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The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries

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ABSTRACT

This study aims to analyze the relationship between carbon dioxide (CO_2) emissions, trade openness, real income and energy consumption in the top ten CO_2 emitters among the developing countries; namely China, India, South Korea, Brazil, Mexico, Indonesia, South Africa, Turkey, Thailand and Malaysia over the period of 1971–2011. In addition, the possible presence of the EKC hypothesis is investigated for the analyzed countries. The Zivot–Andrews unit root test with structural break, the bounds testing for cointegration in the presence of structural break and the VECM Granger causality method are employed. The empirical results indicate that (i) the analyzed variables are co-integrated for Thailand, Turkey, India, Brazil, China, Indonesia and Korea, (ii) real income, energy consumption and trade openness are the main determinants of carbon emissions in the long run, (iii) there exists a number of causal relations between the analyzed variables, (iv) the EKC hypothesis is validated for Turkey, India, China and Korea. Robust policy implications can be derived from this study since the estimated models pass several diagnostic and stability tests.

1. Introduction

Both the volume of international trade and carbon dioxide (CO_2) emissions are simultaneously growing for decades. More precisely, the amount of carbon emissions increased by 75% between 1980 and 2012 according to the U.S. Energy Information Administration (EIA) and the total value of international trade increased by 450% in the same period according to the World Development Indicators (WDI) (EIA, 2013; WDI, 2015). Moreover, not only CO_2 emissions in developing countries have recently gone up at a rapid pace but also carbon emissions in developing countries are anticipated to be 127% higher than in developed countries by 2040 (EIA, 2013: 7).

Some empirical studies (Pao and Tsai, 2010; Alam et al., 2011; Wang et al., 2014) argue that this expectation may occur due to lasting large demands for energy in developing countries while some claim that it may result from free trade policies such that developed countries reduce their dirty-intensive good productions with the advantages of globalization (Carvalho et al., 2013; Shahbaz et al., 2013e). Therefore, important discussions are carried out on the environmental impacts of carbon dioxide emissions embodied in international trade in recent years both in academic and political circles (Mehra and Das, 2008). In this line, Lawrence Summer who was the chief economist of the World Bank further inflamed debates on this issue with the following question "... shouldn't the World Bank be encouraging more migration of the dirty industries to the less developed countries?" (Hausman and McPherson, 2000: 9) According to this view, developing or less developed countries consent to environmental degradation to increase prosperity and life standards through the dirty industries. Therefore, increase in international trade and transfer of production in dirty industries from developed countries to developing and less developed countries, for the sake of tax incentives, inevitably brings along environmental problems. Although developed countries were historically responsible for a large percentage of worldwide emissions, the level of emissions in developing countries appears to be relatively much higher in recent years (IEA, 2014: 13). According to the International Energy Agency (IEA), the total amount of CO_2 emissions emitted by the top 25 countries corresponded to 80% of the 2012 worldwide emissions. Furthermore, 60% of those were caused by

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Table 1
Key indicators of top 25 countries emitting highest CO_2 emissions.

World rank	Total CO_2 Emissions (2012) (million tons) and % change (1990–2012) Source: IEA	CO_2 emissions/GDP (2012) Source: IEA	CO_2 intensity (kg per kg of oil equivalent energy use) (2012) Source: World Bank	Per capita energy consumption (2011) Source: IEA	Openness (Trade/GDP) (2012) Source: World Bank	Per capita GDP (2012) Source: World Bank	GDP (billon) (current, 2012, US$) Source: World Bank
1. China[a]	8250 (262%)	1.73	3.29	2029	45.71	6092	8229
2. United States	5074 (4%)	0.36	2.45	7032	30.6	51,495	16,163
3. India[a]	1954 (236%)	1.41	2.77	613	55.5	1503	1858
4. Russian Fed.	1659 (−23%)	1.69	2.47	5113	51.8	14,090	2017
5. Japan	1223 (15%)	0.26	2.34	3610	31.3	46,679	5954
6. Germany	755 (−20%)	0.25	2.26	3811	85.9	43931	3533
7. Korea, Rep.[a]	592 (158%)	0.55	2.27	5231	109.8	24453	1222
8. Canada	533 (24%)	0.41	1.98	7333	62.0	52,409	1821
9. Iran, Isl. Rep.	532 (197%)	2.17	2.71	2812	–	6578	502
10. Saudi Arabia	458 (203%)	0.92	2.41	6738	83.7	25,945	733
11. United King.	457 (16%)	0.19	2.44	2973	62.5	41,053	2614
12. Brazil[a]	440 (128%)	0.39	1.57	1371	25.2	11,319	2248
13. Mexico[a]	436 (64%)	0.42	2.47	1559	66.3	9817	1186
14. Indonesia[a]	435 (198%)	1.02	2.05	857	49.5	3551	876
15. Australia	386 (48%)	0.42	3.04	5500	42.7	67,524	1534
16. South Africa[a]	376 (48%)	1.22	3.23	2740	60.7	7313	382
17. Italy	374 (−5%)	0.22	2.38	2819	56.1	35,132	2091
18. France	333 (−5%)	0.15	1.38	3869	59.2	40,908	2686
19. Turkey[a]	302 (138%)	0.48	2.83	1539	57.7	10,660	788
20. Poland	293 (−14%)	0.72	3.12	2629	90.3	12879	496
21. Ukraine	281 (−59%)	2.94	2.30	2766	104.0	3873	1766
22. Spain	266 (29%)	0.23	2.11	2686	59.0	28992	1355
23. Thailand[a]	256 (219%)	1.15	2.51	1789	148.8	5479	365
24. Kazakhstan	225 (−4%)	2.59	3.34	4717	75.5	12,120	203
25. Malaysia[a]	195 (288%)	0.99	2.98	2639	158.9	10,439	305

Note: Using IEA (2014) and WDI (2015), the table is composed by authors.
[a] The developing countries analyzed in this study.

developing countries. Furthermore, it is expected that 80% of the global emissions will be emitted by developing countries in the near future (Huwart and Verdier, 2013). On the contrary, non-Annex-I parties in the Kyoto protocol are mostly developing countries with no obligation to reduce carbon emissions. Yet, the responsibilities of developing countries about the environment have not been intensively discussed at a global framework.

Table 1 shows the main indicators of the top 25 CO_2 emitters in 2012. As one can realize that the percentage increases in CO_2 emissions of developing countries between 1990 and 2012 are more than those of developed countries.[2] On the other side, developed countries had a lower CO_2/GDP ratio than developing countries. This may happen since developed countries in Annex-I made commitments to the Kyoto protocol so as to lower the level of CO_2 emissions while developing countries did not. There are mainly two possible reasons why developing countries did not want to assume obligations in these issues. First, developing countries historically contributed to global CO_2 emissions less than developed countries. Second, developing countries believed that environmental regulations would negatively affect their economic growth.

