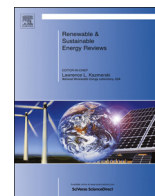




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The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries

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ABSTRACT

Due to tremendous increase in the level of carbon dioxide (CO₂) emissions in the last several decades, a number of studies in the energy-growth-environment literature have attempted to identify the determinants of CO₂ emissions. A major criticism related to the existing studies, we realize, is the selection of panel estimation techniques. Almost all studies use panel methods that ignore the issue of cross-sectional dependence even though countries in the panel are most likely heterogeneous and cross-sectionally dependent. In addition, the majority of existing studies use aggregate energy consumption, and thus fail to identify the impacts of energy consumption by sources on the environment. In order to fulfill the mentioned gaps in the literature, this empirical study analyzes the influence of the real income, renewable energy consumption, non-renewable energy consumption, trade openness and financial development on CO₂ emissions in the EKC model for the top countries listed in the Renewable Energy Country Attractiveness Index by employing heterogeneous panel estimation techniques with cross-section dependence. We find that the analyzed variables become stationary at their first-differences by using the CADF and the CIPS unit root tests, and the analyzed variables are cointegrated by employing the LM bootstrap cointegration test. By using the FMOLS and the DOLS, we also find that increases in renewable energy consumption, trade openness and financial development decrease carbon emissions while increases in non-renewable energy consumption contribute to the level of emissions, and the EKC hypothesis is supported for the top renewable energy countries.

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1. Introduction

Given concerns on the urgent need to protect the environment, a total of 196 countries have joined the United Nations Framework Convention on Climate Change (UNFCCC) as of 2015¹. The parties to the UNFCCC have made annual meetings since 1995 to determine what measures can be taken in order to control for the issues of global warming and greenhouse gas emissions (GHGs). The first notable outcome of the UNFCCC was the Kyoto protocol that brought along binding obligations for developed countries to decrease their GHGs. Nevertheless, the Kyoto protocol never became a real global agreement because the first amendment and the second amendment of the Kyoto protocol included only the European Union and several industrialized countries with bindings, and sadly the world largest emitters the USA, Canada and India among others did not ratify the protocol. On the other hand, in line with the Kyoto Protocol and the UNFCCC, the United Nations Climate Change Conference (UNCC) with the attendance of more than 190 countries took place in Paris in November–December 2015². The parties to the Paris protocol have promised to keep the global warming below 2 °C above pre-industrial level by 2100 even though it is for now doubtful whether or not some nations (e.g. the USA) will ratify the agreement. Notwithstanding some doubts, the Paris protocol should be considered as a milestone in this matter and the achievement of targets is very essential for environmental improvements.

Accomplishment of the aim of keeping the global warming at mentioned level requires tremendous falls in the level of GHGs in the next decades. An important question arises on how nations can reduce the level of emissions; or, alternatively, what are the determinants of GHGs? In order to find an answer to the question of interest, we review the energy-growth-environment literature. A number of research articles [1–42] suggest that aggregate energy consumption and the real income (gross domestic production) influence the level of carbon dioxide (CO₂) emissions for various countries and economic groups³. In addition, several recent studies [43–59] argue that sources of energy consumption (e.g. renewable and non-renewable energy) may have different impacts on the level of emissions and thus explore environmental impacts of renewable and non-renewable energy consumption separately. The state-of-the-art mostly finds that increases in renewable sources in energy mix decrease CO₂ emissions. Recent empirical studies [4,5,9,10,12,14,15,17,20,21,26,30,34,36,37,39,41,42,46,56,57,59] use trade openness and financial development in addition to energy consumption and the real production in modeling the energy-environment-growth nexus so as to indicate that both financial development and trade openness may help explain changes in carbon emissions. Increases in trade openness can impact carbon emissions through composition, scale and technique effects [60]. More precisely, scale effect basically means that increases in trade may lead to higher production, higher energy consumption and higher pollution. Composition effect implies that a country specializes in producing some goods with respect to the comparative advantage, and accordingly increases in trade may lead to higher or lower pollution depending on whether goods that the country keeps producing are in energy-intensive sectors or not. Last, technique effect refers to technology spillover through

trade flows among countries, and thus the adaption of environmentally-friendly technologies in producing goods can lead to environmental improvements. Financial development, on the one hand, may increase energy consumption and carbon emissions due to increases in the purchase of new industrial machines and equipment encouraged by lower financing costs and increased financing networks; on the other hand, financial development may increase energy efficiency and efficiency of business performance resulting in lower energy consumption and CO₂ emissions [12]. The net effect of financial development and trade openness on carbon emissions can be negative or positive depending on which effect dominates which one.

Although a number of studies shown in Table 1 attempt to investigate the influence of the real income, energy consumption, trade and financial development on carbon emissions, almost all studies use conventional panel estimation techniques (i.e. the Im-Pesaran-Shin (IPS) and the Levin-Lin-Chu (LLC) unit root tests, the Johansen and the Pedroni cointegration tests) which fail to take into consideration of cross-sectional dependence and/or heterogeneity across the panel in their estimation processes. Because disregarding the existence of cross-sectional dependence and heterogeneity across the panel can cause misleading results and forecasting errors, the first objective of this empirical study is to fulfill this gap by using heterogeneous panel estimation techniques with cross-section dependence (i.e. the CADF and the CIPS unit root tests, the LM bootstrap cointegration test, the DOLS and the FMOLS). Thus, the reported empirical results become more robust and reliable due to the use of appropriate methods. In addition, we find that the majority of existing studies use aggregate energy consumption in their models, and thus fail to identify the effects of energy consumption by sources. Therefore, the second objective of this study is to analyze the effects of the real income, renewable energy consumption, non-renewable energy consumption, financial development and trade openness on CO₂ emissions in the Environmental Kuznets Curve (EKC) framework for the top countries listed in the Renewable Energy Country Attractiveness Index. Even though existing literature focus on panel of several groups such as the European Union, the Organization for Economic Co-operation and Development (OECD) and the BRICS (Brazil, Russia, India, China, South Africa), the panel of countries listed in the above-mentioned index has not been used in the energy-growth-environment literature. The last objective of this study is to present an extensive review of the energy-growth-environment literature in the next section. The third section explores the model and data, the fourth section discusses the issues of heterogeneity and cross-sectional dependence, the fifth section indicates the methodology and empirical results, the last section presents the conclusion and policy recommendations.

2. Literature review

A large number of studies investigate the energy-growth-environment nexus. For clarity, we decompose the literature review into three parts. Part A presents studies that investigate the relationship between CO₂ emissions, the real income (or economic growth) and aggregate energy consumption [1–42]. Of those, [1–11] do not investigate the validity of the EKC hypothesis. On the contrary, the EKC hypothesis is investigated but not supported for the USA [12–13], Turkey [14], Cambodia [15], Russia [16], Tunisia [17], G7 countries [18], Middle East countries [19], OECD countries [20], BRIC countries [21], and Indonesia, Malaysia and Philippines [22]. On the other hand, the EKC hypothesis is validated for Singapore and Thailand [22], Association of Southeast Asian Nations (ASEAN) [23–24], Italy and Denmark [25], Central and Eastern Europe [26], EU countries [27], Middle East and North Africa

¹ http://unfccc.int/essential_background/convention/status_of_ratification/items/2631.php (accessed 13 December 2015).

