



Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint

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Abstract

A great majority of the environmental Kuznets curve (EKC) literature use CO₂ emissions to proxy for environmental degradation. However, this is an important shortage in application of the EKC concept because environmental degradation cannot be captured by CO₂ emissions only. By using a broader proxy, ecological footprint, this study aims to investigate the presence of environmental Kuznets curve hypothesis for the EU countries. The annual data from 1980 to 2013 is examined with second generation panel data methodologies which take into account the cross-sectional dependence among countries. The results show that there is U-shaped relationship between the real income and ecological footprint. In addition, non-renewable energy increases the environmental degradation while renewable energy and trade openness decrease the environmental degradation in the EU countries. Policy implications are further discussed.

Keywords Ecological footprint · Environmental Kuznets curve · European countries

Introduction

The environmental Kuznets curve (EKC) hypothesis claims that there is an inverted U-shaped relationship between environmental degradation and economic growth. This relationship implies that initial stage of economic growth and development make environmental quality worse, and after per capita income reaches a threshold, economic growth and development enhance environmental quality (Grossman and Krueger 1991, 1995). It, hence, implies that environmental degradation first rises and later falls with increasing development. According to

Grossman and Krueger (1995), there are three contributing causes behind the shape of the EKC. First one is *scale effect* which is first stage of the curve that the environment gradually deteriorates since economic growth needs more resource and sparks off more waste and pollution. As economy grows, however, its structure starts to change from energy intensive industry to services and technology intensive industries. Besides, as technology advances, it reverses polluting production process which also uses more resource, and obsolete technologies are replaced by upgraded new and cleaner technology. These probable positive effects of economic growth on environmental quality are named *composition* and *technique effects* respectively. The composition and technique effects are also supported by individual preferences (Selden and Song 1995; McConnell 1997). These preferences crop out with the environmental awareness. This awareness leads people to increase their demand for eco-friendly goods and services. Thereby people can achieve a higher standard of living and can care more about the quality of environment they live in (Dinda 2004). Additionally, one argument claims that the income elasticity of the environment is greater than one. This means that the demand for clean environment will increase by more than 1% as income rises by 1% (Baldwin 1994). As a natural consequence of these arguments, main policy recommendation for a decent environment is to increase the economic growth and to become rich as stated by Beckerman (1992). If this mechanism really works, policy

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makers should not be concerned that economic growth is driving force of environmental improvements. From this point of view, a large number of studies have been carried out to test the EKC hypothesis for different countries and country groups, and a large part of these studies verify the existence of the EKC hypothesis (Apergis and Ozturk 2015; Hao et al. 2016; Wang et al. 2016; Bilgili et al. 2016; Charfeddine and Mrabet 2017; Mrabet and Alsamara 2017; Pablo-Romero et al. 2017; Álvarez-Herránz et al. 2018; Shahbaz et al. 2017; El Montasser et al. 2018; Balsalobre-Lorente et al. 2018; Sinha and Shahbaz 2018; Aslan et al. 2018).

The most important question thus is not whether the analysis of the EKC hypothesis is necessary—to that it seems there is an overall consensus in society—but “what should be used to proxy for environmental pollution?” A great majority of the EKC literature use CO₂ emissions to represent environmental degradation. Indeed, this is an important shortage in application of the EKC concept because environmental degradation cannot be captured by CO₂ emissions only. There are also other parts of the environmental degradation such as degradation in soil stock, forestry stock, mining stock, oil stock, and so forth. Additionally, CO₂ emissions may really decrease owing to technological innovations or stringent environmental regulations made by governments while aggregate waste and pollution level increases (Stern 2014). Hence, the inverted-U relationship might be valid for emissions of pollutants, but might not be valid for resource stocks (Arrow et al. 1995). So, results may be misleading policy makers when CO₂ emissions is solely used to proxy for environmental degradation. Therefore, researchers should use an inclusive environmental variable to obtain more dependable results.