There is another dimension in this carbon emissions problem. The downward trend in gas emissions in developed countries as a result of the policies implemented with regard to the first commitments period of the Kyoto Protocol seem to be consistent with the Environmental Kuznets Curve (EKC) hypothesis which claims that increases in income after a certain threshold provide environmental improvements and the relationship of income–environment is an inverted U-shape in the long run. However, developed countries indeed reduce their own national gas emissions since they shift their dirty industries to developing countries through the globalization and freer trade according to Carvalho et al. (2013). Therefore, international organizations should consider the problem of *outside pollution* when discussing global environmental problems (Guo et al., 2010). This emerging dilemma with international trade is explained by *pollution-haven hypothesis.* This hypothesis implies that demand for a cleaner environment increases as per capita income raises, and thus dirty industries in developed countries are looking for other places with less environmental standards (Kukla-Gryz, 2009). People living in developing and less developed countries are believed to have less environmental concerns than those in developed countries wherein the former group more cares about increases in income and welfare (Tang, 2015). In response to the desires of population, these pollution-haven countries usually prefer higher levels of income to higher levels of environmental quality.

The fact that Annex-I countries made environmental regulations in accordance with the Kyoto Protocol and host countries for the dirty industries (developing or less developed economies) apply low environmental standards in order to ensure competitive advantage, and thus the carbon-intensive productions flow from developed countries to their own lands. As a result, gas emissions follow an increasing trend in developing countries while CO_2 emissions decline in countries with more stringent regulations. This effect is called as *carbon leakage* in the literature (Kuik and Gerlagh, 2003). According to this view, free trade reveals the impact of *race to bottom* which basically implies that environmental standards in countries decline as long as less environmental standards yield comparative advantages and attract multinational enterprises (Olney, 2013). Hence, unrestricted regulations may lead to an increase in the number of firms producing pollution-intensive export goods and an increase in the volume of dirty-goods

[2] This study uses the World Economic Outlook 2015 published by IMF divides the world into two groups: advanced countries and developing countries. The document is available at the following link: http://www.imf.org/external/pubs/ft/weo/2015/01/weodata/groups.htm (accessed on March 2, 2016).

related foreign direct investment (Kirkpatrick and Scrieciu, 2008).

The net effect of free trade on pollution is ambiguous in general. To explain, the impact of trade openness on the environment depends on the net effect of composition effect, scale effect, and technology effect (Antweiler et al., 2001; Farhani et al., 2014). *Scale effect* indicates that economic growth resulting from trade leads to higher rates of carbon emissions because of more production and energy consumption. But, freer trade and higher income levels can provide environmental improvements at higher levels of development. *Composition effect* argues that countries change their composition of production based on the comparative advantage approach. If the demand for traded goods produced by polluting methods increases, countries tend to produce polluted goods. In practice, this process operates in favor of developed countries. According to Grossman and Krueger (1994), the net composition effect at higher income levels is in the direction of environmental improvements. Last, *technique effect* includes the impacts of transferred know-how and advanced technological production techniques on the environment. Through trade liberalization, the spread of environmentally friendly technologies and energy efficient production technologies among countries can lead to lower emissions. The transfer of renewable energy technologies has recently become more effective in reducing CO_2 emissions in developing countries (Sebri and Ben-Salha, 2014). A closer look to each of these factors, except technology effect, they produce controversial evidences with regard to increase in gas emissions for developed and developing/underdeveloped countries.

Taking these views into consideration, trade openness should be considered as an effective factor on CO_2 emissions (Esty, 2001; Mukhopadhyay, 2007, 2009). A number of studies in the relevant literature include the importance of trade openness in their econometric model (Halicioglu, 2009; Jalil and Mahmud, 2009; Nasir and Rehman, 2011; Jayanthakumaran et al., 2012; Shahbaz et al., 2013a; Farhani et al., 2014; Kasman and Duman, 2015; Dogan et al., 2015; Hua and Boateng, 2015; Dogan and Turkekul, 2016; Dogan and Seker, 2016). However, these studies find controversial results on the net effect of trade openness. Furthermore, a large number of studies use real income (and the square of income) and energy consumption only while analyzing the determinants of CO_2 emissions and the possible presence of the EKC hypothesis (Say and Yucel, 2006; Soytas et al., 2007; Ang, 2008; Apergis and Payne, 2009; Ozturk and Acaravci, 2010a; Pao and Tsai, 2011; Bloch et al., 2012; Omri, 2013; Park and Hong, 2013; Chandran and Tang, 2013; Yavuz, 2014; Farhani and Shahbaz, 2014; Seker et al., 2015; Ajmi et al., 2015). Even though studies, in general, claim that increases in energy consumption can lead to environmental degradation, findings of empirical studies on the coefficient estimate of real income (and the square of real income) are mixed at best. In other words, results for the EKC analysis are controversial as they do not take into account other endogenous variables such as trade (Kukla-Gryz, 2009). Ignoring a relevant independent variable to explain changes in a dependent variable is commonly known as the issue of omitted-variable bias. Based on the facts and theories discussed in the above paragraphs, it can be concluded that the exclusion of trade openness from an econometric model in the energy-environment-growth literature can presumably cause an omitted-variable bias. In addition, the EKC hypothesis is originally based on the study of Grossman and Krueger (1994) which examines the impact of NAFTA free trade zone on the environment claims that free trade has a positive effect on environmental quality because of its income effect.

In light of the above-mentioned arguments, the objective of this study is to investigate the relationship among carbon emissions, economic growth, energy consumption and trade openness in the EKC framework for the ten largest emitters of CO_2 among developing countries over the period 1971–2011.[3] It is worth pointing out that the top ten emitters produced more than 40% of global carbon emissions in 2011 according to the WDI. This study contributes to the literature in several ways. First, to the best of our knowledge, this is the first study that focuses on the top ten developing country emitters by using multi-country time series analysis in the subject matter. Second, the current study employs estimation techniques that account for the presence of structural break in time-series data. Third, this study provides evidence in support of the importance of trade for carbon emissions. Last, it also provides comparison of empirical findings on the analyzed developing countries. The rest of this study is organized as follows. Section 2 presents a review of literature. Section 3 outlines the model, data and methodology. Section 4 reports and discusses the empirical findings and relevant policy implications. The conclusion is provided in Section 5.

2. Literature review

It has become important to analyze the impacts of the potential determinants on the environment in the last few decades. There are numerous empirical studies that use multivariate framework wherein CO_2 emission is the dependent variable, and real GDP, the square of real GDP and energy consumption are independent variables. In addition, many recent studies include relevant additional variables (i.e. international trade) into the multivariate framework (Al-Mulali et al., 2015a; Dogan and Turkekul, 2016). Because of numerous factors such as lack of data, the use of various econometric methods and models, and the exclusion of relevant explanatory variables, satisfactory and consensual results have not been achieved. In addition, the existing studies have found biased and unreliable results because of different perspectives between environmentalist approaches and free trade advocates. However, it nowadays seems more likely to achieve more consistent results through advanced econometric techniques (i.e. econometric tests with structural break) and availability of longer data. The modern literature on this issue goes back to the pioneering work of Grossman and Krueger (1994). After this leading study, the literature on the long-lasting environmental debate can be analyzed by dividing the studies into two strands as in line with this empirical study. Studies that focus on developing or less developed countries are reviewed in the first strand while studies that focus on developed countries in the second category are given in the second strand.