² <http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf> (accessed 13 December 2015).

³ It is worth pointing out that we further show and explain the methodology, time-period and country/region used in the mentioned studies in Table 1 and in the second section.

Table 1
A survey of existing literature.

A) Studies focusing on aggregate energy consumption in the environment-energy-growth literature

Study	Country	Year	Variables	Methods	Long-run results	EKC Hypothesis
[1]	Turkey	1970–2002	CO ₂ , EGY, Y, POP	Regression Analysis (OLS)	Y, EGY and POP contribute to CO ₂	Not investigated
[2]	Bangladesh	1972–2006	CO ₂ , EGY, Y	ADF, Johansen cointegration, ARDL model	EGY contributes to CO ₂	Not investigated
[3]	South Korea	1991–2011	CO ₂ , EGY, Y	MS-RW, MS-AR, ARIMA, ARDL model	Y, EGY and CO ₂ moving together.	Not investigated
[4]	Malaysia	1971–2011	CO ₂ , EGY, Y, FD ² , FD, TR	Ng-Perron unit root, ARDL model	EGY and Y contribute to CO ₂ , TR and FD mitigate CO ₂	Not investigated
[5]	Indonesia	1975Q1–2011Q4	CO ₂ , EGY, Y, FD, TR	ZA unit root, ARDL model	EGY and Y contribute to CO ₂ , TR and FD mitigate CO ₂	Not investigated
[6]	China	1990–2012	CO ₂ , EGY, Y	ADF, Johansen cointegration, error correction model	EGY and Y contribute to CO ₂	Not investigated
[7]	China	1981–2006	CO ₂ , EGY, Y	PP, Johansen cointegration, error correction model	EGY and Y contribute to CO ₂	Not investigated
[8]	MENA	1973–2008	CO ₂ , EGY, Y	LLC, IPS, PP, Pedroni cointegration and Kao cointegration, OLS, FMOLS, DOLS	CO ₂ and Y contribute to EGY	Not investigated
[9]	MENA	1990–2011	CO ₂ , EGY, Y, TR, URB	2SLS, 3SLS, panel GMM	EGY, Y and URB contribute to CO ₂ , TR is insignificant	Not investigated
[10]	Panel of newly industrialized countries	1971–2007	CO ₂ , EGY, Y, URB, TR	ADF, LLC, IPS, Johansen cointegration, error correction model	EGY and Y contribute to CO ₂ , TR mitigates CO ₂	Not investigated
[11]	Panel of 99 countries	1975–2012	CO ₂ , EGY, Y, FD, FD ²	IPS, CADF, Pedroni cointegration, Johansen cointegration, FMOLS	EGY and Y contribute to CO ₂ , higher FD mitigate CO ₂	Not investigated
[12]	USA	1960–2010	CO ₂ , EGY, Y, Y ² , TR, URB, FD	ADF, ZA unit root, ARDL model	EGY and URB contribute to CO ₂ ; TR mitigates CO ₂ ; FD is insignificant	No
[13]	USA	1960–2004	CO ₂ , EGY, Y, K, L	ADF, PP, KPSS, causality test	EGY contributes to CO ₂	No
[14]	Turkey	1960–2005	CO ₂ , EGY, Y, Y ² , TR	ADF, ARDL model	EGY and TR contribute to CO ₂	No
[15]	Cambodia	1996–2012	CO ₂ , EGY, Y, Y ² , TR, URB	GMM, two-stage least squares	EGY, TR and URB contribute to CO ₂	No
[16]	Russia	1990–2007	CO ₂ , EGY, Y, Y ²	Ng-Perron, KPSS, Johansen cointegration, OLS	EGY contributes to CO ₂	No
[17]	Tunisia	1971–2012	CO ₂ , EGY, Y, Y ² , TR, FD, URB	ADF-GLS, ADF-WS, ARDL model	EGY, TR, FD and URB contribute to CO ₂	No
[18]	G7 countries	1960–2010	CO ₂ , EGY, Y	Ng-Perron unit root, ZA unit root, causality test	Y causes CO ₂ in Italy and Japan; EGY causes CO ₂ in France and the USA	No
[19]	Middle East countries	1990–2008	CO ₂ , EGY, Y, Y ²	LM unit root, Westerlund cointegration, FMOLS	EGY contributes to CO ₂	No
[20]	OECD	1995–2010	CO ₂ , EGY, Y, Y ² , TR and tourism	CADF, CIPS, LM cointegration, DOLS	EGY and tourism contribute to CO ₂ , TR mitigates CO ₂	No
[21]	BRIC countries	1992–2007	CO ₂ , EGY, Y, Y ² , FD	LLC, IPS, ADF, PP, OLS	FD and EGY contribute to CO ₂	Yes
[22]	ASEAN	1971–2009	CO ₂ , EGY, Y, Y ²	ADF, PP, ARDL model	EGY contributes to CO ₂ in all countries	Yes for Singapore and Thailand; No for Indonesia, Malaysia and Philippines
[23]	ASEAN	1980–2006	CO ₂ , EGY, Y, Y ²	IPS, Johansen cointegration, DOLS	EGY contributes to CO ₂	Yes
[24]	ASEAN	1980–2008	CO ₂ , EGY, Y	PSTR model	EGY contributes to CO ₂	Yes
[25]	19 European countries	1960–2005	CO ₂ , EGY, Y, EMP	ADF-WS, ARDL model	EGY contributes to CO ₂	Yes in Denmark and Italy only
[26]	Central and Eastern Europe	1980–2002	CO ₂ , EGY, Y, Y ² , TR	OLS with FE and RE	EGY contributes to CO ₂ , TR is insignificant	Yes
[27]	EU Countries	1992–2010	CO ₂ , EGY, Y, Y ² , TR, URB	IPS, Breitung, Hadri, Pedroni cointegration, FMOLS	EGY, TR and URB contribute to CO ₂	Yes
[28]	MENA	1981–2005	CO ₂ , EGY, Y, Y ²	LM unit root, LM cointegration, mean-group estimation	EGY contributes to CO ₂	Yes
[29]	Central America countries	1971–2004	CO ₂ , EGY, Y, Y ²	IPS, Pedroni cointegration, FMOLS	EGY contributes to CO ₂	Yes
[30]	Panel of 93 countries	1980–2008	CO ₂ , EGY, Y, Y ² , TR, FD, URB	IPS, ADF, PP, OLS with FE, GMM	EGY, TR and URB contribute to CO ₂ ; FD mitigates CO ₂	Yes for upper income countries
[31]	Canada, Denmark, Iceland, Finland, Norway, Sweden, USA	1990–2011	CO ₂ , EGY, Y, Y ² , Y ³	DF-GLS, ARDL model	EGY contributes to CO ₂	Yes for Iceland
[32]	France	1960–2000	CO ₂ , EGY, Y, Y ²	ADF, PP, ARDL model	EGY contributes to CO ₂	Yes
[33]	Spain	1874–2011	CO ₂ , EGY, Y, Y ² , Price	ADF, ARDL model	Energy price mitigates CO ₂	Yes

