(-0.3645)$	US$11,498.81	US$10,064.82	EKC not validated
Turning point (conventional)	$-\beta_2/2\beta_3 E\,(-6.4015/2(-0.3645))$	US$6374.12	US$10,064.82	EKC validated
Diagnostic tests	LM version probability χ^2 value (P value)		F version probability χ^2 value (P value)	
Serial correlation (χ^2)	1.5898 (0.2247)		4.7964 (0.0909)	No serial correlation
Functional form (χ^2)	2.6082 (0.0944)		0.93074 (0.344)	Correct functional form
Jarque-Bera (χ^2)	0.5515 (0.7589)		Not applicable	Normally distributed
Heteroscedasticity (χ^2)	0.8751 (0.5915)		13.132 (0.5161)	No heteroscedasticity

, * represent the level of significance at 5% and 1%, respectively

Value of β_e is derived from $EC_t = \beta_e y_t + V_t$

atmosphere. The results depict that if there will be an increase of 1% in the current energy use, it will on the cost of an increase of 0.65% in the CO_2 emissions in the long run in Malaysia. The positive and significant relationship between energy consumption and carbon emissions supports a strand of previous literature (Ali et al. 2017; Azam and Khan 2016; Heidari et al. 2015; Saboori and Sulaiman 2013a). The results of the study reveal that energy consumption in Malaysia is at the cost of environmental quality as the country is dependent on the non-renewable energy resources, including coal, gas, and oil which emit CO_2 into the atmosphere. Thus, the consumption of these non-renewable energy resources will increase the environmental pollution in the long run if not accompanied by some renewable resources, including solar, wind, biofuel, and nuclear energy resources. In the long run, the economic growth of the country is also at the cost of environmental quality as there is a positive and statistically significant relationship between GDP per capita and CO_2 emissions per capita. This outcome of the study is in line with the previous work of Ali et al. (2016) and Begum et al. (2015) in Malaysia, Farhani and Ozturk (2015) in Turkey, and Al-mulali et al. (2014) in Vietnam, among others, who studied the EKC path. The study reveals that an increase of 1% in the economic growth will result in an additional amount of 6.40% of carbon dioxide emissions in the atmosphere. The annual growth rate of carbon emissions during 1971–2012 remained 4.6% while on the other hand the annual growth rate of energy consumption in the country is noted to remain 4.2% during 1971–2012. Since economic growth in the country is dependent mainly on the non-renewable energy resources and the growth rate of carbon emissions is higher than the energy consumption, thus, the economic growth in Malaysia is at the cost of environmental quality. The statistics of Malaysia observed an increase in per capita metric tons of CO_2 emission from 1.34 in 1970 to 8.76 metric tons per capita (553.313% increase) in 2013 while the per capita income increases from US$1383.29 to US$10064.82 (627.600% increase), i.e., an increase in economic growth is also causing an increase in the environmental pollution.

On the other hand, the results revealed that higher economic growth (squared term of GDP) has a negative and significant relationship with carbon dioxide emissions in Malaysia. The results of the study indicate that when the per capita income of the country is higher, the government and regulatory bodies focus more on the environmental protection policies and will spend more for environmental protection. The results reveal that an increase of 1% in the higher income per capita will reduce the environmental pollution by 0.36% in the long run in Malaysia. This result indicates that when the income per capita is higher, the government will be spending more on the environment-friendly technology. This outcome of the study is in line with the fact that with the higher per capita GDP, the government is focused more on the environment-related policies and the improvement of environmental regulations is emphasized to reduce the environmental pollution. The negative relationship between high per capita income and CO_2 emissions may be because the country has moved from an energy-intensive manufacturing sector to a more information-based services sector, thus, reducing the energy consumption and overall emissions in the country.

The negative relationship between higher economic growth and environmental pollution is a necessary but not a sufficient condition for the existence of EKC relationship between income and carbon emissions. Therefore, the study measures the threshold value of the turning point of the EKC curve. The threshold value of the turning point of the EKC curve can be calculated following the work of Itkonen (2012) $E(-\beta_2 - \beta_1\beta_e)/2\beta_3$ which is different from the previous conventional turning point formula $E(-\beta_2/2\beta_3)$ utilized by Ali et al. (2016) and Saboori et al. (2012), among others. Putting the values, the threshold value of the turning point of the curve is $E(-6.4015-(0.620^{*}0.658))/2(-0.3645)$US\$11498.82. Thus, the current study did not support the EKC relationship between economic growth and pollution as the threshold value of the turning point (US\$11498.82) falls outside the range of the current per capita income as the highest value of per capita income in 2013 is US\$10064.81, thus, neglecting the presence of EKC curve in Malaysia in the long run.

The long-run results of the study further concluded that there is a negative and significant impact of structural changes in the economy on the carbon emissions in Malaysia, meaning that structural changes in the economy improve the environmental quality. The results reveal that an increase of 1% in the industry value added will lead to a decrease of 2.21% in the carbon dioxide emissions in Malaysia in the long run. This outcome is in line with the structural change hypothesis which states that a country will experience an increase in the environmental pollution when it moves from basic agriculture economy to a more energy-intensive industrialized economy, but when there occurs a shift in the economy from a more pollution-intensive manufacturing sector to a more information-based less pollutive services sector, the environmental pollution decreases with a further increase in the per capita income of the country. This outcome is supporting the current situation of the industry value added in Malaysia as more than 51% of the share of total GDP is contributed by the services sector and a 22% of the total GDP is shared by the manufacturing sector of the industry. This outcome of the study is in line with the findings of Marsiglio et al. (2016) as the increase in industry value added decreases the environmental pollution. This outcome indicates that most of the activities in the industrial sector in Malaysia have been carried out in the environment-friendly services sector rather than the polluting manufacturing sector during the study period. This outcome may be due to the composition effect of the economic growth, as at first the increasing economic growth causes a shift toward industrialization from basic agriculture economy, which increases the environmental pollution in the country. Moreover, when the balance of economic activities and growth shifted toward more information-based services, it leads to a decrease in the environmental pollution because of the changes in the demand and supply sides.

