Environmental Science and Pollution Research (2020) 27:45148–45160
https://doi.org/10.1007/s11356-020-10399-7

RESEARCH ARTICLE

The interplay among ecological footprint, real income, energy consumption, and trade openness in 13 Asian countries

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Received: 19 April 2020 / Accepted: 4 August 2020 / Published online: 10 August 2020

Abstract

This article investigates the effects of real income, trade openness, and energy consumption on the ecological footprint using a panel data of 13 Asian countries over the 1973–2014 period. The empirical findings suggest that the panel variance-ratio test confirms the existence of a long-run equilibrium relationship among ecological footprint real income, trade openness, and energy consumption. Results from panel **pooled mean group** estimates confirm that the long-run elasticity of real income, trade openness, and energy consumption is 0.16, −0.07, and 0.51, respectively. The real income and energy consumption have a positive impact on the ecological footprint. There are three bidirectional causal relationships that were found between ecological footprint and real income; between energy consumption and ecological footprint; and between trade openness and ecological footprint. In addition, three unidirectional causalities can be found: a unidirectional causality running from real income to trade openness; from real income to energy consumption; and from trade openness to energy consumption. Those causal relationships show that economic indicators are highly related to ecological footprint. The findings recommend that various governments should fund more in renewable energy and efficiency upgrade and continue sustaining their growth without hurting the environment.

Keywords Ecological footprint · Real income · Trade openness · Renewable energy · Energy consumption

Introduction

In recent decades, the Asian region has experienced rapid economic growth. With the fast growth in Asia, many countries have become more competitive and richer. However, the growth and economic development consumes lots of natural resources (crude oil, mineral resources and gas) and followed at the cost of air or water pollution. The living environment is getting worse, and subsequently environmental protection groups protest to their governments and urge for serious environmental regulations. Nowadays human desires from ecological resources have exceeded the supply of environmental biocapacity. As the ecological footprint network indicated, more than 80% of the world's population lives in countries that are running ecological deficits, using more resources than what their ecosystems can renew.[1] Environmental degradation brings climate change and global warming, so good performance in the macroeconomic and socioeconomic indicator may reflect numerous ecological waste and costs. The index of environmental damage in previous studies is usually by CO_2 emissions (Halicioglu 2012; Soytas and Sari 2009; Lean and Smyth 2010; Shahbaz et al. 2013; Saboori and Sulaiman 2013; Jebli et al. 2016; Bulut 2017; Solarin and Bello 2018; Lu 2018; Shahbaz and Sinha 2019). However, Al-mulali et al. (2015a) indicated that using CO_2 emissions to weigh environmental degradation has some drawbacks, because CO_2 emissions only explain a small portion of the total environmental degradation. The ecological footprint provides a more complete perspective of environmental damage, and the ecological environment is increasingly evaluated. More and more researchers have used the ecological footprint to

Responsible Editor: Nicholas Apergis

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[1] The data and description can be found at following address: https://www.footprintnetwork.org/our-work/ecological-footprint/

measure environmental pressure in recent decades. Therefore, the purpose of this study is to utilize the ecological footprint instead of CO_2 emissions to measure environmental damage and to investigate the relationship among ecological footprint, real income, trade openness, and energy consumption in 13 Asian countries. The conclusions obtained in this study can be contrasted with previous researches and provide some insights for policymakers.

The past studies viewed CO_2 emissions as an indicator of environmental degradation, while very few papers have explored the ecological footprint as a measure of environmental decadence. Acknowledging economic development relies on every kind of natural resources (solid resource, forestry resource, and so on) not only to generate air pollution and CO_2 emissions. The stock of natural resource is increasingly respected by various governments. According to the use of natural resources, every country has diversified resource utilization and has implemented various energy policies. Under this background, this study will contribute to the literature on the link of ecological footprint, real income, trade openness, and energy consumption in two novel ways. First, the previous literature has emphasized the relationship between CO_2 emissions and its determinants by estimating the environment Kuznets hypothesis (hereafter EKC). However, many scholars have argued that the ecological footprint can provide a more complete perspective of environmental degradation than the CO_2 emissions does. The per capita value of the ecological footprint becomes more important for analysis. This study introduces the ecological footprint instead of CO_2 emissions to measure environmental degradation and investigates the long-run relationship among ecological footprint, real income, trade openness, and energy consumption in 13 Asian countries. Second, there are some literature examining the nexus of ecological footprint and macroeconomic indicators focused on various countries including the EKC hypothesis test for Qatar (Mrabet and Alsamara 2017), the EKC hypothesis test for 116 countries (Aşici and Acar 2016), the EKC hypothesis test for 21 countries (Ulucak and Bilgili 2018), the nexus of ecological footprint and economic development for 146 countries (Caviglia-Harris et al. 2009), the nexus of ecological footprint and development index for 128 countries (Boutaud et al. 2006), the nexus of ecological footprint and socio-economics variables for 15 MENA countries (Charfeddine and Mrabet 2017), and the ecological footprint-energy-income-trade nexus for the 27 highest emitting countries (Uddin et al. 2017). As the above-mentioned, many published studies consider the link between ecological footprint and macroeconomic indicators around the world. The main objectives of the paper will focus on the dynamic link among ecological footprint, real income, trade openness, and energy consumption. To deal with this issue, we expect to get more helpful insights and achieve environmental goals for policymakers.

The remainder of this paper is organized as follows. The "Literature Review" section describes a brief literature, the "Methodology" section provides methodology and data used in this study, the "Empirical results and discussion" section illustrates the empirical results and discussion, and the final section concludes the study.