[34]	Turkey	1974–2010	CO ₂ , EGY, Y, FD	ZA unit root, ARDL model	EGY and FD contribute to CO ₂	Yes
[35]	Turkey	1960–2007	CO ₂ , EGY, Y, Y ²	Gregory-Hansen cointegration, Johansen cointegration, OLS	EGY contributes to CO ₂	Yes
[36]	Turkey	1974–2010	CO ₂ , EGY, Y, Y ² , FD	ADF, PP, Ng-Perron, Hatemi-J cointegration, ARDL model	EGY and FD contribute to CO ₂	Yes
[37]	China and India	1971–2007	CO ₂ , EGY, Y, Y ² , TR	LM unit root, ARDL model	EGY contributes to CO ₂ China and India; TR mitigates CO ₂ in China but contributes to CO ₂ in India.	Yes
[38]	China	1996–2012	CO ₂ , EGY, Y, Y ² , TR, URB	GMM, mean-group estimation	EGY, TR and URB contribute to CO ₂	Yes
[39]	China	1953–2006	CO ₂ , EGY, Y, Y ² , FD, TR	ADF, ARDL model	EGY and TR contribute to CO ₂ , FD mitigates CO ₂	Yes
[40]	Tunisia	1971–2010	CO ₂ , EGY, Y, Y ² , TR	ZA unit root, ARDL model	EGY and TR contribute to CO ₂	Yes
[41]	Pakistan	1972–2008	CO ₂ , EGY, Y, Y ² , TR	ADF, PP, Johansen cointegration	EGY and TR contribute to CO ₂	Yes
[42]	Vietnam	1976–2009	CO ₂ , EGY, Y, Y ² , FD	ADF, KPSS, Johansen cointegration, error correction model	EGY contributes to CO ₂ ; FD mitigates CO ₂	Yes

B) Studies focusing on energy consumption by sources in the energy-growth literature

Study	Country	Year	Variables	Methods	Long-run results	EKC Hypothesis
[61]	OECD countries	1985–2005	Y, REC, K, L	IPS, Pedroni cointegration, FMOLS	REC, K, L increase Y	
[62]	Eurasia	1992–2007	Y, REC, K, L	IPS, Pedroni cointegration, FMOLS	REC, K, L increase Y	
[63]	Panel of emerging countries	1990–2007	Y, REC, NREC, K, L	LLC, ADF, PP, Pedroni cointegration, FMOLS	NREC, REC, K, L increase Y	
[64]	Central America	1980–2006	Y, REC, K, L	LLC, IPS, ADF, PP, Pedroni cointegration, FMOLS	REC, K, L increase Y	
[65]	Panel of 80 countries	1990–2007	Y, REC, NREC, K, L	LLC, ADF, PP, Pedroni cointegration, FMOLS	NREC, REC, K, L increase Y	
[66]	Central American Countries	1990–2007	Y, REC, NREC, K, L	LLC, ADF, PP, Larsson cointegration	NREC, REC, K, L increase Y	
[67]	Latin American countries	1980–2010	Y, REC, NREC, K, L, TR	LLC, IPS, Pedroni cointegration, DOLS	NREC, REC, K, L, TR increase Y	
[68]	OECD countries	1980–2008	Y, REC	Breitung, IPS, Pedroni cointegration, DOLS	REC increase Y	
[69]	Pakistan	1972:1–2011:4	Y, REC, K, L	NG-Perron, ARDL model, Johansen cointegration	REC, K, L increase Y	
[70]	OECD countries	1990–2010	Y, REC, K, L, R&D	Pedroni cointegration, OLS with FE	REC, K, L, R&D increase Y	
[71]	Turkey	1990–2012	Y, REC, NREC, K, L	ADF, ZA, ARDL, Gregory-Hansen cointegration, ARDL model	NREC, K and L increase Y	
[72]	Panel of top 38 renewable energy countries	1991–2012	Y, REC, NREC, K, L	CD test, CIPS, Pedroni cointegration, DOLS, FMOLS	REC, NREC, K and L increase Y	

C) Studies focusing on energy consumption by sources in the environment-energy-growth literature

Study	Country	Year	Variables	Methods	Long-run results	EKC Hypothesis
[43]	OECD countries	1996–2005	CO ₂ , Y, CPI, REC	Threshold effect	Y and REC contribute to CO ₂ for lower threshold; REC mitigates CO ₂ for upper threshold.	Not investigated
[44]	Panel of developed and developing countries	1984–2007	CO ₂ , Y, Nuclear, REC	LLC, IPS, ADF, PP, LLL cointegration	Nuclear mitigates CO ₂ , REC and Y contribute to CO ₂	Not investigated
[45]	USA, Japan, France, Korea, Spain, Canada	1970–2007	CO ₂ , Y, nuclear	DFGLS, Johansen cointegration	Nuclear mitigates CO ₂ in all countries, Y mitigates CO ₂ in USA, Canada and France	Not investigated
[46]	European countries	1990–2013	CO ₂ , Y, TR, URB, FD, REC by sources (wind, solar, hydro, nuclear, and CRW)	IPS, ADF, PP, Pedroni cointegration, FMOLS	Five sources of REC and TR mitigate CO ₂ ; FD, URB and Y contributes to CO ₂	Not investigated
[47]	Italy	1960–2011	CO ₂ , Y, REC, NREC, TR	ZA unit root, Gregory-Hansen cointegration, ARDL model	REC and Y mitigate CO ₂ , NREC contributes to CO ₂	Not investigated
[48]	EU countries	1990–2008	CO ₂ , Y, Y ² , REC, NREC	OLS with FE	REC and NREC contribute to CO ₂	No
[49]	EU countries	1996–2010	CO ₂ , Y, Y ² , Y ³ , REC	OLS with FE and RE	REC mitigates CO ₂	No
[50]	Panel of 27 advanced countries	1990–2012	CO ₂ , Y, Y ² , REC, NREC, TR, URB, P	ADF, IPS, Kao cointegration, Johansen cointegration, FMOLS	REC mitigates CO ₂ , NREC contributes to CO ₂	Yes
[51]	MENA countries	1980–2009	CO ₂ , Y, Y ² , REC, NREC	Breitung, IPS, Pedroni cointegration, FMOLS, DOLS	REC and NREC contribute to CO ₂	Yes
[52]	OECD countries	1977–2010	CO ₂ , Y, Y ² , REC	LLC, IPS, ADF, Pedroni cointegration, FMOLS, DOLS	REC mitigates CO ₂	Yes
[53]	OECD countries	1980–2010	CO ₂ , Y, Y ² , REC, NREC, TR			Yes

Table 1 (continued)

A) Studies focusing on aggregate energy consumption in the environment-energy-growth literature						
Study	Country	Year	Variables	Methods	Long-run results	EKC Hypothesis
[54]	OECD countries	1980–2011	CO ₂ , Y, Y ² , REC, NREC, POP	Breitung, IPS, LLC, ADF, PP, Pedroni cointegration, FMOLS, DOLS ADF, PP, Breitung, Johansen cointegration, Westerlund cointegration, GMM, AMG	REC and TR mitigate CO ₂ ; NREC contributes to CO ₂ REC mitigates CO ₂ ; NREC contributes to CO ₂	Yes
[55]	Turkey	1961–2010	CO ₂ , Y, Y ² , REC	ADF, KPSS, ARDL model	REC mitigates CO ₂	Yes
[56]	France	1960–2003	CO ₂ , Y, Y ² , nuclear, URB, TR	PP, ARDL model	Nuclear mitigates CO ₂ , URB and TR is insignificant	Yes
[57]	Kenya	1980–2012	CO ₂ , Y, REC, NREC, TR, FD, UB	ADF, PP, LM unit root, ARDL model	REC and FD mitigates CO ₂ ; NREC, TR and URB contributes to CO ₂	Yes
[58]	Vietnam	1982–2011	CO ₂ , REC, NREC, Y, IMP, EXP, CA, L	ARDL model	NREC and IMP contribute to CO ₂	No
[59]	Malaysia	1980–2009	CO ₂ , Y, Y ² , REC, TR	ADF, PP, ARDL model	TR and REC mitigate CO ₂	Yes

