

## Article

# Time-Varying Convergences of Environmental Footprint Levels between European Countries

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**Abstract:** This study proposes the time-varying nonlinear panel unit root test to investigate the convergence of ecological footprints between the EU and candidate countries. Sixteen European countries (such as Albania, Austria, Belgium, Denmark, France, Germany, Greece, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Spain, Sweden and Turkey) and analysis periods are selected according to data availability. This study proposes a cross-sectional Panel KSS with Fourier to test the convergence of the ecological footprints. Then, we combine this methodology with the rolling window method to take into account the time-varying stationarity of series. This study evaluated sub-components of ecological footprints separately and provided more comprehensive findings for the ecological footprint. According to empirical findings, this study proves that convergence or divergence does not show continuity over time. On the other side, this study points out the presence of divergence draws attention when considering the properties of the sub-components in general. As a result, this study shows that international policies by EU countries are generally accepted as successful to reduce ecological footprint, but these are not sufficient as expected. In this point, it is suggested to keep national policies to support international policies in the long term.

**Keywords:** environmental footprint; convergence; nonlinear unit root test; rolling window; time-varying



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## 1. Introduction

Human activities have caused negative and almost permanent impacts on the natural environment. These impacts bring along the extinction risk of natural capital due to consumption of natural resources and over wasting in the long term. Considering that approximately 23.92% of our planet's surface—12.2 billion global hectares by 2019—[1] is usable for humanity's needs and waste disposal, it becomes more important to evaluate the human impact on this amount. Regarding this point, it can be said that understanding the human impact on the natural environment can guide policy makers to decide key areas for sustainable development. The ecological footprint is one of the most highly inclusive indicators that enables the effects of resource utilization by humans [2]. Natural resource utilization by humans can be monitored through this indicator [3]. In other words, it indicates the demand for natural resources. The ecological footprint, which presents a unified index of the pressure on the environment, also guides policy makers for the sustainability of resource consumption and the global distribution of natural resources [4].

On the other side, the rising global trade causes the environmental impacts of countries to be carried beyond their national borders. Thus, environmental pressures have little to do with the point of consumption. The Ecological Footprint charges the task of reallocating environmental pressures to consumers [5]. It evaluates the ecological impact of a country, not only on its borders, but also on the whole world. Especially, developed countries meet a considerable part of their consumption levels from the rest of the world and so the most of their environmental impacts spread to the rest of the world. Therefore, the ecological footprint becomes a more effective indicator when comparing other environmental indicators. While indicators such as greenhouse gas emissions provide only local or regional values, the ecological footprint figures out all of the impacts caused by the consumption of goods and services [6]. One of the important strengths of the ecological footprint indicator is that it addresses not only the environmental impact caused by gas emissions, but also the human impact on forest, farmland, fisheries, etc. When policy makers focus on only climate change, it causes them to ignore other environmental damages [7]. However, it is necessary to consider making more comprehensive sustainable policies due to the rising demand of natural resources, although these sources are so limited in the long term. At this point, the ecological footprint can contribute to help policy makers to make sufficient sustainable policies to prevent and reduce negative impacts of human activities.

This study focuses on testing convergence of the ecological footprint for EU countries. The EU has been a pioneer in the field of environmental policies since the 70's. For example, the EU has an environmental *acquis* consisting of 500 regulations and its decisions [8]. Since decades ago, environmental policies, strategies and plans have become increasingly widespread in the European region. European countries have transformed their environmental policies into a common policy for the EU. However, the EU still has a long way to go to achieve its targets of climate change and energy in the context of the 2030 Sustainable Development Goals [9]. The European Environment Agency [9] points out that the EU should take action to reduce its ecological footprint. The World Wildlife Fund (WWF) Report 2019 states that EU countries, which have 7% of the World population, has consumed 20% of natural resources. At the same time, this report emphasizes that there should be 2.8 planets if everybody lives like a European citizen in the World. Accordingly, it is thought to be an important issue to evaluate ecological footprint for EU countries [10].

This study employs the Fourier KSS test to determine the ecological footprint based on the stochastic convergence approach. This test has the ability to solve the problem of non-linearity and cross-sectional dependency. On the other side, this procedure allows structural breaks with Fourier functions. The Fourier Smooth transition method has some advantages compared to traditional unit root tests. The existing literature on unit root tests assumes only one or several structural breaks in the series. Although more than two structural breaks are possible, it is difficult to obtain asymptotic distributions and critical values for different break combinations. On the other hand, to select the number of breaks and its locations are important in unit root tests. However, previous tests do not have clear information about the number of structural breaks and break times [11,12]. The Fourier method does not require determining the number and type of structural breaks [13]. In our study, different environmental policy shocks in different periods can cause more than one break. Therefore, traditional unit root tests cannot give consistent results. Thus, the Fourier method can give more effective results. On the other hand, the effects of policy shocks may occur over time. The responses of economic units to a particular shock policy emerge gradually [14]. For this reason, unit root tests that allow breaks with a smooth transition process are more suitable [11].