Ecological footprint developed by Wackernagel and Rees (1996) can potentially be more appropriate representative for the environment. It is the sum of six subcomponents (cropland, grazing land, fishing grounds, forest land, built-up land, and carbon footprint (see Lin et al. 2016 for details) and includes in any case CO₂ emissions within the carbon footprint. The ecological footprint answers the question of how much of the regenerative biological capacity of the planet is demanded by given human activities like resources consumption and goods and services production (Kitzes and Wackernagel 2009). It also helps highlighting direct and indirect impacts of production and consumption activities on the environment (McDonald and Patterson 2004). Conceptually, it can be described as the pressure of human activities on the nature (Bartelmus 2008). According to Costanza (2000), it has been widely praised and is an effective heuristic and comprehensible device for considering total resource consumption. It can be used to forecast natural resource consumption limits, international distribution of world resources, and sustainability of resource consumption in the world (Borucke et al. 2013). Since it is a mature aggregate indicator for analysis of human

demand on the nature, the ecological footprint has been used as a variable of environmental degradation for the EKC analysis (Bagliani et al. 2008; Caviglia-Harris et al. 2009; Wang et al. 2013; Al-Mulali et al. 2015; Hervieux and Darné 2015; Aşıcı and Acar 2016; Ozturk et al. 2016; Charfeddine and Mrabet 2017; Mrabet and Alsamara 2017; Ulucak and Bilgili 2018).

The motivation of this paper is to investigate the EKC hypothesis for the EU countries by using the ecological footprint. To the best of our knowledge, this is the first study that analyzes the EKC hypothesis by the ecological footprint for the EU countries. We preferred EU countries because the European Union (EU) is considered by some to have the most extensive environmental laws of any international organization (Jordan and Adelle 2012). Its environmental policy is significantly intertwined with other international and national environmental policies (Selin and VanDeveer 2015). The environmental legislation of the European Union also has significant effects on those of its member states. The EEA (European Environment Agency) provides environmental information to policymakers and the public. According to EEA, the ecological footprint is already developed and produced by the Global Footprint Network and has matured significantly over its 20 years of existence, both with regard to data sources and methodology. It is of high policy relevance because it indicates the overall resource demand of European societies compared to resource availability in Europe. It is a powerful tool for reaching and communicating with a wide range of audiences to promote an understanding of how people’s activities have an impact on the environment, and to support people in making choices to reduce this impact (EU 2018). Based on these reasons, analyzing ecological footprint of EU countries are preferred in this study to make practicable policy implications. Furthermore, this paper includes trade openness, renewable and non-renewable energy as control variables to observe their effects on the environment. The rest of the paper is organized as follows: “Literature review” section summarizes the EKC literature made for European countries. Later, data and methodologies are introduced in “Data and methodology” section and empirical results are presented in “Empirical results” section. Finally, the paper is completed with conclusion and policy implications in “Conclusions and policy implications” section.

Literature review

The EKC hypothesis has been tested for either EU member or European countries using different econometric techniques and variables by many studies so far. However, it is difficult to say that there is a consensus about that economic growth helps to ameliorate environmental quality as claimed by the EKC hypothesis. Some verifies the EKC relationship for the

EU or European countries (e.g., Markandya et al. 2006; Vehmas et al. 2007; Coondoo and Dinda 2008; Lee et al. 2010; Donfouet et al. 2013; Rafaj et al. 2014; López-Menéndez et al. 2014; Arbulú et al. 2015; Kasman and Duman 2015; Al-Mulali et al. 2016b; Dogan and Seker 2016; Ahmed et al. 2016; Pablo-Romero et al. 2017) and some does not (e.g., Mazzanti 2008; Mazzanti and Zoboli 2009; Marrero 2010; Acaravci and Ozturk 2010; Lapinskienė et al. 2014; Bölük and Mert 2014; Abid 2017). These studies may differ from each other in terms of environmental variable as well as methodology and data set and control variables. In their analyses, air pollutants, e.g., CO₂, SO₂, NO_x GHG, water pollution, solid wastes, oil, gas, coal, and other specific environmental indicators are used to represent the environment. CO₂ is the most common used one among these variables as it is in many EKC studies made for different country

or groups. Table 1 briefly summarizes the studies made for EU and European countries by author, period, country, method, and environmental variable used in the analysis and result.

As seen from Table 1, each environmental variable used for the EKC analysis represents only a small portion of total environmental damage. We could not reach any paper that directly analyzes the EKC using the ecological footprint for the EU or European countries. However, Holm and Englund (2009) examines the discrepancy between the potential decrease of use of natural resources for the USA and six West European countries comparatively. They analyze *IPAT* equation that can be commented as a basis for a description of human impact on the ecosystems and mention that the existence of an environmental Kuznets curve is not verified.