Note: IPS (Im-Pesaran-Shin unit root test), LLC (Levin-Lin-Chu unit root test), PP (Phillips-Perron unit root test), ADF (Augmented Dickey-Fuller unit root test), KPSS (Kwiatkowski-Phillips-Schmidt-Shin unit root test), ZA unit root (Zivot-Andrews unit root test), FE (Fixed effects), RE (Random effects), REC (renewable energy consumption), NREC (non-renewable energy consumption), OLS (Ordinary Least Squares), FMOLS (Fully Modified Ordinary Least Squares), DOLS (Dynamic Ordinary Least Squares), Y (real income), EGY (aggregate energy consumption), CPI (consumer price index), CA (current account), IMP (import), EXP (export), POP (population), TR (trade-trade openness), FD (financial development), URB (Urbanization), K (capital), L (labor).

(MENA) [28], Central America countries [29], upper-income economies [30], Iceland [31], France [32], Spain [33], Turkey [34–36], China [37–39], Tunisia [40], Pakistan [41] and Vietnam [42]. In detail, one of the earliest works [1] analyzes the relationship among carbon emissions, energy consumption, economic growth and population for Turkey over the period 1970–2002, and shows that both energy consumption and economic growth increase the level of emissions. Building on the EKC framework, [14] examines the relationship among CO₂ emissions, energy consumption, the real income, the square of real income and trade for Turkey by applying the Autoregressive-Distributed Lag (ARDL) model on the data from 1960–2005, and indicates that increases in energy consumption and trade stimulate carbon emissions, and the EKC hypothesis is not valid. On the other hand, [34,35,36] find the evidence of the EKC hypothesis for Turkey, and also show that energy consumption leads to environmental degradation. In addition, one of the pioneering studies [13] shows that energy consumption boosts the level of emissions, and the EKC is not supported for the USA by using causality approach during the period 1960–2005. The recent study [12] also reaches the same conclusion for the USA, and further shows that trade mitigates carbon emissions whereas urbanization contributes to the level of emissions by using the Zivot-Andrews unit root test with structural break and the ARDL model for the years 1960–2010. For the case of China, [37–39] reveal that increases in energy consumption increase the pollution. Furthermore, [38] exhibits that trade and urbanization contribute to the level of emissions by using the mean-group estimation, and [39] shows that trade increases CO₂ emissions whereas financial development leads to environmental improvements by employing the ARDL model over the period 1953–2006. Regarding panel studies, [23] analyzes the link between CO₂ emissions, the real output, the square of real output and energy consumption for ASEAN by applying the Johansen cointegration test and the dynamic ordinary least squares (DOLS) on the data from 1980–2006, and shows that the EKC hypothesis is supported and energy consumption leads to higher pollution. Moreover, the study [24] reaches the same conclusion for ASEAN. In addition, [27] examines the long-run dynamics of the level of emissions, energy consumption, the real income, the square of real income, trade and urbanization for the EU countries over the period 1992–2010 by using the Pedroni cointegration test and the fully modified ordinary least squares (FMOLS), and indicates that energy consumption, trade and urbanization increase the pollution. The study [20] shows that energy consumption and tourism contribute to CO₂ emissions while trade leads to lower level of emissions for OECD countries for the years 1995–2010, and finds evidence against the existence of the EKC hypothesis by using the CADF and the CIPS unit root tests, the LM cointegration test and the DOLS. The existence of the EKC hypothesis for Central America countries is investigated by [29] using the Pedroni cointegration test and the FMOLS.

The second group of studies given in part B focuses on the relationship between renewable energy, non-renewable energy and economic growth in a multivariate framework wherein studies employ capital and labor as additional variables. Increases in renewable energy consumption increase economic growth in OECD countries [61,68,70], Eurasia [62], panel of emerging countries [63], Central American countries [64,66], panel of 80 countries [65], Latin American countries [67], top renewable energy countries [72] and Pakistan [69]. The second group of studies finds a strong link between energy consumption by sources and economic growth for a variety of countries and regions. Inspired, perhaps, by the second group, the third (and the last) group of studies given in part C analyzes the link between CO₂ emissions, the real income and energy consumption by sources (i.e. renewable and non-renewable energy). It is note-worthy that the number of studies in the last group is

relatively smaller than the first group. Nevertheless, as similar to the first group, some studies do not examine the existence of the EKC hypothesis [43–47]. In addition, the EKC hypothesis is investigated and validated for panel of 27 advanced countries [50], MENA countries [51], OECD countries [52–54], Turkey [55], France [56], Kenya [57], and Malaysia [59]. On the other hand, the EKC hypothesis is not supported for EU countries [48,49] and Vietnam [58]. By using the Pedroni cointegration test, the FMOLS and the DOLS, [52] and [53] show that renewable energy mitigates CO₂ emissions for OECD countries. The study [54] reaches the same conclusion for OECD members by using the Johansen cointegration test, the Westerlund cointegration test and the generalized methods of moments (GMM) during the period 1980–2011. By using the OLS with fixed effects for the years 1980–2008, [48] indicates that both renewable and non-renewable energy lead to environmental degradation for EU countries. On the other hand, [49] reveals that renewable energy decreases the pollution for EU countries over the period 1996–2010 by employing OLS with fixed effects and random effects. The study [51] analyzes the linkage among CO₂ emissions, the real output, the square of real output, renewable and non-renewable energy for MENA countries by applying the Pedroni cointegration test, the FMOLS and the DOLS on the data from 1980–2009, and concludes that both renewable and non-renewable energy increases the level of emissions. For the case of Turkey, the study [55] finds that renewable energy leads to environmental improvements by using the ARDL model from 1961–2010. The study [57] investigates the impacts of the real income, renewable and non-renewable energy, trade, financial development and urbanization for Kenya over the period 1980–2012 by using the ARDL model, and shows that renewable energy and financial development mitigate CO₂ emissions whereas non-renewable energy, trade and urbanization increase the pollution. It is worth pointing out that empirical studies produce further controversial outcomes. More precisely, [9,26,56] find that the coefficient of trade is statistically insignificant while [14,15,17,30,39,41,57] show that trade contributes to the level of pollution, and [5,10,12,20,37,46,53,59] indicate that trade mitigates pollution. In addition, [12] finds that the coefficient of financial development is statistically insignificant and [17,21,34,36,46] show that financial development leads to environmental degradation; on the contrary, [4,5,30,39,42,57] indicate that financial development lessens the level of emissions.