The main contribution of this study to the related literature can be examined as below:

- In reviewing the pioneer empirical literature, it is seen that studies investigating whether the policies are efficient to prevent environmental pollution by linear models [15–19]. However, it is known that macroeconomic indicators have nonlinear features inherently. On the other side, in the analysis period, there can probably be structural breaks in the series. It is seen that the literature gives limited studies that

follow nonlinearity and structural breaks. As a main contribution, this study focuses on nonlinearity and structural breaks together.

- It is seen that the studies testing the convergence of environmental pollution including ecological footprint are so limited in the literature. In addition, current studies generally focus on carbon footprint. Another contribution of this study is that ecological footprints have been taken into consideration while testing the convergence of the environmental burden.
- On the other side, it is observed that the studies examining the convergence focus on the whole period. The most important contribution of this study is to analyze the effect of time-varying by using the rolling window method. In this context, this study can test the convergence for each sub-period. As we know, this study will be the first one in the literature that considers the nonlinearity to investigate time-varying convergence. As a result, it is thought we should guide future studies by giving new empirical evidence.

The main purpose of the study is to ensure that the ecological footprint and its components are taken into account when implementing environmental policies. On the other hand, the study wishes to guide politicians about the effects of policies implemented in different periods. Thus, policy makers will determine which policies are more effective. It will also be a guide for new policies to be implemented.

## 2. Literature Review

There have been several studies on the ecological footprint in the literature. However, studies using econometric models or tests to investigate the ecological footprint are very limited. In this context, we aim to provide new evidence for an ecological footprint by using up-to-date econometrics models for the literature. As a sample of studies using econometric models, it is observed that some researchers focus on the effects of shock policies by testing the stochastic properties of the series. For example, Ulucak and Lin [15] analyzed the ecological footprint of the USA and the stochastic properties of its sub-components in the period 1961–2013 by using traditional unit root tests (ADF, PP, DF-GLS, KPSS and NP) and Fourier unit root tests (Fourier ADF, Fourier LM and Fourier GLS). They determined that the ecological footprint indicator was not stationary.

In addition, the study also showed that carbon footprint, grazing land footprint, forest footprint, built-up land footprint and fishing footprint were all non-stationary excepting cropland footprint. Yilanci et al. [16] investigated ecological footprint and its subcomponents (cropland footprint, grazing land footprint, fishing grounds footprint, forest land footprint, built-up land footprint and carbon footprint) for 25 OECD countries in the period 1961–2013. They used an alternative stationarity test (developed by Bahmani-Oskooee et al. [17]) and they proved that the fishing footprint was not stationary. Ozcan et al. [20] investigated ecological footprint for 113 countries that including “high income countries, upper middle-income countries, lower middle-income countries and low income countries” by using Panel KSS, Fourier KSS panel unit root test and SPSM procedure. The study showed that empirical findings can be changed due to income level of countries. In this point, Ozcan et al. [20] indicated that ecological footprint had a stationary level for high-income countries (all of them), some of the low-income and upper-middle income countries, except for the lower-middle income countries. Solarin and Bello [18] tested the ecological footprint for 128 countries by using Harvey et al. [19] model. They found ecological footprint had non-stationary level for 96 countries.

On the other side, there are some studies that investigate the convergence of the series and the effects of policy shocks based on the stochastic approach. It can be said that the convergence approach can provide better evidence for testing environmental indicators. In general, factors that affect environmental indicators are changed slowly over time, that is, a long memory process. Accordingly, the literature can give different findings for ecological indicators. The fact that the series is not stationary indicates that the effects of the shocks are permanent. as is the presence of long memory process. In other words, the average

level is only possible in the long run. On the other hand, when the series is not stationary, there is convergence in the long run [21,22].

Actually, the convergence is based on the hypothesis that the gap of the development levels between countries will be closer over time and lower income countries catch up with high income countries [23]. The assumption that countries are initially in imbalance supports this capture [24]. In this context, the convergence occurs when higher income countries decrease under the middle income and lower income countries increase. In addition, the convergence is related with the stationary properties of the series. The absence of the unit root of the series means convergence. Finally, the fact that high income country is as rich as the others at the end, that is, the decrease in the cross-section distribution over time points to convergence [25].

There are three main convergence approaches, beta convergence, sigma convergence and stochastic convergence, in the literature [26]. Beta convergence implies that poor countries will grow faster than rich countries, and the difference between countries in the development will eventually disappear. If there is a negative relationship between per capita growth rate and initial income level, there is a beta convergence in the cross section economy [27]. Beta convergence based on the Solow growth model that is also known as the catch-up effect [21]. When the distribution of per capita real income among national economies tends to decrease, there is a sigma convergence [27]. Stochastic convergence considers convergence in the context of the time series perspective. Stochastic convergence refers to the level where the series are stationary around a deterministic trend [28]. Shocks are temporary in series that converge in a stochastic sense, and series are stationary over time. For series that have unit root shocks are permanent and there is no convergence [29]. Beta and sigma convergences require each country to converge to the same stationary level. In stochastic convergence, income inequality between countries follows an average stationary process. That is, shocks only cause temporary deviations [30]. Stochastic convergence does not require each country to converge to the same stationary level [30] and we prefer to follow the stochastic convergence approach in this study.