Studies in the first strand examine individual countries (e.g. Turkey, Malaysia, China, India) as well as country groups (e.g. MENA, BRIC, ASEAN) among developing and less developed economies by using different econometric methodologies (e.g. the ARDL method, the Johansen cointegration test, the VECM Granger Causality test). The use of different countries and different methodologies naturally produces mixed results (Glasure, 2002; Ang, 2008; Soytas and Sari, 2009; Akbostanci et al., 2009; Halicioglu, 2009; Jalil and Mahmud, 2009; Narayan and Narayan, 2010; Ozturk and Acaravci, 2010a, 2010b; Jalil and Feridun, 2011; Du et al., 2012; Saboori et al., 2012; Shahbaz et al., 2012; Atici, 2012; Baek and Kim, 2013; Saboori and Sulaiman, 2013a,b; Chandran and Tang, 2013; Kanjilal and Ghosh, 2013; Shahbaz et al., 2013a, 2013b, 2013c; Al-Mulali and Sheau-Ting, 2014; Hwang and Yoo, 2014; Lau et al., 2014; Shahbaz et al., 2014a, 2014b, 2014c; Seker et al., 2015; Al-Mulali et al., 2015a). In this strand, many studies investigate the dynamic relationship between energy consumption, economic growth, trade openness and CO_2 in a multivariate framework

[3] These countries are China, India, South Korea, Brazil, Mexico, Indonesia, South Africa, Turkey, Thailand, and Malaysia.

(Dogan and Seker, 2016). Antweiler et al. (2001) and Farhani et al. (2014) discuss the relationship between trade liberalization and environmental quality and show that the environmental impact of trade can be positive or negative depending upon the magnitude of scale, technique and composition effects.

Ang (2008), one of the earlier works in this category, analyzes the dynamics of CO_2 emissions, energy consumption and real income for Malaysia over the period 1971–1999 by using the multivariate VECM. The empirical results show that there is long run bidirectional causality between economic growth and energy consumption, and unidirectional causality running from pollution to economic growth in the long run. In a similar vein, Pao and Tsai (2010) finds a cointegration relationship between CO_2 emissions, real income and energy consumption for BRIC countries by using panel cointegration and Granger causality tests. Long run estimation results show that there is a positive link between energy consumption and carbon emissions. The empirical results also show that the EKC hypothesis is valid, and unidirectional causality runs from economic growth and carbon emissions to energy consumption for BRIC countries. Jayanthakumaran et al. (2012) indicates that there exists a long run relationship between the analyzed variables in the presence of structural breaks for India and China by using the bounds testing for cointegration and the VECM approaches. The empirical results show that the impact of energy consumption on carbon emissions is positive and statistically significant, and there is evidence for the validity of the EKC hypothesis. However, it is found that there is no significant link between trade openness and carbon emissions. Atici (2012) analyzes the impact of trade on CO_2 emissions for the group of ASEAN countries. The findings show that an increase in exports increases carbon emissions in the mentioned developing countries. Using threshold cointegration tests of Gregory and Hansen (1996), and Hatemi-J (2008) in the presence of structural breaks, Kanjilal and Ghosh (2013) confirms the existence of threshold cointegration relationship among the variables and the EKC hypothesis for India. The impact of energy consumption on carbon emissions is positive and statistically significant while trade openness negatively affects carbon emissions. Shahbaz et al. (2014a) finds a long run relationship between CO_2 emissions, real income, energy consumption and trade openness by applying the ARDL approach to cointegration in the presence of structural breaks. The empirical results indicate the existence of the EKC hypothesis in Tunisia, and energy consumption and trade openness positively affect carbon emissions in the long run, and there is long run bidirectional causality between energy consumption and carbon emissions, and between trade openness and carbon emissions. Using the ARDL approach to cointegration and the VECM method, Farhani et al. (2014) provides an evidence for the existence of the EKC hypothesis for Tunisia in the long run. This study reports statistically insignificant relationship between trade openness and pollution while it states that an increase in energy consumption causes environmental degradation. In addition, there is bidirectional causality between energy consumption and the environment, and unidirectional causality running from economic growth and trade openness to CO_2 emissions in the long run for Tunisia. Using the ARDL method and the VECM Granger causality approach, Saboori and Sulaiman (2013a) finds a significant positive relationship between energy consumption and pollution for all ASEAN countries both in the long run and short run. The empirical results also reveal that the EKC hypothesis is validated for Singapore and Thailand, and there is long run bidirectional causality between energy consumption and environmental degradation in all investigated countries. Al-Mulali and Sheau-Ting (2014) explores the relationship between trade, energy consumption and real income over the period 1990–2011. The empirical results indicate that there exists a positive relationship between CO_2 emissions, trade and energy consumption in the long run.

Studies in the second strand examine developed countries (e.g. Lindmark, 2002; Day and Grafton, 2003; Ang, 2007; Plassman and Khanna, 2006; Acaravci and Ozturk, 2010; Iwata et al., 2010; Menyah and Wolde-Rufael, 2010; Pao and Tsai, 2011; Fosten et al., 2012; Hossain, 2012; Esteve and Tamarit, 2012; Hamit-Haggar, 2012; Cho et al., 2014). Ang (2007), one of the earlier works in this category, examines the relationship between CO_2 emissions, energy consumption and real output in France with data covering the years 1960–2000. This study finds that Granger causality runs from economic growth to energy consumption and carbon emissions in the long run. Iwata et al. (2010) explores whether or not the EKC hypothesis is valid for France by applying the ARDL method. The empirical findings show that the EKC hypothesis is valid and there is unidirectional causality running from energy consumption to CO_2 emissions. By employing the bounds test for cointegration and the VECM Granger causality test, Acaravci and Ozturk (2010) shows that energy consumption positively affects carbon emissions in Denmark, Germany, Greece, Italy and Portugal, and supports the validity of EKC hypothesis in Denmark and Italy. The empirical results also suggest evidence for bidirectional causality between economic growth and carbon emissions for Switzerland, bidirectional causality between energy consumption and carbon emissions for Italy, and no causal link between the analyzed variables for Germany. Using the VECM method and the non-linear threshold cointegration techniques, Fosten et al. (2012) finds that the EKC hypothesis is valid for the case of the United Kingdom. Hossain (2012) analyzes the impact of trade, energy and income on the environment for the Japan. The results indicate that there exists short-run unidirectional causality running from trade openness and energy consumption to CO_2 emissions. Esteve and Tamarit (2012) investigates the long run relationship between pollution and income in Spain using the threshold cointegration techniques. The empirical findings show the existence of the EKC hypothesis. Dogan and Turkekul (2016) investigates the dynamics of CO_2 emissions, energy consumption, real GDP, trade, financial development and urbanization in the EKC framework for the United States of America (USA) over the period 1960–2010 by applying the ARDL approach to cointegration and the VECM causality test. The empirical results show that energy consumption causes more pollution whereas trade mitigates the level of emissions. In addition, the validity of the EKC hypothesis is not supported for the USA.

The existing empirical literature examining the relationship between energy consumption, economic growth, trade openness and carbon emissions has several characteristics. Firstly, the majority of the existing studies focus on single-country cases and the empirical results reported in these studies are inconclusive. Secondly, there is relatively small number of studies that investigate the long run relationship between the variables of interest in the presence of structural breaks in time-series data, and more importantly only a few of those is related to emerging countries. Thirdly, there is a need for an empirical research to explore more comparative findings for developing countries by using up-to-date data set.

