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Stochastic and club convergence of ecological footprint: An empirical analysis for different income group of countries

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ABSTRACT

The convergence of environmental pollution is one of the contemporary issues in economics. Indeed, most of the long-run climate projections and future predictions of environmental conditions are based on convergence presumption. The pioneer studies initially focused on the convergence of carbon emission per capita, yet convergence of ecological footprint per capita, accepted as a more comprehensive environmental degradation indicator than carbon emission per capita, has been begun to examine by researchers as well. The main point of this paper is to examine the stochastic and club convergence of ecological footprint among different income groups of countries from 1961 to 2016 by a panel stationarity test with smooth shifts and log-t methods. According to the empirical findings, (a) cross-section dependence exists in all income groups, (b) the findings of the panel stationarity test with smooth shifts favored divergence, (c) there are several convergent clubs among different income groups. The existence of club convergence proposes that environmental policies should consider the different convergence paths associated with club membership.

1. Introduction

Global environmental threats such as global warming and climate change are among the most challenging issues facing today's world because the environment is a complex system that consists of physical, chemical, biological, cultural, and socioeconomic resources and values. In this respect, it can be said that various human activities covering a wide spectrum are in complex interactions with the environment. Human activities have already caused the world to warm up to about 1 °C compared to the pre-industrial period. Global warming has already begun to show its negative effects as extreme weather events such as drought and floods, sea-level rise, and melting of the Northern ice sea (The Intergovernmental Panel on Climate Change, 2018). According to The Intergovernmental Panel on Climate Change reports, if global warming cannot be controlled, we will face much worse than today's environmental disasters such as loss of natural habitats and species, devastating consequences that will directly affect human life through health, prosperity, safety, and the economy as a result of melting glaciers and rising sea levels. Indeed, the vital importance of environmental sustainability can be seen in Sustainable Development Goals (SDGs) as well. Indeed, the six of 17 goals are directly associated with the environmental quality, therefore, ensuring environmental sustainability located at the center of the SDGs, and has a key role in achieving sustainable development (Ulucak, Kassouri, İlkay, Altıntaş, & Garang, 2020). In this context, governments need to adopt and implement appropriate and effective policies for "fast and comprehensive" transformations that will reduce environmental degradation in agriculture, energy, industry, buildings, fishing grounds, forest, transport, and cities. Examining the convergence of environmental deterioration indicators is essential to design and implement effective policies to combat global warming.

Following the seminal study of Solow (1956), the subject of convergence has become one of the most popular topics in macroeconomic theory. According to the convergence hypothesis, an important part of the neoclassical growth model, economies move at a decreasing rate towards their steady-state equilibrium; that is, economies with lower capital accumulation at the beginning, and so with a lower level of development, converge their steady-state equilibrium more rapidly than economies with a higher level of development. The convergence phenomenon has been extensively examined in the literature in terms of whether claiming that future income inequalities between similar countries will decrease or the neoclassical foundations on which it is

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based are convenient for empirical application (Barro & Sala-i-Martin, 1992; Mankiw, Romer, & Weil, 1992). The convergence hypothesis is investigated for different economic indicators in a wide range of fields such as education, health, military, tourism, foreign trade, energy, and environment (Ulucak & Apergis, 2018). The convergence on environmental quality is one of the most popular topics in convergence literature owing to environmental concerns as it is mentioned above, and it has been analyzed within the framework of the concepts of beta (β), club convergence, sigma (σ), and stochastic convergence. The convergence of β is familiar with economic growth literature. Let's assume a model to shape this idea as follows: $g_i = \alpha + \beta\gamma_{0i} + \varepsilon_i$. The g_i represents the average growth rate of any ecological indicator for the country of i and γ_{0i} represents the natural logarithm of initial relative per capita indicator. The negative and statistically significant value of β implies absolute convergence. This notation can be expanded through including exogenous control variables, and in this way, the absolute convergence method can be modified to consider individual differences ecological indicator. This notation implies conditional convergence. The club convergence approach is based on the idea of multiple equilibria. In other words, the club convergence approach considers the existence of multiple steady-state paths and, an economy will reach its steady-state path, which depends on its initial position or another country-specific characteristic. Therefore, countries with similar characteristics on different topics such as economic structure, income level, factor endowments, etc. will converge to similar equilibria (Islam, 2003). The convergence of σ is based on the idea of the distribution of the series. The σ convergence approach implies that the distribution of per capita ecological indicators among compared countries has decreased over time (Barro & Sala-i-Martin, 1992). Stochastic convergence, which states that the series does not contain unit roots, implies that the effects of temporary shocks on relative series dissipate over time (List, 1999). Therefore, if the examined series are stochastically convergent, then shocks to the series are temporary, on the contrary, if the series is divergent, shocks to the series are permanent. Nguyen-Van (2005) claimed that environmental convergence would be achieved if countries with low emissions per capita increase their emissions and countries with high emissions per capita reduce their emissions. On the one hand, if relative environmental quality has a stationary process, the relative series will converge to the mean without any intervention. On the other hand, if the environmental quality has a non-stationary process, the series will diverge from the mean. This implies that any shock to the environmental degradation will have long-lasting effects. In this case, environmental policies targeting to decrease environmental pollution can be effective. The stochastic and club convergence approaches are widely adopted by researchers due to the following reasons; (a) stochastic convergence concept allows us to test across-convergence (Islam, 2003), (b) the inferences on conditional and unconditional convergence could be made by stochastic convergence as well (Carlino & Mills, 1993), (c) stochastic convergence process provides researchers and policymakers with crucial information such as predicting the future behavior of relative environmental pollution (Lee & Chang, 2009), (d) club convergence allows us to detect possible multiple equilibria in the case of divergence and gives the possibility to make group-specific inferences. When reviewing the literature on the convergence of existing environmental quality indicators, it can be seen that CO2 emissions are generally accepted as environmental quality indicators. Although CO2 emission is a significant indicator of environmental pollution, it is seen as a one-dimensional variable that does not fully reflect anthropogenic impacts on our ecosystem (Z. Ahmed, Wang, Mahmood, Hafeez, & Ali, 2019; Aşıcı & Acar, 2016; Destek, Ulucak, & Dogan, 2018). Therefore, the concept of the ecological footprint was developed by Wackernagel and Rees (1998) to properly describe the destruction of human in a complex environment.

The concept of ecological footprint, expressing the biologically productive land and water area required to produce the resources consumed by an individual, community, or activity and eliminate the waste it creates with the current technology and resource management, is considered as a more comprehensive indicator than other environmental indicators (Solarin, 2019). The ecological footprint, consisting of six sub-components namely carbon footprint (required ocean and forest area to absorb CO2 emissions), cropland footprint (required area for food), forest footprint (required forest area paper and wood production), grazing land footprint (required area for farming), built-up land footprint (required area for residential, transportation, industrial structures, and power plants), and fishing grounds footprint (required area for seafood production)- takes into account the environmental pressures of human activities in all dimensions (Solarin & Bello, 2018; Ulucak & Lin, 2017). In light of this information, knowing the behavior of ecological footprint is one of the most crucial issues for analysts and policymakers forecasting human pressure on our planet or designing effective and suitable environmental policies. On the one hand, having a convergent pattern of ecological footprint indicates that there is no need for mitigation policies, and the convergent pattern gives information about the prediction of future behavior of the ecological footprint. On the other hand, having a divergent pattern of ecological footprint per capita shows that mitigation policies are required, and the environmental burden of economic development would not ease without exogenous intervention. In that case, it could be stated that knowing the pattern of ecological footprint per capita is crucial for forecasting the future of environmental pollution, planning climate actions, evaluating the success or failure of environmental actions.

