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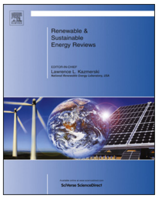

The dynamic impact of renewable energy consumption on CO_2 emissions: A revisited Environmental Kuznets Curve approach

Faik Bilgili [a,*], Emrah Koçak [b,1], Ümit Bulut [c,2]

[a] Erciyes University, Faculty of Economics and Administrative Sciences, Department of Economics, 38039 Melikgazi/Kayseri, Turkey
[b] Ahi Evran University, Mucur Vocational School, 40500 Kirsehir, Turkey
[c] Ahi Evran University, Faculty of Economics and Administrative Sciences, Department of Economics, 40100 Kirsehir, Turkey

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ABSTRACT

This paper considers a revisited Environmental Kuznets Curve (EKC) hypothesis with potential impact of renewable energy consumption on environmental quality. To this end, paper aims at investigating the validity of the EKC hypothesis employing the dependent variable of CO_2 emissions and regressors of GDP, quadratic GDP and renewable energy consumption. This paper, hence, analyzes this revisited EKC hypothesis to observe if (i) there exists an inverted-U shaped relationship between environmental quality (in terms of CO_2 emissions), per capita income and per capita income squared and (ii) there exists a negative causality from renewables to CO_2 emissions within EKC model.

Paper employs a panel data set of 17 OECD countries over the period 1977–2010 and launches panel FMOLS and panel DOLS estimations. The findings support the EKC hypothesis for the panel and indicate that GDP per capita and GDP per capita squared have the impacts on CO_2 emissions positively and negatively, respectively, and that renewable energy consumption yields negative impact on CO_2 emissions. Another remark of this paper is that the validity of EKC does not depend on income level of individual countries of panel in which EKC hypothesis holds.

Eventually, paper argues that if countries carry out (i) policies, i.e., for fair and easy access to the electricity from renewable sources and (ii) policies to increase renewables supply through i.e. improved renewable energy technologies, they will be able to contribute to combating global warming problem as they increase their GDP's.

Contents

1. Introduction

One may claim that scientists, in the 21st century, are aware of air pollution's growing severe threat to human health and welfare. Hence, the subject of source of environmental pollution becomes today most serious concern of the scientific literature on environment, climate change and global warming. The institutional

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[*] Corresponding author. Tel.: +90 352 207 66 66x30502.
E-mail addresses: fbilgili@erciyes.edu.tr, faikbilgili@gmail.com (F. Bilgili), ekocak@ahievran.edu.tr (E. Koçak), ubulut@ahievran.edu.tr (Ü. Bulut).
[1] Tel.: +90 386 812 29 77.
[2] Tel.: +90 386 280 49 20.

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concerns of environmental facts appear in the early 1970s. For instance, The Club of Rome's report entitled "The Limits to Growth" underlines the potential possible correlation of environmental quality/inferiority with economic growth (Meadows et al. [1]). This report implies that growth is not sustainable in terms of natural sources and environment (Dinda [2]). Then, scientists consider employing environmental data to measure the impact of economic growth on pollution and/or global warming through especially the foundation of Global Environmental Management Services (GEMS).

Some seminal papers reveal that, within the process of economic growth, environmental pollution level first scales up and later scales down. This is an inverted U-shaped relationship between GDP per capita and pollution level (Grossman and Krueger [3,4], Panayotou [5], Shafik [6], Selden and Song [7]). Since this relationship resembles the relationship between GDP per capita and income inequality produced by Kuznets [8], Panayotou [5] calls it Environmental Kuznets Curve (EKC).

According to the EKC hypothesis, the level of environmental pollution initially intensifies because of economic growth, later tampers after GDP per capita reaches a threshold value (Panayotou [5], Suri and Chapman [9]; Stern [10]). Therefore, this hypothesis implies a dynamic process in which structural change occurs together with economic growth (Dinda [2]). Grossman and Krueger [3] first clarify how the EKC arises. They explore that economic growth affects environmental quality through three channels: (i) scale effect, (ii) structural effect, and (iii) technological effect. Fig. 1 presents the EKC within the periods of (i), (ii) and (iii).

According to the scale effect, given the level of technology, more resources and inputs are employed to produce more commodities at the beginning of economic growth path. Hence, more energy resources and production will induce more waste and pollutant emissions, and the level of environmental quality will get worse (Torras and Boyce [11], Dinda [2], Prieur [12]). The structural effect states that the economy will have a structural transformation, and economic growth will affect environment positively along with continuation of growth. In other words, as national production grows the structure of economy changes, and the share of less polluting economic activities increases gradually. Besides, an economy experiences a transition from capital-intensive industrial sectors to service sector and reaches technology-intensive knowledge economy (the final stage of the structural change). Due to the fact that technology-intensive sectors utilize fewer natural sources, the impact of these sectors on environmental pollution will be less. The last channel of the growth process is the technological effect channel. Since a high-income economy can allocate more resources for research and development expenditures, the new technological processes will emerge. Thus, the country will replace old and dirty technologies with new and clean technologies, and environmental quality will deepen (Borghesi [13], Copelan and Taylor [14]). Consequently, environmental pollution initially increases and later decreases as a result of scale, structural and technological effect emerging along with growth path.