3. Model, data and methodology

This study uses a log-linear specification to examine the effects of real income, the square of real income, energy consumption and trade openness on carbon emissions as well as to investigate the presence of the EKC hypothesis. Following Halicioglu (2009), Nasir and Rehman (2011), Kanjilal and Ghosh (2013), Farhani et al. (2014), Kasman and Duman (2015), Al-Mulali et al. (2015a) and Dogan and Turkekul (2016) among others, the relationship between the variables is specified as in Eq. (1):

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln EC_t + \beta_2 \ln Y_t + \beta_3 \ln Y_t^2 + \beta_4 \ln TR_t + \varepsilon_t \qquad (1)$$

where $\ln CO_{2t}$ is the natural log of per capita carbon emissions (measured in metric tons), $\ln Y_t$ ($\ln Y_t^2$) is the natural log of per capita real GDP measured in constant 2005 US$ (the square of per capita real GDP), the natural log of per capita energy consumption (measured in kg of oil equivalent) is indicated by $\ln EC_t$, and $\ln TR_t$ is the natural log of trade openness equal to the sum of exports and imports over GDP, and ε_t is the regression error term. The time-series data are transformed into their natural logarithms so as to attain direct elasticities and provide more consistent and efficient results. Besides, the log-linear specification increases the stationarity of the series (Shahbaz et al., 2013a; Lau et al., 2014). The annual time-series data for the 10 developing countries from 1971 to 2011 are derived from the World Development Indicators (WDI). The analyzed developing countries are Malaysia, Thailand, Turkey, India, Brazil, South Africa, Mexico, China, Indonesia and Korea. β_1, β_2, β_3 and β_4 are the long run elasticities of carbon dioxide emissions with respect to energy consumption, the real GDP, the square of real GDP and trade openness, respectively. The sign for β_1 is expected to be positive because large amounts of energy consumption should result in higher pollution (Pao and Tsai, 2011). Based on the EKC hypothesis, the expected signs for β_2 and β_3 are positive and negative, respectively. This means that there exists an inverted U-shaped relation between economic growth and environmental pollution (Acaravci and Ozturk, 2010). Because the net effect of trade on the environment is ambiguous, trade may lead to environmental improvements or deteriorations; therefore, the sign for β_4 can be positive or negative.

In this study, the long run and causal relationships between the analyzed variables are examined by applying a three-step estimation strategy. The first step is to detect the order of integration of CO_2 emissions, real GDP (the square of real GDP), energy consumption and trade openness by using the Zivot–Andrews unit root test with structural break. In the second step, a long run relationship between the analyzed variables is examined by using the ARDL bounds testing approach to cointegration in the presence of structural break. This study also estimates the long run coefficients in the same stage. The last step deals with the causal relationships between the analyzed variables through the VECM Granger causality test.

3.1. Zivot–Andrews unit root test

The majority of researches in the energy-environment-growth literature employ the conventional unit root tests such as ADF, PP and DF-GLS to determine integration properties of the time-series. Shahbaz et al. (2013a, 2013b) point out that the above-mentioned tests lead to biased and spurious findings because they do not take into account the structural break in the data. Therefore, we use the Zivot–Andrews unit root test with endogenously determined structural break proposed by Zivot and Andrews (2002). The following regression in Eq. (2) is used:

$$\Delta y_t = c + \alpha y_{t-1} + \beta t + dDU_t + dDT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \mu_t \qquad (2)$$

where DU_t represents mean shift dummy variable which happens at each possible break-date (TB) while DT_t represents trend shift dummy variable. They can be identified as:

$$DU_t = \begin{cases} 1 & \text{if } t > TB \\ 0 & \text{if } t < TB \end{cases} \quad \text{and} \quad DT_t = \begin{cases} t - TB & \text{if } t > TB \\ 0 & \text{if } t < TB \end{cases}$$

The null hypothesis of the Zivot and Andrews test suggests the unit root process with drift while alternative hypothesis implies trend stationary with one unknown break. The Zivot–Andrews test determines all of the points for potential possible time break and estimates regression for all these possible break dates recursively. Finally, the break point is selected by defining time break which decreases one-sided t statistics to test $\hat{\alpha}(= \alpha - 1) = 1$.

3.2. Bounds testing approach to cointegration

In order to investigate the long run relationship between economic growth, energy consumption, trade openness and CO_2 emissions, we apply the ARDL approach to cointegration in the presence of structural break. The bounds testing approach has several advantages over traditional cointegration methods. Firstly, the ARDL model is applicable if variables are found $I(1)$ or $I(0)$ or $I(1)/I(0)$. Secondly, this model is appropriate for examining the existence of a long run relationship between variables in levels. Thirdly, this approach presents efficient and consistent findings for small sample. Finally, the unrestricted error correction model (UECM) derived from the ARDL bounds testing integrates the short run dynamics with the long run equilibrium (Pesaran and Shin, 1999). The UECM version of the ARDL model is modeled as follows:

$$\begin{aligned} \Delta \ln CO_{2t} = {} & \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \ln CO_{2t-i} + \sum_{i=0}^{p} \alpha_{2i} \Delta \ln EC_{t-i} \\ & + \sum_{i=0}^{p} \alpha_{3i} \Delta \ln Y_{t-i} + \sum_{i=0}^{p} \alpha_{4i} \Delta \ln Y_{t-i}^2 + \sum_{i=1}^{p} \alpha_{5i} \Delta \ln TR_{t-i} \\ & + \delta_1 \ln CO_{2t-1} + \delta_2 \ln EC_{t-1} + \delta_3 \ln Y_{t-1} + \delta_4 \ln Y_{t-1}^2 \\ & + \delta_5 \ln TR_{t-1} + \delta_6 DUM + \mu_t \end{aligned} \qquad (3)$$

where Δ is the first difference operator, μ_t is error term assumed to be independently and identically distributed and DUM is dummy variable for structural break point shows 1 after break date and 0 otherwise. The Akaike information criterion (AIC) is employed to determine the appropriate lag structure of the first difference regression. We apply the F-test developed by Pesaran et al. (2001) to investigate the presence of a long run relationship between the variables. The null hypothesis of no cointegration $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$ is tested against the alternative hypothesis $H_1: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq 0$ in Eq. (3). Here, the computed F-statistic is compared with the critical bounds – the upper critical bound (UCB) and lower critical bound (LCB) – generated by Pesaran et al. (2001). It is concluded that there exists a long run relationship between the variables, if the calculated F-statistic is greater than UCB. There is no long run relationship between the variables, if the calculated F-statistic does not exceed LCB. If the calculated F-statistic lies between LCB and UCB, the result is inconclusive. After the determination of the ARDL model by the AIC, the long run coefficients of the analyzed variables are computed from ARDL model.

To check the robustness of the ARDL model, the diagnostic and stability tests are conducted. The diagnostic tests are the tests for serial correlation, functional form, normality of error term and heteroscedasticity. Furthermore, we use the CUSUM and $CUSUM_{SQ}$ tests proposed by Brown et al. (1975) and Chow (1960) test to examine the presence of parameter stability.