Studies investigating the relationship between convergence and carbon emissions by testing the Environmental Kuznets Curve hypothesis provide new literature [29,31–33]. The convergence of carbon dioxide emissions can give practical implications for international policy makers. However, the ecological footprint is a broader indicator of environmental policy. For this reason, this study tests the stochastic convergence of the ecological footprints. We consider that the ecological footprint variable converges stochastically and reveals a number of important consequences for policy makers. At this point, this study focuses on testing the consequences of environmental convergence for European countries. The convergence of the environmental indicators of the countries is seen as sharing the fair right to pollute countries. However, countries have different natural resources and there is a transfer of resources between them.

The stationarity of the series gives information about whether the shocks in the series are permanent or temporary. The fact that the series is stationary means that the shocks are temporary. Hence, the disappearance of the shock effect means that the series of each country converges stochastically to the sample mean. The fact that the series is not stationary means that the shocks in the series are permanent, that is, the series deviates from the sample mean [21,34]. When the series is not stationary, policies affecting the ecological footprint will have long-term and permanent effects [15]. In this case, the stationarity of the series has important effects on policy makers' policy implementation. Shock policies implemented in the presence of convergence will be ineffective. At the same time, the convergence of countries' ecological footprints necessitates international policies in this regard [4]. The lack of convergence shows that the policies are permanent and international policies are successful. There are some pioneer studies for the link between the convergence and ecological footprint. Solarin [4] tested the stochastic convergence of the ecological footprint data of 27 OECD countries between 1961 and 2013 by using LM and RALS-LM unit root tests. It was observed in the study that the ecological footprint and

carbon footprint are stationary for 25 countries. They kept beta and sigma convergences in the study. In beta convergence, 13 out of 25 countries that converge stochastically have converged. In the carbon footprint, there is a convergence in 15 countries out of 25 stochastically converging countries. In Sigma convergence, the carbon footprint and ecological footprint have reached results that support the convergence. Not all countries meet the conditions for convergence. However, converging countries can act jointly on environmental policies. Erdogan and Okumus [35] tested the ecological footprint of countries of different income groups for the years 1961–2016 with stochastic and club convergence. In the study, the presence of cross-sectional dependency between country groups was determined with the LM test. Panel statistics of FPKPSS for high, middle and low-income countries show that the per capita ecological footprint shows a non-stationary process. Country-specific stationarities were also tested with FKPSS method in the study. In this context, six of 26 high-income countries and eight of 38 middle-income countries have a stationary ecological footprint. Eight of the 25 low-income countries are stationary. In the study in which club convergence was also tested, it was concluded that there were convergence clubs among different income groups. Bilgili et al. [36], tested the stationarity for 15 countries which were selected from Asian, African, American and European continents. They confirmed that there was no stationarity for the Asian panel, which showed that convergence was not valid in the Asian sample. There was a stationary under structural break in Africa, America and Europe. Bilgili and Ulucak [37] tested the ecological footprint for G20 countries using stochastic and club convergence approaches. They confirmed stochastic convergence and determined two convergence clubs. With the club convergence approach developed by Phillips and Sul [38], Solarin et al. [39] indicated club convergence in ecological footprints and its subcomponents for 92 countries. Ulucak and Apergis [40] determined the existence of club convergence for 20 European countries, and Haider and Akram [41] confirmed the club convergence for 77 countries.

### 3. Materials and Methods

#### 3.1. Data

In this study, we utilize the technique of rolling nonlinear unit root tests with the Fourier function to obtain time-varying estimates of the convergence of ecological footprints within the EU and candidate countries. We selected 16 European countries (Albania, Austria, Belgium, Denmark, France, Germany, Greece, Italy, Luxembourg, Netherlands, Poland, Portugal, Romania, Spain, Sweden and Turkey) according to data availability. Thus, it is analyzed whether the environmental burdens of European countries aim similar environmental goals converge for the period 1961–2016. We use five different indicators of ecological footprints (Cropland, Grazing land, Fishing, Forest and Total Footprint). These footprints indicators are the measures of ecological footprints of consumption in global hectares (gha (see the Global Footprint Network website for a detailed explanation. Global hectares are the accounting unit for the Ecological Footprint and bio-capacity accounts. These productivity weighted biologically productive hectares allow researchers to report both the bio-capacity of the earth or a region and the demand on bio-capacity (the Ecological Footprint). A global hectare is a biologically productive hectare with world average biological productivity for a given year.)) divided by population (per capita). Global Footprint Network currently determines that the ecological footprint calculates how much area (lands and seas) we used and then how much of them left in the World. However, the ecological footprint mostly refers to the ecological footprint of consumption. In detailed, the ecological footprint can show country's or economies' footprint including lands and seas. According to the Global Network Footprint, the main sub-components of ecological footprint can be classified as cropland footprint, fishing footprint, forest footprint and grazing land footprint. Total footprint is the sum of all footprints. In Table 1 can be seen the descriptive statistics of ecological footprints [1].