Literature review

Many researchers began to study environmental degradation and economic development because of the severity of climate change and global warming. The relationship among GDP, energy consumption, environmental degradation, and the other determinants of environmental quality has been exhaustively studied by different scholars. The empirical framework of past literature mainly focused on the EKC hypothesis. Environmental degradation that depends on income, energy consumption, and some other variables such as trade openness, urbanization, electricity consumption, and financial development have been incorporated into the EKC framework to understand their impacts on the environment. These studies have already applied different econometric methods and have also considered different samples of regions or countries. As far as I know, the results of the EKC from previous studies attained to different conclusions, whereas most of the previous studies used CO_2 as an indicator of environmental degradation (Halicioglu 2012; Soytas and Sari 2009; Lean and Smyth 2010; Acaravci and Ozturk 2010; Al-Mulali 2011; Saidi and Hammami 2015; Zhu et al. 2016; Liu and Hao 2018; Chandia et al. 2018). Another examples regarding the research of a single country or region includes Soytas et al. (2007) for the USA, Al-mulali et al. (2015a, b) for Vietnam, Shabbir et al. (2014) for Pakistan, Saboori et al. (2012) for Malaysia, Magazzino (2014) for Italy, Chang (2009) for China, Ang (2007) for France, Soytas and Sari (2009) for EU, Saidi and Hammami (2015) for 58 countries, and Lean and Smyth (2010) for five ASEAN countries. Overall, earlier empirical researches are built on the EKC framework and obtain inconsistent results, with the exception of the above-mentioned studies, when we keep an eye on the environmental indicators of greenhouse gas emissions such as Lu (2017), Tsaurai (2018), and Baležentis et al. (2019).

Recently, many scholars have become well aware of the incomplete measure of environmental degradation such as carbon emissions. The most important cause is that the carbon emissions solely considers to reduce the level of CO_2 emissions and ignores other kinds of deterioration resource, including land stock, forestry stock, mining stock, and so on. Stern (2014) argued that the CO_2 emissions per capita gradually decreased by virtue of carbon reduction technology, but other pollutants per unit of output are increasing in developed countries. Therefore, more and more researchers, including Al-Mulali et al. (2015b), Ozcan et al. (2019), Ulucak and Lin

(2017) have found that when we utilized the ecological footprint to represent an indicator of environmental degradation, it is more suitable. In the field of ecological footprint and energy economics, there are two strands of literature that are shown in the literature. First, a few studies focused on the time series characteristics of ecological footprint. Solarin and Bello et al. (2018) investigated the persistence of ecological footprint for 128 developing and developed countries. Ulucak and Lin (2017) analyzed the persistence of policy shocks to ecological footprint for the USA. For the purpose of the ecological footprint forecast, if the ecological footprint is alerted to be nonstationary, forecasting may not be feasible based on previous data of the series. Knowing that the existence of the long-term persistence of ecological footprint implies the ecological footprint is nonstationary and the environmental policies, such as provision of subsidy on cleaner energy or the imposition of carbon tax, will have long-term effects. Those studies provide the influential policy insight for environmental policy. Another strand of literature has heavily focused on ecological footprint, income, and other determinants of ecological footprint including (1) the ecological footprint-electricity consumption nexus (Bello et al. 2018); (2) the income-ecological footprint nexus (Aşici and Acar 2016); (3) the relationship among ecological footprint, tourism GDP growth, trade openness, and urbanization (Ozturk et al. 2016); (4) the income-ecological footprint for 27 emitting countries (Uddin et al. 2017); (5) the link among real income, trade openness, human capital, and ecological footprint for low-, middle-, and high-income countries (Ulucak and Bilgili 2018); (6) The relationship among ecological footprint, natural resources, and economic growth (Hassan et al. 2019); (7) the impact of economic development and social-political factors on ecological footprint (Charfeddine and Mrabet 2017); (8) the relationship among energy consumption, urbanization, trade openness, financial development, and income for 93 countries (Al-mulali et al. 2015a, b); (9) the hydroelectricity, fossil fuels consumption, real income and ecological footprint for Malaysia (Bello et al. 2018); (10) the impact of energy and economic development on ecological footprint for 146 countries (Caviglia-Harris et al. 2009); and (11) the dynamic link among financial development, trade openness, and ecological footprint in Qatar (Mrabet and Alsamara 2017). Those researches mainly concentrated on the ecological footprint and its relative determinants; performing those issues have followed two crucial reasons: first, verifying the EKC hypothesis to get an income and environmental degradation relationship, and second, considering other economic and social variables by the framework of the STIRPAT model is to affirm those variables' impact on ecological footprint. The conclusions in literature are inconsistent and depend on the dataset. The important results of past literature are summarized and reported in Table 1.

This study addresses this gap in the literature and focuses on the dynamic links between ecological footprint, real income, trade openness, and energy consumption. Third, a major criticism of previous studies is that their empirical results are inconsistent. These inconsistent conclusions were due to their use of different countries, environmental degradation measurements, time intervals, and econometric methods. To address these issues, we consider a relatively new panel method for investigating the relationships between the variables we have considered.

Methodology

Panel unit root test

Before performing cointegration tests, we should find the long-run relationships between variables and implement the panel unit root tests to detect whether all variables are stationary or nonstationary. If a variable contains a unit root, it implies an important implication for econometric theory. For instance, through understanding the stationary of an environmental indicator such as the ecological footprint, we can know the shocks to the pollutions resulting from better adoption of environment technologies (Solarin and Bello 2018). In addition, knowing the stationary properties of an environmental indicator allows us to check the EKC hypothesis, because the existence of EKC relies on the stationary properties of each variables used in research. For the purposes and a panel data setting in this study, following the specification of Pesaran (2007), the panel data model for checking the existence of the unit root is as follows:

$$y_t = (1-\rho)\mu + \rho y_{t-1} + e_t \quad \mathrm{t} = 1, \cdots, \mathrm{T} \tag{1}$$

where $y_t = (y_{1t}, \cdots, y_{nt})'$, $y_{t-1} = (y_{1t-1}, \cdots, y_{nt-1})'$, $e_t = (e_{1t}, \cdots, e_{nt})'$, y_t denote each of the variables we analyzed in this study, and e_t distributed with mean zero and covariance Ω_t. As the setting of Eq. (1), we apply two heteroscedasticity-robust tests: the white-type test of Herwartz and Siedenburg (2008) and the white-type Cauchy test of Demetrescu and Hanck (2012) to address the stationary or not. Both tests are robust to heteroscedasticity, and the first test is robust to cross-sectional dependence.