In the case of openness to trade, the results revealed a positive and significant relationship between carbon emissions and international trade openness, meaning that openness to trade in Malaysia is at the cost of environmental quality. The results observed that an increase of 1% in the openness to trade will result in an increase of 0.77% in the carbon emissions in the long run in Malaysia. This outcome may be because of the production of emissions polluting products for export purposes. This might also be because Malaysia is not obligated to reduce carbon emissions under the Kyoto Protocol as the country is a developing country. This outcome is in line with the work of previous researchers who claimed that international trade is one of the key components in deteriorating the environmental quality in developing countries (Farhani et al. 2014a; Managi et al. 2009; Omri et al. 2015; Shahbaz and Leitão 2013; Yunfeng and Yang 2010). Since openness to trade is one of the key policy variables for Malaysia to cope with the pace of economic growth, thus, this outcome may also be because of the scale effect of trade as openness to trade improves the economic growth of the country which leads to the deterioration of environmental quality. The emissions-leading international trade in Malaysia is in line with the results of the Grossman and Krueger (1995) who claimed that there will be a greater share of the polluting industries in the developing countries due to no strict environmental regulations rather than developed economies. Since most of the major trading partners of Malaysia including Singapore, Japan, EU, and the United States among others have strict environmental regulations than Malaysia, thus, Malaysia per the Heckscher-Ohlin model has a comparative advantage in the polluting industries because of the laxer environmental regulations. Therefore, trading with these developed economies of the world, the exports of Malaysia including electrical and electronic products (35.8%), chemicals and chemical products (7.5%), and petroleum products (6.7%)[1] will be more polluting as compared to these countries. On the other hand, the imports of the country, including electrical and electronic products (30.5%), chemicals and chemical products (10.3%), refined and crude petroleum, transport machinery, and others, can emit carbon dioxide into the atmosphere in the process of utilization in Malaysia in all these sectors.

Last but not the least, the results of the study indicate that there is a negative but insignificant relationship between population density and environmental pollution, meaning that the population density in Malaysia does not alter environmental quality. The population density in Malaysia is very small as compared to other countries, including Indonesia, Singapore, and Thailand, so the population density is not a problem to deteriorate the environmental quality. This outcome of the study can be supported by looking into the work of Ian Angus, where he demonstrated the effect of population density on the environmental quality and concluded that population density is not causing an increase in the environmental

[1] http://www.matrade.gov.my/en/malaysia-exporters-section/33-trade-statistics/4554-top-10-major-export-products-2016

Table 4 ARDL short-run results

Regressor	Coefficient	Standard error	T-ratio	Probability
ΔlnEC	0.506202	0.162218	3.120502	0.0044
ΔlnGDPPc	−18.129352	4.964332	−3.651922	0.0012
$\Delta \ln GDP^2$	1.079666	0.302216	3.572496	0.0014
ΔlnInvad	−0.238118	0.194485	−1.224349	0.2318
ΔlnTrade	0.026491	0.122701	0.215902	0.8307
ΔlnPop	−21.809490	1.440915	−15.135860	0.0000
ECM (−1)	−0.768536	0.116889	−6.574899	0.0000
Diagnostic tests				
R^2	0.71	DW statistic	2.41	
Adjusted R^2	0.55	SE of regression	0.056	
F-statistics (probability)	0.0003	RSS	0.083	

*, **, and *** represent the significance level at 10%, 5%, and 1%, respectively

pollution. The study presented the case of G-20 countries and low-emission countries and observed that even countries with more denser population (e.g., Sierra Leone, Uganda, Rwanda, and Malawi, among others) have less per capita CO_2 emissions than the ones with low population density (e.g., USA, Australia, and Canada among other G-20 countries).[2]

The lower half of Table 3 represents the results of the diagnostic tests for the goodness of fit of the model, including serial correlation, functional form, heteroscedasticity, and normality. The LM-serial correlation test results indicate that there is no first-order serial correlation in the model as the chi-square and *P* values of 1.5898 (0.2247) do not reject the null hypothesis of no serial correlation between the variables. The results also reveal that there is no problem in the functional form of the model as the chi-square and probability values of 2.6082 (0.0944) do not account for the wrong functional form under Ramsey's RESET test. The study further investigated the model for the problem of heteroscedasticity and concluded that there is no problem of heteroscedasticity in the model as the chi-square and *P* value of the test 0.8751 (0.5915) do not reject the null hypothesis of homoscedasticity. Moreover, the normality property of the variables is tested applying the Jarque-Bera normality test, and the results indicate that the data in the model is normally distributed and we cannot reject the null hypothesis of the normal distribution of the residuals with 0.5515 (0.7589) chi-square and probability values.

ARDL short-run results

The short-run results of the study are estimated by the error correction mechanism (ECM) under ARDL approach and are shown in Table 4. The results of the study indicate that energy consumption in Malaysia is at the cost of environmental quality in the short run, meaning that the consumption of energy resources is increasing the environmental pollution as the country is dependent upon the non-renewable energy sources, including coal, gas, and oil, among others, for its production and transport activities. The results also disclose that economic growth in the short run is having a negative relationship with the environmental pollution, meaning that economic growth in the short run is not at the cost of environmental quality in Malaysia. This outcome of the study is in line with the previous work of Ali et al. (2016), Begum et al. (2015), and Saboori and Sulaiman (2013b) in Malaysia and Ozturk and Acaravci (2013) in Turkey. The study further concluded that there is no EKC relationship between income and carbon dioxide emissions in Malaysia in the short run. This outcome can be justified as the EKC is a long-run phenomenon, not a short-run phenomenon (Dinda 2004).

The study further discloses that there is a negative but insignificant relationship between structural changes in the economy and environmental pollution. The results claim that the relationship between international trade and carbon dioxide emissions is positive but the impact is insignificant, meaning that openness to international trade cannot influence the environmental quality in the short run in Malaysia. This outcome of the study supports the previous work of Managi et al. (2009) in non-OECD countries and Halicioglu (2009) in Turkey, among others. Similar to the long-run results, there is a negative relationship between environmental pollution and population density in Malaysia in the short run. This outcome is opposing the previous work of Lantz and Feng (2006) in Canada and Martínez-Zarzoso et al. (2007) in European countries. It is argued that the overall emissions of a country are not dependent upon the population density as Fred Pearce (2010) in his work "Peoplequake" argued that 50% of the world CO_2 is created by the half billion richest people of the world while in contrast only 7% of the world CO_2 emissions are created by 3 billion people. The relationship between population and environment can be influenced by the government policies,

[2] http://climateandcapitalism.com/2010/04/28/overpopulation-and-global-warming-dissecting-the-numbers-part-one/