Table 1 Summary literature review of EKC

Author/s	Period	Country	Method	Environmental variable/s	EKC relationship
Markandya et al. (2006)	1870–2001	EU12	Panel FE, panel RE	SO ₂	Yes
Vehmas et al. (2007)	1980–2000	EU15	Linking analysis	DMF	Yes
Mazzanti (2008)	1997–2001, 1995–2000	EU15, EU28	Panel FE, panel RE	PW, MW	No
Coondoo and Dinda (2008)	1960–1990	Europe and other regions	Panel FE, panel RE	CO ₂	Yes for Europe
Mazzanti and Zoboli (2009)	1995–2005	EU25	Panel FE	Wastes	No
Marrero (2010)	1990–2006	EU27	Panel GMM	GHG	No
Acaravci and Ozturk (2010)	1960–2005	EU19	ARDL	CO ₂	No
Lee et al. (2010)	1980–2001	Europe and other regions	Panel GMM	Water pollution	Yes
Donfouet et al. (2013)	1961–2009	41 European countries	Panel GMM and spatial panel	CO ₂	Yes
Rafaj et al. (2014)	1960–2010	39 European countries	Index decomposition analysis	CO ₂ SO ₂ NO _x	Yes
Lapinskienė et al. (2014)	1995–2010	EU27	OLS	GHG	Mixed results
López-Menéndez et al. (2014)	1996–2010	EU27	Panel FE, panel RE	CO ₂	Yes
Bölük and Mert (2014)	1990–2008	EU16	Panel FE, panel RE	CO ₂	No
Arbulú et al. (2015)	1997–2010	32 European countries	Panel FE	Municipal wastes	Yes
Kasman and Duman (2015)	1992–2010	EU15	Panel FMOLS	CO ₂	Yes
Menegaki and Tsagarakis (2015)	1990–2010	33 EU member and candidates	Panel RE and GMM	RES, oil, gas, coal	Yes for RES and oil; no for gas and coal
Al-Mulali et al. (2016a)	1980–2010	Central, East, and West Europe	Panel DOLS	CO ₂	Yes
Dogan and Seker (2016)	1980–2012	EU15	Panel DOLS	CO ₂	Yes
Ahmed et al. (2016)	1980–2010	24 European countries	Panel ARDL	CO ₂	Yes
Khan et al. (2016)	2000–2013	9 European countries	Panel GMM	PFC, ED, RD	Yes for ED and RD; no for PFC
Pablo-Romero et al. (2017)	1995–2009	EU27	Panel RE	EC	Yes
Abid (2017)	1990–2011	41 European countries	Panel GMM	CO ₂	No
Pablo-Romero and Sanchez-Braza (2017)	1990–2013	EU28	FGLS	REC	Yes

PW packaging wastes, *MW* municipal wastes, *DMF* direct material flows, *PFC* per fluorocarbons, *ED* energy depletion, *RD* resource depletion, *GHG* greenhouse gases, *EC* energy consumption, *RES* renewable energy sources, *REC* residential energy consumption

The *IPAT* is the form of an equation combining environmental impact (*I*) with population size (*P*), affluence (*A*, per capita consumption or production), and technology (*T*) known as $I = PAT$ (Fan et al. 2006).

Contrary to most of the aforementioned studies that use CO₂, SO₂, NO_x, waste or any specific and limited variable for environmental degradation, there is a growing body of research utilizing the ecological footprint as an indicator of environmental degradation. Table 2 exhibits the limited number of studies in the relevant literature following the ecological footprint as an environmental indicator for estimating the EKC hypothesis. Aşıcı and Acar (2016), Charfeddine and Mrabet (2017), Mrabet and Alsamara (2017), Ulucak and Bilgili (2018) find evidence for the EKC while Bagliani et al. (2008), Caviglia-Harris et al. (2009), Wang et al. (2013), Hervieux and Darné (2015) and Al-Mulali et al. (2016a) could not find evidence for the EKC. The other two studies find similar results. Their results confirm the EKC for upper-middle and high income countries but disconfirm it for low and lower-middle income countries. Brief details for these studies are presented in Table 2.

Data and methodology

In order to investigate the validity of EKC hypothesis for the ecological footprint and compare relative performances of renewable and non-renewable energy consumption on environmental pollution, the annual data of 1980–2013 is examined for the 15 EU countries: Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, and

the UK. The other EU countries could not be included into our analyses since they do not have data for the period of 1980–2013. The panel version of empirical model is constructed as follows:

$$\ln EF_{it} = \gamma_0 + \gamma_1 \ln Y_{it} + \gamma_2 \ln Y_{it}^2 + \gamma_3 \ln RC_{it} + \gamma_4 \ln NC_{it} + \gamma_5 \ln TR_{it} + \mu_{it} \quad (1)$$