$$t_{HS} = \frac{\sum_{t=1}^{T} y'_{t-1}\Delta y_t}{\sqrt{\sum_{t=1}^{T} y'_{t-1}\hat{e}_t\hat{e}'_t y_{t-1}}} \quad \mathrm{t} = 1, \cdots, \mathrm{T} \tag{2}$$

$$t_{DH} = \frac{\sum_{t=1}^{T} sgn(y_{t-1})'\Delta y_t}{\sqrt{\sum_{t=1}^{T} sgn(y_{t-1})'\hat{e}_t\hat{e}'_t sgn(y_{t-1})}} \quad \mathrm{t} = 1, \cdots, \mathrm{T} \tag{3}$$

Table 1 Recent literature review of ecological footprint

Author(s)	Period	Method	Country	Conclusions
Aşici and Acar (2016)	2004–2008	Panel fixed effect model	116 countries	Support EKC; Income growth relocates ecological footprint; Validate "Pollution Haven" hypotheses and urge the importance of environmental regulations.
Ulucak and Bilgili (2018)	1961–2013	Panel cointegration method, unit root tests, CUP-FM estimator, CUP-BC estimator	21 countries including 7 high-income countries, 7 middle-income countries, and 7 low-income countries	EKC hypothesis is held in low-income, middle-income, and high-income group countries
Charfeddine and Mrabet (2017)	1975–2007	Panel unit root tests, Pedroni (2004) cointegration test, and panel Granger causality test	15 MENA countries (Middle East and North African)	Energy use will worsen the ecological footprint. In the sample of oil-exporting countries, the EKC hypothesis is validated. Some socio-demographic variables like urbanization, life expectancy at birth and fertility rate ameliorate the environment in the long term
Uddin et al. (2017)	1991–2012	Panel unit root tests, dynamic ordinary least squares (DOLS) method, Pedroni (2001) coefficient estimation	27 highest emitting countries	Income has the positive effect on ecological footprint. A negative and insignificant association exists between trade openness and ecological footprint for the selected countries
Slarin and Bello et al. (2018)	1961–2013	Both linear and Non-linear unit root test. Time series model	128 developed and developing countries	The series of ecological footprint are nonstationary (96 countries or 81% of the sample). The imposition of carbon tax, a subsidy on cleaner energy, and the appropriate land use will have long-term effects on ecological footprint
Ulucak and Lin (2017)	1961–2013	Fourier unit root test	USA	Ecological footprint is nonstationary which suggests the policies affecting the Ecological footprint will have permanent effects.
Al-mulali et al. (2015)	1980–2008	Three types of unit root tests are used (IPS test, Fisher-type ADF and PP test), Panel fixed effect model, panel generalized method of moments (GMM) is utilized	93 countries	EKC hypothesis is held in upper middle group countries and high-income group countries. Energy consumption, urbanization, and trade openness damage the environmental quality; however financial development relies on environmental degradation
Bello et al. (2018)	1971–2016	Panel unit root tests with breaks, ARDL, VECM	Malaysia	EKC hypothesis is validated in Malaysia. Hydroelectricity significantly reduces environmental degradation. The unidirectional causality running from hydroelectricity and fossil fuels consumption to ecological footprint and real GDP
Ozturk et al. (2016)	1988–2008	System panel generalized method of moments (GMM)	144 countries	EKC hypothesis is more present in the upper middle- and high-income countries. GDP growth is negatively related to ecological footprint
Mrabet and Alsamara (2017)	1980–2011	ARDL	Qatar	The EKC hypothesis of inverted U-shaped hypothesis is not valid in Qatar. However, the long-term relationship among financial development, trade

Table 1 (continued)

Author(s)	Period	Method	Country	Conclusions
				openness, CO_2 emissions, and the ecological footprint is found
Caviglia-Harris et al. (2009)	1961–2000	Fixed effect and dynamic panel data model	146 countries	No empirical evidence of an EKC relationship between the EF and economic development. Energy is largely responsible for the lack of an EKC relationship, and that energy consumption levels would have to be cut by over 50% in order for a statistically significant EKC relationship to emerge from the data
Liu et al. (2018)	1990–2013	VECM, Johansen cointegration tests	Japan, Korea, China	Japan and Korea satisfy the EKC hypothesis but China does not display the same tendency
Sabir and Gorus (2019)	1975–2017	ARDL	South Asian countries	EKC holds in the South Asian countries
Ahmed and Wang (2019)	1971–2014		India	EKC holds in the India
Ahmed et al. (2019)	1971–2014	ARDL, Bayer and Hanck cointegration test, GC	Malaysia	Energy consumption and economic growth stimulate the ecological footprint and carbon footprint in Malaysia.
Acar and Aşici (2017)	1961–2008	ARDL, cointegration test	Turkey	An inverted U-shaped, hence EKC-type, relationship only be found between production footprint and income
Yilanci and Pata (2020)	1965–2016	Fourier ARDL	China	EKC hypothesis is not valid for China
Ansari et al. (2020)	1991–2017	PMG, DOLS, and GMM estimator	Asian countries	EKC in ecological footprint exist in case of whole panel with Central and East Asian sub-panel.