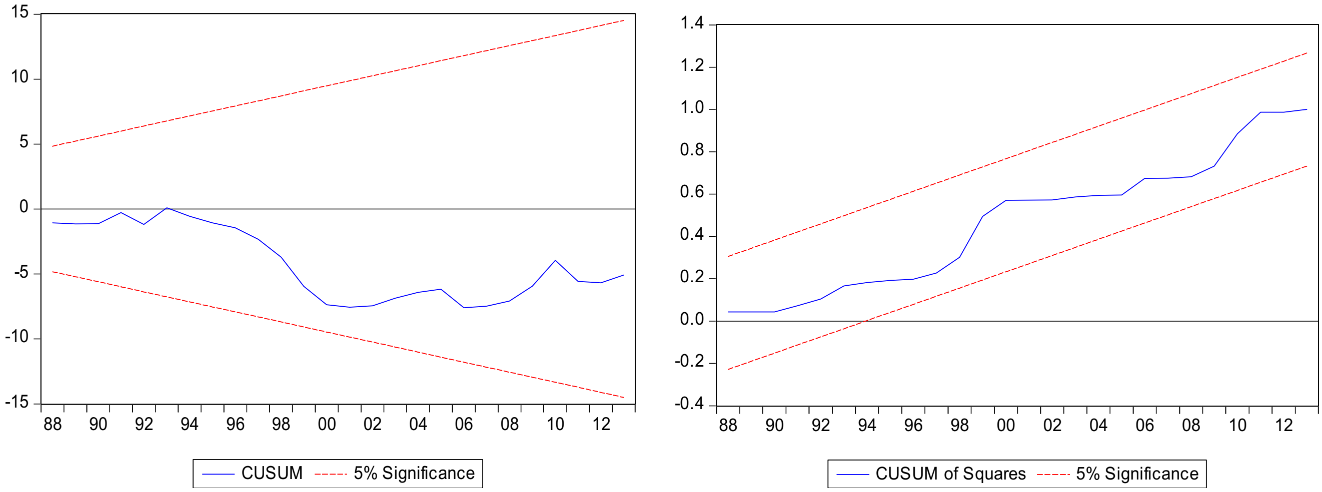

Fig. 1 CUSUM and CUSUMSQ test results

existing technology, and culture of the people. Technological changes are thought to be affecting the environmental conditions of the country more than other things due to its dependence on the energy use.

The lower part of Table 4 shows the diagnostic results of the model, including R^2 of 71%, adjusted R^2 of 55%, among others. The value of 71% of R^2 indicates that 71% of the variation in the dependent variable carbon emissions are explained by the changes in the current independent variables. The study further emphasized the overall stability of the model by investigating CUSUM and CUSUMSQ test under 5% critical values. The results indicate that the model is a good fit as both the line of the CUSUM and CUSUMSQ recursive residuals are well inside the 5% critical lines (Fig. 1).

Granger causality results

The presence of the long-run association between the variables infers the presence of the causal relationship between the variables either unidirectional or bidirectional (Engle and Granger 1987; Johansen and Juselius 1990). The current study analyzed the model for a causal relationship by applying the Granger causality test within the VECM framework. The long-run causal relationship is calculated by the error correction term of the VECM model, and the F-statistics of the Wald test are used to calculate the short-run causal relationship between the variables. Tables 5 and 6 represent the short- and long-run results of the Granger causality test. The short-run results of the study disclose that there run bidirectional causal relationships between carbon emissions, energy consumption, economic growth, structural changes, and international trade in Malaysia. The results depict that all these variables cause each other in the short run, meaning that changes in the economic growth, energy consumption, shares of industry value added, and international trade can influence the environmental quality in Malaysia in the short run. The study also observed a feedback effect from carbon dioxide emissions on all these variables, meaning that the total emissions of carbon dioxide in the country can affect the pace of economic growth, alter the energy mix in the country, influence the share of manufacturing and services sectors to GDP, and can affect the international trade patterns in the country to be more import or export oriented. It is very general that economic growth can influence the environmental quality, but the feedback effect of environment toward the economic growth of the country may be in the shape of the health of people which can cause the changes in the productivity, thus, economic growth. Similarly, the feedback relationship between energy consumption and carbon emissions concludes that carbon emissions can alter the energy mix by targeting the renewables and low-emitting technologies.

The short-run results of the study further reveal that population density can cause the carbon emissions unidirectionally, meaning that increase or decrease in the population may be one of the sources that can affect the environmental quality. The results also observed a bidirectional relationship between population density and energy consumption and between population density and international trade. The feedback relationship between population density and energy consumption is very general and can be justified as an increase in the population of the country will increase the consumption of the energy resources in the economy. On the other hand, energy consumption can also influence the population density, as there will be more energy consumption and there will be more food production and other goods the people need. With these good available, the population will grow, as more energy consumption leads to more economic growth, which in turn increases the population growth. The results also reveal that CO_2 emissions, economic growth, and structural changes in the economy unidirectionally cause the population density.

Table 5 Short-run Granger causality results (Wald *F*-statistics)

	$\Delta lnCO_2$	ΔlnEC	ΔlnGDP	$\Delta lnGDP^2$	ΔlnINDVA	ΔlnTrade	ΔlnPop
$\Delta lnCO_2$	–	10.37 (0.003)***	33.95 (0.000)***	31.14 (0.000)***	39.96 (0.000)***	43.95 (0.000)***	147.58 (0.000)***
ΔlnEC	15.74 (0.000)***	–	12.47 (0.001)***	5.17 (0.03)**	16.66 (0.000)***	20.98 (0.000)***	11.68 (0.009)***
ΔlnGDP	6.60 (0.016)***	3.79 (0.03)**	–	12,668.27 (0.000)***	5.02 (0.007)***	4.190 (0.02)**	7.46 (0.009)***
$\Delta lnGDP^2$	6.09 (0.02)**	5.97 (0.007)***	15,578.78 (0.000)***	–	9.46 (0.000)***	5.73 (0.008)***	29.29 (0.000)***
ΔlnINDVA	353.78 (0.000)***	9.61 (0.000)***	0.30 (0.587)	2.78 (0.06)*	–	38.18 (0.000)***	112.99 (0.000)***
ΔlnTrade	7.86 (0.000)***	20.97 (0.000)***	41.22 (0.000)***	39.19 (0.000)***	15.21 (0.000)***	–	4.93 90.03)**
ΔlnPop	1.10 (0.99)	3.23 (0.05)*	1.55 (0.22)	2.13 (0.13)	0.16 (0.68)	4.82 (0.015)**	–