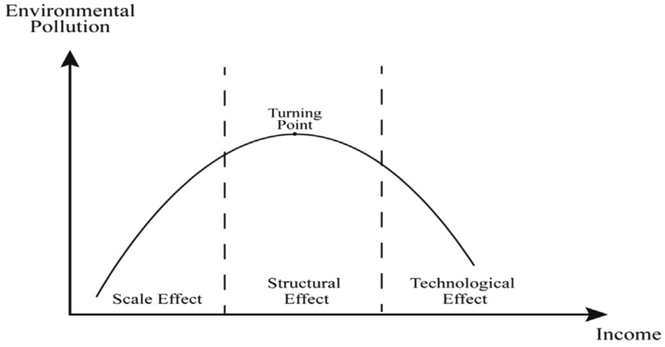

Fig. 1. Environmental Kuznets Curve.

Some studies of EKC hypothesis consider income elasticity of clean environment demand (Beckerman [15], Selden and Song [16], McConnel [17], Panayotou [18], Carson et al. [19], Brock and Taylor [20]). Accordingly, the share of low-income people's expenditures for food and basic necessities is higher than that of high-income societies' expenditures for the same type of commodities (Engel's Law). As income level and life standards rise in conjunction with economic growth, the societies' demand for clean environment advances. Besides, societies make often pressure on policy makers to protect the environment through new regulations. One might argue that, because of these reasons, clean environment is a luxury commodity and the demand elasticity of clean environment is higher than unity (Dinda [2]).

Some studies on the EKC hypothesis observe the effects of foreign trade on environmental quality. There are two different arguments on this subject. The first one claims that free trade affects environmental quality positively (Anderson and Blackhurst [21], Jones and Rodolfo [22], Lee and Roland-Holst [23]). Accordingly, free trade makes pressure for more efficient usage of resources through increasing competition (Cole [24]). Moreover, communication level among countries improves due to foreign trade, and, thus, especially developing countries can transfer cleaner technologies through foreign direct investments. Therefore, environmental pollution will diminish in these countries in the long run (Dinda [2], Bo [25]). The second argument emphasizes that environmental depredation raises as a result of expanding of trade volume in especially developing countries (Antweiler et al. [26], Cole and Elliot [27], Cole [24]). When the structure of international trade is considered, it is clear that there exists a transition from heavy industry to light industry and service sector in developed countries, and that the share of heavy industry in industrial sector boosts rapidly in developing countries. Production of heavy industrial goods requires more energy consumption, and they induce more pollution. Therefore, while a low-income country is a net exporter of heavy industrial goods, a high-income country is a net importer of industrial goods (Suri and Chapman [9]). Hence, one claims that, while free trade lowers pollution level in developed countries, it amplifies the pollution level in developing countries.

Finally, some studies on the EKC hypothesis follow environmental regulations and foreign direct investments (Bartlett [28], Panayotou [18], Van Beers and Van den Bergh [29], Suri and Chapman [9], Dinda [2], Cole [24], Orubu and Omotor [30]). Subsequently, there are important differences between high-income countries and low-income countries regarding environmental regulations. The production costs of heavy industrial goods are higher in developed countries having high environmental standards than those of developing countries employing low environmental standards. Therefore, exclusively multinational corporations invest in developing countries to produce heavy industrial goods causing more pollution. Thus, as EKC arises in developed countries, it may not appear in developing countries. One may expand the list of seminal works within literature of EKC hypothesis.

Our EKC work differs from other EKC papers available in the literature since (i) this work, besides other common variables, launches specifically renewable energy consumption data to estimate the changes in air pollution as all other works, except Sulaiman et al. [31] and Jebli et al. [32], follow either total energy consumption or fuel oil and/or coal consumption to determine the pollution, (ii), whereas Sulaiman et al. [31] considers individual time series data and Jebli et al. [32] employs panel output, this work reveals both panel OECD data parameter estimations and individual country parameter estimations to evaluate the EKC hypothesis.

To this end, this paper tests the validity of the EKC hypothesis and investigates the long run relationship between CO_2 emissions and renewable energy consumption. The rest of the paper is organized as follows: Section 2 introduces empirical literature on the EKC hypothesis. Section 3 presents materials and method. Section 4 yields estimation results, and Section 5 reveals main findings of estimations and some policy implications.