1. The dependent variable is ecological footprint for all above-mentioned literature

2. Definition of notations and abbreviations. *ARDL* autoregressive distributed lag, *GC* Granger causality, *EKC* environmental Kuznets curve, *VECM* vector error correction model, *GMM* generalized method of moments, *DOLS* dynamic ordinary least squares, *FMOLS* fully modified ordinary least squares, *CUP-FM* continuous updated fully modified, *CUP-BC* continuous updated fully modified bias corrected, *PMG* pooled mean group estimation

where t_{HS} is the test statistic of Herwartz and Siedenburg (2008), t_{DH} denotes the test statistic of Demetrescu and Hanck (2012), and sgn(.) represents the sign function. In literature, both t_{HS} and t_{DH} can be applied to the panel unit root test even if the error term is heteroscedasticity. If the t_{HS} or t_{DH} exceeds the critical value, then $H_0 : \rho = 1$ is rejected against an alternative hypothesis ($H_1 : \rho < 1$) of a stationary process.

Panel cointegration test

As a next step, this study is to verify for the absence of cointegration. According to the econometric theory, if there exists a cointegration relationship, those variables may have long-run equilibrium; in other words, the variables including ecological footprint, real income, trade openness, and energy consumption may have long-run equilibrium; they move contemporaneously, and various governments could provide environmental policies to resist environmental degradation. In order to investigate the relationship between ecological footprint, real income, trade openness, and energy consumption in 13 Asian countries, this study specified the following model:

$$EF_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 TRD_{it} + \beta_3 EU_{it} + \varepsilon_{it} \quad (4)$$

where EF_{it} is the ecological footprint per capita, GDP_{it} is the real income per capita, and TRD_{it} is trade to GDP, and EU_{it} represents energy consumption per capita. All variables represent the natural log form. The parameters in equation (4) from β_1 to β_3 stand for the long-run effect of ecological footprint per capita with respect to real income, trade openness, and energy consumption, respectively.

With regard to the expected signs in Eq. (4), one would think that the sign of β_1 is expected to be positive. The reason of expected signs of β_1 is similar with the definition of the EKC hypothesis; initially, pursuing economic development brings both higher income and pollutants and then eventually increases environmental awareness and reduces pollution by environmentalist initiative or social pressure. The sign of $\beta_2$was expected to be positive because an increase in trade openness will lead to high pollution, and because the dirty industry immigrates to the countries with loose environmental regulations (Halicioglu 2012). The sign of β_3 was expected to be positive because an increase in energy consumption will result in environmental degradation (Charfeddine and Mrabet 2017).

Several studies have assessed the link among ecological footprint, real income, trade openness, energy consumption, and other determinants by exploring panel econometric models such as Pedroni's panel cointegration test (Uddin et al. 2017), dynamic generalized method of moments (Al-mulali et al. 2015b; Ozturk et al. 2016), and the cointegration tests of Gregory and Hansen (Mrabet and Alsamara 2017) which assume the presence of structural breaks, (Westerlund and Edgerton 2008) panel cointegration applied by Ulucak and Bilgili (2018) which consider common factors as a cross sectional dependence. This study conducts the panel variance-ratio test of Westerlund (2005) (hereafter VR) on our panel dataset. The features and merits of the VR test include simple and allowance of short-run dynamics and temporal dependencies. According to the VR test designed by Westerlund (2005), it follows two steps to obtain the test statistic: First, using ordinary least squares to estimate Eq. (4), getting the estimated residuals ($\widehat{e}_{i,t}$) from Eq. (4) and then fitting the following autoregression:

$$\widehat{e}_{i,t} = \rho\widehat{e}_{i,t-1} + v_{i,t} \quad (5)$$

where ρ is the AR parameter and $v_{i,\ t}$ is a stationary error term. Second, the group mean and panel variance-ratio statistics are derived from

$$VRG = \sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{E}_{i,t}^{2}\widehat{R}_i^{-1} \text{ and } VRP = \sum_{i=1}^{N}\sum_{t=1}^{T}\widehat{E}_{i,t}^{2}\left(\sum_{i=1}^{N}\widehat{R}_i\right)^{-1}, \quad (6)$$

in which $\widehat{E}_{i,t} = \sum_{j=1}^{t}\widehat{e}_{ij}$ and $\widehat{R}_i = \sum_{t=1}^{T}\widehat{e}_{i,t}^{2}$, respectively. This test has a common null hypothesis of no cointegration. The two alternative hypotheses of the VR test are that the series in some of the panels (group-mean statistic) are cointegratied and all series in the panel (panel statistic) are cointegrated, respectively. The test results will be shown in the next section.

Common correlated effects mean group (CCEMG) estimators

According to Pesaran (2006), the CCEMG estimators are advantageous because they are robust to cross-sectional reliance and slope heterogeneity. I revised the description on page 9. It reads as follows: "The empirical model is expressed as:

$$y_{i,t} = \alpha_i^{'} d_t + \beta_i^{'} x_{i,t} + u_{i,t} \quad (7)$$

$$u_{i,t} = w_{i1} f_{1,t} + w_{i2} f_{2t} + \ldots + w_{im} f_{mt} + e_{it} = w_i^{'} f_t + e_{it} \quad (8)$$

where $x_{i,\ t}$ stands for the regressors on the ith cross-sectional countries at time t. d_t signifies the common effects. $f_t = (f_{1,\ t}, f_{2t}, \ldots f_{mt})$ and $w_i = (w_{i1}, w_{i2}, \ldots w_{im})$ represents the common factors and factor loadings, respectively. e_{it} is the error term which could be cross-sectionally weakly dependent. Pesaran (2006) shows that Eq. (7) can be estimated by approximating the unobserved common variables with cross-section means of the explained variables $\overline{y}_{i,t}$ and $\overline{x}_{i,t}$.[2] The following auxiliary regression must be estimated:

$$y_{i,t} = \beta_i x_{i,t} + c_i \overline{x}_{i,t} + \vartheta_i \overline{y}_{i,t} + u_{i,t}. \quad (9)$$