where *t*, *i*, and μ_{it} refer to time period, cross-section, and residual term respectively. In addition, $\ln EF_{it}$ is natural log of the ecological footprint per capita, $\ln Y_{it}$ ($\ln Y_{it}^2$) is natural log of real GDP per capita (natural log of the square of real GDP per capita), $\ln RC_{it}$ is natural log of renewable energy consumption per capita, $\ln NC_{it}$ is natural log of non-renewable energy consumption per capita and $\ln TR_{it}$ is trade openness. The ecological footprint is measured in the sum of cropland, grazing land, fishing grounds, forestland, and carbon and built-up land footprints; the real GDP is measured in 2010 constant US dollar; renewable and non-renewable energy consumption is measured in Kwh and the trade openness is measured in the total trade share in GDP. The data of real GDP and trade openness is obtained from World Development Indicators, the data of renewable energy and non-renewable energy use is retrieved from US Energy Information Administration, and the data of the ecological footprint is downloaded from Global Footprint Network.

Panel data methodologies which ignore the cross-sectional dependence may lead to unreliable results due to high integration throughout the world. Therefore, we first test the existence of cross-sectional dependence among EU countries. Breusch and Pagan (1980) developed Lagrange Multiplier

Table 2 Summary literature review of EKC using ecological footprint

Author	Period	Country	Method	Results
Bagliani et al. (2008)	2001	144 countries	Cross section, OLS, weighted LS	No
Caviglia-Harris et al. (2009)	1961–2000	146 countries	Panel FE, 2SLS, GMM	No
Wang et al. (2013)	2005	150 countries	Spatial econometric approach	No
Hervieux and Darné (2015)	1961–2007	7 Latin American countries	Time series cointegration	No
Aşıcı and Acar (2016)	2006	105 countries	Cross-section analysis	Yes
Al-Mulali et al. (2015)	1980–2008	93 countries	Panel FE, GMM	No for low and lower middle income, yes for upper-middle and high income
Ozturk et al. (2016)	1988–2008	144 countries	Time series GMM, S-GMM	No for low and lower-middle income, yes for upper-middle and high income
Aşıcı and Acar (2016)	2004–2008	116 countries	Panel FE	Yes
Al-Mulali et al. (2016b)	1980–2009	58 countries	Panel FE and GMM	No
Charfeddine and Mrabet (2017)	1995–2007	MENA 15	Panel FMOLS panel DOLS	Yes
Mrabet and Alsamara (2017)	1980–2011	Qatar	ARDL	Yes
Ulucak and Bilgili (2018)	1961–2013	45 countries	CUP-FM, CUP-BC	Yes

(LM hereafter) test on the purpose of examining the cross-sectional dependence. LM test is examined with the use of the following equation;

$$y_{it} = a_i + \beta_i x_{it} + \varepsilon_{it} \quad \text{for } i = 1 \dots, N \text{ and } t = 1 \dots, T, \quad (2)$$

where i and t state respectively the cross-section dimension and the time period. While the null hypothesis of $H_0 : \text{Cov}(\varepsilon_{it}, \varepsilon_{jt}) = 0$ states that there is no any dependency between the cross-sections, the alternative hypothesis of $H_1 : \text{Cov}(\varepsilon_{it}, \varepsilon_{jt}) \neq 0$ indicates the dependency between at least one pair of cross-sections. And the computation of the LM test is as follows;

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij}^2 \square \chi_{N(N-1)/2}^2 \quad (3)$$

where $\hat{\rho}_{ij}$ is the sample of the pair-wise correlation of the residuals from ordinary least squares estimation of Eq. 2 for each cross section. While the LM test is suitable for panels providing the condition of small N and sufficiently large T , for situations where $T \rightarrow \infty$ and $N \rightarrow \infty$, the Lagrange multiplier statistic for cross-sectional dependence (CD_{LM} hereafter) version developed by Pesaran (2004) is as follows;

$$CD_{LM} = \left(\frac{1}{N(N-1)} \right)^{1/2} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \left(T \hat{\rho}_{ij}^2 - 1 \right) \square N(0, 1) \quad (4)$$

Due to CD_{LM} test tends to dimension failures in case of large N and small T , Pesaran (2004) developed a more comprehensible test. The calculation of the new cross-sectional dependence test (CD hereafter) is as follows;

$$CD = \sqrt{\left(\frac{2T}{N(N-1)} \right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \left(\hat{\rho}_{ij} - 1 \right) \square N(0, 1) \quad (5)$$

However, the CD test will lack power in certain situations where the population average pair-wise correlations are zero. Therefore, Pesaran et al. (2008), suggest a bias-adjusted test which is a modified version of the LM test. The bias-adjusted LM test (LM_{adj} hereafter) is;

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)} \right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \frac{(T-k) \hat{\rho}_{ij}^2 - \mu_{Tij}}{\sqrt{\nu_{Tij}^2}} \square N(0, 1) \quad (6)$$

where k , μ_{Tij} , and ν_{Tij}^2 are the number of regressors, exact mean, and variance of $(T-k) \hat{\rho}_{ij}^2$ (Pesaran et al. 2008).