**Table 1.** Descriptive Statistics.

Variables	Explanations	Obs	Mean	Std. Dev.	Min	Max
cropland	Cropland Footprint	896	0.939	0.208	0.367	1.633
fishing	Fishing Footprint	896	0.212	0.309	0.000	2.199
forest	Forest Footprint	896	0.586	0.420	0.008	3.271
grazing	Grazing Land Footprint	896	0.306	0.169	0.025	0.925
total	Total Footprint	896	5.465	2.773	1.091	17.723

In Table 1, the mean of cropland, fishing, forest, grazing land and total ecological footprint are 0.94, 0.21, 0.58, 0.30 and 5.47, respectively. The minimum value of cropland, fishing, forest, grazing land and total ecological footprint are 0.36, 0.00, 0.00, 0.02 and 1.09, respectively. Furthermore, the maximum value of cropland, fishing, forest, grazing land and total ecological footprint are 1.63, 2.19, 3.27, 0.92 and 17.7, respectively.

### 3.2. Methodology

Macroeconomic variables can have nonlinear properties by their natures. On the other hand, conventional tests such as ADF, PP or KPSS cannot capture the mean-reverting properties [42]. Therefore, in our study, the Panel KSS [43] test proposed by Ucar and Omay [44], which takes into account the nonlinear characteristics, is preferred. This test is also very useful in capturing the mean reversion of series.

Let us assume that our series has a panel exponential smooth transition autoregressive process of order one (PESTAR (1)).

$$\Delta y_{i,t} = \mu_i + \alpha_i y_{i,t-1} + \gamma_i y_{i,t-1} \left[ 1 - \exp\left(-\theta_i y_{i,t-d}^2\right) \right] + \varepsilon_{i,t} \quad (1)$$

where,  $d$  is the delay parameter  $d \geq 1$ .  $\theta_i$  shows the speed of mean reversion for all  $i$   $\theta_i > 0$ . Time ( $t = 1, 2, \dots, T$ ) and the cross-section units ( $i = 1, 2, \dots, N$ ). We follow Ucar and Omay [44] and set  $\alpha_i = 0$  for all  $i$  ( $y_{i,t}$  has a unit root) and  $d = 1$  ( $y_{i,t}$  follows PESTAR process).

$$\Delta y_{i,t} = \mu_i + \gamma_i y_{i,t-1} \left[ 1 - \exp\left(-\theta_i y_{i,t-1}^2\right) \right] + \varepsilon_{i,t} \quad (2)$$

In Equation (2), we test the null hypothesis  $\theta_i = 1$  for all  $i$  against  $\theta_i > 0$  for some  $i$  under the alternative hypothesis for Panel KSS test. Thus, we can capture nonlinear properties. However, it cannot be directly tested  $\theta_i$  because  $\gamma_i$  is not identified under the null [44]. Kapetanios, et al. [43] used a Taylor's first-order approximation of the ESTAR process for solving this problem. Thus, we can obtain Equation (3).

$$\Delta y_{i,t} = \mu_i + \alpha_i y_{i,t-1}^3 + \sum_{j=1}^k \beta_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t} \quad (3)$$

where: the null hypothesis is  $\alpha_i = 0$ . for all  $i$  with linear non-stationarity and alternative hypothesis is  $\alpha_i \neq 0$  for some  $i$  with nonlinear stationarity.

An important problem in panel unit root tests is heterogeneity. In Equation (3), this problem is solved with the fixed effect model. However, another problem is the cross-section dependency. In the literature, it is seen that the cross-sectional averages (CA) method is widely used.

Another important issue is that the IPS test is a first-generation test (making the assumption of cross section independence).

Pesaran [45] proposed the Cross-Sectionally Augmented IPS (CIPS) test, which considers the cross-sectional dependency by extending the IPS test with the CA method. This test extends the standard ADF regression with first differences and lagged values of cross-

sections to panel data and can be used in both  $T > N$  and  $N > T$ . The average of the CADF test statistics of each cross-sectional unit (countries) gives the CIPS (Cross-Sectionally Augmented IPS) test statistics [45].

KSS test is based on IPS test. Thus, in our study, we ensure that cross-section dependency is taken into account by expanding the KSS test with CA method like CIPS methodology. Cross-section dependency and nonlinear properties are taken into consideration with the CA-KSS test. In Equation (4), the KSS test with CA method can be seen.

$$\Delta y_{i,t} = \mu_i + \alpha_i y_{i,t-1}^3 + \delta_{i,t} \bar{y}_{i,t-1} + \varphi_{i,t} \Delta \bar{y}_{i,t} + \sum_{j=1}^k \beta_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t} \quad (4)$$

where  $\bar{y}_{i,t-1}$  represents the mean of  $y_{i,t-1}$ ,  $\Delta \bar{y}_{i,t}$  represents the mean of  $\Delta y_{i,t-1}$ ,  $k$  is the maximum number of lagged terms  $\Delta y_{i,t-1}$ ,  $\delta_{i,t}$  is a parameter estimated for averages of each lagged term and  $\varphi_{i,j}$  is a parameter estimated for averages of each first-differenced lagged term.  $\varepsilon_{i,t}$  is the contemporaneous error term and is assumed independent and identically distributed with zero mean and finite variance.