[2] $\overline{y}_{i,t} = \frac{1}{N}\sum_{i=1}^{N} y_{i,t}$ and $\overline{x}_{i,t} = \frac{1}{N}\sum_{i=1}^{N} x_{i,t}$

Based on above equation, the common correlated effect estimators $\widehat{\beta}_{i,CCE}$ are expressed as

$$\widehat{\beta}_{i,CCE} = \left(X_i^{'}\overline{D}X_i\right)^{-1} X_i^{'}\overline{D}Y_i, \tag{10}$$

where $X_i = (x_{i1}, x_{i2}, \ldots, x_{jT})^{'}$, $Y_i = (y_{i1}, y_{i2}, \ldots, y_{jT})^{'}$, $\overline{D} = I_t - \overline{M}\left(\overline{M}^{'}\ \overline{M}\right)^{-1}\overline{M}^{'}$, $\overline{M} = \left(D, \overline{Z}\right)$, D and $\overline{Z}$ are the matrices of observations on d_t and $\overline{Z}_{it} = (\overline{y}_{i,t}, \overline{x}_{i,t})$. The CCEMG estimators are expressed as:

$$\widehat{\beta}_{i,CCEMG} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\beta}_{i,CCE} \tag{11}$$

Pesaran shows that under some general conditions, $\widehat{\beta}_{i,CCEMG}$ is asymptotically unbiased for β and as $(N, T) \rightarrow \infty$.

Pooled mean group regression

If the panel cointegration test confirms a cointegrating relationship between the variables, this study will then apply the pooled mean group regression method to estimate the long-run and short-run effects and adjustment speeds in our sample. The empirical model is expressed in Eq. (4). It may be reparameterized into the error correction equation as:

$$\Delta y_{i,t} = \varphi_i\left(y_{i,t-1} - \theta_i^{'}x_{i,t}\right) + \sum_{j=1}^{p-1} b_{ij}\Delta y_{i,t-1} + \sum_{j=1}^{p-1} a_{ij}^{'}\Delta x_{i,t-j} + \mu_i + e_{i,t} \tag{12}$$

where $j = 1, 2, \ldots, p-1$, φ_i represents the error-correcting speed of adjustment term. If $\varphi_i = 0$, then there is no long-run relationship. φ_i is expected to be negative under the assumption that the variables show a return to long-run equilibrium. b_{ij} and a_{ij} are short-run coefficients. θ_i represents long-run coefficients. μ_i and e_{it} denote country-specific fixed effects and time variant effects, respectively. Finally, this study follows the econometric procedures of Pesaran et al. (1999) and Blackburne and Frank (2007) in estimating the parameters.

The empirical results will be discussed in the next section.

Panel causality test

When the long-run cointegration relationship exists, it implies the existence of Granger causality. As causality analysis Granger developed, the following step should examine the direction of the causality relationship between the variables. Therefore, we test the Granger causality among ecological footprint, real income, trade openness, and energy consumption. This study applies the panel causality test introduced by Dumitrescu and Hurlin (2012). The panel data model is considered as follows:

$$\mathrm{y_{i,t}} = \alpha_\mathrm{i} + \sum_{k=0}^{K}\gamma_i^{(k)}\mathrm{y}_{\mathrm{i,t}-k} + \sum_{k=1}^{K}\beta_i^{(k)}\mathrm{x}_{\mathrm{i,t}-k} + \epsilon_{\mathrm{i,t}} \tag{13}$$

where K denotes the lag length; x and y represent each variable under consideration, variables observed for N individuals in T periods in our model; α_i are fixed individual effects; $\gamma_i^{(k)}$ denotes autoregressive parameters; and $\beta_i^{(k)}$ are regression coefficients varied across countries. The homogeneous non-Causality hypothesis and its null are defined as:

$$\mathrm{H_0}: \beta_i = 0, \forall \mathrm{i} = 1, \ldots, \mathrm{N} \text{ with } \beta_\mathrm{i} = \left(\beta_i^1, \beta_i^2 \ldots \beta_i^{(k)}\right) \tag{14}$$

$$\mathrm{H_1}: \beta_i \neq 0, \forall \mathrm{i} = 1, \ldots, \mathrm{N} \tag{15}$$

$$\beta_i \neq 0, \forall \mathrm{i} = \mathrm{N_1}+1, \mathrm{N_1}+2 \ldots, \mathrm{N} \tag{16}$$

Dumitrescu and Hurlin (2012) proposed the average statistic $W_{NT}^{HNC} = \frac{1}{N}\sum_{i=1}^{N} W_{i,t}$, and $W_{i,\,t}$ includes individual Wald statistical values for the each country. Under the null hypothesis of non-causality, each individual Wald statistic converges to a chi-squared distribution. The average statistic (W_{NT}^{HNC}) has an asymptotic distribution associated with the null hypothesis. The standardized test statistic Z_{NT}^{HNC} for T, $\mathrm{N} \rightarrow \infty$ is as follows:

$$Z_{NT}^{HNC} = \sqrt{\frac{N}{2K}}\left(W_{NT}^{HNC} - K\right) \rightarrow N(0,1) \tag{17}$$

For fixed T samples, the standardized test statistic Z_{NT}^{HNC} is as follows:

$$Z_{NT}^{HNC} = \sqrt{\frac{N}{2K} \times \frac{T-2K-5}{T-K-3}} \times \left[\frac{T-2K-3}{T-2K-1} W_{NT}^{HNC} - K\right] \rightarrow N(0,1) \tag{18}$$