The main purpose of this study is to unveil whether the convergence hypothesis is valid among different income level of countries from 1961 to 2016 by using stochastic and club convergence approaches, hence, this paper aims to contribute to the existing literature on the following aspects; (a) we investigated the convergence of ecological footprint per capita among different income levels complying with Environmental Kuznets Curve (EKC) approach and the scope of international treaties. For instance, the Kyoto Agreement makes emission abatement obligatory for developed countries, while voluntarily abatement policies were principally envisaged for developing countries. Further to that, it can be seen in Paris Agreement (United Nations Climate Change, 2020) that each Party should prepare and maintain its nationally determined contributions (NDCs), however, it is obvious that the dynamics of NDCs varies in each income group, and even in countries which belong to same income group. Therefore, data characteristics of ecological indicators can differ among income groups; in other words, the steady-state path of each income groups can differ, and any paper, examining whether stochastic and club convergence of ecological footprint per capita hold among different income groups, was not found in the literature (to the best of our knowledge), (b) distinctively from a great part of former literature, we used panel stationarity methods, considering cross-section dependency in stochastic convergence analysis. It is widely known that many international initiatives have been taken since Stockholm Conference, and many international agreements such as Kyoto Protocol, Millennium Development Goals (MDGs), Sustainable Development Goals (SDGs), Paris Agreement have been accepted on ecological issues. Thus, it may be inferred that environmental diplomacy, occurring since the Stockholm Conference caused to mutual dependencies among countries (Erdogan & Acaravci, 2019; Hajer et al., 2015). Further to that, several economic and environmental policy changes or fluctuations such as Kyoto Protocol (1997) and Oil Crises in 1974 and 1979 occurred in the relevant period and inherently affected resource use, as well as the ecological footprint of countries, and this led to change of dynamic behavior of environmental indicators. Hence; if one deals with both economic and empirical approach, it could be said that omitting cross-section dependency, and structural shifts in ecological footprint data may induce biased hypothesis tests and policy inferences (Chudik & Pesaran, 2013; Perron, 1989), (c) traditional panel stationarity and unit root tests with structural change presume occurrence of sharp shifts on data. However, Enders and Lee (2012) evidenced that gradual changes may occur more than sharp ones in economic data. Therefore, the use of

Table 1
Empirical studies on convergence of CO2 and other GHG emissions.

Study	Period	Sample	Methodologies	Variable	Results
Strazicich and List (2003)	1960–1997	21 industrial countries	Panel unit root test and cross-sectional regressions	CO2	Stochastic and conditional convergence
Nguyen Van (2005)	1966–1996	100 countries	Non-parametric methods	CO2	βconvergence for industrial countries
Aldy (2006)	1960–2000	88 countries and 23 OECD countries	Markow chain transition matrix	CO2	σconvergence for 23 OECD countries and mixed results for 88 countries
Ezcurra (2007)	1960–1999	87 countries	Non-parametric approach	CO2	σconvergence
Westerlund and Basher (2008)	1870–2002	Developed and developing countries	Panel unit root tests	CO2	Stochastic convergence
Lee and Chang (2008)	1960–2000	21 OECD countries	SURADF unit root test	CO2	Mixed results
Lee & Chang (2009)	1960–2000	21 OECD countries	Unit root test with structural break		Stochastic convergence
Barassi et al. (2008)	1950–2002	20 OECD countries	Hadri panel unit root test	CO2	Divergence
Panopoulou and Pantelidis (2009)	1960–2003	128 countries	log-*t* test	CO2	Club convergence
Jobert et al. (2010)	1971–2006	22 EU countries	The Bayesian shrinkage estimation method	CO2	Conditional convergence
Criado and Grether (2011)	1960–2002	166 world areas	Spatial distributions	CO2	Mixed results
Barassi et al. (2011)	1870–2004	18 OECD countries	KPSS, ADF, NP unit root test	CO2	Mixed results
Herrerias (2012)	1920–2007	25 EU countries	The dynamics of the distribution approach	CO2	σconvergence
Herrerias (2013)	1980–2009	162 countries	Pair-wise unit root, log-*t* test	CO2 from oil, coal, gas	Mixed results
Li and Lin (2013)	1971–2008	110 countries	AR, Hansen test	CO2	Mixed results
Camarero et al. (2013)	1960–2008	23 OECD countries	log-*t* test	CO2 intensity	Mixed results
Solarin (2014)	1960–2010	39 African countries	LM unit root test	CO2	Mixed results
Brännlund et al. (2014)	1985–2010	124 countries	Parametric and nonparametric panel data techniques	CO2	βconvergence
Payne et al. (2014)	1900–1998	The U.S. states	RALS-LM unit root test	SO2	Stochastic convergence
Wang et al. (2014)	1995–2011	China and its provinces	log-*t* test	CO2	Mixed results
Li et al. (2014)	1990–2010	The 50 U.S. states	Fourier unit root test, SPSM procedure	CO2	Mixed results
El-Montasser et al. (2015)	1990–2011	G7 countries	Panel unit root test	GHG	Divergence
Sun et al. (2016)	1971–2010	10 largest economies	Fourier unit root test	CO2	Mixed results
Burnett (2016)	1960–2010	48 the U.S. states	log-*t* test	CO2	Mixed results
Acaravci and Erdogan (2016)	1960–2011	7 regions of the world	CADF	CO2	Divergence
Robalino-Lópezet al. (2016)	1980–2010	10 South American countries	log-*t* test	CO2 intensity	Mixed results
Morales-Lage (2017)	1960–2012	28 EU countries	Time series methods	CO2	Mixed results
Apergis et al. (2017)	1997–2013	The 50 U.S. states	Panel unit root tests	CO2	Mixed results
Ahmed et al. (2017)	1960–2010	162 countries	Wavelet unit root analysis	CO2	Stochastic convergence for 38 countries
Tiwari and Mishra (2017)	1972–2010	18 Asian countries	Parametric and non-parametric tests	CO2	$\beta$and σ convergence
Apergis and Payne (2017)	1980–2013	50 U.S. states	log-*t* test	CO2	Mixed results
Presno et al. (2018)	1901–2009	28 OECD countries	Non-linear unit root test	CO2	Mixed results
Churchill et al. (2018)	1900–2014	44 developed and developing countries	RALS-LM unit root test	CO2	Conditional convergence
Brännlund and Karimu (2018)	1971–2008	94 countries	Set of panel estimation methods	Environmental performance index	Conditional β convergence for global sample
Liu et al. (2018)	2003–2015	285 cities in China	log-*t* test, logit regression analysis	Air pollutant emissions	Mixed results
Yu et al. (2018)	1995–2015	24 industrial sectors in China	CIPS unit root test, CCEMG, log-*t* test	CO2 intensity	Mixed results
Erdogan and Acaravci (2019)	1960–2014	28 OECD countries	Fourier PANKPSS unit root test	CO2	Stochastic convergence
(Haider & Akram, 2019b)	1980–2016	53 countries	log-*t* test	CO2 total and its components (from oil, coal and gas)	Mixed results
Emir et al. (2019)	1990–2016	EU-28 Members	log-*t* test	CO2 intensity	Club Convergence
Solarin and Tiwari (2019)	1850–2005	32 OECD Countries	Fourier PANKPSS	SO2	Convergence
Payne and Apergis (2020)	1972–2014	Developing Countries	CADF, PANKPSS, Log-*t* test	CO2	Stochastic and Club Convegence

a panel unit root/stationarity test with smooth shifts can be more insightful to make inferences about the nature of ecological data. Furthermore, panel unit stationary tests with a Fourier term may have better performance in capturing potential changes in the nature of data (Cai and Menegaki, 2019a, 2019b; Cai & Wu, 2019; Erdogan & Acaravci, 2019). In this study, a panel stationarity test with a Fourier term employed to abstain from biased estimations and purposed to contribute to filling the gap in the literature. (d) Last, we employed a log-t approach to determine whether club convergence exists among different income groups of countries. The investigation of club convergence allows us to observe whether the countries, which are in the same income group, exhibit either different or similar movement patterns, and it may be key for policy-makers to take collective action on environmental issues.

2. Literature review

Due to global problems such as global warming and climate change in recent years, the convergence of environmental pollution indicators in various forms (stochastic, absolute and conditional β, σ and club convergence) is one of the most debated issues in the existing literature. CO2 emissions are the most widely studied indicator of environmental pollution convergence. The results of the convergence studies of CO2 emissions vary according to the methodologies, sample, period, and convergence form (see Payne, 2020). An extensive summary of the literature on the convergence of CO2 and some greenhouse gas emissions is presented in Table 1.