The current study falls into the third group and aims to analyze the relationship between the real income, the square of real income, renewable energy, non-renewable energy, financial development and trade as well as to investigate the presence of the EKC hypothesis for the panel of top renewable energy countries by employing heterogeneous panel estimation approaches with cross-section dependence. Thus, this study employs recently developed second generation econometric tools in reaching the above-mentioned goals as opposed to the majority of the state-of-the-art which use first generation tests that fail to consider both issues that may exist in the panel.

3. Model and data

The studies [16,19,22,23,28,32,35] investigate the environment-output-energy nexus under the base EKC framework in which carbon emissions are regressed on the real income, the quadratic income and aggregate energy consumption (EGY). In addition, the studies [48,51] disaggregate energy consumption by sources and then investigate the environment-energy-growth nexus under the base EKC framework in which the level of CO₂ emissions are regressed on the real income (Y), the quadratic real income (Y²), renewable energy consumption (REC) and non-renewable energy consumption (NREC). The EKC model assumes that the pollution

rises with income in early stages of economic growth, but after a turning point, increase in income leads to environmental improvement [73]. In other words, the EKC hypothesis presumes a quadratic relationship between economic growth and environmental pollution. In addition, the study [74] also indicates an assumption that the elasticity of CO₂ emissions with respect to real output is the same across countries although carbon emissions may vary across economies at any given level of real output. The base EKC model (Model 1) can be shown as:

$$\text{Model 1: } (CO_2)_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 REC_{it} + \beta_4 NREC_{it} + e_{it}$$

Recent studies including [26,37,40,41,53,59] argue that trade openness (TR) can explain the variation in the level of carbon emissions, and include it into the base EKC model. Accordingly, a modified EKC model (Model 2) can be written as:

$$\text{Model 2: } (CO_2)_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 REC_{it} + \beta_4 NREC_{it} + \beta_5 TR_{it} + e_{it}$$

In addition to trade openness, some recent studies including [11,18,39,36,42,57] discuss the importance of financial development (FD) in determining the level of gas emissions, and therefore insert it to the base EKC model. By accounting for the impact of FD on CO₂ emissions, we can indicate Model 3 as follow⁴:

Model 3: $(CO_2)_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 REC_{it} + \beta_4 NREC_{it} + \beta_6 FD_{it} + e_{it}$ where *i* and *t* stands for cross-sections and the time; *e* denotes normally distributed error term; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ are the coefficient estimates of the relevant variables. If the EKC hypothesis is valid, we will expect that $\beta_1 > 0$, and $\beta_2 < 0$. In addition, β_3 is expected to be negative whereas β_4 is expected to be positive suggested by the recent state-of-the-art. The estimates of β_5 and β_6 can be greater or smaller than zero depending on the net effect of trade openness and financial development on carbon emissions. As regards to data selection, CO₂ emissions are in metric tons; *Y* is gross domestic product in 2005 US\$; *TR* is trade openness measured as the sum of exports and imports of goods and services as a share of *Y*; *FD* is financial development measured as domestic credit to private sector as a share of *Y*; *REC* is electricity power from renewable sources (e.g. wind, solar, geothermal, biomass and waste) in kilowatt-hours; *NREC* is electricity power from non-renewable sources (e.g. coal, oil, natural gas) in kilowatt-hours. Following [51,55,53,72] electricity is used as proxy for energy consumption. The annual panel time-series data are from 1985–2011. The data on CO₂, *Y*, *TR* and *FD* come from “the World Development Indicators” (<http://data.worldbank.org>), and the data on *REC* and *NREC* are drawn from “the US Energy Information Administration” (www.eia.gov).

The data used in this study are transformed into the natural logarithm in order to interpret the coefficient estimates as the elasticities of the response variable (CO₂ emissions) with respect to the independent variables (*Y*, *Y*², *REC*, *NREC*, *TR* and *FD*). It is note-worthy that we optimize the data in that we employ the longest available data with the greatest number of cross-section as possible. Out of 40 countries listed in the Renewable Energy Country Attractiveness Index (www.ey.com), this study covers Turkey, Italy, Australia, Japan, Norway, the USA Austria, Brazil, Canada, Chile, the UK, Denmark, France, Indonesia, Kenya, Mexico, Netherlands, Belgium, Spain, Peru, Philippines, Portugal, Sweden. According to descriptive statistics indicated in Table 2, the largest CO₂ emission is in the USA in 2005 whereas the lowest carbon emission is in Kenya in 1985. In addition, the highest real income is in the USA in 2011 while the lowest real income in Kenya in

⁴ Although several studies [4,13,17,30,39,47] simultaneously include both trade openness and financial development into the base EKC model, we analyze them in separate models because the LM bootstrap cointegration test and the DOLS estimator are not working with more than 6 variables given the length of data used in this study.

Table 2
Descriptive statistics.

	CO ₂	Y	REC	NREC	TR	FD
Mean	18.87	26.79	3.48	3.63	3.95	4.12
Std. Dev.	1.40	1.43	2.45	1.97	0.5	0.72
Minimum	15.14	23.01	-3.98	-2.28	2.57	2.24
Maximum	22.48	30.25	8.74	8.00	5.08	5.42
Observations	621	621	621	621	621	621

1985. Moreover, the USA is the largest consumer of renewable energy and non-renewable energy in 2011 and 2007, respective; on the contrary, Kenya is the smallest consumer of non-renewable energy in 1989, and the UK is the smallest consumer of renewable energy in 1986. Regarding trade openness, Peru has the lowest level in 1987 and Belgium has the highest level in 2011. In addition, Peru is the least financially developed country in 1991 whereas Japan is the highest financially developed economy in 1999. Last, large standard deviations of variables imply that data points are far from the mean, indicating possible heterogeneity across cross-sections for the analyzed variables. We further discuss this issue in the next section. In addition, the cross-sectional independence (CD) test is used to explore whether or not error terms are cross-sectionally dependent. The study [75] uses the following regression in Eq. (1):

$$CD = \sqrt{\frac{2T}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right)} \quad (1)$$

where T is time period, N is sample size and $\hat{\rho}_{ij}$ is the sample estimate of cross-sectional correlation of errors of country i and j. Moreover, this study further investigate integration properties of carbon emissions, the real income, renewable and non-renewable energy consumption, trade and financial development by using the cross-sectionally augmented ADF (CADF) unit root test and the cross-sectionally augmented IPS (CIPS) unit root test [76]. The application processes of both tests are identical except the CIPS test use the cross-section average of the CADF test. Eq. (2) shows the model for the panel unit root tests:

$$\Delta X_{it} = \alpha_i + \beta_i X_{it-1} + \rho_i T + \sum_{j=1}^n \theta_{ij} \Delta X_{it-j} + \varepsilon_{it} \quad (2)$$

where X_{it} stands for an analyzed variable, ε_{it} is error term, and Δ is the difference operator, and α and T are individual intercepts and time trends, respectively. The appropriate lag lengths are selected based on the Schwarz Information Criterion. Both tests perform the null hypothesis that all individuals within a panel data are not stationary versus the alternative hypothesis that at least one individual is stationary. In the next stage, we employ Pedroni cointegration test, Kao cointegration test and the LM bootstrap cointegration test in order to find out whether or not the analyzed variables have a long-run relationship. The Pedroni panel cointegration test proposed by [77,78] uses the following regression in Eq. (3) and seven test statistics (panel v-statistic, panel rho-statistic, panel PP-statistic, panel ADF-statistic, group rho-statistic, group PP-statistic and group ADF-statistic):

$$Y_{it} = \alpha_i + \delta_i T + \sum_{j=1}^k \beta_{ij} X_{jit} + \varepsilon_{it} \quad (3)$$

where α_i and β_i are intercept and slope coefficients that can vary across regions. The null hypothesis of no cointegration is determined based on error term ($\varepsilon_{i,t}$) such that the null hypothesis cannot be rejected if the error term is integrated of order one (I (1)). The regression $\varepsilon_{i,t} = \rho_i \varepsilon_{i,t-1} + \mu_{i,t}$ is used for this purpose. Next, this study also employs the Kao panel cointegration test [79]. This test is based on the ADF statistics for which residuals are obtained through the following regression in Eq. (4) and the ADF

test statistic is calculated from Eq. (5):