In order to take into account the cross-sectional dependence, we use well-known and frequently used unit root test developed by Pesaran (2007). The computation of the cross-sectional ADF ($CADF$) regression is as following:

$$\Delta y_{it} = a_i + \rho_i y_{it-1} + \beta_i \bar{y}_{t-1} + \sum_{j=0}^k \gamma_{ij} \Delta \bar{y}_{t-1} + \sum_{j=0}^k \delta_{ij} y_{it-1} + \varepsilon_{it} \quad (7)$$

where a_i is deterministic term, k is the lag order, \bar{y}_t is the cross-sectional mean of time t . Following above equation, t -statistics are obtained with the computation of individual ADF statistics. Furthermore, $CIPS$ is retrieved from the average of $CADF$ statistic for each i as follows;

$$CIPS = \left(\frac{1}{N} \right) \sum_{i=1}^N t_i(N, T) \quad (8)$$

The critical values of $CIPS$ for different deterministic terms are given by Pesaran (2007).

To test the validity of the long-run relationship between real income, the square of real income, renewable energy consumption, non-renewable energy consumption, trade openness, and ecological footprint, we utilize error correction based cointegration method proposed by Westerlund (2007). In testing procedure, there are four statistics ($G_t, G_\alpha, P_t, P_\alpha$) to test the null hypothesis of no cointegration. The test can be performed by testing the significance of the error correction term in the constrained panel error correction model. The main error correction model of the test can be written as follows:

$$\Delta Y_{it} = \delta'_i d_t + a_i Y_{i,t-1} + \lambda'_i X_{i,t-1} + \sum_{j=1}^{p_i} a_{ij} \Delta Y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} X_{i,t-1} + e_{it} \quad (9)$$

where d_t refers to the deterministic terms; $d_t = 0$ (no deterministic term), $d_t = 1$ (with constant term), and $d_t = (1, t)$ (with constant term and trend). Moreover, a_i determines the speed at which the system returns to the equilibrium, after an unpredictable shock.

Empirical results

In the first step of analysis, we examine the presence of cross-sectional dependence among countries. According to the findings from Table 3, the null of cross-sectional independence is rejected for all tests. This means a shock occurred in one of sample country may spill over other countries. The validity of cross-sectional dependence implies that we should using second-generation panel tests which allow cross-sectional dependence.

In the second step of analysis, we use augmented IPS ($CIPS$) unit root test of Pesaran (2007) which allows the

Table 3 Cross-sectional dependence test results

	lnEF	lnY	lnY ²	lnRC	lnNC	lnTR
LM	168.424 [0.000]	1591.691 [0.000]	1510.072 [0.000]	789.026 [0.000]	818.846 [0.000]	688.279 [0.000]
CD _{LM}	4.377 [0.000]	102.591 [0.000]	96.959 [0.000]	47.202 [0.000]	49.260 [0.000]	40.250 [0.000]
CD	-2.964 [0.002]	-3.632 [0.000]	-3.658 [0.000]	-2.496 [0.006]	-2.605 [0.005]	-3.369 [0.000]
LM _{adj}	2.094 [0.009]	37.305 [0.000]	37.019 [0.000]	13.427 [0.000]	13.427 [0.000]	12.343 [0.000]

Numbers in brackets are *p* values

cross-sectional dependence among countries to determine the degree of integration level of variables. The findings reported in panel A of Table 4 show that the null hypothesis of unit root process cannot be rejected for the level form of all variables. However, at first differenced form, the null hypothesis is rejected and all series become stationary. The next step should be to investigate whether the ecological footprint, the real income, renewable and non-renewable energy consumption, and trade are cointegrated; or, in other words, they have a long-run relationship.