Recently, there is an ongoing debate on the convergence of ecological footprint, a more comprehensive indicator of environmental degradation. For instance, Ulucak and Apergis (2018) utilized the log-*t* test to explain the club convergence of ecological footprint in 20 EU countries from 1961 to 2013 and confirmed the presence of a small number of convergence clubs. Bilgili and Ulucak (2018) employed a bootstrap-based panel KPSS and log-*t* test to analyze the validity of converging clubs and stochastic convergence in ecological footprint in G-20 countries from 1961 through 2014. They found stochastic and deterministic convergence in ecological footprint. Haider and Akram (2019a) investigated club convergence in ecological footprint and carbon footprint in 77 countries over the period 1961–2014 applying log-*t* test and empirical analysis revealed that there are mixed results in the case of club convergence in ecological and carbon footprints. Solarin et al. (2019) investigated the existence of converging clubs in ecological footprint and its sub-components in 92 countries for the period from 1961 to 2014 utilizing log-*t* test and Schnurbus et al. (2017) club convergence approaches. As a result of the analysis, there are mixed results for 92 countries. Solarin (2019) analyzed the convergence of CO2, carbon, and ecological footprint in the group of OECD countries from 1961 to 2013. According to the results of RALS-LM and LM unit root tests, β convergence confirmed for 12 of 27 members in the case of CO2 emissions, 15 of 27 members in the case of carbon footprint, and 13 of 27 members in the case of ecological footprint. Okumus and Erdogan (2019) examined the convergence of ecological footprint per capita among G-7 countries between 1961 and 2016 by using CADF and PANKPSS test and evidenced the existence of convergence. Bilgili et al. (2019) examined the convergence of ecological footprint per capita in 15 countries of each continent from 1961 to 2014 and they reported mixed results. Ulucak et al. (2020) investigated the convergence of ecological footprint among Sub-Saharan Africa for the period of 1961–2014 by utilizing a club convergence approach and reported that there is no sign of club convergence as a whole, whereas there are some converging clubs some sub-components. Yilanci and Pata (2020) examined the convergence of ecological footprint per capita among ASEAN-5 countries from 1961 to 2016 by using a threshold autoregressive panel unit root test and reported mixed results.

It could be seen in the literature review that papers, investigating convergence on ecological indicators, mainly focused on convergence on carbon emissions per capita, whereas there is a limited paper on convergence on other greenhouse gas such as SO2; however, researchers did not reach a compromise on whether greenhouse gas has a convergent or divergent pattern. On the other hand, it could be noticed that there is a growing literature on convergence on ecological footprint per capita in recent, and researchers generally examined the club convergence; however, it could be said that there has been no consensus yet. To the best of our knowledge, there is no study, examining the convergence of ecological footprint per capita among different income groups, which could be more compatible with the EKC concept and scope of international agreements. This study mainly focused on stochastic and club convergence on ecological footprint per capita among high-, middle-, and low-income countries from 1961 to 2016 and aimed to fill the existing gap in the literature.

3. Data, methodology, and empirical results

3.1. Data

Owing to data constraints, we investigated the validity of convergence of ecological footprint in 89 countries by using annual data from 1961 to 2016. We used ecological footprint, obtained from The Global Footprint Network (2019), as a proxy of environmental degradation because of being a comprehensive measure of pollution. Based on Carlino and Mill's (1993) methodology; to understand better the dynamic movement of country-specific ecological footprint per capita, we have obtained relative ecological footprint per capita for each country by the following specification; EF_{it}/EF_t, where EF_{it} is the ecological footprint per capita of the country of i at tth period, while EF_t is average ecological footprint per capita level of related group at tth period, and we used logarithmic values of relative ecological footprint per capita in analyses.

Moreover, the determination of the sample is a challenging issue in convergence analyses. If it is noted that environmental degradation is mostly the result of anthropogenic activities such as production and consumption, income level may be used as a good proxy to determine groups. Provided that it is paid attention to Strazicich and List's (2003) statement on income level-environmental pollution nexus, it could be concluded that convergence of environmental degradation is an implication of the environmental Kuznets curve (EKC) concept asserting that environmental degradation would increase to a certain extent of income, yet it would begin to decrease higher income level than those certain level (Acaravci & Akalin, 2017; Grossman & Krueger, 1991). When the convergence concept is used, income level and environmental degradation become closely associated with each other. In light of those explanations, because of having excessively heterogeneous data characteristics, our sample is divided into three sub-groups as high-, middle- and low-income countries according to the World Bank's classification principle. Such an approach may help to examine the dynamic movement of per capita ecological footprint and its steady-state path and also prevent biased estimations and policy implications (Bimonte, 2009; Cai & Wu, 2019; Erdogan & Acaravci, 2019).

We reported the descriptive statistics for each group in the appendix (TAble A1, Table A2). First, Luxembourg has a maximum ecological footprint per capita as 1.082, while Portugal has a minimum of −1.777 and belongs in high-income countries. Second, Myanmar has a maximum ecological footprint per capita value as 1.004, while Brazil has a minimum as −1.107 in middle-income countries. Third, Syria has a maximum ecological footprint per capita value as 0.682, while Haiti has a minimum of −0.838 in low-income countries. Moreover, positive values of skewness were more than negative ones in high-income countries, whereas negative values of skewness were more than positive ones in middle- and low-income countries. It can be said that data structures were either fairly or moderately skewed in each group.

3.2. Methodology

First, we used the Bias-Adjusted LM test (LM_{adj}) test (Pesaran, Ullah, & Yamagata, 2008) to extract prelusive information of the data. Pesaran et al. (2008) augments the standard LM test (Breusch & Pagan, 1980) through utilizing variance and mean to address size distortions, revealing in the case of T < N. The LM_{adj} procedure can be formed as follows:

$$LM_{adj} = \sqrt{2/N(N-1)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\left((T-k)\widehat{p}_{ij}^{2}-\mu_{Tij}\right)\Big/\upsilon_{Tij} \tag{1}$$

where k is the number of parameters, μ_{Tij} is the mean, and $\upsilon_{Tij}$is the variance. The LM_{adj} uses null of the "($H_0 : Cov(u_{it}, u_{jt}) = 0$-*for all t and*

$i \neq j$- " and alternative of "$H_1: Cov(u_{it}, u_{jt}) \neq 0$ -at least *one pair of* $i \neq j$-".

In this study, we utilized the FPKSS test (Nazlioglu & Karul, 2017) to detect long-run dynamic behavior of ecological footprint per capita. As distinct from traditional panel unit root methods, the FPKPSS test uses Fourier functions to detect structural shifts and adopts the null hypothesis of stationarity ($H_0: \sigma^2_{u_{it}} = 0$-*for all i-)* instead of non-stationarity ($H_1: \sigma^2_{u_{it}} > 0$ ($i = 1,...,N_1$)., and the FPKPSS allows us to smoothly model structural shifts and consider country-specific heterogeneities, which cope with cross-section dependence. The FPKPSS test combines the time series stationarity method of Becker et al. (2006), in which shifts in data are considered with a Fourier estimation, and the panel stationarity approach of Hadri and Kurozumi (2011, 2012), in which cross-section dependence is modeled by using common structure. In FPKPSS, the test utilizes a Monte Carlo procedure to examine small sample properties, and it is reported that the FPKPSS has a satisfying size and power performance (Erdogan, Akalin, & Oypan, 2020). The DGP of the FPKPSS procedure can be shown as follows (Erdogan & Acaravci, 2019; Nazlioglu & Karul, 2017):

$$y_{it} = \alpha_i(t) + r_{it} + \lambda_i F_t + \varepsilon_{it} \tag{2}$$

$$r_{it} = r_{it-1} + u_{it} \tag{3}$$

where $r_{it}$is a stochastic term, and $r_{i0} = 0$ for all i, without loss of generality as heterogeneous intercept terms are incorporated. $\varepsilon_{it}$and u_{it} are identically distributed and correlatively independent *(i.i.d)* across i and over t. F_t is an unobserved common factor, and λ_i is the loading weights. Eq. (2) defines the deterministic term as a time-independent function denoted by $\alpha_i(t)$. Provided that the intercept subjects to any structural change in an uncertain form, then the Fourier procedure with a single-frequency component is as follows:

$$\alpha_i(t) = a_i + \gamma_{1i} sin(2\pi kt/T) + \gamma_{2i} cos(2\pi kt/T) \tag{4}$$

where $\gamma_{1i}$and $\gamma_{2i}$are the amplitude and displacement of changes, respectively. Eq. (4) estimates the term of time-varying intercept with non-zero values ofγ_{1i} and $\gamma_{2i}$to detects gradual changes in the intercept. Moreover, the FPKPSS test allows to fluctuate the slope of both intercept and time trend. Jones and Enders (2014) developed a Fourier expansion to approximate the nonlinear trend function either with structural breaks or another form of nonlinearity as follows:

$$\alpha_i(t) = a_i + b_i t + \gamma_{1i} sin(2\pi kt/T) + \gamma_{2i} cos(2\pi kt/T) \tag{5}$$