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$ADF = \frac{t_{ADF} + \frac{(\sqrt{6N}\hat{\sigma}_v)}{2\hat{\sigma}_{0v}}}{\sqrt{\left(\frac{\hat{\sigma}_{0v}^2}{2\hat{\sigma}_v^2}\right) + (10\hat{\sigma}_{0v}^2)}} \quad (5)$$

where $\hat{\sigma}_v^2 = \sum_{i \in E} - \sum_{i \in E} \sum_{i \in E}^{-1}$, $\hat{\sigma}_{0v}^2 = \Omega_u - \Omega_{ue} \Omega_e^{-1}$, Ω is the long run covariance matrix and t_{ADF} is the t-statistic in the ADF regression. Further, the LM test for the bootstrap panel cointegration test is calculated by following model in Eq. (6) [80]:

$$LM_N^+ = 1/NT^2 \sum_{i=1}^N \sum_{t=0}^T \hat{\omega}_t^{-2} S_{i,t}^2 \quad (6)$$

where, $\hat{\omega}_t$ and $S_{i,t}$ indicate the long-run variance and the partial sum process of the residuals, respectively. Last, this study uses the DOLS and the FMOLS estimators in order to show long-run coefficient estimates of the real income, the square of real income, renewable and non-renewable energy consumption, financial development and trade openness for CO₂ emissions. The regression of the weighted FMOLS and the weighted DOLS estimators are given in equation 6 and 7 [81,82]:

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \quad (6')$$

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \sum_{j=-k}^k c_{ij} \Delta X_{i,t-j} + \mu_{i,t} \quad (7)$$

where Y_{it} is the dependent variable and X represents the vector of the independent variables. In addition, α_i , β_i , $-k$ and k , and μ_{it} represent individual effect, coefficient of slope, lead and lag of difference, and error term, respectively.

4. Issues of cross-sectional dependence and heterogeneity

Table 3 indicates the average annual growth rates of CO₂ emissions, real production, renewable and non-renewable energy consumption, trade openness and financial development for each country under consideration. There is a noticeable heterogeneity

Table 3
Average annual growth rate of each variable: 1985–2011 (percent).

Country	CO ₂	Y	REC	NREC	TR	FD
Australia	1.85	3.65	12.97	3.42	1.03	5.21
Austria	0.77	2.56	8.47	2.06	1.74	0.79
Belgium	-0.29	2.34	21.91	1.61	1.20	3.42
Brazil	3.85	3.18	10.62	8.43	0.88	1.42
Canada	0.61	2.73	10.68	1.99	0.69	3.13
Chile	5.67	5.99	13.85	10.33	1.32	1.66
Denmark	-1.73	1.81	43.56	-1.29	1.42	6.34
France	-0.73	2.23	14.02	-0.79	0.96	1.22
Indonesia	6.68	5.78	12.29	8.35	0.71	1.84
Italy	0.29	1.54	10.87	2.15	1.14	2.97
Japan	1.13	1.86	4.03	2.84	0.98	0.74
Kenya	5.56	4.09	8.93	7.34	0.38	-0.13
Mexico	2.09	2.83	6.16	5.35	3.94	2.96
Netherlands	0.55	2.73	18.34	2.05	0.97	1.26
Norway	0.91	2.64	25.03	10.85	-0.41	2.55
Peru	4.35	3.86	4.54	7.92	3.03	1.90
Philippines	4.66	4.41	0.36	6.02	1.69	2.00
Portugal	2.59	2.67	12.61	5.33	0.74	3.94
Spain	1.29	3.08	19.85	3.16	1.50	4.04
Sweden	-0.78	2.45	9.92	-2.14	1.34	1.97
Turkey	4.78	4.75	28.45	8.54	2.11	4.84
UK	-0.97	2.59	46.03	0.49	0.74	6.01
USA	0.72	2.97	13.28	1.92	2.70	2.46

Note: The growth rates are calculated by the authors.

across cross-sections for the analyzed variables. For instance, the average annual growth rate of emissions is positive and big for some countries such as Indonesia and Chile whereas it is negative for Belgium, Denmark, France, Sweden and the UK. A similar picture is held for non-renewable energy consumption, trade openness and financial development. The average annual growth rate of renewable energy consumption is positive for all cross sections but the magnitude significantly varies across them. It is 12.97% for Australia, 25.03% for Norway and 43.56% for Denmark. The average annual growth rate of non-renewable energy is higher than that of renewable energy in Peru and Philippines while the opposite case is valid for the rest. Furthermore, sample countries fall into different categories in terms of income level (e.g. high-income countries, middle-income countries, low-income countries). Given the fact that heterogeneity exists across sample countries for the analyzed variables and one can be able to analyze the proposed models for each country using time-series econometric

models, we should employ heterogeneous panel techniques in which the parameters vary across cross sections.

In addition to heterogeneity, one should be suspicious about cross-sectional dependence across the panel when a panel study is carried out. The CD test due to [75] is thus applied to the analyzed variables to explore whether or not each time-series panel data has cross-sectional independence. The results from the Pesaran's CD test for cross-sectional independence are given in Table 4. Referring to the associated p-values, we can reject the null hypothesis of cross-sectional independence for carbon emissions, $Y (Y^2)$, renewable energy, non-renewable energy, trade openness and financial development. Given the fact that the variables under investigation have cross-sectional dependence, we should proceed with heterogeneous panel techniques with cross-section dependence. Henceforth, this study uses the cross-sectionally augmented Dickey-Fuller (CADF) unit root test and the cross-sectionally augmented IPS (CIPS) unit root tests [76], which take into account both issues.

Table 4
Results from cross-sectional independence test.

	CO ₂	Y (Y ²)	REC	NREC	TR	FD
CD-test	30.69**	79.35**	63.38**	51.00**	50.19**	25.85**
P-value	0.00	0.00	0.00	0.04	0.00	0.00

Note:
** denotes the statistical significance at 1% level. The CD-test performs the null hypothesis of cross-sectional independence.

Table 5
Results from panel unit root tests.

	CADF		CIPS	
	Level	Δ	Level	Δ
CO ₂	-1.63	-3.78**	-2.11	-5.54**
Y (Y ²)	-2.26	-3.97**	-1.73	-3.16**
REC	-1.94	-3.88**	-2.20	-5.29**
NREC	-2.29	-3.97**	-2.61	-5.50**
TR	-1.83	-3.12**	-1.94	-4.32**
FD	-2.32	-3.26**	-2.32	-4.20**

Note:
** denotes the statistical significance at 1% level. Critical values are not given for the sake of brevity but can be provided upon request.