2. Literature review

One observes, throughout the energy/environment literature, that testing the validity of the EKC approach has notably increased in recent years.

Results of these studies may differ from each other in terms of dependent variable of pollution [arsenic, cadmium, nitrate, lead, coliform, phosphorus or CO2], explanatory variables [GDP, non-renewable or renewable energy consumption], models [linear, quadratic or cubic], time period(s) and countries.

Table 1 yields a summary of empirical literature findings. Papers, observing if EKC hypothesis holds or not, (i) launch common variables of a pollution data as dependent variable and independent variables of GDP and quadratic GDP, (ii) differ from each other in terms of additional explanatory data of energy consumption; the majority of them follow the T/F data (either total energy consumption or fossil fuel energy consumption data) as very few of them employ RE data (renewables energy consumption data) as energy consumption. Some papers also analyze additionally the impact of GDP cubed on pollution through their cubic models. One observes from related literature that EKC is verified by works as in [3–5,7,9,11,24,30–41,48–50,52–58,60,61], and, that EKC is not confirmed in [42–46,51,59], and, finally, that estimations about EKC reveal mixed output as in [47]. Although a majority of papers confirms EKC hypothesis (depicted by EKC), there still exists a considerable number of works disconfirming the EKC relationship (represented by No EKC) in the literature as given in the Table 1.

The motivation of this paper lies in two points. First of all, this paper employs a model to observe specifically the effect of renewable energy usage on pollution level, whereas, except Sulaiman et al. [31] and Jebli et al. [32], all related papers in the literature testing EKC hypothesis investigate the impact of non-renewables on pollution. Secondly, while Sulaiman et al. [31] launch time series model and Jebli et al. [32] observe panel data model, this paper follows both individual time series data and panel data simultaneously to predict the impulses of renewables on environmental pollution. To this end, this paper will launch, as it will be explained in detail in Materials and Method section, both panel of 17 OECD countries' estimations and individual 17 OECD countries' predictions to explore, if exist, the statistical significance of economic growth and renewable energy consumption on CO_2

Table 1
Summary of the empirical literature regarding EKC relationship.

Author(s)	Data	Model	Period(s)	Findings
Grossman and Krueger [3]	T/F-Different Panels	Quadratic and cubic	Different periods	EKC
Grossman and Krueger [4]	T/F-Different Panels	Cubic	Different periods	EKC
Shafik and Bandhopadhyay [33]	T/F-149 countries	Quadratic and cubic	1960–1990	EKC
Panayotou [5]	T/F-68 countries	Quadratic	Different periods	EKC
Selden and Song [7]	T/F-30 countries		1979–1987	EKC
Cole et al. [34]	T/F-11 countries	Quadratic	1970–1992	EKC
Dinda et al. [35]	T/F-33 countries	Quadratic	1979–1990	EKC
Stern and Common [36]	T/F-73 countries	Quadratic	1960–1990	EKC
Dijkgraaf and Vollebergh [38]	T/F-24 countries	Cubic	1960–1997	EKC
Jalil and Mahmud [39]	T/F-China	Quadratic	1975–1995	EKC
Nasir and Rehman [40]	T/F-Pakistan	Quadratic	1972–2008	EKC
Moomaw and UT/Fuh [42]	T/F-16 countries	Cubic	1950–1992	No EKC
Agras and Chapman [43]	T/F-34 countries	Quadratic	1971–1991	No EKC
He and Richard [44]	T/F-Canada	Cubic	1948–2004	No EKC
Akbostancı et al. [45]	T/F-Turkey	Cubic	1968–2003	No EKC
Saboori et al. [37]	T/F-Malaysia	Quadratic	1980–2009	EKC
Fodha and Zaghoud [46]	T/F-Tunisia	Cubic	1961–2004	No EKC
Lee et al. [47]	T/F-97 countries	Cubic	1980–2001	Mixed
Orubu and Omotor [30]	T/F-Different Panels	Cubic	Different periods	EKC
Cole [24]	T/F-Different Panels	Cubic	1980–1997	EKC
Ahmed and Long [48]	T/F-Pakistan	Cubic	1971–2008	EKC
Jayanthakumaran and Liu [49]	T/F-China	Quadratic	1990–2007	EKC
Suri and Chapman [9]	T/F-33 countries	Quadratic	1971–1990 1971–1991	EKC
Apergis and Payne [52]	T/F-6 countries	Quadratic	1971–2004	EKC
Shahbaz et al. [41]	T/F-Pakistan	Quadratic	1971–2009	EKC
Roca and Alcántara [54]	T/F-Spain	Linear	1972–1997	No EKC
Shahbaz et al. [55]	T/F-Romania	Quadratic	1980–2010	EKC
Shahbaz et al. [56]	T/F-South Africa	Quadratic	1965–2008	EKC
Tiwari et al. [50]	T/F-India	Quadratic	1966–2009	EKC
Lean and Smyth [57]	T/F-5 countries	Quadratic	1980–2006	EKC
Iwata et al. [58]	T/F-France	Quadratic	1960–2003	EKC
Torras and Boyce [11]	T/F-Different Panels	Cubic	Different periods	EKC
Gangadharan and Valenzuala [59]	T/F-51 countries	Cubic	Different periods	No EKC
Leitão [60]	T/F-94 countries	Nonlinear	1981–2000	EKC
Castiglione et al. [61]	T/F-28 countries	Nonlinear	1996–2008	EKC
Jebli et al. [32]	RE-25 countries	Quadratic	1980–2009	EKC
Sulaiman et al. [31]	RE-Malaysia	Quadratic	1980–2009	EKC