The country-specific statistics can be estimated by using the KPSS procedure of Becker et al. (2006), with *(k)* given as follows:

$$\eta_i(k) = (1/T^2) \sum_{t=1}^{T} \tilde{S}_{it}(k)^2 / \tilde{\sigma}^2_{\varepsilon i} \tag{6}$$

where $\tilde{S}_{it}(k) = \sum_{j=1}^{t} \tilde{\varepsilon_{ij}}$ is the partial sum process by utilizing the OLS errors from Eq. (2) and $\tilde{\sigma}^2_{\varepsilon i}$ is a computation of the long-run variance of ε_{it} that is specified as $\sigma^2_{\varepsilon i} = \lim_{T\to\infty} T^{-1}E(S^2_{it})$. The panel statistics *FP(k)* is the simple average of country-specific statics, which could be obtained by the following procedure: $FP(k) = (1/N)\sum_{i=1}^{N} \eta_i(k)$. *FP(k)* converges to the standard normal distribution with the mean $\xi(k)$ and variance $\xi^2(k)$ $FZ(k) = \sqrt{N}(FP(k) - \xi(k)/\zeta(k)/\tilde{}N(0,1)$. Furthermore, $\xi(k)$ and $\xi^2(k)$ estimated by the Monte Carlo technique. To test club convergence, we utilized a time-varying common factor approach proposed by Phillips and Sul (2007, 2009). The theoretical background of Phillips and Sul's method can be explained as follows:

$$y_{it} = \theta_{it} \nu_t \tag{7}$$

where $\theta_{it}$and ν_t time-varying components and $\nu_t$shows the aggregate common evolvement of y_{it} , and θ_{it}represents time-varying idiosyncratic component showing the deviation of a country i from common path determined by the common factor ν_t. In this regard, either all countries or a part of the sample will converge to its steady-state path if $\lim_{p\to\infty} \theta_{it+p} = \theta$ for all *i*, without considering the related country's distance from the steady-state. The club convergence approach that based on the idea of the average of the difference between θ_{it} and θ diminishes up to a rate proportional to $1/(t^{\varsigma}(log(t+1))$ *for* $\varsigma \geqslant 0$ and $\theta_{it} = \theta$ for each *i*. This concept allows us to detect convergence by testing whether factor loadings converge (Phillips and Sul, 2007, 2009, Ulucak et al, 2020). In order to estimate θ_{it}, Phillips and Sul (2007) rescale the Eq. (7) to remove $\nu_t$by using the cross-section average:

Table 2
LMadj Test Results.

Group	Stat.	Prob.
Low-Income Countries	10.145	0.000
Middle-Income Countries	79.967	0.000
High-Income Countries	43.262	0.000

Note: Probability values of the model with constant and trend for cross-section dependence test were shown in parenthesis.

$$h_{it} = y_{it}/1/N \sum_{k=1}^{N} y_{kt} = \theta_{it}/1/N \sum_{k=1}^{N} \theta_{kt} \tag{8}$$

where $h_{it}$is an indicator showing transition path with respect to the cross-section average. The cross-sectional variation ratio can be estimated by using the following specification:

$$H_t = 1/N \sum_{i}^{N} (h_{it} - 1)^2 \tag{9}$$

The null and alternative hypothesis of club convergence are $H_0 = \theta_i = \theta\, and\, \varsigma \geqslant 0,\ and\, H_1 = \theta_i \neq \theta\, and\, \varsigma < 0$, respectively, and those hypotheses are tested by utilizing the following *Log-t* specification:

$$\begin{aligned} &Log(H_1/H_t) - 2LogL(t) = a + blogt + \varepsilon_{2t} \\ &for\, t = [\phi T], [\phi T] + 1..., T > 0 \end{aligned} \tag{10}$$

where $L(t) = \log(t)$, and Phillips and Sul (2007) proposed that ϕ should be in the interval $[0.2, 0.3]$ and shows disposed fraction from the sample. The log-t approach utilizes a one-sided *t*-test and the null hypothesis of convergence is rejected in the case of *t* statistic is less than -1.65 at the 5% significance level. The clustering process of Phillips and Sul (2007) for determining convergent clubs performs as follows (Ulucak et al., 2020); (a) sort the sample based on the values of the last observations, (b) designate all possible groups (G_k) by picking the first k highest countries, where $2 \leqslant k < N$, and utilize log-*t* test to detect whether convergence exists in each k sized subgroups, (c) unearth that all panel members converge to the similar steady-state path following with the core group G^*, and this stage shows the first convergence club in the sample. This procedure is repeated for the remaining body of the sample to determine the next convergence club, and this procedure replicates until the remaining members of the sample fail to converge. Moreover, it should be noted that the log-t approach also gives robust results under the presence of heterogeneity and stationarity (Burnett, 2016).

3.3. Empirical results

The cross-section dependence may cause biased inferences about findings and policy implications in panel data estimations. Thus, we employed the LM_{adj} test as an initial test and we reported cross-section dependence test results in Table 2. The LM_{adj}test results evidenced that the null of "no cross-section dependence" is strongly rejected for all samples; hence, ecological footprint per capita cross-sectionally dependent among those country groups. The cross-section dependence may result from the following factors; (i) shared institutions shaping environmental policies and initiatives such as United Nations, (ii)

Table 3
FPKPSS Test Results.

High-Income Countries

Country	k = 1	Country	k = 1	Country	k = 1	Country	k = 1	Country	k = 1
Argentina	0.057	Chile	0.061	Italy	0.058	Panama	0.049	UK	**0.046**
Australia	0.054	Denmark	**0.042**	Japan	0.053	Poland	0.057	USA	0.053
Austria	0.050	France	**0.036**	Luxembourg	0.055	Portugal	0.056		
Barbados	**0.045**	Germany	0.064	Netherlands	0.076	South Korea	**0.045**		
Belgium	0.051	Greece	0.061	Spain	0.062	Sweden	0.055		
Canada	0.063	Israel	0.059	Norway	**0.033**	Switzerland	0.061		
Panel: 9.554 (0.000)									

Middle-Income Countries

Country	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**
Albania	0.052	Guyana	0.059	St. Lucia	0.058	Cote d'Ivoire	**0.028**	Nigeria	0.060
Brazil	**0.041**	Jordan	0.052	Thailand	0.051	El Salvador	0.060	Pakistan	0.053
China	0.057	Lebanon	0.053	Turkey	**0.045**	Ghana	0.056	Philippines	0.059
Colombia	0.062	Malaysia	0.050	Venezuela	0.054	India	0.059	Sri Lanka	0.054
Costa Rica	0.057	Mexico	0.052	Angola	**0.046**	Indonesia	0.066	Tunisia	0.057
Cuba	0.051	Paraguay	0.051	Bolivia	0.057	Kenya	0.065	Viet Nam	0.053
Dominican Rep.	0.052	Peru	0.059	Cameroon	0.062	Myanmar	**0.047**		
Fiji	**0.032**	Romania	**0.047**	Congo	0.064	Nicaragua	**0.033**		
Panel: 11.123 (0.000)									

Low-Income Countries

Country	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**	**Country**	**k = 1**
Afghanistan	0.057	Chad	0.049	Laos	0.058	Niger	**0.031**	Syria	0.063
Benin	0.066	Congo DR	**0.047**	Madagascar	0.058	Rwanda	**0.046**	Togo	0.061
Burkina Faso	0.066	Gambia	**0.031**	Mali	**0.046**	Sierra Leone	0.048	Uganda	0.059
Burundi	0.056	Guinea	0.050	Mozambique	**0.028**	Somalia	0.052	Yemen	0.053
Central African Rep.	**0.038**	Haiti	0.060	Nepal	0.052	North Korea	0.060	Zimbabwe	**0.037**
Panel: 8.166 (0.000)									

Bold statistics indicate that the null hypothesis of stationarity cannot be rejected at least at the %10 significance level. Critical values for country specific statistics are 0.0471 (%10), 0.0546 (%5) and 0.0716 (%1) for k = 1 (Becker et al. (2006)). Owing to having better size levels with our data structure, this paper employs one Fourier frequency (k = 1). The consistent long-run variance is estimated by using Bartlett kernel with the Kurozumi (2002) boundary rule.

environmental diplomacy mentioned formerly leading to common environmental policies, (iii) economic globalization. Therefore, any environmental shock in one country could affect other member countries' ecological indicators in the related sample.