Next, we examine the presence of long-run relationship between variables using three cointegration tests which are illustrated in panel B of Table 4. First, the results from ADF and PP-based statistics of Pedroni (1999) show that null or having no cointegration is strongly rejected. Similarly ADF-based statistic of Kao (1999) also rejected the null hypothesis. Moreover, we utilized the error correction-based cointegration test of Westerlund (2007) to check the consistency of our

Table 4 Panel unit root and cointegration test results

<i>Panel A: unit root</i>	CIPS-stat. (level)	CIPS-stat. (first differences)
lnEF	-2.162	-6.016 ^a
lnY	-1.597	-3.428 ^a
lnY ²	-1.642	-3.413 ^a
lnRC	-2.215	-6.193 ^a
lnNC	-2.239	-5.929 ^a
lnTR	-2.065	-4.287 ^a
<i>Panel B: cointegration</i>	Statistic	<i>p</i> value
Pedroni-ADF	-3.466 ^a	0.000
Pedroni-PP	-3.127 ^a	0.000
Kao-ADF	-3.216 ^a	0.000
G _t	-3.108 ^b	0.010
G _α	-7.485	0.370
P _t	-11.393 ^b	0.020
P _α	-8.091	0.100

Critical values for the CIPS test of Pesaran (2007) are -2.56, -2.64, and -2.81 at 10, 5, and 1% level, respectively. Pedroni-ADF, Pedroni-PP and Kao-ADF indicate ADF-based, PP-based test of Pedroni (1999), and ADF-based test of Kao (1999). G_t, G_α, P_t, and P_α stand for the cointegration test of Westerlund (2007).

^a, ^b, and ^c indicate the statistical significance at 1, 5, and 10% level, respectively

findings. At a first glance, it can be seen that the results from Westerlund's test are quite mixed. The findings from G_α and P_α confirm the null hypothesis while G_t and P_t statistics show the evidence of rejection of null hypothesis which implies there is no cointegration. Therefore, it is concluded that real GDP per capita, the square of real GDP per capita, renewable energy use per capita, non-renewable energy use per capita, trade openness, and the ecological footprint per capita are cointegrated. Because we find that the analyzed variables have a long-run relationship, we should estimate the impact of each independent indicator on the ecological footprint.

In the next step, we examine the effect of selected explanatory variables on the ecological footprint for the whole panel using with the group-mean FMOLS estimator of Pedroni (2000) and the group-mean DOLS estimator of (Pedroni 2001). In addition, we also utilized the dynamic common correlated effect estimator (DCCE) of Chudik and Pesaran (2015) to consider the cross-sectional dependence among countries. The findings from Table 5 reported that the coefficient of real income on the ecological footprint is negative and the coefficient of the square of real income is positive for both estimators. This result confirms the invalidity of EKC hypothesis. In addition, according to the results of FMOLS estimator, it is concluded that an increase in renewable energy use by 1% will decrease the ecological footprint by 0.109%; an increase in non-renewable use by 1% will increase the ecological footprint by 0.274% and an increase in trade openness by 1% will decrease the ecological footprint by 0.229% for the EU countries. Similarly, based on the DOLS results, the coefficient of real income (square of real income) is negative (positive),

Table 5 Panel mean group estimator results

	MG-FMOLS	MG-DOLS	DCCE-MG
lnY	-10.638 ^a [0.000]	-13.781 ^b [0.011]	-3.760 ^b [0.013]
lnY ²	0.530 ^a [0.000]	0.675 ^b [0.011]	0.205 ^a [0.009]
lnRC	-0.109 ^a [0.000]	-0.093 ^b [0.023]	-0.045 ^c [0.057]
lnNC	0.274 ^a [0.000]	0.216 ^c [0.095]	0.162 ^c [0.093]
lnTR	-0.229 ^a [0.000]	-0.485 ^a [0.000]	-0.181 ^a [0.002]

^a, ^b, and ^c indicate the statistical significance at 1, 5, and 10% level, respectively. Numbers in brackets are *p* values

therefore the U-shaped relationship is found. Dynamic OLS estimator results also show that an increase in renewable energy use and trade openness by 1% will decrease the ecological footprint by 0.093% and 0.485%, respectively. In addition, an increase in non-renewable energy use by 1% will increase the ecological footprint by 0.216% in the EU countries. In case of cross-sectional dependence, obtained findings from DCCE estimation also show that the validity of EKC hypothesis is rejected because the U-shaped relationship exists between real income and ecological footprint. Furthermore, DCCE results indicate that an increase in renewable energy usage and trade openness by 1% will decrease ecological footprint by 0.045% and 0.181%, respectively. However, an increase in non-renewable energy consumption will increase ecological footprint by 0.162%.