emissions. Thereby, this paper, eventually, intends to provide policy makers with (i) panel evidence-based environmental EKC information and (ii) specific country evidence-based environmental EKC information.

3. Materials and method

The majority of the literature follows a quadratic model as is in Cole et al. [34], Orubu and Omotor [30], Shahbaz et al. [41]; Saboori and Sulaiman [37] to test the validity of the EKC hypothesis given in Eq. (1).

$$E = f\left(Y, Y^2, Z\right) \tag{1}$$

where E, Y, Y^2 and Z represent environmental pollution, income, income squared and other factors affecting environment, respectively. The adapted form of this model employed in this paper is as follows:

$$CO_2 = f\left(Y, Y^2, RE\right) \tag{2}$$

where CO_2, Y, Y^2 and RE represent carbon monoxide emissions, GDP, GDP squared and renewable energy consumption, respectively. Shahbaz et al. [41] argue that log-linear models give more efficient results than linear models give. Therefore, following Orubu and Omotor [30], Shahbaz et al. [41] and Sabaori and Sulaiman [37], Eq. (2) is re-written as follows:

$$\ln CO_{2,it} = \beta_{0i} + \beta_{1i}\ln Y_{it} + \beta_{2i}\ln Y^2_{it} + \beta_{3i}\ln RE_{it} + \varepsilon_{it} \tag{3}$$

where the null hypotheses (i) $\beta_1 = \beta_2 = 0$ indicates that CO_2 is not related to income, (ii) $\beta_1 > 0$ and $\beta_2 = 0$ refers a monotonically increasing relationship between CO_2 and income, (iii) $\beta_1 < 0$ and $\beta_2 = 0$ remarks a monotonically decreasing relationship between CO_2 and income, (iv) $\beta_1 < 0$ and $\beta_2 > 0$ expresses a U-shaped relationship between CO_2 and income and (v) $\beta_1 > 0$ and $\beta_2 < 0$ specifies an inverted U-shaped EKC relationship between CO_2 and income. The expected sign of β_3 is negative since renewable energy are considered clean energy power and since renewables induce far fewer pollutant gas emissions when they are compared to fossil energy sources, such as petrol, coal and natural gas. Bilgili [62], for instance, states, following US data, that fossil fuel consumption and biomass consumption affect CO_2 emissions positively and negatively, respectively.

This paper employs data for 17 OECD countries (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Greece, Italy, Luxemburg, Netherlands, New Zeland, Norway, Portugal, Sweden, Turkey, and the USA) for the period 1977–2010. The variables are carbon monoxide emissions per capita (metric ton), GDP per capita (current US$), the GDP per capita squared and renewable energy consumption (as the share of combustible renewables) and waste in total energy as is in Ocal and Aslan [63], respectively. Data are extracted from the World Bank database [64].

Table 2
Descriptive statistics and correlation matrix for ln CO_2, ln Y, ln Y^2 and ln RE for panel 17 OECD countries (1977–2010).

Descriptive statistics	ln CO_2	ln Y	ln Y^2	ln RE
Mean	2.2097	9.7603	95.9093	1.4598
Median	2.1734	9.9139	98.2861	1.5417
Maximum	3.5088	11.6265	135.1757	3.2423
Minimum	.5455	7.1278	50.8063	−5.085
Std. deviation	.5485	.8031	15.2163	1.0765
Observations	578	578	578	578
Correlation matrix				
ln CO_2	1.0000			
ln Y	.5835	1.0000		
ln Y^2	.5645	1.0000	1.0000	
ln RE	−.4065	−.0206	−.0034	1.0000

Descriptive statistics and correlation matrix are presented in Table 2. One notes that the mean and median statistics of per capita GDP (ln Y) are greater than those of CO_2 emissions (ln CO_2) and renewable energy consumption (ln RE) and that the mean, median and maximum values of ln CO_2 and lnRE are close to each other in comparison with related statistics of other variables. One may notices as well that CO_2 emissions are positively correlated with ln Y and the GDP per capita squared (ln Y^2) but negatively correlated with lnRE.