3.3. The VECM Granger causality

The study by Engle and Granger (1987) suggests that there must be either unidirectional or bidirectional Granger-causality between these variables if there is cointegration relationship between the variables. The ARDL bounds testing approach does not examine the causal relations between variables. Therefore, we use the Granger causality test based on VECM approach developed by Engle and

Granger (1987) to investigate the causal relations between CO_2 emissions, energy consumption, real income, the square of real income and trade openness. The error correction term (ECT_{t-1}) is included into the VAR system as an additional variable. The empirical equations of the VECM Granger causality approach is modeled as follows:

$$(1-L)\begin{bmatrix} \ln CO_{2t} \\ \ln EC_t \\ \ln Y_t \\ \ln Y_t^2 \\ \ln TR_t \end{bmatrix} = \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \\ \gamma_4 \\ \gamma_5 \end{bmatrix} + \sum_{i=1}^{p}(1-L)\begin{bmatrix} a_{11i} & a_{12i} & a_{13i} & a_{14i} & a_{15i} \\ a_{21i} & a_{22i} & a_{23i} & a_{24i} & a_{25i} \\ a_{31i} & a_{32i} & a_{33i} & a_{34i} & a_{35i} \\ a_{41i} & a_{42i} & a_{43i} & a_{44i} & a_{45i} \\ a_{51i} & a_{52i} & a_{53i} & a_{54i} & a_{55i} \end{bmatrix} \times \begin{bmatrix} \ln CO_{2t-1} \\ \ln EC_{t-1} \\ \ln Y_{t-1} \\ \ln Y_{t-1}^2 \\ \ln TR_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha \\ \beta \\ \varphi \\ \theta \\ \delta \end{bmatrix} ECT_{t-1} + \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \\ \varepsilon_{5t} \end{bmatrix} \quad (4)$$

where $(1-L)$ is the lag operator and ECT_{t-1} is the lagged residual generated from the long run relationship; $\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t}, \varepsilon_{4t}$ and ε_{5t} are error terms assumed to be $N(0,\sigma)$. A significant t-statistic on the coefficient of ECT_{t-1} implies the existence of the long run causality between the variables. This also implies that there exists a long run relation between the series.

4. Empirical findings

4.1. Unit root test

This study uses the Zivot–Andrews unit root test with structural break following Shahbaz et al. (2013a, 2013b), Dogan (2015). The results of the Zivot–Andrews test reported in Table 2 show that trade openness for Turkey, and real GDP, the square of real GDP and trade openness for Indonesia are stationary at their levels. This implies that they are integrated at $I(0)$. The results also show that other variables are non-stationary at their levels but stationary at their first differences. This implies that the subsequent variables are integrated at $I(1)$. Therefore, the findings allow us to apply the ARDL bounds testing approach to cointegration in investigating the long run relationship between CO_2 emissions, real income, quadratic income, energy consumption and trade openness since they are either $I(0)$ or $I(1)$. Table 2 also shows the break dates that correspond to structural changes in the time-series. The break dates generally refer to several elements including energy crises, economic downturn, economic boom, and changes in legislations and openness of markets.

4.2. Cointegration test

In this sub-section, F-statistic is computed to investigate the existence of cointegration between the variables through the ARDL techniques with structural break. The structural break dates for CO_2 emissions obtained from the Zivot–Andrews unit root test are used as structural breaks in the ARDL approach to cointegration. In other words, the structural break is 1991, 1989, 1985, 2001, 1978, 1989, 1978, 2003, 1998 and 1993 for Malaysia, Thailand, Turkey, India, Brazil, South Africa, Mexico, China and Indonesia, respectively. The calculation of F-statistic is quite sensitive to the selection of lag order. Optimal lag length selection is based on the minimum value of AIC. Table 3 reports the results of the ARDL bounds testing approach to cointegration in the presence of structural break in the time series. The results reveal that the calculated F-statistics are greater than UCB in Thailand, Turkey, India, Brazil, China, Indonesia and Korea. This implies that we have enough evidence to reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration for the mentioned countries. Henceforth, we can support the presence of a long run relationship between CO_2 emissions, energy consumption, real income, the square of real income and trade openness in the cases of Thailand, Turkey, India, Brazil, China, Indonesia and Korea. Consequently, we can estimate the long run coefficients on the explanatory variables in the above-mentioned countries only. In addition, the bounds testing for cointegration used in this study passes several diagnostic tests such as non-normality, misspecification, autocorrelation and serial correlation as shown in Table 3.

4.3. Results from the long run estimator

The long run results are presented in Table 4. The empirical results show that an increase in energy consumption statistically and significantly stimulates CO_2 emissions in all countries except Brazil and Indonesia. More precisely, the estimate of energy consumption ranges from 0.76% to 1.54% in the analyzed countries. As expected, energy consumption raises the level of pollution in most of the analyzed developing countries. The positive effect of energy consumption is consistent with many studies including Ang (2008), Pao and Tsai (2010), Halicioglu (2009), Shahbaz et al. (2013a, 2013b, 2013c, 2013d, 2014a, 2014b), Saboori and Sulaiman (2013a), Farhani et al. (2014), Kasman and Duman (2015), Al-Mulali et al. (2015a) and Dogan and Turkekul (2016). Because energy consumption is a very important and necessary source in the production process, it is quite impossible for countries to stop using energy. However, the analyzed countries should find some options to minimize its effect on the environment, as energy consumption is found to be one of main contributors to the environmental pollution. One of the possible actions should be to upgrade energy efficiency referring to Wang et al. (2015) which shows that low energy efficiency is one of the main contributors to the level of emissions in China. The other possible action should be to increase the share of renewable energy in the total energy consumption referring to Shafiei and Salim (2014), Boluk and Mert (2015), Dogan and Seker (2016) and Jebli et al. (2016) which claim that non-renewable energy increases the level of pollution whereas renewable energy mitigates the increase in CO_2 emissions. This implies that renewable energy is an environmentally-friendly source on which the policy makers should pay more attention for the sake of environmental quality.

The empirical results in Table 4 reveal that real GDP has statistically significant and positively effects on the CO_2 emissions for Turkey, India, China and Korea. Furthermore, we find a negative and significant relationship between the square of real GDP and CO_2 emissions for the same countries. Therefore, we have enough evidence to assert that the EKC hypothesis is valid for Turkey, India, China and Korea in the long run. This finding is in line with Pao and Tsai (2010, 2011), Jalil and Feridun (2011), Jayanthakumaran et al. (2012), Shahbaz et al. (2013b), Tiwari et al. (2013), Shahbaz et al. (2014a), Lau et al. (2014), Farhani and Shahbaz (2014), and Kasman and Duman (2015), and Seker et al. (2015). This finding implies that increases in the level of real income stimulate carbon emissions up to a certain point, and then mitigates pollution

Table 2
Zivot-Andrews unit root test with structural break.