If the basic hypothesis cannot be rejected, it is concluded that shocks related to footprint levels have a permanent effect. In other words, if the series have a unit root ( $\alpha_i = 0$ , for all  $i$ , linear non-stationarity), it is decided that the effects of shocks like tax rates or similar regulations are permanent. In this case, it is seen that the footprint levels of the countries are diverged. On the other hand, if the series is stationary ( $\alpha_i < 0$ , for some  $i$ , nonlinear stationarity), it is concluded that the shocks are temporary. In this case, it is decided that policy implementations do not have an impact on footprint levels. In this case, it is seen that the footprint levels of the countries converge.

### 3.2.1. The Flexible Fourier Form Cross-Sectional KSS Unit Root Test

Becker et al. [46,47], using the Fourier approach, proposed a test process in which no preliminary information on the number, location and form of structural breaks is required. Enders and Lee [48] apply this test procedure to Dickey Fuller type regression. Lee et al. [49] adapted this method to CIPS test. Thus, they develop a panel unit root test under structural breaks for ADF-based cross-sectional IPS test. On the other hand, Nazlıoğlu and Karul [50], following Becker et al. [47], extended the KPSS test with the Fourier function. As a result, authors show that if the error terms are i.i.d, the test shows good size and power properties even in small samples and if the error terms are serially correlated, the test has reasonable size and high power.

Christopoulos and Leon-Ledesma [51] proposed a new test considering nonlinearity. In this test procedure, the nonlinear KSS test is combined with the Fourier function. Thus, authors develop a panel unit root test that allows smooth/gradual transitions in the deterministic term on the one hand and nonlinearity on the other.

The Fourier terms are formed as follows:  $\varphi_1 \sin\left(\frac{2\pi k * t}{T}\right) + \varphi_2 \cos\left(\frac{2\pi k * t}{T}\right)$ . Here  $\varphi_1$  and  $\varphi_2$  denote the amplitude and displacement of the structural change, respectively and  $k$  denotes Fourier frequency.

In the literature, it is seen that cross-section dependency, nonlinearity or both are generally ignored. In this context, we propose a test that considers nonlinearity and cross-sectional dependence and structural breaks with smooth/gradual transitions in the deterministic term. Since there is no critical value for the panel KSS test, we obtained the critical values and probability values ourselves with the bootstrap method in our study.

In the literature, it is seen that the convergence of ecological indicators is generally investigated with methods that do not take into account structural breaks. The main problem is that unit root analysis tends to reject the basic hypothesis if structural breaks are not taken into account and leads to spurious results. Another problem here is that the data and form of the structural breaks must be known a priori. However, in most cases, a priori information on the date and form of structural breaks is not available. In this study, we considered structural breaks with the Fourier approach. In this approach, a priori

knowledge of the form and date of structural breaks is not needed. Thus, an important contribution of our this is that it takes into account structural breaks with the Fourier approach. The main reason why this method is suitable for the subject of this study is that there are many sub-periods (windows) and there may be different forms and dates of structural breaks for each window. In other words, each window has different period and breaks can occur in this period range. If there is a break, this approach allows the selection of the appropriate form. Within the scope of our study, firstly, the existence of structural breaks for five different frequencies (Fourier form) are investigated for structural breaks. In case of structural breaks, the most suitable frequency in each window is selected according to the residual sum of squares. On the other hand, the analysis method we propose within the scope of this study provides evidence regarding the change of effectiveness of policy strategies over time with the rolling window approach. In this context, the stationarity for each window is considered with a separate statistical value. In this way, evidence of the effectiveness of the policies can be presented on a periodic basis. For this evidence, the possible effects of policy changes and policy recommendations are presented in the conclusion section.

As a result, unlike the literature, the method we propose can capture the change in policy strategies, present policy changes separately for each window, and take into account structural breaks, heterogeneity, cross-sectional dependency and nonlinearity features due to the nature of policy strategies. Thus, this method is a very suitable for the subject of analysis.

### 3.2.2. Rolling Window

We use the rolling unit root test to investigate the degree of convergence during different sub-sample periods of the full sample using the cross-sectional KSS test with Fourier functions. Using rolling window approach, we analyse the time-varying stationarities of the series.

One of the moving window procedures frequently considered is rolling window. The key issue here is to choose an optimum window for KSS regression. We compute the KSS test in rolling subsamples for  $t = \tau - 1 + h, \tau - 1, \tau = h, h + 1, \dots, T$ . Here  $h$  shows the fixed size of subsamples. Rolling KSS test statistics are calculated over a rolling window of fixed size for all estimations. At each step of the unit root test procedure, the window's start and end point are incremented one observation at a time.

The window size selection in rolling window estimation is not rigid [52]. For Example, Pesaran and Timmermann [53] select optimum window size according to root mean square error. In other words, in the literature there is no statistical procedure for the selection of the optimum window size. Thus, the selection of the windows size is arbitrary [54]. In many others, it is seen that the authors chose among different fixed sub-periods according to parameters such as robustness, frequency, etc. we follow Caspi [55] article for selecting of the window length and we decided that the optimum window length is 14 years.