Table 6
Results from the Pedroni cointegration test.

Common AR coefficients (within-dimension)						
	Model 1		Model 2		Model 3	
	Statistic	Weighted statistic	Statistic	Weighted statistic	Statistic	Weighted statistic
Panel v-statistic	1.33	0.47	0.16	-1.18	0.59	-0.46
Panel rho-statistic	-0.94	-1.72*	0.65	-0.3	-0.04	-1.05
Panel PP-statistic	-5.12**	-7.12**	-4.30**	-7.81**	-5.52**	-8.33**
Panel ADF-statistic	-5.41**	-7.63**	-3.87**	-8.33**	-5.05**	-8.41**
Individual AR coefficients (between-dimension)						
	Model 1		Model 2		Model 3	
	Statistic	Weighted statistic	Statistic	Weighted statistic	Statistic	Weighted statistic
Group rho-statistic	0.08		1.64		1.14	
Group PP-statistic	-8.04**		-8.30**		-7.87**	
Group ADF-statistic	-8.00**		-6.42**		-6.80**	

Note:
** denote the statistical significance at 1% level respectively.
* denote the statistical significance at 5% level, respectively.

5. Methods and Empirical Findings

5.1. Panel unit root tests

This empirical work uses the CADF and the CIPS unit root tests instead of first generation unit root tests such as IPS and LLC unit root tests because the latter ones fail to take into account the issue of cross-sectional dependence. Importantly, the CADF and the CIPS tests produce reliable results in the presence of both cross-sectional dependence and heterogeneity across the sample countries.

The results from second generation unit root tests are reported in Table 5. Both tests indicate that carbon emissions, $Y (Y^2)$, renewable energy consumption, non-renewable energy consumption, trade

Table 7
Table: Results from the Kao panel cointegration test.

	Model 1		Model 2		Model 3	
	t-statistics	p-value	t-statistics	p-value	t-statistics	p-value
ADF	-3.30**	0.00	-3.29**	0.00	-3.50**	0.00

Note:
** denotes the statistical significance at 1% level.

Table 8
Results from the LM bootstrap panel cointegration test.

Tests	Model 1		Model 2		Model 3	
	LM statistic	Bootstrap p-value	LM statistic	Bootstrap p-value	LM statistic	Bootstrap p-value
LM bootstrap	12.9	0.99	20.92	0.99	21.39	0.99

Note: The LM bootstrap test statistics are calculated using 5,000 replications.

openness and financial development contain unit root at their levels but become stationary at their first differences. In other words, we can conclude that CO_2 , Y (Y^2), REC, NREC, TR and FD are all I (1). The panel data should be either stationary or cointegrated at their levels in order for researchers to assess statistically and economically meaningful coefficient estimates. Because CO_2 , Y (Y^2), REC, NREC, TR and FD include unit root at their levels, this study applies panel cointegration tests; namely, the Pedroni cointegration test, the Kao cointegration test and the LM bootstrap cointegration test to see whether or not the analyzed variables have a long-run relationship. The mentioned panel cointegration tests require that variables must be non-stationary at levels, and the analyzed variables meet the necessary requirement.

5.2. Panel cointegration tests

This study searches for possible cointegration relationship between the analyzed variables in Model 1, Model 2 and Model 3 by firstly using the Pedroni panel cointegration test due to [77] and [78] as it is applicable for heterogeneous panels. The study [77] indicates that there are seven tests statistics as shown in Table 6. The results from the Pedroni panel cointegration test indicate that the analyzed variables in Model 1, Model 2 and Model 3 are cointegrated with respect to the majority of the test statistics.

The second panel cointegration test is the Kao panel cointegration test [79]. This test follows a similar procedure as the Pedroni test but includes cross-homogeneous coefficients on the first-stage regressors. Referring to the results from the Kao panel cointegration test in Table 7, the analyzed variables in Model 1, Model 2 and Model 3 are cointegrated and have long-run relationships since we have enough evidence to reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration at 1% level of significance.

Even though the Pedroni and the Kao panel cointegration tests have been numerously used in various literatures including the energy-environment-growth literature (as shown in Table 1), both have drawbacks of assuming cross-section independence, and thus are considered as first generation cointegration tests. Failure of considering the presence of cross-section dependence across countries has consequences of causing loss of power in procedures of first generation cointegration tests. Therefore, this study also employs a second generation cointegration test; namely, the LM bootstrap panel cointegration test due to [80] in order to check the verdicts of the former tests. The LM bootstrap panel cointegration test accounts for both issues of cross-sectional dependence and heterogeneity across the panel in identifying the cointegration relation among the variables, and thus is superior to the first generation cointegration tests. In addition, this test differs from the former tests in that the LM bootstrap cointegration test assumes the null hypothesis of cointegration. The results from the LM bootstrap panel cointegration test are reported in Table 8. Because there is no evidence to reject the null hypothesis of cointegration, this study indicates that CO_2 , Y , Y^2 , REC, NREC, (TR) and {FD} in Model 1, (Model 2) and {Model 3} are cointegrated. The conclusion that we reach on the existence of the cointegration between the analyzed variables for the top renewable energy

countries become more robust and stronger since the mentioned panel cointegration test accounts for heterogeneity and cross-sectional dependence across the countries.

5.3. Long-run Estimates

After we find that carbon emissions, the real income, the quadratic real income, renewable energy, and non-renewable energy (Model 1), and emissions, Y , Y^2 , renewable energy consumption, and non-renewable energy consumption and trade openness (Model 2), and CO_2 emissions, the real income, the quadratic real income, REC, NREC and financial development (Model 3) are cointegrated, it is of interest for researchers to pin down long-run coefficient estimates of the independent variables (Y , Y^2 , REC, NREC, TR, FD). The ordinary least squares (OLS) estimator is very popular and among commonly used ones in a variety of literatures; however, the fully modified ordinary least squares (FMOLS) and the dynamic ordinary least squares (DOLS) estimators have been recently preferred to the OLS estimator [83]. These methods are also quite effective in eliminating the endogeneity issues in the regressors and serial correlations in the error terms and so the variables also have asymptotic properties [72,84]. In addition, the FMOLS estimator gets rid of the problems of endogeneity and autocorrelation by using non-parametric approach while the DOLS estimator eliminates the difficulties by using parametric approach, and lags and leads of the explanatory variables. Thus, we estimate the three models using second generation estimators; namely, the DOLS and the FMOLS. More precisely, we use the weighted DOLS estimator allowing for heterogeneity in the long-run variances [81] and the weighted FMOLS technique for heterogeneous cointegrated panels [82]⁵.