Descriptive statistics of course are to provide one with some initial and/or preliminary inspection for the EKC hypothesis. One needs to employ, beyond Table 2 observations, some statistical models to obtain unbiased and efficient output through unit root and cointegration estimations. In order to determine whether the series are stationary or not, one may follow the test of Levin et al. (LLC, [65]), Im et al. (IPS, [66]), and ADF-Fisher (Maddala and Wu [67]), respectively. The LLC panel unit root tests are conducted by Eq. (4).

$$\Delta y_{it} = \delta y_{it-1} + \sum_{L=1}^{pi} \theta_{iL}\Delta y_{it-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}, \; m = 1, 2, 3. \tag{4}$$

where Δ, d_{mt} and α_m represent first difference operator, vector of deterministic variables, and corresponding vector of coefficients, respectively, for the model as $m = 1, 2, 3$. The dummies are defined as; $d_{1t} = \emptyset$ (the empty set), $d_{2t} = \{1\}$, and $d_{3t} = \{1, t\}$. The null hypothesis of $\delta = 0$ for all i is tested against the alternative hypothesis of $\delta < 0$ for all i. The rejection of the null hypothesis indicates stationary process of panel. The parameter δ is homogenous across i for LLC test whereas Im et al. [66] suggest a panel unit root test allowing δ to vary across all i. Therefore, the Eq. (4) is re-written as follows:

$$\Delta y_{it} = \delta_i y_{it-1} + \sum_{L=1}^{pi} \theta_{iL}\Delta y_{it-L} + \alpha_{mi} d_{mt} + \varepsilon_{it}, \; m = 1, 2, 3. \tag{5}$$

While the null hypothesis is $\delta = 0$ for all i, the alternative hypothesis is $\delta < 0$ for at least one i. The rejection of the null hypothesis implies a panel stationary process. Fisher-ADF Test proposed by Maddala and Wu [67] combines the p-values from unit root tests for each cross section i. The test is non-parametric and has a chi-square distribution with $2n$ degrees of freedom as is given in (6).

$$\lambda = -2\sum_{i=1}^{n} \log_e(p_i) \sim \chi^2_{2n(d.f.)} \tag{6}$$

where ρ_i is the p-value from the ADF unit root test for unit i and n is the number of countries in the panel. The Maddala and Wu test [67] has the advantage of not depending on different lag lengths in the individual ADF regressions (Hossain and Saeki [68]). Pedroni [69,70] suggests seven test statistics having the null hypothesis of no cointegration in order to analyze of the cointegration (long run) relation, if exists, among variables in a panel data model. While large positive values imply the rejection of null hypothesis of no cointegration by the panel variance statistic, the large negative values state the rejection of null by other six panel statistics (Pedroni [69]).

After determining the cointegration relation, the next step is to estimate the cointegration coefficients of independent variables by employing panel fully modified ordinary least squares (FMOLS) and panel dynamic ordinary least squares (DOLS) methods developed by Pedroni [71,72]. The FMOLS estimator generates consistent estimations of the parameters in small samples and controls for the possible endogeneity of the regressors and serial correlation (Kiran et al. [73]). The panel FMOLS estimator can be constructed as is in Pedroni [72].

$$\hat{\beta}^*_{GFM} = N^{-1}\sum_{i=1}^{N}\hat{\beta}^*_{FM,i} \tag{7}$$

where $\hat{\beta}^*_{FM,i}$ is the conventional FMOLS estimator applied to ith member of the panel. The associated t-statistic is given in Eq. (8).

$$t_{\hat{\beta}^*_{GFM}} = N^{-1/2}\sum_{i=1}^{N} t_{\hat{\beta}^*_{FM,i}} \tag{8}$$

To obtain the panel DOLS estimator, the following model is estimated using the OLS for each member of the panel:

$$\begin{aligned}\ln CO_{2t} = {} & \beta_{0i} + \beta_{1i}\ln Y_{it} + \beta_{2i}(\ln Y)^2_{it} + \beta_{3i}\ln RE_t \\ & + \sum_{k=-K_i}^{K_i}\alpha_{ik}\Delta \ln Y_{it-k} + \sum_{k=-K_i}^{K_i}\lambda_{ik}\Delta(\ln Y)^2_{it-k} + \\ & + \sum_{k=-K_i}^{K_i}\Omega_{ik}\Delta \ln RE_{it-k} + \varepsilon_{it}\end{aligned} \tag{9}$$

where $-K_i$ and K_i are leads and lags. The panel DOLS estimator can be built up as in (10).