Country	Regressors	Level	Time break	First difference	Time break
Malaysia	CO_{2t}	−4.528[b] (0)	1991	−9.026[b] (0)[***]	1997
	EC_t	−3.820[b] (0)	1991	−6.576[b] (1)[***]	1991
	Y_t	−3.571[b] (3)	1993	−6.295[b] (0)[***]	1988
	Y_t^2	−3.695[b] (3)	1993	−6.277[b] (0)[***]	1988
	TR_t	−3.873[b] (1)	1998	−6.697[b] (0)[***]	1987
Thailand	CO_{2t}	−3.158[b] (1)	1989	−5.338[b] (0)[**]	1997
	EC_t	−3.412[b] (3)	1988	−6.539[b] (0)[***]	1984
	Y_t	−3.536[b] (1)	1988	−5.255[b] (0)[**]	1997
	Y_t^2	−3.461[b] (1)	1988	−5.343[b] (0)[**]	1997
	TR_t	−3.674[b] (0)	1988	−7.340[b] (0)[***]	1987
Turkey	CO_{2t}	−4.150[b] (0)	1985	−7.775[a] (4)[***]	2003
	EC_t	−4.766[b] (4)	1987	−5.649[b] (0)[***]	2003
	Y_t	−3.803[b] (0)	1979	−4.932[b] (4)[*]	1982
	Y_t^2	−3.746[b] (0)	1979	−4.642[a] (4)[*]	1982
	TR_t	−6.661[b] (1)[***]	1980	–	–
India	CO_{2t}	−4.328[a] (0)	2001	−7.272[a] (0)[***]	1997
	EC_t	−3.507[b] (0)	2001	−7.172[b] (0)[***]	2000
	Y_t	−1.956[b] (4)	2003	−5.413[b] (3)[**]	2000
	Y_t^2	−1.726[b] (4)	2003	−7.943[b] (0)[***]	1979
	TR_t	−3.206[b] (0)	1981	−7.543b (0)[***]	1987
Brazil	CO_{2t}	−3.952[a] (0)	1978	−10.017[a] (0)[***]	1983
	EC_t	−4.674[a] (0)	1978	−7.153[a] (0)[***]	1983
	Y_t	−4.685[b] (1)	1985	−6.373[b] (0)[***]	1982
	Y_t^2	−4.694[b] (1)	1985	−6.380[b] (0)[***]	1982
	TR_t	−4.646[b] (1)	1998	−6.138[b] (1)[***]	1995
South Africa	CO_{2t}	−3.127[b] (0)	1989	−7.156[b] (0)[***]	1985
	EC_t	−3.940[b] (0)	1989	−7.344[b] (0)[***]	2003
	Y_t	−3.894[b] (1)	1998	−5.285[b] (0)[**]	1982
	Y_t^2	−3.893[b] (1)	1998	−5.303[b] (0)[**]	1982
	TR_t	−3.896[b] (0)	1990	−6.528[b] (2)[***]	1994
Mexico	CO_{2t}	−3.952[a] (0)	1978	−10.017[a] (0)[***]	1983
	EC_t	−4.674[a] (0)[*]	1978	−7.163[a] (0)[***]	1983
	Y_t	−4.685[b] (1)	1985	−6.373[b] (0)[***]	1982
	Y_t^2	−4.694[b] (1)	1985	−6.380[b] (0)[***]	1982
	TR_t	−4.646[b] (1)	1998	−6.138[b] (1)[***]	1995
China	CO_{2t}	−3.751[a] (1)	2003	−7.775[a] (4)[***]	2003
	EC_t	−4.518[b] (1)	2001	−5.649[b] (0)[***]	2003
	Y_t	−3.137[b] (1)	2001	−4.932[b] (4)[*]	1982
	Y_t^2	−2.767[a] (1)	2005	−4.642[a] (4)[*]	1982
	TR_t	−4.402[b] (1)	1995	−5.748[b] (1)[***]	2002
Indonesia	CO_{2t}	−3.902[a] (0)	1998	−6.502[a] (0)[***]	1979
	EC_t	−4.917[a] (0)[*]	1990	−6.947[a] (0)[***]	1986
	Y_t	−6.606[b] (1)[***]	1998	–	–
	Y_t^2	−5.931[b] (1)[***]	1998	–	–
	TR_t	−6.177[b] (0)[***]	1998	–	–
Korea	CO_{2t}	−4.086[b] (0)	1993	−7.980[b] (0)[***]	1998
	EC_t	−3.677[b] (0)	1990	−7.196[b] (0)[***]	1998
	Y_t	−3.102[b] (0)	1994	−7.190[b] (0)[***]	1982
	Y_t^2	−3.029[b] (0)	1987	−7.129[b] (0)[***]	1982
	TR_t	−3.877[b] (0)	1989	−6.167[b] (1)[***]	1994

Note:
[a] The results of model with constant.
[b] The results of model with constant-trend.
Figures in parentheses are the optimal lag orders.
[*] Statistical significance at 10% level.
[**] Statistical significance at 5% level.
[***] Statistical significance at 1% level.

in Turkey, India, China and Korea. On the other hand, the elasticity estimates of CO_2 emissions with respect to real income and the square of real income are found to be negative and positive (statistically insignificant), respectively, for Brazil and Indonesia. This empirical finding indicates that the EKC hypothesis cannot be supported in these developing economies since we find a U-shaped relationship between economic growth and the environmental pollution. The absence of the EKC hypothesis suggests that increases in real GDP first lead to environmental improvements but stimulates CO_2 emissions after some threshold level. The absence of the EKC hypothesis is found in several previous studies such as Ozturk and Acaravci (2010a), Wang et al. (2011), Chandran and Tang (2013), Govindaraju and Tang (2013), Onafowora and Owoye (2014), Al-Mulali et al. (2015a), Dogan et al. (2015) and Farhani and Ozturk (2015). Referring to carbon leakage hypothesis, one possible reason for this phenomenon can be the fact that economies stop caring about the environment in order to attract multinational companies into their home land. This action results in an increased

Table 3
Bounds testing for cointegration.

Panel A: Bounds testing for co-integration

Country	Optimal lag	Structural break	*F*-statistics	Co-integration
Malaysia	1	1991	3.061	No
Thailand	3	1989	4.817**	Yes
Turkey	3	1985	5.727***	Yes
India	4	2001	4.519**	Yes
Brazil	3	1978	4.163**	Yes
South Africa	4	1989	1.220	No
Mexico	4	1978	1.370	No
China	2	2003	4.937**	Yes
Indonesia	4	1998	6.430***	Yes
Korea	1	1993	4.304**	Yes

Panel B: Pesaran et al. (2001) critical value bounds of the *F*-statistic: unrestricted intercept and no trend

Significance level (%)	Lower bounds, $I(0)$	Upper bounds, $I(1)$
1	3.74	5.06
5	2.86	4.01
10	2.45	3.52

Panel C: Narayan (2005) critical value bounds of the *F*-statistic: unrestricted intercept and no trend

Significance level (%)	Lower bounds, $I(0)$	Upper bounds, $I(1)$
1	4.42	6.25
5	3.20	4.54
10	2.66	3.83

Panel D: Diagnostic tests	R^2	*F*-statistics	J-B normality [*p*-value]	Ramsey RESET [*p*-value]	ARCH LM [*p*-value]	B-G LM [*p*-value]
Malaysia	0.709	3.736***	1.039 (0.594)	[1]: 0.433	[1]: 0.583	[4]: 0.063
Thailand	0.929	5.819***	5.416 (0.066)	[1]: 0.885	[1]: 0.744	[1]: 0.299
Turkey	0.976	17.902***	0.591 (0.743)	[1]: 0.907	[1]: 0.450	[1]: 0.115
India	0.976	6.843**	0.723 (0.696)	[1]: 0.447	[1]: 0.470	[4]: 0.091
Brazil	0.962	11.406***	0.259 (0.878)	[1]: 0.690	[1]: 0.817	[1]: 0.161
South Africa	0.954	3.462*	0.260 (0.877)	[1]: 0.874	[1]: 0.125	[1]: 0.131
Mexico	0.926	2.099	0.147 (0.928)	[1]: 0.169	[2]: 0.518	[1]: 0.745
China	0.943	14.306***	0.939 (0.625)	[1]: 0.190	[1]: 0.384	[1]: 0.308
Indonesia	0.976	6.997**	1.856 (0.395)	[1]: 0.159	[1]: 0.426	[1]: 0.586
Korea	0.847	8.496***	0.270 (0.873)	[1]: 0.206	[2]: 0.147	[1]: 0.431

Note: The model with constant is used for co-integration analysis. The optimal lag length is selected using AIC.
* Statistical significance at 10% level.
** Statistical significance at 5% level.
*** Statistical significance at 1% level.

volume of polluted goods. Thus, such countries should regulate environmental policies such as tax regulations to lower the production of polluted goods.