Finally, country-specific fully modified OLS and dynamic OLS estimator results are reported in Table 6. In case of the findings from the FMOLS, the coefficient of real GDP (square of real GDP) is negative (positive) and statistically significant in Austria, Denmark, Germany, Italy, Netherlands, Portugal, Spain, and the UK. Therefore, the U-shaped relationship between real GDP and the ecological footprint is found for these countries. However, the inverted U-shaped EKC hypothesis is found only for Portugal. In addition, the negative and statistically significant coefficient of renewable energy use is found in almost all countries except Austria, Netherlands, and Sweden. The coefficient of trade openness is also negative and statistically significant in Denmark, Germany, Italy, Netherlands, Portugal, and the UK. Moreover, we found the positive coefficient of non-renewable energy use in Austria, France, Germany, Greece, Ireland, Portugal, and the UK. As seen in Table 6, the dynamic OLS estimation results are highly consistent with the results of fully modified OLS estimation. In case of dynamic OLS estimation, the U-shaped relationship between income and the ecological footprint is confirmed for Austria, Denmark, Finland, Germany, Italy, Netherlands, Spain, and the UK while the inverted U-shaped relationship is supported for France and Portugal. Additionally, the negative coefficient of renewable energy use is valid for 10 EU countries.

To sum up, based on the mean-group results, it is concluded that the U-shaped relationship exists between economic growth and the ecological footprint. Contrary to EKC hypothesis, these results mean that economic growth sparks off environmental degradation after a threshold although it leads degradation to decrease at earlier process of its trend path till that threshold. In addition, we found that increasing renewable energy consumption (non-renewable energy consumption) decreases (increases) the ecological footprint. Moreover, increasing trade openness reduces environmental degradation in the EU countries.

Table 6 Individual FMOLS and DOLS estimator results

	FMOLS					DOLS				
	lnY	lnY ²	lnRC	lnNC	lnTR	lnY	lnY ²	lnRC	lnNC	lnTR
Austria	-33.248 ^b [0.010]	1.592 ^b [0.010]	0.088 [0.561]	0.217 ^b [0.015]	-0.052 [0.792]	-42.987 ^a [0.006]	4.442 ^a [0.006]	0.620 [0.159]	0.886 ^b [0.015]	-0.054 ^c [0.055]
Belgium	-11.364 [0.251]	0.569 [0.227]	-0.056 ^b [0.040]	0.127 [0.451]	-0.134 [0.341]	-16.792 [0.548]	0.763 [0.567]	-0.077 ^b [0.032]	0.802 [0.122]	-0.209 [0.573]
Bulgaria	-8.034 [0.715]	0.522 [0.686]	-0.130 [0.523]	-0.480 [0.110]	-0.598 [0.170]	-4.104 [0.894]	0.346 [0.848]	-0.230 [0.345]	0.981 [0.629]	-0.227 ^b [0.015]
Denmark	-37.033 ^c [0.097]	1.771 ^c [0.087]	-0.072 ^a [0.007]	0.095 [0.162]	-0.873 ^a [0.002]	-90.947 ^b [0.031]	4.779 ^b [0.029]	-0.059 [0.242]	-0.065 [0.662]	-1.917 ^a [0.009]
Finland	-12.196 [0.276]	0.600 [0.260]	-0.424 ^a [0.000]	0.086 [0.418]	0.069 [0.585]	-36.278 ^a [0.005]	1.722 ^a [0.005]	-0.701 ^a [0.000]	0.885 ^a [0.000]	0.237 [0.156]
France	36.004 [0.103]	-1.698 [0.106]	-0.139 ^b [0.024]	0.297 ^a [0.073]	-0.166 [0.243]	57.970 ^c [0.056]	-2.797 ^c [0.053]	-0.303 ^a [0.005]	0.010 [0.968]	-0.471 ^c [0.069]
Germany	-43.920 ^a [0.004]	2.103 ^a [0.005]	-0.028 ^b [0.014]	0.425 ^a [0.001]	-0.210 ^b [0.026]	-35.096 ^c [0.080]	1.719 ^c [0.078]	-0.090 ^b [0.011]	0.257 ^c [0.064]	-0.043 [0.620]
Greece	11.463 [0.177]	-0.541 [0.195]	-0.144 ^a [0.000]	0.358 ^a [0.000]	-0.076 [0.125]	10.493 [0.438]	-0.534 [0.416]	-0.183 ^a [0.000]	0.435 ^a [0.003]	0.147 [0.218]
Ireland	-3.292 [0.397]	0.150 [0.405]	-0.097 ^b [0.037]	0.574 ^b [0.019]	-0.053 [0.710]	-2.400 [0.607]	0.129 [0.544]	-0.089 [0.281]	0.159 [0.667]	-0.239 [0.181]
Italy	-27.207 ^a [0.000]	1.340 ^a [0.000]	-0.099 ^a [0.000]	0.136 [0.156]	-0.211 ^a [0.000]	-42.071 ^a [0.000]	2.032 ^a [0.000]	-0.151 ^b [0.010]	0.635 ^a [0.002]	-0.546 ^c [0.000]
Netherlands	-15.461 ^b [0.027]	0.752 ^b [0.024]	-0.011 [0.332]	0.058 [0.758]	-0.400 ^a [0.004]	-26.212 ^a [0.007]	1.327 ^a [0.005]	-0.057 ^a [0.083]	0.863 ^a [0.000]	-0.947 ^a [0.002]
Portugal	28.983 ^a [0.000]	-1.438 ^a [0.000]	-0.072 ^c [0.090]	0.016 ^b [0.038]	-0.394 [0.005]	22.953 ^a [0.004]	-1.130 ^a [0.004]	-0.114 [0.237]	0.121 [0.538]	-0.466 ^c [0.073]
Spain	-17.116 ^b [0.041]	0.918 ^b [0.035]	-0.374 ^a [0.000]	0.311 [0.259]	0.094 [0.267]	-10.146 ^c [0.082]	0.513 ^c [0.059]	-0.313 ^c [0.094]	0.613 [0.441]	0.139 [0.497]
Sweden	11.990 [0.472]	-0.561 [0.472]	-0.011 [0.917]	0.067 [0.552]	-0.116 [0.438]	38.165 [0.157]	-1.720 [0.168]	-0.629 ^b [0.019]	0.464 ^b [0.047]	-1.143 ^b [0.022]
UK	-15.164 ^c [0.056]	0.759 ^c [0.056]	-0.087 ^a [0.007]	0.082 ^b [0.024]	-0.551 ^a [0.004]	-18.468 ^c [0.094]	0.912 ^c [0.097]	-0.230 ^b [0.006]	0.171 ^c [0.081]	-1.996 ^c [0.005]