We reported FPKPSS findings in Table 3. The panel statistics of FPKPSS for high-, middle- and low-income countries show that ecological footprint per capita exhibits a non-stationarity process. Herein, it should be noted that the FPKPSS approach uses the stationarity hypothesis in null *($H_0 : \sigma^2_{u_{it}} = 0$-for all i-)*; it is likely that rejection of the null hypothesis at least in one country may lead to rejection of stationarity for the panel. Therefore, it would be more proper to consider country-specific estimations, and similar features can be observed for individual estimations as well. Within this scope, the six of 26 high-income countries exhibit the stationarity process, while eight of 38 middle-income countries exhibit the stationarity process. Ultimately, eight of 25 low-income countries exhibit the stationarity process; hence, it could be concluded that the major part of FPKPSS estimations is favored of divergence rather than convergence. These findings are partially consistent with Bilgili et al. (2019), Yilanci, and Pata (2020), whereas in contradiction with Solarin (2019), Okumus and Erdogan (2019). Moreover, Figs. 1, 2, and 3 show the actual form of series (blue line) and Fourier approximations (red line). The Fourier approximations are highly consistent with the historical movement of the series, and it can be inferred from figures that Fourier approximations give early warnings about fluctuations of the ecological footprint per capita. For instance; environmental degradation of Switzerland hit the top in the 1990 s, however, an upward movement signal of ecological degradation occurred in the 1965 s. It is possible to see similar tendencies in middle and low-income countries.

Due to the existence of divergence, the possibility of club convergence emerges (Herrerias, 2013). To test club convergence, we began our analysis by utilizing the Hodrick-Prescott filtering procedure, afterward, we investigated club convergence by utilizing a log-t approach. According to the results (Table 4), we determined several convergent clubs for different income groups. There are four clubs in the high-income group, and club three has the largest number of members while club four smallest number of members. Phillips & Sul (2009) propose the investigation of possible merging clubs to detect whether larger group membership exists among adjacent clubs. Therefore, we investigated the existence of merging clubs, and results show that merging clubs among adjacent club one and club two was confirmed, whereas convergence among other adjacent clubs could not be confirmed.

There are two convergent clubs whereas there is a non-convergent group (club three) in the middle-income group, and club one has the largest number of members, while club three has the smallest. Moreover, merging clubs among adjacent groups was not confirmed in the middle-income group. There are two convergent clubs in low-income countries, and club two has 13 members, while club one has 12. Moreover, there are no merging clubs in low-income countries, and club memberships for different income groups were reported in Table 5. The existence of club convergence confirms the results of Bilgili and Ulucak (2018), Ulucak and Apergis (2018), and Ulucak et al., (2020).

4. Discussion

Within the context of stochastic convergence, we observed that the majority of the empirical findings refer to the divergence of convergence on ecological footprint. The divergent pattern of ecological footprint per capita can be associated with four challenges: nonperforming international treaties, lack of international organizations with sanction power on ecological issues, limited use of eco-friendly technologies, and limited scope of international agreements. First, the international treaties on mitigation have barely been implemented by party countries

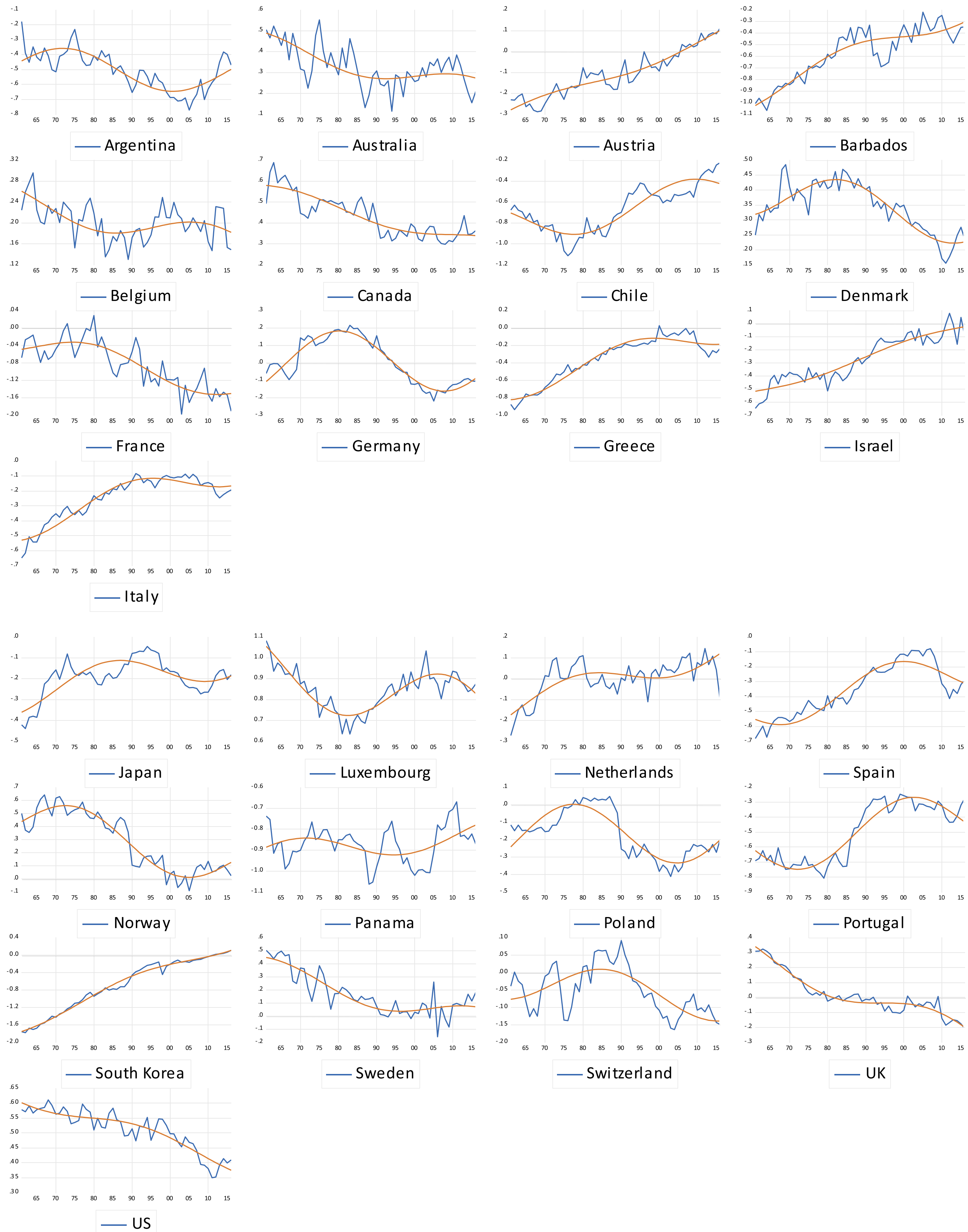

Fig. 1. Fourier Approximations for High-Income Countries.