Data

The data set is a balanced panel of 13 Asian countries and covers the period from 1973 to 2014. The dimensions of the panel data set are selected to include as many countries as possible with a reasonable time length of observations. The Asian countries contained in the sample are Bangladesh, China, Japan, South Korea, Malaysia, Nepal, Pakistan, Thailand, Turkey, Sri Lanka, the Philippines, Singapore, and India. The ecological footprint per capita is taken from the Global Footprint Network [49]. The real income per capita is measured using real GDP per capita (constant 2000 US dollars). The trade openness is measured by the sum of exports and imports of goods and services to GDP. The energy consumption per capita is measured by energy use (kg of oil

Table 2 Descriptive statistics

	Mean	Std. Dev.	Minimum	Maximum
EF	0.52	0.77	−0.77	2.14
GDP	7.84	1.50	5.54	10.86
GDP^2	63.73	24.49	30.65	118.02
TRD	3.94	0.85	2.08	6.09
EU	6.65	1.03	4.53	8.91

equivalent per capita). The real income per capita, trade openness, and energy consumption are obtained from the World Development Indicator of the World Bank (2013) online data base. Table 2 shows the descriptive statistics of the five variables for all countries. For convenience, we also sketch the time series plots of real income, energy consumption, and trade openness reported in Fig. 1 and the time series diagrams of ecological footprint in Fig. 2 for all countries showing the plots of ecological footprint. As we expected in Fig. 1, the time series data among energy consumption, real income, and trade openness tend to move together across time. This result is consistent with past empirical research and reveals that those variables have long-run links and deserve to be studied. Figure 2 shows the time variation for each country, displaying the fact that the ecological footprint increases over time except in the Philippines and Nepal. That is, the slope of ecological footprint curve is positive and a threat of environment exists. After reading Figs. 1 and 2, we think that the relationship between those variables is worth exploring.

Empirical results and discussion

Based on Eq. (1), this study utilized the white-type test of Herwartz and Siedenburg (2008) (t_{HS}) and the white-type Cauchy test of Demetrescu and Hanck (2012) test (t_{DH}) to test the stationarity of the various variables. The traditional unit root test such as the Levin et al. (2002), and the Im et al. (2003) can generate biased and spurious results by reason of their inability to account for heteroscedasticity or cross-sectional dependence. Compared with the traditional panel unit root test, those two tests are robust to heteroscedasticity and cross-sectional dependence. The results of the unit root test are reported in Table 3. Both t_{HS} and t_{DH} in Table 3 do not exceed critical value in levels but significantly surpass critical value in first differences. Thus, all variables used in this study are nonstationary and integrated of order 1 (i.e., I(1)), so we will explore whether the five variables are cointegrated in this section. The nonstationary conclusion of ecological footprint is in accordance with previous evidence of the persistence of policy shocks to ecological footprint. For example, Ulucak and Lin (2017) found that ecological footprint is nonstationary in the USA, whereas Solarin and Bello et al. (2018) also point out that the 96 of 128 countries are nonstationary for ecological footprint in 128 developed and developing countries. The results suggest that government policies affecting the ecological footprint have long-term effects.

Turning to the panel cointegration tests, this study finds, based on Eq. (4) under the alternative hypothesis, that all series in the panel are cointegrated and the panel VR statistic (*VRP*) rejects the null hypothesis of no cointegration at a 10%