## 4. Results

In our study, we present the Panel KSS test results for the intercept model and graphically for the intercept and trend model. In our estimation model, the appropriate frequency for Fourier functions is chosen for the value where the residual sum of squares is minimum. In addition, there are no breaks for some sub-periods. For this reason, Fourier terms are included in the model for the periods when structural breaks are available and the result of the appropriate frequency is presented in the graphics. Fourier terms are not included in the model and cross-sectional KSS test results are presented in the sub-periods when there are no structural breaks. Figure 1 shows the results of the intercept model.



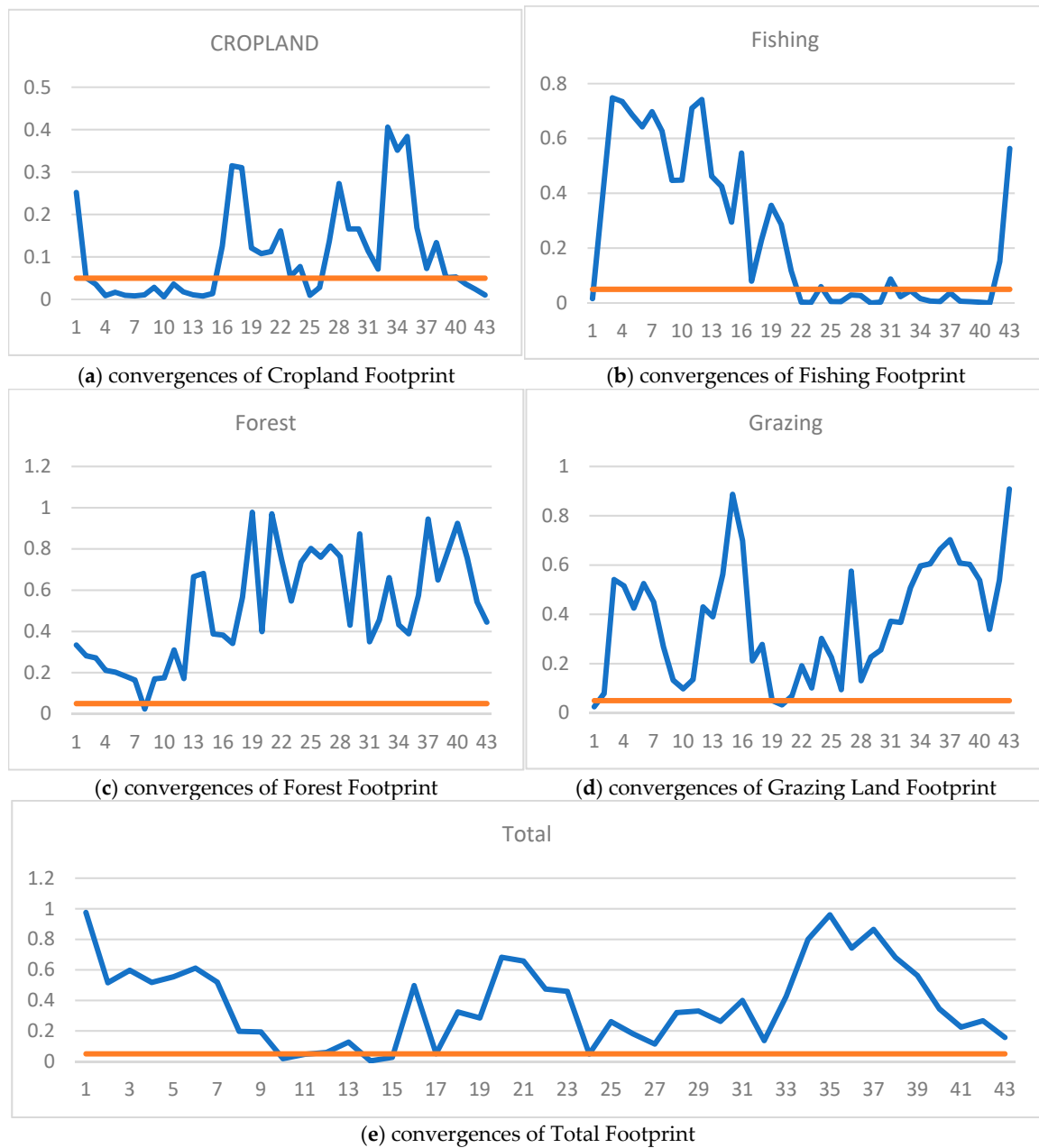


Figure 1. Intercept Model Results.

In Figure 1 five different panels for footprints can be seen. Panel a shows the convergences of Cropland Footprint, Panel b shows convergences of Fishing Footprint, Panel c shows the convergences of Forest Footprint, Panel d shows the convergences of Grazing Land Footprint and finally and Panel e shows the convergences of Total Footprint. In the analysis according to minimum window size, there are 43 periods in the horizontal axis. Blue lines show the unit root test statistics for each rolling windows. Test statistics are obtained for intercept and intercept and trend models. In Figure 1, these test statistics are obtained according to intercept models.