a, b, and c indicate the statistical significance at 1, 5, and 10% level, respectively. Numbers in brackets are p values

Conclusions and policy implications

The purpose of this study is to examine the validity of environmental Kuznets curve on the ecological footprint and to compare the relative effect of renewable and non-renewable energy consumption on environmental pollution for the period from 1980 to 2013 in the 15 EU countries. For this purpose, the relationship among the real income, the square of real income, renewable energy use, non-renewable energy use, trade openness, and the ecological footprint is investigated using with second generation panel data methodologies which take into account the cross-sectional dependence.

The cross-sectional dependence among countries is an expected situation because of globalization and international agreements and empirical findings confirm that the cross-sectional dependence is valid across the EU countries. According to the mean group estimators, it is concluded that there is U-shaped relationship between real income and the ecological footprint. In addition, we found that renewable energy consumption usage and trade openness decreases the ecological footprint while non-renewable energy consumption increases the environmental pollution. When the findings are evaluated for each cross-section, according to the FMOLS estimation results, it seems U-shaped relationship between real income and the ecological footprint is valid in Denmark, Germany, Italy, Netherlands, Portugal, Spain, and the UK while the inverted U-shaped EKC hypothesis is found only for Portugal. The negative and statistically significant coefficient of renewable energy use is found in Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Spain, and the UK. Moreover, non-renewable energy consumption usage increases environmental pollution in Austria, France, Germany, Greece, Ireland, Portugal, and the UK. In case of the DOLS estimation results, U-shaped relationship between real income and the ecological footprint is valid in Austria, Denmark, Finland, Germany, Italy, Netherlands, Spain, and the UK while the inverted U-shaped relationship is supported for France and Portugal.

The message from this research to policy makers is the importance of renewable energy source in reducing environmental degradation. Based on this implication, policy makers should introduce legislations and set regulations that support the production and consumption of renewable energy and discourage the production and consumption of non-renewable energy. It seems that this strategy should be supported by subsidies and tax credits.

Overall, we found that the inverted U-shaped EKC hypothesis does not hold in the EU countries and existing environmental regulation standards of the EU countries are inadequate for the purpose of reducing environmental degradation. In addition, based on the empirical finding that renewable energy (non-renewable energy) consumption reduces

(increases) the environmental degradation, it is recommended that reducing environmental degradation will be possible by sweeping away from fossil-fuel energy consumption-based growth policies in the EU countries.

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