Fig. 1 Time series plots of GDP, energy consumption, and trade openness

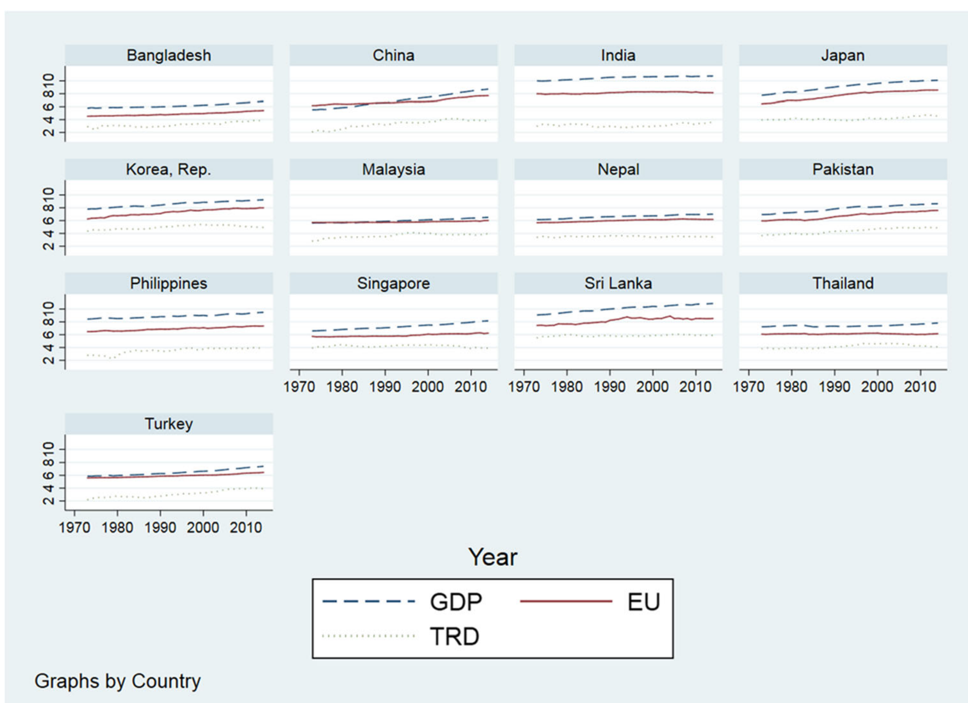

Fig. 2 Time series plots of ecological footprint

statistically significant level. This implies that all panels are cointegrated. Regarding to the mean group variance-ratio tests (*VRG*), used to test the null hypothesis of no cointegration against the alternative hypothesis that some panels are cointegrated under the framework of Westerlund (2005), *VRG* indicates that it rejects the null hypothesis of no cointegration among ecological footprint, real income, trade, and energy consumption in favor of the alternative that at least some panels are cointegrated at a 1% statistically significant level. The test results are reported in Table 4. Those findings in cointegration tests reveal that a long-run equilibrium exists among these macroeconomic variables and the environmental variable (ecological footprint). Knowing of their relations helps us to estimate and establish environmental policy. Based on the previous studies which use ecological footprint as an indicator of environmental degradation, Ozturk et al. (2016) found that there is a cointegration relationship among ecological footprint, GDP from tourism, trade openness and urbanization. In the case of Malaysia, Bello et al. (2018) also probed and proved the long-run relationships among ecological footprint, GDP, and urbanization. Other similar results from Uddin et al. (2017), Ulucak and Bilgili (2018), and Aşici and Acar (2016) also checked and confirmed the long-run relationship between ecological footprint and other control variables. The results in this study also clarified the long-run relationship between ecological footprint, real income, trade openness, and energy consumption.

Based on Eq. (7), the CCEMG estimation results of this study are reported in Table 5. For the relationship between real income and ecological footprint, this study found that a 1% increase in real income increases the ecological footprint by 0.57. That is, when real income increases, the ecological footprint rises. However, the nexus of trade openness and ecological footprint is not significant and is quite weak. This result is consistent with past evidence in the field of CO_2 emissions and GDP (Lean and Smyth 2010; Saboori and Sulaiman

Table 3 Panel unit root heteroscedasticity-robust test results

	Level		First difference	
	t_{HS}	t_{DH}	t_{HS}	t_{DH}
EF	1.11	2.12	-1.66^{*}	-1.77^{**}
GDP	0.88	1.01	-2.04^{**}	-1.99^{**}
GDP^2	0.94	1.16	-2.01^{**}	-1.61^{*}
TRD	0.52	1.09	-3.01^{***}	-3.48^{***}
EU	1.04	2.11	-2.33^{***}	-2.08^{**}

"***", "**", and "*" indicate significance at the $P < 0.01$ level, $P < 0.05$ level, and $P < 0.01$ level, respectively

Table 4 Variance ratio tests for panel cointegration

	Statistic	*P* value
VRG	-2.24^{***}	0.007
VRP	-1.31^{*}	0.091

Note: "***", "**", and "*" indicate significance at the P < 0.01 level,

$P < 0.05$ level and $P < 0.01$ level, respectively

Table 5 CCEMG estimation results

Variables	Coefficient	t-statistic
GDP	0.57***	2.71
TRD	−0.01	−0.39
EU	0.34***	2.66

"***", "**", "*" indicate significance at the $P<0.01$ level, $P<0.05$ level, and $P<0.01$ level, respectively

2013). For the use of the ecological footprint as an environmental indicator, the GPD-ecological footprint nexus of this study can be compared with the previous studies of high-income, middle-income, and low-income countries (Ulucak and Bilgili 2018), including Pakistan (Hassan et al. 2019) and Malaysia (Bello et al. 2018). It partly supports the EKC hypothesis as discussed in Aşici and Acar (2016), Charfeddine and Mrabet (2017), and Solarin and Bello (2018). The impact of energy consumption on ecological footprint is significant. A 1% increase in energy consumption increased the ecological footprint by 0.34%. The changes in energy consumption affecting the ecological footprint have the same sign but a different magnitude, as other scholars have found, including Al-mulali et al. (2015b) and Charfeddine and Mrabet (2017). Energy consumption is an important source of environmental damage. Trade does not have material effect on ecological footprint and its coefficient is estimated by −0.01. The impact of trade openness on ecological footprint is not noticeable. Because trade openness does not hurt the environment, policymakers should provide regulatory policies for energy use that address environmental needs.

Based on Eq. (12), the pooled mean group regression (PMG estimators) are listed in Table 6. The findings indicate that a 1% rise in GDP causes a 0.16% increase in ecological footprint in the long run. However, there is a significantly negative relationship between trade and ecological footprint in the long run. A 1% increase in trade will cause a 0.07% fall in ecological footprint. The long-run coefficient between energy consumption and energy use is 0.51. This means that a 1% increase will cause 0.51% rise in ecological footprint in the long run. The coefficient of the error correction term is −0.32, which is statistically significant at the 1% level. This means that a deviation from the long-run equilibrium is corrected by 32% each year, and the convergence process reasonably exists in the target region. For the short-run evidence, the effect of GDP on ecological footprint is significantly positive. Therefore, GDP has an important influence in both the short run and the long run. Both trade and energy consumption have significantly positive effects on ecological footprint in the short run. Since control of energy use remains important for environmental protection, policy makers should create regulatory policies for energy use. This result is similar with the past evidence in the field of CO_2 emissions and GDP (Lean and Smyth 2010; Saboori and Sulaiman 2013). Regarding using ecological footprint as an environmental indicator, the EKC hypothesis is confirmed as including high-income, middle-income, and low-income countries (Ulucak and Bilgili 2018); Pakistan (Hassan et al. 2019); Malaysia (Bello et al. 2018); and partly support EKC hypothesis, including Aşici and Acar (2016), Charfeddine and Mrabet (2017), and Solarin and Bello et al. (2018). The changes in energy consumption affecting the ecological footprint have the same sign but a different magnitude as the other scholars found, by Al-mulali et al. (2015b) and Charfeddine and Mrabet (2017). Energy consumption is an important source for environmental damage. Finally, the impact of trade openness on ecological footprint seems not to be noticeable. Trade openness does not hurt the environment and the policymaker should directly provide a regulation policy in energy use.