Red horizontal lines in figures show the 5% significance level. Thus, in the figures, time varying convergences can be analyzed with blue and red lines. When the test statistics are below this value, it is decided that the series is stationary in the relevant period. In this case, the policy strategies are ineffective and footprint values converge for the period. Statistical values above the horizontal line show that the series is nonstationary. In this case, the policy strategy becomes effective and footprint values diverge.

According to test results, the Cropland series becomes stationary and converges after 1963, 1985 and 2001. Since these dates, policy strategies lose their effectiveness. Fishing series become stationary and converge after 1961 and 1980. However, these series have been nonstationary since 2002. Policies implemented after these dates become effective. The Forest series are stationary after 1968 and the Grazing series are stationary after 1963, 1985 and 2001. Finally, the Total series are stationary after 1970, 1974 and 1984. After these dates, the series converges and policy strategies lose their effectiveness.

All footprint series are nonstationary for most of the periods. On the other hand, in some periods, series become stationary. This change in the stationarity of the series indicates the periods when policy implementations became ineffective.

In Figure 2, five different panel for footprints can be seen; Panel a: Cropland, Panel b: Fishing Footprint, Panel c: Forest Footprint, Panel d: Grazing Land Footprint and Panel e: Total Footprint. In the analysis according to minimum window size, there are 43 periods. Blue lines show the unit root test statistics for each rolling windows. In Figure 1, test statistics are obtained for intercept model, in Figure 2, test statistics are obtained for intercept and trend models. Similar to Figure 1, red lines in figures show the 5% significance level. Thus, in the figures, time varying convergences can be analyzed with blue and red lines.

According to the test results in Figure 2, it can be seen that the results from the intercept model and from the intercept and trend model are very similar. All footprint series are nonstationary for most of the periods. On the other hand, in some periods, series become stationary. The Cropland series becomes stationary and converges after 1963, 1985 and 2001. The Fishing series becomes stationary and converges after 1961 and 1980. However, these series have been nonstationary since 2002. The Forest series are stationary after 1968 and the Grazing series are stationary after 1961 and 1980. Finally, the Total series are stationary after 1970, 1974, 1977 and 1984. After these dates, the series converges and stationarity changes. This change in the stationarity of the series indicates the periods when policy implementations became ineffective.

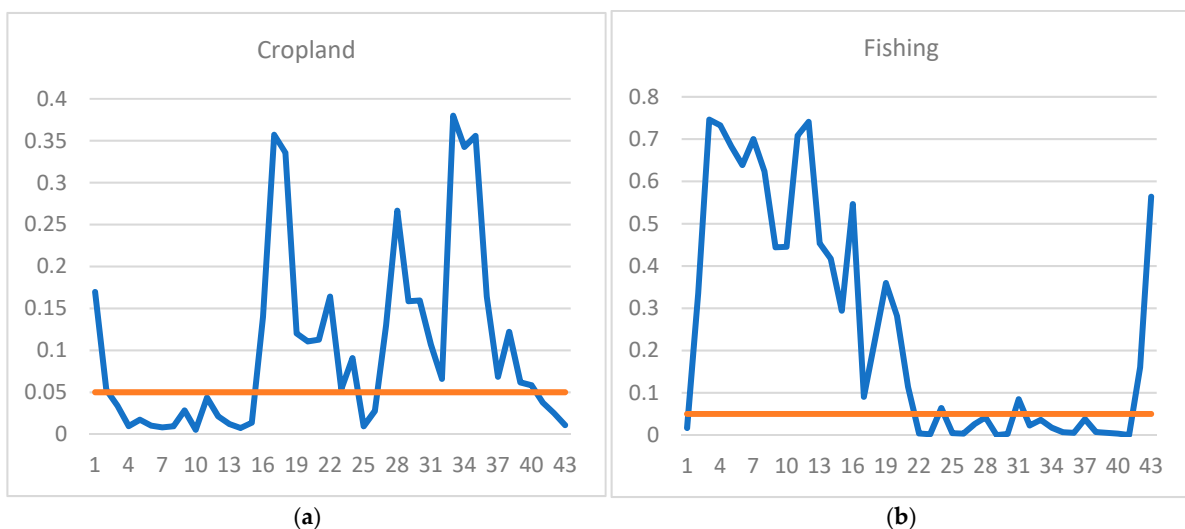
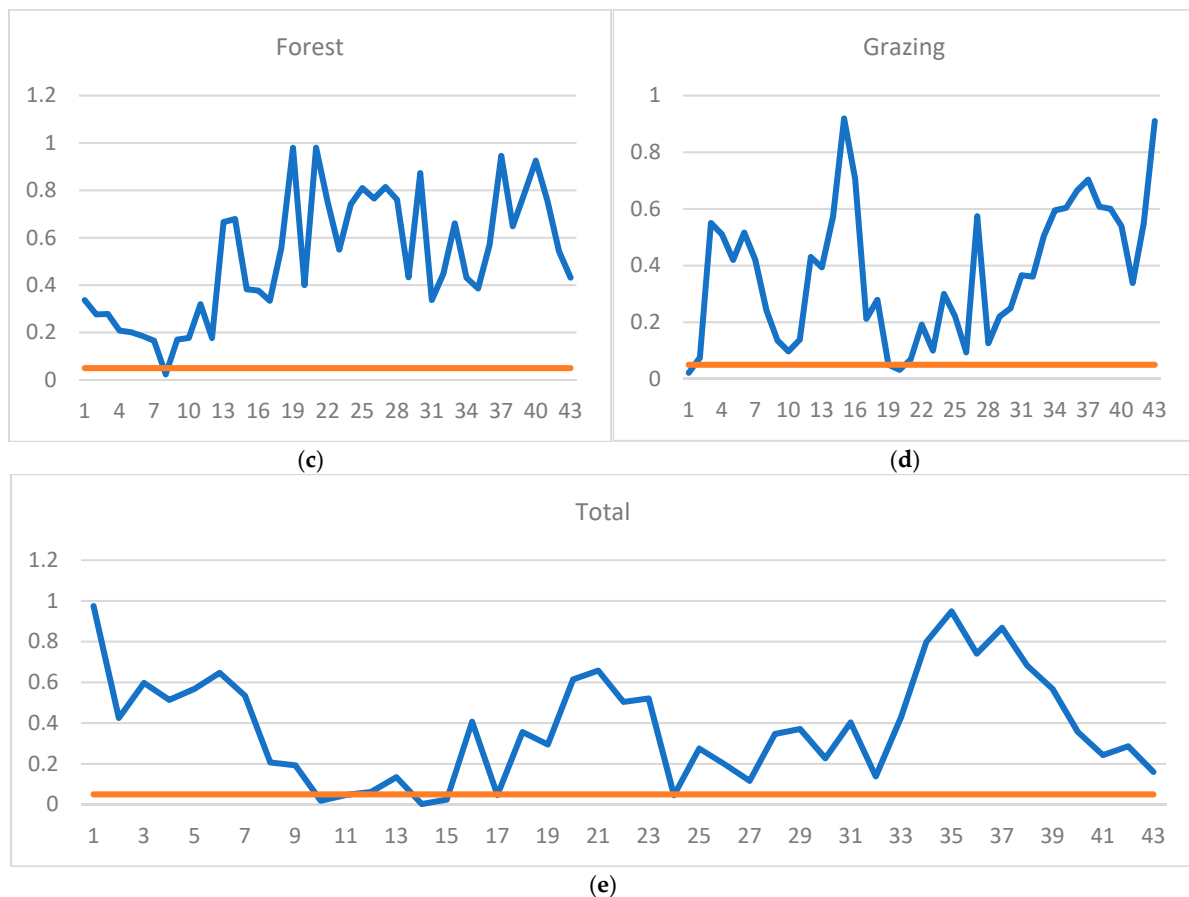