$$\hat{\beta}^*_{GD} = N^{-1}\sum_{i=1}^{N}\hat{\beta}^*_{D,i} \tag{10}$$

where $\hat{\beta}^*_{D,i}$ is the conventional DOLS estimator, applied to the ith member of the panel. The associated t-ratio follows as in Eq. (11).

$$t_{\hat{\beta}^*_{GD}} = N^{-1/2}\sum_{i=1}^{N} t_{\hat{\beta}^*_{D,i}} \tag{11}$$

4. Estimation results

Table 3 depicts panel unit root test results. The six unit root test statistics (LLC, IPS and ADF-Fisher with intercept and intercept and trend) have mixed results on the null hypotheses for the series at their levels. On the other hand, all of six statistics indicate that first-differenced forms of the series are stationary. Therefore one can state that the series are integrated of order one [$I(1)$].

The results for the panel cointegration tests are reported in Table 4. One can remark that, there is a cointegration relation between ln CO_2, ln Y, ln Y^2 and ln RE by Panel PP, Panel ADF, Group PP and Group ADF statistics (considering intercept form of the model), and that, they are found cointegrated as well by Panel ADF-Statistic (considering Intercept and Trend form of the model).

Table 3
Panel unit root tests for panel 17 OECD countries (1977–2010).

Variable	LLC[a]		IPS		ADF-FISHER	
	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend
ln CO_2	−2.625[b]	1.085	−1.325[d]	1.130	45.441[d]	35.284
ln Y	−2.956[b]	.148	2.175	−3.062[a]	18.537	60.405[b]
(ln $Y)^2$	−2.439[b]	.270	2.835	−3.187[a]	15.476	63.333[b]
ln RE	−6.590[b]	−.456	−1.478[d]	−.148	55.474[c]	38.819
Δln CO_2	−19.008[b]	−16.062[b]	−19.405[b]	−17.136[a]	336.814[b]	323.276[b]
Δln Y	−14.274[b]	−12.999[b]	−12.157[b]	−9.785[a]	200.176[b]	147.588[b]
Δ(ln $Y)^2$	−14.450[b]	−12.975[b]	−12.421[b]	−10.068[a]	205.500[b]	152.411[b]
Δln RE	−17.433[b]	−11.116[b]	−16.271[b]	−14.924[a]	295.765[b]	248.352[b]

Notes:

[a] Newey–West bandwidth selection with Bartlett Kernel is used for LLC test.
[b] Illustrates 1% statistical significance.
[c] Illustrates 5% statistical significance.
[d] Illustrates 10% statistical significance.

Table 4
Panel cointegration tests for panel 17 OECD countries (1977–2010).

Test[a]	Intercept	Intercept and trend
Panel v-Statistic	1.005	−.445
Panel rho-Statistic	−1.16	−.670
Panel PP-Statistic	−2.604[b]	−1.508
Panel ADF-Statistic	−2.577[b]	−1.856[b]
Group rho-Statistic	.395	1.669
Group PP-Statistic	−2.066[b]	−1.118
Group ADF-Statistic	−2.139[b]	−1.531

Notes:

[a] Newey–West bandwidth selection with Bartlett Kernel is used.
[b] Illustrates 5% statistical significance.

Table 5 denotes the output of panel FMOLS and panel DOLS estimations. The upper part of the table show individual countries' estimations and lower part, the bottom line, explores panel estimations. When one considers panel estimators, he/she observes that both panel FMOLS and panel DOLS estimators figure out the same results. The coefficients of ln Y and of ln Y^2 yield positive and the negative estimators, respectively, on CO_2 for the pool of all countries. Then one concludes that the EKC happens for the panel sample. Considering Eq. (2) given in Materials and method section, one may want to observe, as well, the impact of renewable energy consumption (ln RE) through time on CO_2 as EKC occurs within panel. Table 5 gives negative coefficient of renewable energy consumption on CO_2 for the panel indicating that increasing renewable energy consumption leads CO_2 emissions to diminish.

As one observes the coefficients for the individual countries, he/she realizes that the results of the analyses are mixed and they differ from each other in terms of the EKC relationship type. According to FMOLS estimations, while there is a U-shaped relation in three countries (Austria, Canada and Turkey), there exists an inverted U-shaped relation and hence the EKC hypothesis holds in five countries (Denmark, France, Greece, Netherlands and Sweden). The results of panel DOLS explore that, while there is a U-shaped relation in four countries (France, Luxemburg, Netherlands and Norway), the countries Australia, Belgium, Greece, New Zealand, Portugal and Turkey have inverted U-shaped relation, hence EKC occurs in these six countries. Therefore, for individual countries in which EKC holds, air pollution in terms of carbon dioxide emissions are influenced positively by linear GDP and effected negatively by quadratic GDP.