Table 6 Results from PMG estimation

Variables	Coefficient	Standard error
Long-run coefficients		
GDP	0.16***	0.01
TRD	−0.07***	0.01
EU	0.51***	0.02
Error correction coefficient	−0.32***	0.06
Short-run coefficients		
ΔGDP	0.39***	0.16
ΔTRD	0.04**	0.02
ΔEU	0.26***	0.09

"***", "**", and "*" indicate significance at the $P<0.01$ level, $P<0.05$ level, and $P<0.01$ level, respectively

The results of the Dumitrescu-Hurlin panel causality test across all countries are revealed in Table 7. It's not surprising that a bidirectional causal relationship was found between ecological footprint and real income. Two bidirectional causal relationships were also found between energy consumption and ecological footprint and between trade openness and ecological footprint. The existence of those bidirectional causal relationships also confirms the results of the panel cointegration test and is consistent with the previous literature, although most of the studies in the literature have used carbon emissions (CO_2) as the environmental index. Additionally, there exist three unidirectional causal relationships running from income to trade openness, from income to energy consumption, and from trade openness to energy consumption. As discussed in the energy economic literature, income (GDP) is highly connected with trade openness and energy consumption. It goes without saying that most of the countries in our sample are developing countries and their economic growth relies on energy consumption and trade openness. While those countries experienced rapid growth and an increase in GDP,

Table 7 Panel Granger causality results

Direction of causality	W_{NT}^{HNC}	Z_{NT}^{HNC}	$P-$value
$EF \rightarrow GDP$	4.30^{***}	3.49^{***}	0.001
$GDP \rightarrow EF$	7.32^{***}	8.33^{***}	0.000
$EF \rightarrow EU$	3.24^{*}	1.79^{*}	0.073
$EU \rightarrow EF$	6.33^{***}	6.73^{***}	0.000
$EF \rightarrow TRD$	3.87^{***}	2.79^{***}	0.005
$TRD \rightarrow EF$	6.60^{***}	7.16^{***}	0.000
$GDP \rightarrow TRD$	4.25^{***}	3.40^{***}	0.001
$TRD \rightarrow GDP$	2.96	1.34	0.179
$EU \rightarrow GDP$	2.05	0.12	0.903
$GDP \rightarrow EU$	4.17^{***}	3.29^{***}	0.001
$EU \rightarrow TRD$	3.01	1.42	0.155
$TRD \rightarrow EU$	5.91^{***}	6.06^{***}	0.000

1. "X→Y" indicates that there is a causality running from X to Y

2. "***", "**", and "*" indicate significance at the $P < 0.01$ level, $P < 0.05$ level, and $P < 0.01$ level, respectively

3. All lag lengths selected automatically on the criterion of the AIC

more foreign investment will be introduced in domestic production. Finally, the continual increase in the income and trade openness has led to the increasing demand of energy consumption.

Conclusion and policy implications

Most of the researches have focused on the relationship among carbon emissions, real income, trade openness, and energy consumption over the last few decades. The interest here does not utilize carbon emissions as an index of environmental degradation because many scholars have become alerted that carbon emissions is a small portion of environmental degradation. Instead, this study introduced the ecological footprint as an environmental degradation to investigate the long-run link among real income, trade openness, energy consumption and ecological footprint based on the framework of EKC hypothesis. The results from our empirical analysis have drawn the following conclusion:

- The empirical results show that the existence of long-run cointegration among the variables because of the variance-ratio (VR) test of Westerlund (2005).
- Long-run estimates reveal that real income have an significantly positive impact on the ecological footprint. Moreover, the trade openness has a negative effect on ecological footprint, and energy consumption has a positive impact on ecological footprint. Energy consumption is an important source of environment degradation, but trade openness is not. Those results recommended that countries have to improve energy efficiency and saving, and reduce the energy consumption to sustain the ecological system.
- Not surprisingly, three bidirectional causal relationships were found between ecological footprint and real income; between energy consumption and ecological footprint; and between trade openness and ecological footprint. Granger causality results indicate the existence of a unidirectional causality running from real income to trade openness; from real income to energy consumption; and from trade openness to energy consumption. Those causal relationships show that economic indicators interrelate with ecological footprint. When governments make economic policy, the environmental regulation needs to be taken into account.

Through the above-mentioned empirical findings, this study provides following policy implications: first, heavy pollution, global warming, and climate change are increasingly serious and policymakers should enact urgent strategies to address these problems. Second, the ecological footprint represents the exhaustion of forests, water, fresh air, and other resources. Consideration of ecological footprint will give us a broader prospective for investigation of environmental needs. Third, the environment-GDP-energy nexus is an important issue for every country. Understanding their relationships can help us generate novel ideas for environmental and energy policies. The results of this study are robust and offer several important policy implications.

1. Since GDP growth increases the ecological footprint and reduces environmental quality, national energy plans should focus on improving energy efficiency, enhancing environmental regulation, and exploiting renewable and sustainable energy to facilitate economic growth.

2. Since production and consumption consume more physical resources and reduce environmental quality, resource utilization must change. Instead of fossil energy, we need use energy from sustainable resources (such as wind and solar). Successful experiences of alternative energy must be transplanted to home countries to reduce the failure rate of new energy resource development.

The pollution haven hypothesis contends that weak environmental policies attract pollution-intensive industries from advanced (developed) countries to poor (developing) countries. The richer countries tend to externalize ecological damage by outsourcing dirty production to poor countries. The trade-ecological footprint relationship has different signs for the long-run and short-run effects. This study finds insufficient evidence to support the pollution haven hypothesis. Policies that lead to environmental protection and at the same time raise energy efficiency and renewable energy investment can reduce such critiques of globalization.

This study recommends that the various governments should plan to improve energy efficiency, enhance environmental regulations, and exploit renewable and sustainable fuels because those solutions could be a good project to decrease pollution and subsequently improve the ecological environment. Another way is to transplant the successful experience of alternative energy to home country to reduce the failure opportunities of developing new energy sources. Besides pollution prevention, efficient energy saving and renewable energy investment projects not only bring the growth of its own economic development without environmental damage but also reduce the protests against the rise in pollution.

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