The empirical results in Table 4 also exhibit that trade has no significant effect on the levels of CO_2 emissions for Thailand, Brazil and Korea. This result is in line with Jalil and Mahmud (2009), Jayanthakumaran et al. (2012), Farhani et al. (2014), and Al-Mulali et al. (2015b) shown in Table 5. As discussed in the introduction section, the effects on the environment of trade openness can be categorized as scale effect, composition effect and technique effect. It seems that no effect can dominate others and thus the net effect of trade on CO_2 emissions becomes insignificant in Thailand, Brazil and Korea. On the other hand, trade openness is found to have a statistically significant positive impact on carbon emissions for Turkey, India, China and Indonesia. The elasticity estimate of CO_2 emissions with respect to trade ranges from 0.06% to 1.06%. The increasing relationship among trade openness and pollution is consistent with many studies including Jalil and Feridun (2011), Tiwari et al. (2013), Shahbaz et al. (2014a, 2016) shown in Table 5. This supports the pollution-haven hypothesis which claims that the demand for a cleaner environment increases as real income goes up, and thus dirty industries in developed countries are looking for other places with less stringent environmental standards. Because essential environmental regulations for the environment are not effective in the most of less developed and developing countries (e.g. India, China, Indonesia and Turkey), companies move their plants and factories to countries with less environmental regulations from developed countries with high level of environmental standards. It is a fact that developing countries face a tradeoff between attracting multinational firms to their lands and imposing environmental-friendly regulations. Thus, it is a political choice to make to allow higher levels of pollution through trade related polluted goods.

The results reported in Table 4 also reveal that the estimates of ECT_{t-1} are statistically significant with negative signs in all countries. This consolidates the presence of a long run relationship between the analyzed variables. The coefficient estimates indicate that changes in gas emissions are corrected each year by nearly 40%, 71%, 89%, 3%, 80%, 59% and 62% for Thailand, Turkey, India, Brazil, China, Indonesia and Korea, respectively. The estimated long run models successfully pass several diagnostic and stability tests at 5% significance level. More precisely, we have no evidence of non-normality, autocorrelation, misspecifications and serial correlation as the related p-values are greater than 0.10, which implies that the empirical results can be used for policy implication. In addition, the goodness of fit of the specifications (R^2) is 0.99, which indicates that the independent variables explain the changes in dependent variable well enough. Moreover, the statistically significant *F*-statistic confirms the joint significance of explanatory variables in the ARDL model.

Table 4
Long run results.

Countries	ARDL models	EC_t	Y_t	Y_t^2	TR_t	ECT_{t-1}
Thailand	1, 0, 2, 1, 0	0.763*	3.308	−0.154	0.032	−0.398***
Turkey	1, 1, 0, 0, 1	0.958***	4.470**	−0.253**	0.056*	−0.705***
India	3, 0, 2, 2, 3	1.545***	4.358***	−0.379***	0.110**	−0.891***
Brazil	1, 2, 1, 2, 2	8.032	−116.924	6.210	−5.255	−0.030***
China	1, 0, 0, 0, 1	1.419***	1.614***	−0.103***	0.062**	−0.795***
Indonesia	3, 4, 4, 4, 3	−0.746	−10.887	0.893**	1.062**	−0.593***
Korea	1, 0, 0, 1, 0	0.956***	1.261**	−0.085**	0.114	−0.618***

Diagnostic tests	R^2	F-statistics	J-B normality [p-value]	Ramsey RESET [p-value]	ARCH LM [p-value]	B-G LM [p-value]
Thailand	0.998	1709.259	1.720 (0.423)	[1]: 0.156	[4]: 0.056	[1]: 0.812
Turkey	0.996	1217.723	1.052 (0.590)	[1]: 0.384	[1]: 0.771	[1]: 0.328
India	0.998	1387.923	1.992 (0.369)	[1]: 0.023	[1]: 0.646	[1]: 0.744
Brazil	0.992	247.213	2.367 (0.306)	[1]: 0.942	[1]: 0.765	[1]: 0.443
China	0.998	3872.029	0.288 (0.865)	[1]: 0.494	[1]: 0.484	[1]: 0.539
Indonesia	0.995	112.522	1.666 (0.436)	[1]: 0.986	[3]: 0.092	[3]: 0.073
Korea	0.997	1638.216	1.054 (0.590)	[1]: 0.174	[1]: 0.122	[1]: 0.215

Stability tests	CUSUM	CUSUM of squares	Chow
Thailand	Stable at 5% level	Stable at 5% level	–
Turkey	Stable at 5% level	No stable at 5% level	Stable at 5% level
India	No stable at 5% level	Stable at 5% level	Stable at 5% level
Brazil	Stable at 5% level	Stable at 5% level	–
China	Stable at 5% level	Stable at 5% level	–
Indonesia	Stable at 5% level	Stable at 5% level	–
Korea	No stable at 5% level	Stable at 5% level	Stable at 5% level

Note: The optimal lag length is selected using AIC.
* Statistical significance at 10% level.
** Statistical significance at 5% level.
*** Statistical significance at 1% level.

Table 5
Summary of the selected empirical studies.

Authors	Country	Period	Methodology	Long run results
Panel A: Time series analyses				
Shahbaz et al. (2016)	Malaysia	1970Q1–2011Q4	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR → CO_2
Charfeddine and Khediri (2016)	UAE	1975–2011	Gregory- Hansen and Hatemi-J tests, VECM Granger causality	TR has positive impact on CO_2 TR → CO_2
Shahbaz et al. (2014a)	Tunisia	1971–2010	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR ↔ CO_2
Onafowora and Owoye (2014)	Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa	1970–2010	ARDL bounds test	TR has positive impact on CO_2 in Mexico, Nigeria and South Africa; TR has negative impact on CO_2 in Brazil, China and Japan
Boutabba (2014)	India	1971–2008	ARDL bounds test, VECM Granger causality	TR → CO_2
Farhani et al. (2014)	Tunisia	1971–2008	ARDL bounds test, VECM Granger causality	TR has no impact on CO_2 TR → CO_2
Ozturk and Acaravci (2013)	Turkey	1960–2007	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR → CO_2
Kohler (2013)	South Africa	1960–2009	ARDL bounds test, VECM Granger causality	TR has negative impact on CO_2TR ↔ CO_2
Tiwari et al. (2013)	India	1966–2011	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR → CO_2
Kanjilal and Ghosh (2013)	India	1971–2008	ARDL bounds test, Gregory-Hansen and Hatemi-J test	TR has negative impact on CO_2
Jayanthakumaran et al. (2012)	China and India	1971–2007	ARDL bounds test	TR has no impact on CO_2 in China and India
Shahbaz et al. (2012)	Pakistan	1971–2009	ARDL bounds test, VECM Granger causality	TR has negative impact on CO_2
Nasir and Rehman (2011)	Pakistan	1972–2008	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR ↔ CO_2
Jalil and Feridun (2011)	China	1953–2006	ARDL bounds test	TR has positive impact on CO_2
Halicioglu (2009)	Turkey	1960–2005	ARDL bounds test, VECM Granger causality	TR has positive impact on CO_2 TR → CO_2
Jalil and Mahmud (2009)	China	1975–2005	ARDL bounds test, Pair-wise Granger causality	TR has no impact on CO_2