Considering either FMOLS or DOLS estimations' output, one may monitor simultaneously that the validity of EKC hypothesis is independent of income level of countries. EKC arises in both relatively low income countries and relatively high income countries. Considering per capita income scale of IWA [74] from low to high income, the countries of this work in which EKC hypothesis holds are Turkey (10.400$), Portugal (21.250$), Greece (25.030$), New Zealand (29.350$), France (44.420$), Belgium (46.160$), Australia (46.200$), Netherlands (49.730), Sweden (53.230$), Denmark (60.390$), Luxemburg (78.130$), and Norway (88.890$), respectively. EKC does not hold, on the other hand, in some relatively high per capita income countries of Italy (35.330$), Canada (45.560$), Austria (48.300$), Finland (48.420$) and USA (48.450$).

Recalling Eq. (2), one may also need to monitor the influence of renewables consumption on CO_2 emissions. Whereas the results of panel FMOLS indicate that CO_2 emissions are positively related to renewable energy consumption in Canada and the USA, the outcome of panel DOLS yields that CO_2 emissions are positively correlated with renewables in Finland, Netherlands, and Norway. Besides, while the panel FMOLS estimator indicates that CO_2 emissions are affected negatively by renewable energy consumption in Australia, Austria, Belgium, Greece, New Zealand, Portugal,

Table 5
Panel cointegration coefficients for panel 17 OECD countries (1977–2010).

Country	Individual FMOLS[a]			Individual DOLS[a,b]		
	ln Y	ln Y^2	ln RE	ln Y	ln Y^2	ln RE
Australia	2.81[e]	−.14	−.19[c]	2.44[c]	−.11[c]	.10
	[1.75]	[−1.64]	[−4.12]	[4.90]	[−4.53]	[1.08]
Austria	−2.30[c]	.11[c]	−.06[e]	.84	−.03	−.22[c]
	[−3.38]	[3.13]	[−2.04]	[.93]	[.70]	[−4.58]
Belgium	−1.33	.09	−.10[c]	6.25[c]	−.29[c]	−.26[c]
	[−.45]	[.59]	[−3.80]	[11.10]	[−10.83]	[−11.37]
Canada	−4.59[d]	.24[d]	.28[c]	.26	−.01	−.17
	[−2.43]	[2.44]	[3.49]	[.13]	[−.01]	[−.75]
Denmark	3.79[d]	−.17[d]	−.15	.71	−.03	−.34[c]
	[2.53]	[−2.58]	[−1.33]	[.69]	[−.57]	[−4.19]
Finland	1.36	−.08	−.18	.91	−.04	.27[e]
	[.64]	[−.71]	[−1.31]	[.83]	[−.71]	[1.82]
France	10.41[e]	−.50[e]	.14	−3.91[e]	.18[e]	.14
	[2.02]	[−1.94]	[.82]	[−2.02]	[1.91]	[.58]
Greece	3.55[c]	−.21[c]	−.23[c]	4.99[c]	−.24[c]	−.34[c]
	[5.52]	[−5.84]	[−2.97]	[9.23]	[−8.69]	[−4.52]
Italy	−1.06	.06	.01	1.29	−.06	.01
	[−.56]	[.62]	[.19]	[.89]	[−.81]	[.15]
Luxemburg	−.53	.01	−.19	−5.41[c]	.27[c]	−.65[c]
	[−.15]	[.05]	[−.83]	[−5.12]	[5.07]	[−5.79]
Netherlands	3.52[d]	−.15[e]	−.00	−4.29[c]	.19[c]	.15[c]
	[2.66]	[−2.06]	[−.10]	[−3.99]	[3.78]	[5.75]
New Zealand	1.35	−.06	−.46[e]	6.62[c]	−.33[c]	.18
	[.36]	[−.32]	[−2.00]	[4.87]	[−4.64]	[.95]
Norway	1.10	−.01	−.06	−8.54[c]	.41[c]	.94[c]
	[1.17]	[−.30]	[−.33]	[−4.15]	[4.27]	[2.77]
Portugal	.91	01	−.29[d]	6.18[c]	−.31[c]	−.63[c]
	[1.27]	[.26]	[−2.24]	[9.14]	[−8.62]	[−5.07]
Sweden	9.60[c]	−.47[c]	−.31[e]	−1.93	.08	−.16
	[8.61]	[−7.55]	[−1.75]	[−1.08]	[.93]	[−1.11]
Turkey	−1.21[e]	.06[e]	−.42[c]	1.45[c]	−.08[c]	−.38[d]
	[−1.98]	[1.70]	[−5.18]	[3.53]	[−3.56]	[−2.44]
USA	−.30	.01	.19[e]	.63	−.02	−.21[c]
	[−.25]	[.24]	[1.99]	[.37]	[−.32]	[−3.13]
	Panel FMOLS[a]			Panel DOLS[a]		
Panel	1.59[c]	−.07[c]	−.12[c]	.50[c]	−.02[c]	−.09[c]
	[4.20]	[−3.37]	[−5.22]	[7.35]	[−6.82]	[−7.48]