*, **, *** represent the significance level at 10%, 5%, and 1%, respectively

The long-run results of the Granger causality test reveal that carbon emissions and energy consumption has the feedback relationship between them, meaning that energy consumption and carbon emission can cause each other in the long run. This outcome is in line with the previous work of Ali et al. (2016) and Saboori and Sulaiman (2013a, b) in Malaysia, and Pao and Tsai (2011) for Brazil. The result of the study deduces that in the current setup of the energy mix in Malaysia, decoupling of the carbon emissions is very difficult. This outcome indicates that energy consumption can influence carbon emissions which is very common as an increase in energy consumption will emit more carbon dioxide into the atmosphere and will increase the CO_2 concentration. On the other hand, more carbon emissions in an economy can also influence the energy mix in the country, as more environmental pollution will force the government and regulatory bodies to implement strict environmental regulations which will limit the energy use of non-renewable resources and will focus more on the renewables. The long-run Granger causality results also revealed a bidirectional causality between structural changes in the economy and carbon emissions, meaning that carbon emissions and industry value added of the country can influence each other significantly. This outcome of the study is supporting the previous work of Al-Mulali and Ozturk (2015) in MENA countries. This outcome of the feedback relationship between industry value added and carbon emissions can be justified as more industrial production especially in the energy-intensive manufacturing sector could lead to an increase in the concentration of carbon emissions and also the industrial waste can deteriorate the clean water reservoirs. On the other hand, when there will be more environmental pollution, the government, policy makers, and regulatory bodies will focus more on the less polluting and less energy-intensive industrial production, i.e., a shift from more manufacturing activities toward less polluting services sector to minimize the environmental pollution. Thus, this outcome can alter the share of manufacturing and services sector to total GDP in the country. The long-run causality results also revealed a bidirectional causality relationship between energy consumption and structural changes in the economies, meaning that changes in the pattern of the current energy mix can affect the manufacturing and services sector activities in the country as energy is the sole component of all the activities in the industrial sector of the economy. On the other hand, changes in the activities and patterns of industrial sector of the economy can increase or decrease the consumption of energy resources, as a shift from agriculture to manufacturing sector can enhance the energy use and a further shift from manufacturing sector to services sector, which is less energy intensive and more information based, can decrease the energy use to some extent.

The long-run results of the study further revealed unidirectional causalities running from economic growth and the quadratic term of economic growth toward environmental

Table 6 Granger causality relationship flows

Variables	Short-run Granger causality results	Long-run Granger causality results	ECT(−1) (*t*-statistics)
$lnCO_2$	EC, INDVA,GDP, GDP^2 Trade, Pop → CO_2		−0.2514 (−2.28)**
lnEC	CO_2, GDP, GDP^2, INDVA, Trade, Pop → EC	EC ↔ CO_2, INDVA	−0.2904 (−3.77)***
lnGDP	CO_2, EC, GDP^2, INDVA, Trade, Pop → GDP	GDP → CO_2	−0.0343 (−0.68)
$lnGDP^2$	CO_2, EC, GDP, INDVA, Trade, Pop → GDP^2	GDP^2 → CO_2	−0.5735 (−0.66)
lnINDVA	CO_2, EC, GDP^2, Trade, Pop → INDVA	INDVA ↔ CO_2, EC	−0.1079 (−2.13)**
lnTrade	CO_2, EC, GDP, GDP^2, INDVA, Pop → Trade	Trade → CO_2, EC	0.1101 (1.31)
lnPop	EC, Trade → Pop	Pop → EC, CO_2	0.0016 (3.84)

*, **, *** represent the significance level at 10%, 5%, and 1%, respectively

pollution and energy consumption. This outcome of the study is similar to the work of Govindaraju and Tang (2013) in India and China, and Hatzigeorgiou et al. (2011) in Greece. These outcomes of the study infer that the economic growth of the country should not slow down the pace of economic growth and at the same time carbon emissions should not be a limiting factor toward economic growth in Malaysia. Similarly, the study observed a long-run unidirectional causality running from international trade and population density toward carbon emissions in the country. The results indicate that openness to international trade can influence the environmental quality via scale effect as international trade enhances the economic growth of the country. This outcome of the study is in line with the work of Farhani et al. (2014) in Tunisia. Last but not the least, the study observed unidirectional causalities running from population density toward energy consumption and environmental pollution in the long run. This outcome can be justified as there will be more population in an area and there will be more energy use to meet the energy demand for production and other economic activities. Similarly, an increase in the population density in an area can influence the carbon emissions considering the economic and industrial activities, cultural preferences, and technology use in the country. Furthermore, the study exposes a unidirectional causal relationship from trade opens toward industry value added, meaning that the structural change opportunities can be enhanced via international trade to attract more investors to invest in the industrial sector of the economy by targeting the production of the economy, so a shift in production may occur. The outcome of the study can be supported by the previous work of Ederington et al. (2004) who argued that structural changes in the economy may be because of the international trade, as the composition of industries can be directly affected by the international demand, thus trade. Last but not the least, the study also noted that industry value added can be influenced by the changes in the population density, as a more populated area will favor the shift of labor toward more capital-intensive industry from a more labor-intensive industry, which may increase the productivity and, thus, can shift the course of the production. The study did not observe any causal relationship between international trade, population, and economic growth in the long run.

Robustness analysis

Dynamic ordinary least squared (DOLS) model

The study further applied another single equation estimator technique of DOLS to countercheck the long-run estimates of the ARDL approach if they are robust. DOLS technique can be applied regardless of the order of integration of the variables in the cointegrated framework and prefer the mixed order of integration for analysis. The estimation of the DOLS test regresses the $I(1)$ variables against other $I(1)$ variables by applying leads (p) and lags of first difference (_p) and the other variables in the model have the integration order of $I(0)$ with a constant term included (Alcántara and Padilla 2009). Since the integration order of the study variables is mixed, i.e., $I(1)$ and $I(0)$, the test regresses these variables against the other $I(1)$ and $I(0)$ variables with leads (p) and lags (_p) to measure the long-run robust estimates. DOLS technique is preferred over other techniques due to its ability to solve the problem of small sample biases and the possible endogeneity problems.

The DOLS technique estimated the efficient cointegrating vectors and significant long-run estimates consistent with the long-run estimates of the ARDL approach. The study observed that the estimates are significant and the signs of the coefficient are identical to those of the ARDL long-run estimates. All the coefficients of the variables become more significant, and there is a little change in the values of the coefficients. The results of the DOLS test are presented in Table 7.