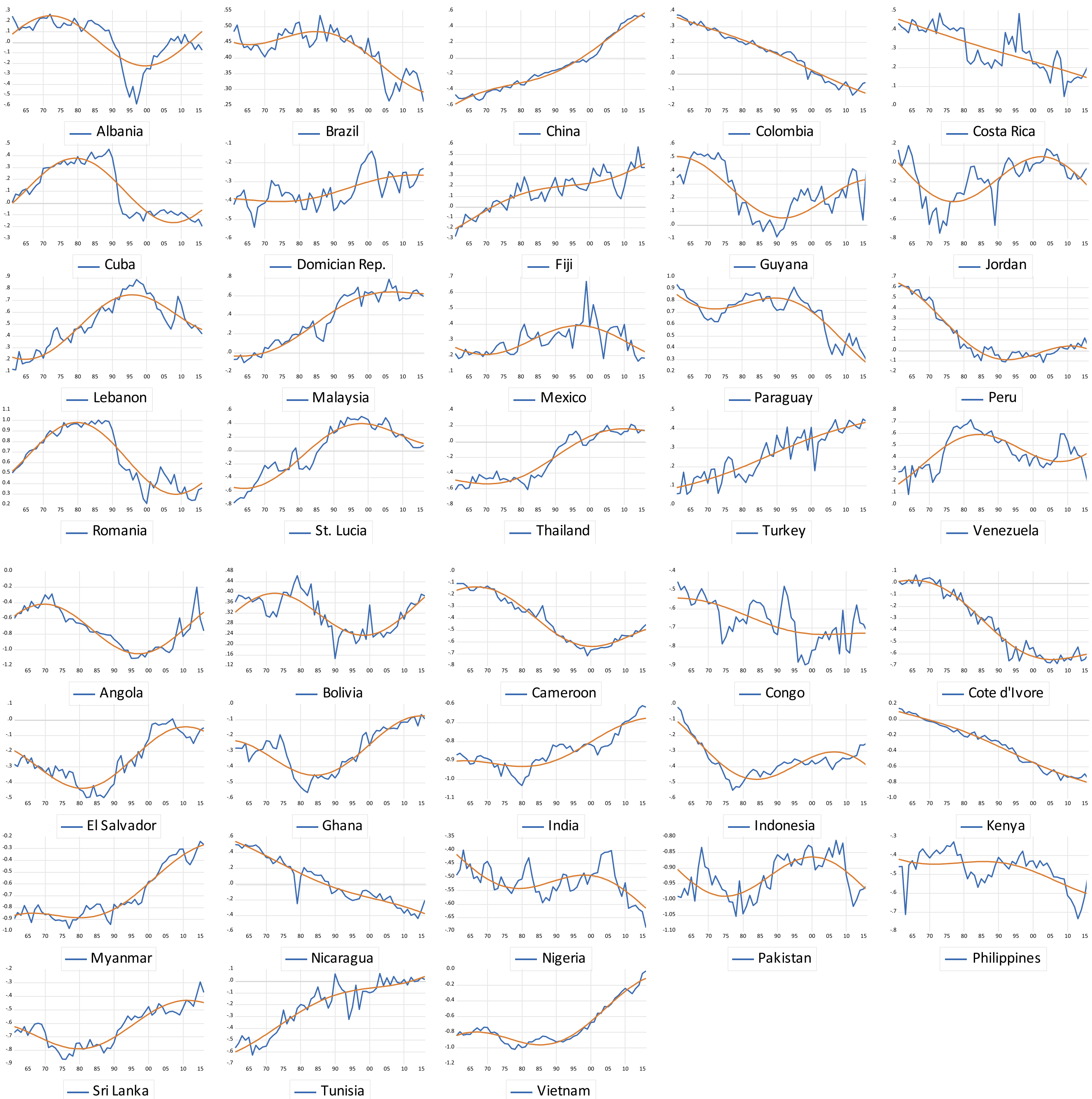

Fig. 2. Fourier Approximations for Middle-Income Countries.

since it came in to force. For instance, the Kyoto protocol, considered as a milestone for environmental efforts, was signed in 1995 and came into force in 2005, however, many issues have occurred during the commitment period. For instance, the treaty was ill-planned because of focusing on only developed countries, and it was considered that developing countries would show voluntary actions against environmental degradation, thus, the United States (U.S.) has opposed to treaty due to exempting the major part of pollutant countries. Beyond that, Canada withdrew from the treaty before the end of the first commitment period, and Russia, Japan, and New Zealand objected to taking part in the second commitment period (Santos, 2017). The Paris Agreement is likely to end up like the Kyoto Treaty. Indeed, President Obama signed the Paris Agreement (2015) on behalf of the U.S., whereas President Trump abolished. Hence, such malfunctions have aggravated the implementation of common policies and their success and hindered the creation of a steady dynamic pattern of ecological footprint neither in developed nor developing countries. Second, lack of international organizations, which have the power to form and enforce the implementation of common ecological policies or put sanctions on countries, violating the contract provisions of ecological treaties, creates serious challenges for the ecosystem (Evans, 2012). Third, the high cost of eco-friendly technologies poses some other risks. (Stern, 2006). For instance, due to being cheapest than clean energy sources, fossil fuels are being widely used around the world. Indeed, U.S. National Research Council (2013) revealed that low prices of pollutant energy sources will lead to the wide use of it for more several decades; and, currently declining oil prices prove the consistency of those forecasts. Another clean technology for mitigation is considered as vehicles with electricity power, however, Santos (2017) emphasized that the high-costs of electric vehicles hamper market penetration of it. Forth, the limited scope of

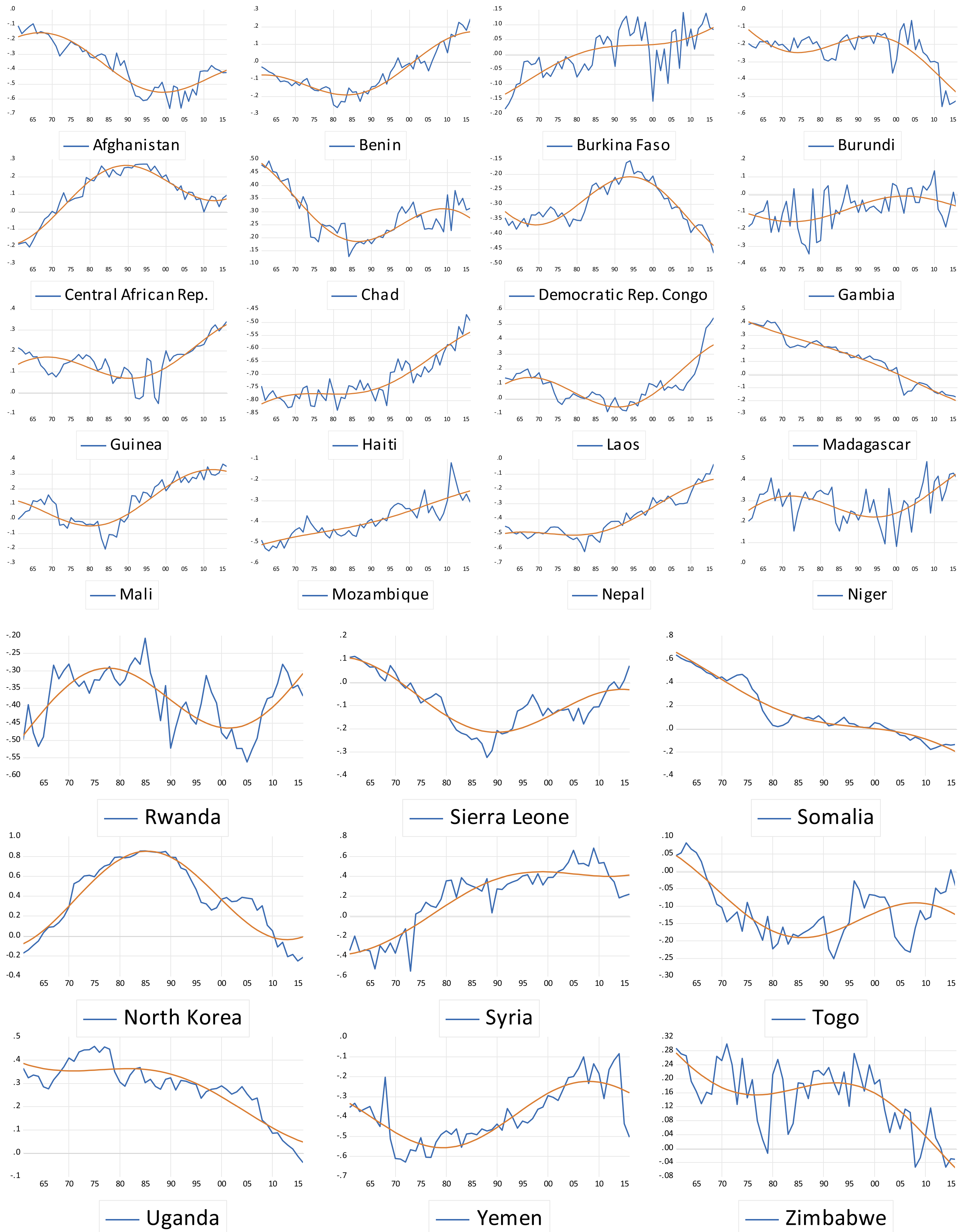

Fig. 3. Fourier Approximations for Low-Income Countries.