Table 5 (*Continued*)

Authors	Country	Period	Methodology	Long run results
Panel B: Panel data analyses				
Kang et al. (2016)	China	1997–2012	Spatial panel model	TR has negative impact on CO_2
Li et al. (2016)	28 provinces of China	1996–2012	Panel GMM, panel ARDL	TR has positive impact on CO_2
Al-Mulali et al. (2015b)	129 countries	1980–2011	Panel cointegration test, Panel DOLS	TR has no impact on CO_2 in low income countries, and positive impact on CO_2 in lower-middle countries
Alam and Paramati (2015)	18 developing countries	1980–2012	Panel cointegration tests, panel VECM Granger causality	TR $\leftrightarrow$ CO_2
Hossain (2011)	NIC	1971–2007	Johansen panel cointegration, panel GMM, panel VECM Granger causality	TR has negative impact on CO_2
Sharma (2011)	69 countries	1985–2005	Panel GMM	TR has positive impact on CO_2

Note: $\rightarrow$ indicates a one way causal relationship, and $\leftrightarrow$ indicates a bi-directional causal relationship. TR and CO_2 show trade openness and carbon emissions per capita, respectively.

Table 6
Long run VECM Granger causality analysis.

	Long run causality ECT_{t-1} (*t*-statistics)
Thailand	
ΔCO_{2t}	−1.951*
ΔEC_t	0.434
ΔY_t	−0.783
ΔY_t^2	−0.441
ΔTR_t	−0.187
Turkey	
ΔCO_{2t}	−1.683*
ΔEC_t	−0.755
ΔY_t	−0.892
ΔY_t^2	−0.888
ΔTR_t	1.113
India	
ΔCO_{2t}	−1.835*
ΔEC_t	1.576
ΔY_t	−1.624
ΔY_t^2	−1.478
ΔTR_t	0.127
Brazil	
ΔCO_{2t}	−1.792*
ΔEC_t	0.013
ΔY_t	0.235
ΔY_t^2	0.250
ΔTR_t	−1.998*
China	
ΔCO_{2t}	−1.793*
ΔEC_t	−0.359
ΔY_t	−0.691
ΔY_t^2	−0.657
ΔTR_t	−1.831*
Indonesia	
ΔCO_{2t}	−2.388**
ΔEC_t	0.461
ΔY_t	0.312
ΔY_t^2	0.307
ΔTR_t	1.102
Korea	
ΔCO_{2t}	−2.560**
ΔEC_t	−0.124
ΔY_t	−0.712
ΔY_t^2	−0.855
ΔTR_t	−1.418

Note: The optimal lag length is selected using AIC.
* Statistical significance at 10% level.
** Statistical significance at 5% level.

4.4. Results from the Granger causality test

Long run causality tests are presented in Table 6. We have enough evidence to support one-way long run causality running from energy consumption, the real income (the square of real income) and trade to CO_2 emissions for Thailand, Turkey, India, Indonesia, China, Brazil and Korea because the coefficient estimates of ECT_{t-1} on carbon emissions are found to be statistically significant for the respective countries. In addition, the empirical findings show that the long run Granger causality runs not only from energy consumption, the real GDP (the square of real GDP) and trade openness to CO_2 emissions but also from pollution, energy consumption and the real GDP (the square of real GDP) to trade openness in Brazil and China. The overall output is in line with Halicioglu (2009), Nasir and Rehman (2011), Ozturk and Acaravci (2013), Tiwari et al. (2013), Boutabba (2014), Shahbaz et al. (2014a), and Farhani et al. (2014), and Charfeddine and Khediri (2016) shown in Table 5. The empirical results imply that energy consumption, the real income (the square of real income) and trade openness jointly contributes to pollution in the long run. The overall outcomes not only confirm the presence of pollution-haven hypothesis, but also exhibit that energy consumption is one of the main factors affecting environmental degradation. This study reaches a similar conclusion in the previous long run estimates section. Possible policy implications are that countries should increase energy efficiency (or decrease energy intensity), meet energy demands by using as more renewable energy as possible, and impose tax regulations on energy-related carbon emissions and trade-related carbon emissions to deter firms from producing dirty products.

5. Conclusion and policy implications

This study investigates the relationship among real income, the square of real income, energy consumption, trade openness and carbon emissions in the EKC framework for the top ten emitters of CO_2 among emerging countries over the period of 1971–2011. It applies unit root test with structural break to examine stationarity of the series, the bounds testing approach to cointegration in the presence of structural breaks so as to test the long run relationship between the analyzed variables, the ARDL model to produce long run estimates, and the VECM Granger causality test to explore possible causal relationship between the analyzed variables. The empirical results indicate that CO_2 emissions, real income, quadratic income, energy consumption and trade openness are co-integrated for Thailand, Turkey, India, Brazil, China, Indonesia and Korea. In addition, we find that energy consumption stimulates environmental pollution in most of the analyzed countries, and trade openness increases CO_2 emissions in Turkey, India, China and Indonesia while it has no effect on the environment in Thailand, Brazil and Korea. Hence, pollution-haven hypothesis is supported for Turkey, India, China and Indonesia while the net effect of trade based on scale, composition and technique effects is insignificant in Thailand, Brazil and Korea. The presence of the EKC hypothesis is validated for Turkey, India, China and Korea in the long run. The empirical results also show that carbon emissions are determined by economic growth, energy consumption and trade openness in the long run. The VECM Granger causality reveals a number of long run causal relations between the analyzed variables.

A number of policy implications can be derived from the findings of this empirical study. Firstly, developing countries can reduce the use of energy for lower pollution without harming the economy because we find that increases in energy consumption lead to environmental degradation and energy consumption does not Granger cause economic growth in the long run. In case that it is impossible to decrease energy consumption, developing countries should financially support scientific intuitions and researches through projects to increase energy efficiency and decrease energy intensity referring to Wang et al. (2015) which finds that high energy intensity is a possible reason for increased levels of carbon emissions. Secondly, developing countries should continue to increase real GDP through boosting production of goods and services because we find that the EKC hypothesis, an inverted U-shape relationship between economic growth and pollution, is validated for most of the analyzed countries. Thirdly, even though emerging countries are supposed to decrease the amount of trade for lower pollution as we find that the coefficient on trade openness is statistically significant and positive for most cases, it may worsen the economy of emerging countries. Mukhopadhyay (2009) mentions that trade openness is a fundamental contributor to economic growth of several emerging countries including China, Indonesia and Thailand while trade openness in conjunction with economic growth due to the use of fossil fuels cause environmental deterioration. Free traders that consider trade restriction as evil are also opposed to the trade reduction policies (Esty, 2001). In this line, imposing taxes on trade-related gas emissions and other environmental regulations may also discourage multinational firms to move to emerging countries, which probably results in lower level of production for developing countries. Emerging countries are advised to use clean and environmentally-friendly technologies in the production of trade goods. Future empirical research can investigate the environmental impact of trade openness in the EKC model for the top ten emitters from developed countries.

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