Summary and conclusions

The current study investigated the long-run relationship between carbon emissions, structural change, economic growth, energy consumption, trade openness, and population density in Malaysia over a period 1971–2013. The study analyzed the long-run relationship by focusing on the role of structural change in the environmental perspective and investigated the presence of EKC relationship between income and pollution. The ARDL approach observed the presence of long-run relationship between carbon emissions and its determinants in Malaysia but did not witness the presence of EKC relationship between income per capita (higher per capita income/GDP^2) and carbon dioxide per capita in the long run. The study adopted the turning point formula of the EKC presented by Itkonen (2012) and found that in the biased version of Itkonen

Table 7 Results of DOLS model

Variable	Coefficient	SE	Probability
lnEC	1.615504	0.272626	0.0000***
lnGDPPc	27.18238	5.882110	0.0003***
lnGDP^2	−1.659486	0.362120	0.0004***
lnINDVA	−4.964424	0.682488	0.0000***
lnTrade	1.205324	0.170249	0.0000***
lnPop	−0.513069	0.368217	0.1838
C	−104.4216	22.53586	0.0003***

*** represents 1% level of significance

(2012), the turning point of the EKC arrives in the later period and at higher per capita income than the unbiased (conventional) formula of the turning point of EKC. The results of the study revealed a positive relationship between energy consumption and carbon dioxide emissions in the short and long run, meaning that energy consumption in Malaysia is at the cost of environmental quality. This outcome is very common in the case of Malaysia as the country is dependent on the non-renewable energy resources, including coal, gas, and oil, among others. The results suggest that the government of Malaysia should revise the pricing mechanism of energy to stimulate and reassure energy efficiency in the industrial, commercial, and residential sectors. This outcome of the study suggests that decoupling the carbon emissions in the presence of the current energy mix in Malaysia is not possible as more than 90% of the energy demand is met by non-renewable energy resources. Thus, the policy makers should focus on other alternate policies, including the conservation of energy, encouraging the efficient use of energy, decreasing the intensity of the non-renewable energy, and focusing more on the utilization of cleaner and greener sources of energy including biomass, hydro, wind, and solar energy.

The results further claimed that structural shift from manufacturing sector toward services sector in the economy can improve environmental quality as services sector activities are less energy intensive and more information based. In the case of Malaysia, the country is in the stage of transition from developing to a fully developed nation; the country has moved from more manufacturing (energy-intensive) sector to services (less-polluting) sector, thus, reduced the environmental pollution. The results thus suggest that the government should encourage the investments in the services sector of the industry to improve its performance and to make sure the share of the services sector to GDP is far greater than the manufacturing share of GDP. The results suggest that there should be more investment in the innovation-based activities and services to enhance the production capacity. Investments in less-polluting industries rather than polluting capital industries and environmentally friendly projects by multinational companies can also help reduce the environmental pollution. The study suggests that the policy makers should emphasize on distribution, transportation, and sale of the goods from producer to consumers by providing the services of retailing and wholesaling facilities rather than manufacturing these goods which emit pollutants in the atmosphere. The government should also encourage the multinational companies to invest in knowledge- and information-based industrial sector activities and to share the corresponding know-how and technology transfer.

The study further observed that international trade and economic growth are polluting the environment in Malaysia, and this result can be connected to the trade theory of Heckscher and Ohlin, which stated that the country will specialize in the factors that are abundant in the economy and are easy to approach regardless of their polluting capacity.[3] The study thus suggests that government and policy makers should focus more on the export-oriented trade rather than the dirty imports from developed economies. The government should impose some tight trade limitation on the imports of the high energy-intensive products and on the investments in the domestic production of energy-intensive products. The impact of trade openness on the environment depends upon some factors in the country, thus, the government should focus to improve the level of development, comparative advantages to be more services oriented, trade of less energy-intensive products, improvement of environmental awareness, and implementation of environmental policies. The results also concluded that population density in the case of Malaysia has no environmentally polluting effect and there is a negative relationship between population density and carbon emissions. This outcome thus suggests that population per square area is not a big concern for Malaysia as there is no denser population in Malaysia relative to other neighboring countries, including Indonesia, Singapore, and Thailand. On the other hand, population density has its own characteristics regarding the energy consumption. In the case of energy use, a denser population in an area may be useful to improve the economics of the system of public transport, thus, can minimize the per capita per kilometer energy consumption in such places. Similarly, other attributes of a multi-family system in a populated area can also improve the energy efficiency relative to single-family houses.

The study found a bidirectional causal relationship between energy use and carbon emissions both in the short and long run in Malaysia. This feedback relationship between the variables suggests that there is a dire need to refurbish some energy-related policy reforms to ensure the installations of some new technologies that are energy efficient. This bidirectional relationship reveals that energy conservation is not a good option in the country. The results reveal that the country should focus more on decreasing the intensive use of non-renewable energy and utilize the greener sources of energy, including solar energy, wind energy, hydropower, and biomass, among others. The results also reveal a bidirectional feedback causal relationship between structural change and carbon emissions in the country both in the short and long run. This feedback relationship between the variables suggests that the government, regulatory bodies, and industrialists should focus more on the provision of those services which

[3] Malaysia is a labor-intensive country, so exports and imports that are capital intensive in developed economies of the world are labor intensive in Malaysia, e.g., electrical machinery, mineral fuels, chemicals, and plastic products, among others, are capital-intensive export in developed economies (Singapore, USA, UK, etc.), while in Malaysia it is more labor intensive due to the abundant labor factor endowments. So, more resources will be wasted as the efficiency of a machine is better than man.

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are less polluting and environment friendly rather than energy-intensive manufacturing activities. The causality results further implicate that economic growth and trade openness is at the cost of environmental quality as economic growth and trade openness are unidirectionally causing CO_2 emission and energy consumption in the long run. These outcomes reveal that CO_2 emissions and energy use can be minimized by focusing more on the energy-efficient economic activities and changes in the international trade patterns. Finally, the empirical findings of the DOLS replicate the outcomes of the long-run ARDL approach and confirmed the existence of long-run relationship between the variables with the same signs as ARDL with more robust estimates.

The current study can be helpful to policy makers, regulatory bodies, and future researchers as there are some good theoretical and practical implications of the results from the environmental perspective. This work can be extended further in the future by emphasizing the technological innovation, as structural changes in the economy along with the modern technology can affect the environmental quality in a more better way as per the theory of ecological modernization.