Table 4
Club convergence analysis.

High-Income Countries	Coefficient	Standard Error	t-stat
Club 1	0.879	0.058	15.018
Club 2	0.541	0.054	9.936
Club 3	0.221	0.042	5.170
Club 4	−1.566	1.075	−1.456
Club 1 + 2	0.712	0.143	4.956
Club 2 + 3	−0.187	0.070	−2.639
Club 3 + 4	−0.772	0.041	−18.466
Middle-Income Countries	Coefficient	Standard Error	t-stat
Club 1	2.229	1.584	1.406
Club 2	0.605	0.111	5.452
Club 3	−2.610	0.251	−10.401*
Club 1 + 2	−0.942	0.044	−20.972
Club 2 + 3	−0.606	0.037	−16.227
Low-Income Countries	Coefficient	Standard Error	t-stat
Club 1	0.145	1.266	0.114
Club 2	2.813	0.144	19.483
Club 1 + 2	−0.931	0.009	−95.248

*: not convergent group

Table 5
Club Memberships for Ecological Footprint.

High-Income Countries	Club 1	Club 2	Club 3	Club 4
Countries	Canada, Portugal, United States.	Australia, Barbados, Belgium, Denmark.	Argentina, Austria, Chile, France, Germany, Greece, Israel, Italy, Japan, Netherlands, Spain, Norway, Poland, South Korea, Sweden, Switzerland, United Kingdom.	Luxembourg, Panama.
Middle-Income Countries	Club 1	Club 2	Club 3*	Club 4
Countries	Albania, Brazil, China, Colombia, Costa Rica, Cuba, Dominican Republic, Fiji, Guyana, Jordan, Lebanon, Malaysia, Mexico, Paraguay, Peru, Romania, St. Lucia, Thailand, Turkey, Venezuela, Bolivia, Cameroon, Cote d'Ivoire, El Salvador, Ghana, Indonesia, Kenya, Myanmar, Nicaragua, Philippines, Tunisia, Vietnam.	Angola, Congo, India, Nigeria.	Pakistan, Sri Lanka.	–
Low-Income Countries	Club 1	Club 2	Club 3	Club 4
Countries	Benin, Burkina Faso, Central African Republic, Chad, Guinea, Laos, Mali, Mozambique, Nepal, Niger, Syria, Yemen,	Afghanistan, Burundi, Congo DR, Gambia, Haiti, Madagascar, Rwanda, Sierra Leone, Somalia, North Korea, Togo, Uganda, Zimbabwe	–	–

*: Not convergent group.

international treaties makes it difficult to take holistic measures to ensure environmental sustainability. Hajer et al. (2015) stated that despite its promising aspects, SDGs is far from forming holistic targets to hinder ecological diversity loss, to reduce resource use, and to combat climate change, and do not determine any deadline for targets. Therefore, it is not certain in SDGs that when a goal will be considered as accomplished. In brief, it can be inferred that those challenges have hampered to stabilizing the dynamic movement of ecological per capita among country groups.

Moreover, we observed that there are several convergent clubs among different income groups of countries, whereas there is one non-convergent club in middle-income countries. It can be concluded that the dynamic movement path of environmental degradation of the countries affecting by different factors, even they have the same income level, and it may be associated with the position of countries on the EKC. For instance, environmental conditions may not be the same in the countries, either at beginning of the scale effect or transitioning from scale effect to technique effect. Moreover, the existence of convergent clubs may create the possibility to take collective actions in these clubs (Ulucak et al., 2020). Indeed, the existence of merging clubs in the high-income group may ease the extension of collaboration on the environment.

5. Conclusion

Although the convergence concept was used to unveil income differences among developed and less-developed countries at the beginnings, it is used to reveal environmental issues as well. One could be observed at a glance that most of the convergence of environmental indicators focused on the convergence of carbon emission per capita, yet it was emphasized that degradation of environmental issues to carbon emission per capita may be a restrictive approach, and environmental convergence should be more comprehensively dealt. To this end, ecological footprint per capita, the comprehensive indicator of environmental degradation, has been used to examine the validity of convergence; however, it could be said that general findings are far from being reached to consensus in the former literature. In this study, the empirical findings show that ecological footprint per capita is cross-sectionally dependent among high-, middle- and low-income countries. The great part of the FPKSS findings favored non-stationarity of ecological footprint per capita, therefore, ecological footprint per capita has divergent patterns rather than convergence. Due to the existence of divergence, we investigated club convergence by using a log-t approach and confirmed that there are several convergent clubs in different income groups.

Having a divergent pattern of ecological footprint per capita has

Table A2
Descriptive statistics.

	High-Income Countries										
Country	Mean	Max.	Min.	Std. Dev.	Skew.	Country	Mean	Max.	Min.	Std. Dev.	Skew.
Argentina	−0.50	−0.17	−0.77	0.13	0.02	Japan	−0.19	−0.04	−0.43	0.08	−0.85
Australia	0.32	0.55	0.11	0.10	0.20	Luxembourg	0.84	1.08	0.63	0.09	−0.13
Austria	−0.10	0.11	−0.28	0.10	0.26	Netherlands	−0.001	0.14	−0.27	0.09	−0.94
Barbados	−0.57	−0.21	−1.06	0.22	−0.47	Spain	0.28	0.64	−0.09	0.22	0.03
Belgium	0.20	0.29	0.13	0.03	0.12	Norway	−0.87	−0.67	−1.06	0.08	−0.003
Canada	0.43	0.68	0.29	0.10	0.58	Panama	−0.16	0.04	−0.41	0.13	−0.14
Chile	−0.66	−0.22	−1.11	0.22	0.01	Poland	−0.50	−0.24	−0.80	0.19	0.13
Denmark	0.34	0.48	0.15	0.08	−0.35	Portugal	−0.67	0.10	−1.77	0.58	−0.09
France	−0.08	0.02	−0.19	0.05	−0.09	South Korea	−0.35	−0.07	−0.68	0.17	−0.41
Germany	0.00	0.21	−0.21	0.12	0.11	Sweden	0.16	0.50	−0.15	0.16	0.64
Greece	−0.35	0.02	−0.93	0.25	−0.66	Switzerland	−0.05	0.09	−0.16	0.06	0.27
Israel	−0.27	0.08	−0.64	0.17	−0.09	UK	0.01	0.32	−0.20	0.13	0.77
Italy	−0.24	−0.08	−0.64	0.14	−1.04	USA	0.51	0.61	0.35	0.06	−0.76
	Middle-Income Countries										
Country	Mean	Max.	Min.	Std. Dev.	Skew.	Country	Mean	Max.	Min.	Std. Dev.	Skew.
Albania	0.01	0.26	−0.58	0.21	−1.21	Venezuela	−0.32	0.14	−0.77	0.29	−0.02
Brazil	−0.72	−0.20	−1.10	0.24	−0.87	Angola	0.50	0.87	0.11	0.20	0.16
China	0.32	0.46	0.14	0.07	0.63	Bolivia	0.34	0.77	−0.10	0.27	−0.18
Colombia	0.42	0.53	0.26	0.06	−0.14	Cameroon	0.29	0.67	0.16	0.09	0.21
Costa Rica	−0.41	−0.10	−0.71	0.19	−0.06	Congo	−0.70	−0.23	−0.97	0.21	−0.24
Cuba	−0.10	0.54	−0.53	0.33	0.19	Cote d'Ivoire	0.02	0.50	−0.43	0.28	0.19
Dominican Rep.	0.12	0.37	−0.13	0.15	0.47	El Salvador	−0.51	−0.39	−0.68	0.06	0.15
Fiji	−0.66	−0.45	−0.89	0.11	−0.15	Ghana	−0.92	−0.81	−1.05	0.06	−0.19
Guyana	0.29	0.48	0.04	0.11	0.08	India	0.69	0.93	0.29	0.17	0.63
Jordan	−0.34	0.07	−0.68	0.27	−0.86	Indonesia	0.13	0.62	−0.11	0.23	1.10
Lebanon	0.10	0.45	−0.19	0.21	−0.07	Kenya	−0.47	−0.32	−0.73	0.09	−0.09
Malaysia	−0.34	−0.13	−0.54	0.08	−0.16	Myanmar	0.64	1.00	0.21	0.26	0.82
Mexico	−0.25	0.006	−0.49	0.15	1.24	Nicaragua	−0.63	−0.29	−0.86	0.14	0.27
Paraguay	0.14	0.57	−0.28	0.17	−0.86	Nigeria	0.00	0.50	−0.77	0.37	−0.19
Peru	−0.29	−0.06	−0.56	0.13	1.06	Pakistan	−0.20	0.21	−0.61	0.29	−0.002
Romania	0.24	0.54	−0.08	0.18	−0.05	Philippines	−0.20	0.06	−0.62	0.20	−1.07
St. Lucia	−0.84	−0.60	−1.03	0.09	−0.42	Sri Lanka	0.26	0.45	0.05	0.12	0.15
Thailand	−0.35	−0.02	−0.54	0.10	0.07	Tunisia	0.44	0.71	0.08	0.15	−0.54
Turkey	−0.16	0.18	−0.74	0.22	−0.08	Viet Nam	−0.71	−0.02	−1.01	0.26	1.11