Notes:

[a] The values in parentheses are *t*-statistics.
[b] The individual tests are done with 1 lag for each cross-section.
[c] Illustrates 1% statistical significance.
[d] Illustrates 5% statistical significance.
[e] Illustrates 10% statistical significance.

Sweden and Turkey, the panel DOLS estimator expresses that CO_2 emissions depend negatively on renewable energy consumption in Austria, Belgium, Denmark, Greece, Luxemburg, Portugal, Turkey and the USA. Finally, one notices that FMOLS and DOLS have common result of negative impact of renewable energy consumption on CO_2 emissions for five countries (Austria, Belgium, Greece, Portugal and Turkey). Following FMOLS or DOLS estimations' results, one may indicate that the occurrence of negative impact of renewables on air pollution in terms of CO_2 emissions does not depend on country income level either.

5. Conclusion and policy implications

This paper investigates the validity of Environmental Kuznets Curve (EKC) hypothesis for CO_2 emissions within the framework of renewable energy consumption following annual data from 1977 to 2010 for 17 OECD countries and underlines the necessity of renewable consumption to enhance environmental quality. After conducting the panel unit root tests, paper employs panel FMOLS and panel DOLS estimations suggested by Pedroni [71,72] to obtain long-term coefficients. The results of the estimations through observation of pooled data indicate that (i) CO_2 emissions are positively related to GDP per capita and (ii) negatively correlated with the GDP per capita squared and (iii) negatively correlated with renewable energy consumption.

The results have two important implications. First, the EKC appears and secondly, renewable energy consumption diminishes CO_2 emissions for the panel data employed. Considering first output, on the other hand, researcher needs to know (a) if EKC happens in all individual countries in the World or not and (b) whether or not EKC is permanent and sustainable in the long run (Dinda, [2]). The possible ambiguous answers for (a) and (b) would yield country/region specific EKC and/or time and technology specific EKC. Accordingly, the outcome of this paper implies that, although panel data confirms EKC, the EKC analyses employing individual countries data do not yield robust estimations. The following next two important conclusions from individual countries data are that EKC may occur in any country no matter if she is low income or high income country and that negative causality from renewables consumption to air pollution may appear, as well, regardless of individual countries' per capita GDP magnitude.

Therefore, this paper may suggest countries from relatively low income level to relatively high income level, in which EKC happens, that they can carry out policies to increase renewables production and consumption through short term-midterm policies and long term policies. Within short term-midterm, policy makers may follow (i) tax incentives of US Energy Policy Act (EIA [75]), (ii) subsidies for low-emitting energy sources (Galinato and Yoder [76]), (iii) sectoral subsidies, e.g. in agricultural sector, to increase the production/usage of biomass which is one of the major sources of renewables (Bilgili [77]),

(iv) a system of fair and easy access to the electricity from renewable sources (Reiche and Bechberger [78]), (v) feed in tariffs (Meyer [79], and Kalkuhl et al. [80]) and green certificate trading (Brick and Visser [81]). In the long run, executives may launch the policies to improve (i) renewable energy technologies (Fischer and Newell [82]), (ii) investment grant policies (Ragwitz and Rathmann [83]) and (iii) investment subsidies (Brunner [84], EWEA [85]).

Considering available renewable energy data for the countries, one, for instance, observes that Norway and Sweden are in relatively better positions in terms of renewable consumption than other European countries. Eurostat [86] shows that the shares of renewable energy in gross final energy consumption in Norway and Sweden are 65% and 46.8%, respectively in 2011. Therefore, one may argue that these countries relatively carry out more effective policies regarding renewable energy production as they cooperate with each other for a joint green electricity certificate market as of January 2012. One may suggest, hence, for instance, that (i) the renewable policies and renewable consumption of countries in general need to converge to those of Norway and Sweden and (ii) US Energy Policy Act (EPACT) of 1992, 1999 and 2001 (EIA [75]) to promote renewable energy production might be widened among other countries. Throughout implementations of these policies, countries not only reduce their energy dependency, but also contribute to combating global warming.

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