The results from the DOLS and the FMOLS estimators are given in Tables 9 and 10, respectively. The reported coefficients are statistically significant at 1% level or 5% level. Because the natural logarithm values of the panel time-series data are used, long run coefficient estimates of Y , Y^2 , REC, NREC, TR and FD are econometrically equal to the elasticities of CO_2 with respect to the real income, the square of real income, renewable energy consumption, non-renewable energy consumption, trade openness and financial development, respectively. Although the magnitudes of coefficient estimates in Model 1, Model 2 and Model 3 vary across the used estimators, the overall outcome of the FMOLS is the same as the DOLS. It is found that the signs of coefficient estimates of Y and the square of Y are positive and negative although their magnitudes change across the three models. More precisely, the (partial) marginal effect of Y on CO_2 is calculated by $\beta_1 + 2\beta_2 * Y$, indicating that the (partial) marginal effect of real production on carbon emissions is clearly positive for the group of low-income countries; but, it decreases and eventually becomes negative as they shift to the group of high-income countries. In other words, as the top renewable energy countries pass the threshold income level, increases in the real income lead to environmental improvements. This implies that the EKC hypothesis is validated

⁵ For more information, please refer to the references.

Table 9
Results from the weighted DOLS.

Regressors	Model 1		Model 2		Model 3	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Y	2.47**	0.00	2.12**	0.00	2.88**	0.00
Y ²	−0.04**	0.00	−0.03**	0.00	−0.05**	0.00
REC	−0.03**	0.00	−0.03**	0.00	−0.03**	0.00
NREC	0.24**	0.00	0.23**	0.00	0.23**	0.00
TR			−0.08**	0.00		
FD					−0.03**	0.01
R ²	0.998		0.999		0.999	

Note: The dependent variable is CO₂.

** denotes the statistical significance at 1% level.

Table 10
Results from the weighted FMOLS.

Regressors	Model 1		Model 2		Model 3	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Y	2.54**	0.00	2.56**	0.00	2.55**	0.00
Y ²	−0.05**	0.00	−0.04**	0.00	−0.04**	0.00
REC	−0.04**	0.00	−0.04**	0.00	−0.04**	0.00
NREC	0.21**	0.00	0.20**	0.00	0.20**	0.00
TR			−0.03**	0.01		
FD					−0.03*	0.02
R ²	0.991		0.994		0.994	

Note: The dependent variable is CO₂.

** denotes the statistical significance at 1% level respectively.

* denotes the statistical significance at 5% level, respectively.

for the analyzed top renewable energy countries. The existence of the EKC hypothesis is in line with [21–43,50–57,59].

Regarding the environmental effects of energy consumption by sources, increases in renewable energy consumption mitigate carbon emissions whereas increases in non-renewable energy consumption stimulate the level of emissions. A 1% increase in REC lessens the level of emissions by 3%–4%; on the contrary, a 1% rise in NREC boosts CO₂ by 20–24%. The findings are consistent with the-state-of-the-art in that [43,46,47,49,50,52–55,57,59] suggest that renewable energy leads to environmental improvements, and [47,48,50,51,53,54,57,58] show that the use of non-renewable energy leads to environmental degradation. An optimal project to sustain the aim of keeping global warming below 2 °C above pre-industrial levels and consequently leave a clean environment to next generations is to raise the share of renewable sources in energy mix. More importantly, the parties to the protocol as well as the top renewable countries under consideration should spend enough efforts to accomplish the given targets. Given the fact the price of petroleum per barrel is around \$35–40 (www.oil-price.net) and the cost of energy from non-renewable sources is currently less than that from renewable energy, one possible option to keep track of the aims is to financially support scientific institutions, universities and researchers to get generating energy from renewable sources at cheaper costs. The other option should be to regulate necessary policies to increase public awareness of renewable energy and clean environment.

The elasticities of CO₂ emissions with respect to trade openness and financial development are −0.03 (−0.08) and −0.03, respectively. This implies that increases in both trade openness and financial development decrease carbon emissions in top renewable energy countries. As discussed in the introduction section, trade and financial development may have negative or positive impact on the environment. The result of the current empirical study indicates that the net environmental impact of

both trade openness and financial development is positive, implying reductions in environmental deteriorations. It makes sense because developed countries in particular have made a good progress in inventing new technologies for over the last several decades, and the analyzed countries seem to take benefit of technology spillover through trade and financial networks. Furthermore, it is likely that the top renewable energy countries produce and exports non-energy intensive and environmentally-friendly goods, and imports dirty and environmentally-unfriendly goods. The negative coefficient estimate of trade openness is in line with that of [5,10,12,20,37,46,53,59]. Also, the adverse effect of financial development on carbon emissions is consistent with [4,5,30,39,42,57].

The reported results are strong, robust and reliable since we employ multiple unit root tests, cointegration tests and long-run estimators, and importantly the verdict of one test is confirmed by the other test in the same category. In addition, this study employs second generation econometric approaches. On the other hand, further studies can potentially obtain more robust results once longer data become available although we use the longest available data on the analyzed variables for the sample countries. Moreover, further studies may investigate the effects on the level of emissions of type of renewable energy consumption (i.e. wind and solar), and type of non-renewable energy consumption (i.e. coal and natural gas) for the sample countries.

6. Conclusions and policy recommendations

Efforts made in the United Nations Framework Convention on Climate Change for years, and participation of nearly 200 countries to the Paris conference make environmental concerns (i.e. global warming and greenhouse gas emissions) worldwide attractive and discussed subject. In addition to review objective of this study, the purpose of this empirical work is to explore the environmental impacts of the real income, energy consumption by sources, trade and financial development to guide nations to handle increased carbon emissions. Thus, we focus on the long-run dynamic relationship of CO₂ emissions, the real income (Y), the quadratic real income (Y²), renewable energy consumption (REC), non-renewable energy consumption (NREC), trade (TR) and financial development (FD) in the EKC framework for the top countries listed in Renewable Energy Country Attractiveness Index for the period 1985–2011. Moreover, we use second generation panel methods that take into account the presence of heterogeneity and cross-sectional dependence across countries for the analyzed variables. Thus, the results found in the current study are accurate, robust and reliable. The findings and policy recommendations can be summarized as follow:

- By looking at the average annual growth rates of each variable, and applying the Pesaran's CD test to the panel time-series data, we detect the presence of heterogeneity and cross-sectional dependence across countries for the analyzed data.
- The CADF and the CIPS unit root tests report that the analyzed variables are non-stationary at their levels but become stationary at their first differences.
- The Pedroni, the Kao and the LM bootstrap cointegration tests show that the analyzed variables are cointegrated and hence have a long-run relationship.
- The DOLS and the FMOLS estimators indicate that increases in REC, TR and FD lead to environmental improvements whereas increases in NREC lead to environmental degradation for the top renewable energy countries.
- The EKC hypothesis is detected, indicating that increases in the real production lead to environmental improvements after the

threshold income level. Countries should project to boost their gross domestic productions.

- Given the reality that countries can currently produce energy using non-renewable sources at a lower cost than renewable energy, they should support universities and researchers to make the opposite case happen. Therefore, the implementation of increased renewable sources in energy mix can also be economically sustainable for countries.
- In order to protect future renewable energy investments from the great plunge in petroleum prices, additional measures (e.g. tax cut, and consumption and production subsidies for renewable energy) should be taken in countries, especially in undeveloped and developing ones.
- As suggested in the Paris protocol, developed countries should do their bit in financially supporting undeveloped and developing countries for adaptation and mitigation.
- The use of renewable energy and the adoption of renewable energy technologies should be further introduced in production processes.
- Increases in trade and financial development can also help countries (through technology spillover) adopt and use new environmentally-friendly technologies.
- Regulatory policies should be implemented to increase public awareness of renewable energy and environmental protection.

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