References

Acaravci A, Ozturk I (2010) On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. Energy 35(12):5412–5420. doi:10.1016/j.energy.2010.07.009

Agras J, Chapman D (1999) A dynamic approach to the Environmental Kuznets Curve hypothesis. Ecol Econ 28(2):267–277. doi:10.1016/S0921-8009(98)00040-8

Al-Mulali U, Fereidouni HG, Lee JYMM, Sab CNBC (2013) Exploring the relationship between urbanization, energy consumption, and CO_2 emission in MENA countries. Renew Sust Energ Rev 23:107–112. doi:10.1016/j.rser.2013.02.041

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. doi:10.1016/j.energy.2015.03.004

Al-mulali U, Saboori B, Ozturk I (2014) Investigating the environmental Kuznets curve hypothesis in Vietnam. Energy Policy 76:123–131. doi:10.1016/j.enpol.2014.11.019

Alcántara V, Padilla E (2009) Input-output subsystems and pollution: an application to the service sector and CO_2 emissions in Spain. Ecol Econ 68(3):905–914. doi:10.1016/j.ecolecon.2008.07.010

Ali W, Abdullah A, Azam M (2016) The dynamic linkage between technological innovation and carbon dioxide emissions in Malaysia: an autoregressive distributed lagged bound approach. Int J Energy Econ Policy 6(3):389–400

Ali W, Abdullah A, Azam M (2017) Re-visiting the environmental Kuznets curve hypothesis for Malaysia: fresh evidence from ARDL bounds testing approach. Renew Sust Energ Rev. doi:10.1016/j.rser.2016.11.236

Ang JB (2007) CO_2 emissions, energy consumption, and output in France. Energy Policy 35(10):4772–4778. doi:10.1016/j.enpol.2007.03.032

Ang JB (2009) CO_2 emissions, research and technology transfer in China. Ecol Econ 68:2658–2665

Antweiler W, Copeland BR, Taylor MSMS (2001) Is free trade good for the environment? Am Econ Rev 91(4):877–908. doi:10.1257/aer.91.4.877

Apergis N, Payne JE (2009) CO_2 emissions, energy usage, and output in Central America. Energy Policy 37(8):3282–3286. doi:10.1016/j.enpol.2009.03.048

Apergis N, Payne JE (2010a) The causal dynamics between coal consumption and growth: evidence from emerging market economies. Appl Energy 87(6):1972–1977. doi:10.1016/j.apenergy.2009.11.035

Apergis N, Payne JE (2010b) The emissions, energy consumption, and growth nexus: evidence from the commonwealth of independent states. Energy Policy 38:650–655. doi:10.1016/j.enpol.2009.08.029

Azam M (2016) Does environmental degradation shackle economic growth? A panel data investigation on 11 Asian countries. Renew Sust Energ Rev 65:175–182. doi:10.1016/j.rser.2016.06.087

Azam M, Khan AQ (2016) Testing the Environmental Kuznets Curve hypothesis: a comparative empirical study for low, lower middle, upper middle and high income countries. Renew Sust Energ Rev 63:556–567. doi:10.1016/j.rser.2016.05.052

Azam M, Qayyum A, Zaman K, Ahmad M (2015) Factors determining energy consumption: evidence from Indonesia, Malaysia and Thailand. Renew Sust Energ Rev 42(2015):1123–1131. doi:10.1016/j.rser.2014.10.061

Copeland B, Taylor S (2004a) Trade and the environment: theory and evidence. World Trade Review 3(2):330–332. doi:10.1017/S1474745604221905

Baek J, Kim HS (2013) Is economic growth good or bad for the environment? Empirical evidence from Korea. Energy Econ 36:744–749. doi:10.1016/j.eneco.2012.11.020

Banerjee A, Dolado J, Mestre R (1998) Error-correction mechanism tests for cointegration in a single-equation framework. J Time Ser Anal 19(3):267–283. doi:10.1111/1467-9892.00091

Begum RA, Sohag K, Abdullah SMS, Jaafar M (2015) CO_2 emissions, energy consumption, economic and population growth in Malaysia. Renew Sust Energ Rev 41:594–601. doi:10.1016/j.rser.2014.07.205

Bongaarts J (1992) Population growth and global warming. Popul Dev Rev 18(2):299–319

Copeland BR, Taylor MS (1994) North-South trade and the environment. Q J Econ 109(3):755–787

Brock WA, Taylor MS (2005) Economic growth and the environment. Handbook of Economic Growth, Volume 1(Part B):1749–1821. doi:10.1016/S1574-0684(05)01028-2

Brown RL, Durbin J, Evans JM (1975) Techniques for testing the constancy of regression relationships over time. J R Stat Soc Ser B Methodol 37(2):149–192

Charfeddine L, Ben Khediri K (2016) Financial development and environmental quality in UAE: cointegration with structural breaks. Renew Sust Energ Rev 55:1322–1335. doi:10.1016/j.rser.2015.07.059

Chichilnisky G (1994) North-South trade and the global environment. Am Econ Rev 84(4):851–874

Copeland BR, Taylor MS (2004b) Trade, growth, and the environment. J Econ Lit XLII:7–71

De Bruyn SM, Van Den Bergh JCJM, Opschoor JB (1998) Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves. Ecol Econ 25(2):161–175. doi:10.1016/S0921-8009(97)00178-X

Dinda S (2004) Environmental Kuznets curve hypothesis: a survey. Ecol Econ. doi:10.1016/j.ecolecon.2004.02.011

Ederington J, Minier J, Levinson A (2004) Trade liberalization and pollution havens. Advances in Economic Analysis & Policy 4(2):1–22. doi:10.2202/1538-0637.1330

El Hedi Arouri M, Youssef AB, Hatem MM, Christophe Rault H, Tunis ESC (2012) Energy consumption, economic growth and CO_2 emissions in Middle East and North African countries. Energy Policy 45: 342–349. doi:10.1016/j.enpol.2012.02.042

Engle RF, Granger CWJ (1987) Co-integration and error correction: representation, estimation, and testing. Econometrica 55(2):251–276. doi:10.2307/1913236

Farhani S, Chaibi A, Rault C (2014) CO_2 emissions, output, energy consumption, and trade in Tunisia. Econ Model 38:426–434. doi:10.1016/j.econmod.2014.01.025

Farhani S, Ozturk I (2015) Causal relationship between CO_2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22(20): 15663–15676. doi:10.1007/s11356-015-4767-1

Ghosh S (2010) Examining carbon emissions economic growth nexus for India: a multivariate cointegration approach. Energy Policy 38(6): 3008–3014. doi:10.1016/j.enpol.2010.01.040

Govindaraju CVGR, Tang CF (2013) The dynamic links between CO_2 emissions, economic growth and coal consumption in China and India. Appl Energy 104:310–318. doi:10.1016/j.apenergy.2012.10.042

Grossman GM, Krueger AB (1991) Environmental impacts of a North American Free Trade Agreement. National Bureau of Economics Research Working Paper, No. 3194, NBER, Cambridge 57