several implications. First, exhibiting the unit root process of ecological footprint per capita shows that divergence is valid rather than stochastic convergence; hence, any shocks on ecological footprint per capita may have a long-lasting effect, and ecological footprint per capita may not revert back to its steady-state path without policy intervention after any possible shocks occur (Ozcan, Ulucak, & Dogan, 2019). Second, it may be emphasized that all countries, surpassing the threshold of per capita income as it is envisaged in the EKC hypothesis, should abandon the traditional pollutant resources such as fossil fuel energy consumption, the economic development model based on more resource use and devastating policies such as deforestation, oil and mineral exploration in natural habitats; hereby, environmental degradation may be reduced. Third, despite the partial success in some sample such as OECD as can be seen in former literature, having a divergent pattern of environmental degradation may point that out expected impacts of mitigation commitments and plans, envisaged in international agreements such as the Kyoto Protocol, MDGs, SDGs, Paris Agreement, have not been occurred yet. Fourth, it is known that the future steady-state path of ecological footprint per capita cannot be forecasted by using former data in case of exhibiting the unit root process. It means that climate projections and the future of global warming cannot be easily estimated. Fifth, having a divergent pattern of ecological footprint per capita may trigger the transfer of pollutant production sectors from countries with a high footprint to countries with a low footprint complying with the pollution haven hypothesis (Destek & Okumus, 2019), and the existence of convergent clubs establish collaboration opportunity for countries on environmental issues

Therefore; we propose that international treaties on environmental issues should be reviewed and raised their operability through participative and inclusive management mechanisms, which in turn ease the proper implementation of contract provisions. Moreover, international organizations, which have the power of sanction, might be established to ensure efficient implementation of treaties. Thus, violating the articles of agreements for no cost may be prevented. International organizations should closely monitor the commitment of countries on the environment to ensure the sustainability of efforts against climate change. The monitoring mechanisms may allow tracking the transported pollutant industries from high-polluter countries to low-polluter ones, and this may contribute to reducing environmental pollution not only on statistical tables of the high-polluter country but also in total actual values. Thus, the expected effects of those treaties may occur.

Furthermore, governments should take a proactive role to diminish environmental degradation, and measures, taken to reduce environmental pollution, would be efficient because of a divergent pattern of environmental degradation. At this point instrument of taxation and environmental laws might be forceful on limiting the use of pollutant production technologies such as factories without filters. Moreover, policy-makers should subsidize eco-friendly resources and technologies, such as hydrogen or electric-powered vehicles, installation of individual eco-friendly power generation systems (i.e. solar, wind) to ease the use of high-cost of clean technologies. To extend the utilization of clean technologies not only in high-income countries but also in middle- and low-income countries, international credit and grant funds should be constituted to make clean technologies affordable for all income groups. Although some technology transfer mechanisms and financial flows were planned in the Paris Agreement, however, the fate of the treaty became unclear by the withdrawal of the U.S. which is one of the most emitter countries. Therefore, establishing new effective mechanisms or carrying Paris Agreements' articles into effect should be done. On the one hand, governments should support both private and public R&D

Table A2
Descriptive statistics.

Country	Low-Income Countries Mean	Max.	Min.	Std. Dev.	Skew.	Country	Mean	Max.	Min.	Std. Dev.	Skew.
Afghanistan	−0.37	−0.09	−0.66	0.16	−0.02	Mozambique	−0.39	−0.11	−0.54	0.08	0.72
Benin	−0.06	0.24	−0.26	0.12	0.79	Nepal	−0.39	−0.03	−0.62	0.13	0.80
Burkina Faso	0.002	0.14	−0.18	0.08	−0.22	Niger	0.29	0.48	0.08	0.08	−0.26
Burundi	−0.23	−0.06	−0.55	0.10	−1.65	Rwanda	0.39	0.85	−0.25	0.34	−0.37
Central African Rep.	0.10	0.27	−0.20	0.13	−0.73	Sierra Leone	−0.38	−0.20	−0.56	0.08	0.01
Chad	0.28	0.49	0.12	0.09	0.64	Somalia	−0.08	0.11	−0.32	0.10	0.65
Congo DR	−0.30	−0.15	−0.46	0.07	0.28	North Korea	0.14	0.63	−0.17	0.23	−0.27
Gambia	−0.08	0.13	−0.34	0.10	−0.38	Syria	0.18	0.68	−0.55	0.32	−0.76
Guinea	0.15	0.34	−0.05	0.08	−0.19	Togo	−0.11	0.08	−0.25	0.08	0.59
Haiti	−0.72	−0.47	−0.83	0.08	1.04	Uganda	0.28	0.45	−0.04	0.11	−0.98
Laos	0.09	0.54	−0.08	0.13	1.69	Yemen	−0.39	−0.08	−0.62	0.14	0.46
Madagascar	0.12	0.41	−0.17	0.18	−0.17	Zimbabwe	0.14	0.30	−0.05	0.09	−0.49
Mali	0.11	0.36	−0.20	0.14	−0.09						

activities on the development of renewable fuels, on the other hand, governments should halt to subsidize fossil fuel exploration. If it is considered that governments give a huge amount of incentives to fossil fuel exploration (Santos, 2017), promoting clean energy technologies may not produce an effect as expected without halting subsidies of fossil fuel exploration. Further to that, environmental pollution does not only result from industrial activities but also result from individual activities such as overfishing, overgrazing, excessive lumbering, unregulated urbanization. Therefore, the regulatory role of the government is crucial to limit those anthropogenic activities. Last, a common theme for many of the convergent clubs may be the result of either the environmental condition or the economic structure of countries (Payne & Apergis, 2020). The existence of convergent clubs and merging possibility among adjacent clubs may create the possibility of extending the collaboration on environmental issues mentioned above. Therefore, policy-makers should consider seeking international collaboration possibilities, and collective action against environmental degradation will support the achieving environmental aims of international treaties and SDGs.

CRediT authorship contribution statement

Sinan Erdogan: Conceptualization, Writing - original draft, Formal analysis. **Ilyas Okumus:** Investigation, Writing - original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

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