Grossman GM, Krueger AB (1995) Economic growth and the environment. Q J Econ 110(2):353–377

Halicioglu F (2009) An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. Energy Policy 37(3):1156–1164. doi:10.1016/j.enpol.2008.11.012

Hatzigeorgiou E, Polatidis H, Haralambopoulos D (2011) CO_2 emissions, GDP and energy intensity: a multivariate cointegration and causality analysis for Greece, 1977–2007. Appl Energy 88(4):1377–1385. doi:10.1016/j.apenergy.2010.10.008

Heidari H, Turan Katircioğlu S, Saeidpour L (2015) Economic growth, CO_2 emissions, and energy consumption in the five ASEAN countries. Electrical Power & Energy Systems 64:785–791. doi:10.1016/j.ijepes.2014.07.081

Hettige H, Mani M, Wheeler D (2000) Industrial pollution in economic development: the environmental Kuznets curve revisited. J Dev Econ 62(2):445–476. doi:10.1016/S0304-3878(00)00092-4

Holtz-Eakin D, Selden TM (1995) Stoking the fires? CO_2 emissions and economic growth. J Public Econ 57(1):85–101. doi:10.1016/0047-2727(94)01449-X

Itkonen JVA (2012) Problems estimating the carbon Kuznets curve. Energy 39(1):274–280. doi:10.1016/j.energy.2012.01.018

Jayanthakumaran K, Verma R, Liu Y (2012) CO_2 emissions, energy consumption, trade and income: a comparative analysis of China and India. Energy Policy 42:450–460. doi:10.1016/j.enpol.2011.12.010

Johansen S, Juselius K (1990) Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. Oxf Bull Econ Stat. doi:10.1111/j.1468-0084.1990.mp52002003.x

Jorgenson AK, Clark B (2010) Assessing the temporal stability of the population/environment relationship in comparative perspective: a cross-national panel study of carbon dioxide. Population Environment 32:27–41. doi:10.1007/s11111-010-0117-x

Kaika D, Zervas E (2013) The Environmental Kuznets Curve (EKC) theory—Part A: concept, causes and the CO_2 emissions case. Energy Policy 62:1392–1402. doi:10.1016/j.enpol.2013.07.131

Kaivo-oja J, Luukkanen J, Panula-Ontto J, Vehmas J, Chen Y, Mikkonen S, Auffermann B (2014) Are structural change and modernisation leading to convergence in the CO_2 economy? Decomposition analysis of China, EU and USA. Energy 72:115–125. doi:10.1016/j.energy.2014.05.015

Kijima M, Nishide K, Ohyama A (2010) Economic models for the environmental Kuznets curve: a survey. J Econ Dyn Control 34(7): 1187–1201. doi:10.1016/j.jedc.2010.03.010

Kivyiro P, Arminen H (2014) Carbon dioxide emissions, energy consumption, economic growth, and foreign direct investment: causality analysis for sub-Saharan Africa. Energy 74:595–606. doi:10.1016/j.energy.2014.07.025

Lantz V, Feng Q (2006) Assessing income, population, and technology impacts on CO_2 emissions in Canada: where's the EKC? Ecol Econ 57(2):229–238. doi:10.1016/j.ecolecon.2005.04.006

Lau L-SS, Choong C-KK, Eng Y-KK (2014) Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: do foreign direct investment and trade matter? Energy Policy 68(1998): 490–497. doi:10.1016/j.enpol.2014.01.002

Lean HH, Smyth R (2010) CO_2 emissions, electricity consumption and output in ASEAN. Appl Energy 87(6):1858–1864. doi:10.1016/j.apenergy.2010.02.003

Liddle B (2015) What are the carbon emissions elasticities for income and population? Bridging STIRPAT and EKC via robust heterogeneous panel estimates. Glob Environ Chang 31:62–73. doi:10.1016/j.gloenvcha.2014.10.016

Ling CH, Ahmed K, Binti Muhamad R, Shahbaz M (2015) Decomposing the trade-environment nexus for Malaysia: what do the technique, scale, composition, and comparative advantage effect indicate? Environ Sci Pollut Res 22(24):20131–20142. doi:10.1007/s11356-015-5217-9

López RE, Anríquez G, Gulati S (2007) Structural change and sustainable development. J Environ Econ Manag 53:307–322. doi:10.1016/j.jeem.2006.10.003

Luukkanen J, Panula-Ontto J, Vehmas J, Liyong L, Kaivo-oja J, Häyhä L, Auffermann B (2015) Structural change in Chinese economy: impacts on energy use and CO_2 emissions in the period 2013–2030. Technol Forecast Soc Chang 94:303–317. doi:10.1016/j.techfore.2014.10.016

Managi S, Hibiki A, Tsurumi T (2009) Does trade openness improve environmental quality? J Environ Econ Manag 58(3):346–363. doi:10.1016/j.jeem.2009.04.008

Márquez-Ramos L (2015) The relationship between trade and sustainable transport: a quantitative assessment with indicators of the importance of environmental performance and agglomeration externalities. Ecol Indic 52:170–183. doi:10.1016/j.ecolind.2014.11.023

Marsiglio S, Ansuategi A, Gallastegui MC (2016) The environmental Kuznets curve and the structural change hypothesis. Environ Resour Econ 63(2):265–288. doi:10.1007/s10640-015-9942-9

Martínez-Zarzoso I, Bengochea-Morancho A, Morales-Lage R (2007) The impact of population on CO_2 emissions: evidence from European countries. Environ Resour Econ 38(4):497–512. doi:10.1007/s10640-007-9096-5

McMillan M, & Rodrik D (2011) Globalization, structural change and productivity growth. Making globalization socially sustainable. Retrieved from http://www.nber.org/papers/w17143

McMillan MS, Rodrick D (2011) Globalization, structural change and productivity growth. NBER Working Paper Series. Retrieved from http://www.nber.org/papers17143

Menyah K, Wolde-Rufael Y (2010) CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy 38(6):2911–2915. doi:10.1016/j.enpol.2010.01.024

Mugableh MI (2013) Analysing the CO_2 emissions function in Malaysia: autoregressive distributed lag approach. Procedia Economics and Finance 5(13):571–580. doi:10.1016/S2212-5671(13)00067-1

Narayan PK (2005) The saving and investment nexus for China: evidence from cointegration tests. Appl Econ 37(17):1979–1990. doi:10.1080/00036840500278103

Omri A (2013) CO_2 emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models. Energy Econ 40:657–664. doi:10.1016/j.eneco.2013.09.003

Omri A, Daly S, Rault C, Chaibi A (2015) Financial development, environmental quality, trade and economic growth: what causes what in MENA countries. Energy Econ 48:242–252. doi:10.1016/j.eneco.2015.01.008

Ouattara B (2004) Modelling the long run determinants of private investment in Senegal. Centre for Research in Economic Development and International Trade, 37. Retrieved from http://sci-hub.cc/http://econpapers.repec.org/RePEc:man:sespap:0413

Ozturk I, Acaravci A (2013) The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. Energy Econ 36(c):262–267. doi:10.1016/j.eneco.2012.08.025

Panayotou T (2000) Economic Growth and the Environment. CID Working Paper No. 56

Panayotou T (2003) Economic Growth and the Environment 2003. Economic Survey of Europe. In *UNECE* 2

Pao H-T, Tsai C-M (2010) CO_2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy 38(12):7850–7860. doi:10.1016/j.enpol.2010.08.045

Pao H-T, Tsai C-M (2011) Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. Energy 36(5):2450–2458. doi:10.1016/j.energy.2011.01.032

Pearce F (2010) Peoplequake: Mass migration, ageing nations and the coming population crash. London: Eden Project Books, p 122.

Pesaran M, Pesaran B (1997) Working with Microfit 4.0: interactive economic analysis. Oxford University Press

Pesaran MH, Shin Y, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Econ 16(3):289–326. doi:10.1002/jae.616

Pethig R (1976) Pollution, welfare, and environmental policy in the theory of comparative advantage. J Environ Econ Manag 2(3):160–169. doi:10.1016/0095-0696(76)90031-0

Pezzey J (1992) Analysis of unilateral CO_2 control in the European Community and OECD. Energy J 13:159–171

Richmond AK, Kaufmann RK (2006) Is there a turning point in the relationship between income and energy use and/or carbon emissions? Ecol Econ 56(2):176–189. doi:10.1016/j.ecolecon.2005.01.011

Saboori B, Sulaiman J (2013a) CO_2 emissions, energy consumption and economic growth in Association of Southeast Asian Nations (ASEAN) countries: a cointegration approach. Energy 55:813–822. doi:10.1016/j.energy.2013.04.038

Saboori B, Sulaiman J (2013b) Environmental degradation, economic growth and energy consumption: evidence of the environmental Kuznets curve in Malaysia. Energy Policy 60:892–905. doi:10.1016/j.enpol.2013.05.099

Saboori B, Sulaiman JB, Mohd S (2012) An empirical analysis of the environmental Kuznets curve for CO_2 emissions in Indonesia: the role of energy consumption and foreign trade. International Journal of Economics and Finance 4(2):243–251. doi:10.5539/ijef.v4n2p243

Sbia R, Shahbaz M, Hamdi H (2014) A contribution of foreign direct investment, clean energy, trade openness, carbon emissions and economic growth to energy demand in UAE. Econ Model 36:191–197. doi:10.1016/j.econmod.2013.09.047

Shafik N (1994) Economic development and environmental quality: an econometric analysis. Oxf Econ Pap 46:757–773

Shafik N, Bandyopadhyay S (1992) Economic growth and environmental quality: time series and cross section evidence policy. Research Working Paper No. WPS904, The World Bank

Shahbaz M (2013) Does financial instability increase environmental degradation? Fresh evidence from Pakistan. Econ Model 33:537–544. doi:10.1016/j.econmod.2013.04.035

Shahbaz M, Kumar Tiwari A, Nasir M (2013a) The effects of financial development, economic growth, coal consumption and trade openness on CO_2 emissions in South Africa. Energy Policy 61:1452–1459. doi:10.1016/j.enpol.2013.07.006

Shahbaz M, Leitão CN (2013) Portuguese carbon dioxide emissions and economic growth: a time series analysis. Bulletin of Energy Economics 1:1–7

Shahbaz M, Muhammad QAH, Tiwari AK, Leitão NC (2013b) Economic growth, energy consumption, financial development, international trade and CO_2 emissions in Indonesia. Renew Sust Energ Rev 25:109–121. doi:10.1016/j.rser.2013.04.009

Shahbaz M, Salah Uddin G, Ur Rehman I, Imran K (2014) Industrialization, electricity consumption and CO_2 emissions in Bangladesh. Renew Sust Energ Rev 31:575–586. doi:10.1016/j.rser.2013.12.028

Shahzad SJH, Kumar RR, Zakaria M, Hurr M (2017) Carbon emission, energy consumption, trade openness and financial development in Pakistan: a revisit. Renew Sust Energ Rev 70:185–192. doi:10.1016/j.rser.2016.11.042

Sharif Hossain M (2011) Panel estimation for CO_2 emissions, energy consumption, economic growth, trade openness and urbanization of newly industrialized countries. Energy Policy 39(11):6991–6999. doi:10.1016/j.enpol.2011.07.042

Singh K (2011) India's emissions in a climate constrained world. Energy Policy 39(6):3476–3482. doi:10.1016/j.enpol.2011.03.046

Smulders S (2004) Endogenous Technical Change, Natural Resources and Growth. In Scarcity and Growth in the New Millennium, Resources for the Future. (pp. 156–177)

Smulders S, Bretschger L (2000) Explaining environmental Kuznets curves: how pollution induces policy and new technologies. ECONSTAR Working Paper

Soytas U, Sari R (2009) Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member. Ecol Econ 68(6):1667–1675. doi:10.1016/j.ecolecon.2007.06.014

U.S. Energy Information Agency (2013) International Energy Outlook 2013. Outlook 2013. Retrieved from http://www.eia.gov/forecasts/ieo/pdf/0484(2013).pdf

Wang SS, Zhou DQ, Zhou P, Wang QW (2011) CO_2 emissions, energy consumption and economic growth in China: a panel data analysis. Energy Policy 39(9):4870–4875. doi:10.1016/j.enpol.2011.06.032

Yunfeng Y, Yang L (2010) China's foreign trade and climate change: a case study of CO_2 emissions. Energy Policy 38(1):350–356. doi:10.1016/j.enpol.2009.09.025

You W-H, Zhu H-M, Yu K, Peng C (2015) Democracy, financial openness, and global carbon dioxide emissions: heterogeneity across existing emission levels. World Dev 66:189–207. doi:10.1016/j.worlddev.2014.08.013

Zhang X-P, Cheng X-M (2009) Energy consumption, carbon emissions, and economic growth in China. Ecol Econ 68(10):2706–2712. doi:10.1016/j.ecolecon.2009.05.011