Figure 2. Cont.



**Figure 2.** Intercept and Trend Model Results, five different panel for footprints can be seen; panel (a): Cropland, panel (b): Fishing Footprint, Panel (c): Forest Footprint, Panel (d): Grazing Land Footprint and Panel (e): Total Footprint.

## 5. Discussion

This study investigated the stationarity characteristics of the ecological footprint and its subcomponents due to testing the convergence and the effects of shock policies. The results showed that the total ecological footprint of the countries changed only in 1970, 1974 and 1984 for the intercept model, and also it changed in 1970, 1974, 1977 and 1984 for the intercept and trend model. In other words, the series are stationary in the period from 1961 to 2017. Therefore, shock policies applied during the periods are not effective. However, the series show difference in stationary characteristics in general. This means that the common policies implemented are successful. On the other hand, it means that a joint policy initiative to reduce ecological footprint will not encounter strong resistance, that is, the policy will be effective over time. It can be said that the policies to be implemented to reduce ecological footprint for these countries will also be effective.

Determination of sub-component of ecological footprint convergence is also an important issue, as much as the convergence of total footprint, to develop more effective policies suitable for the properties of the components. The Cropland footprint changes for both intercept model and intercept and trend model in 1963, 1985 and 2001. The Grazland footprint similarly changes for the intercept model in 1963, 1985 and 2001, and for the intercept and trend model in 1961 and 1980. It is thought that the Common Agricultural Policy, which aimed to ensure productivity in the 1960s and 1970s, was effective in these changes. Throughout the 60s and 70s, farmers were encouraged to increase the production and productivity of agricultural areas by providing price support. This practice resulted in product surpluses in the early 1980s [56]. However, in 1985, with the green book mentioning the effect of agriculture on the environment, CAP was revised in 1985 and measures to protect the environment were emphasized [57].

In Forest footprint, there was a change in the intercept model with the intercept and trend model in 1968. It is thought that the CAP policy, which was implemented in the 1960s and 70s, was also effective in the change here. Because investments based on forestry were directed within the framework of CAP, as in other areas [58]. The fact that the variable is not stationary except for the 1968 period shows that the series did not converge and that common environmental policies were also effective. Another ecological footprint variable examined in the study is fishing footprint. In the Fishing series, a change is observed in the intercept model and intercept and trend model in 1961 and 1980. The series has not been stationary since 2002. The reason for the series not being static after 2002 is thought to be the fisheries reform revised in 2002. Therefore, it can be said that the fisheries reform implemented after 2002 has been effective. After this date, the series diverged.

## 6. Conclusions

In the study, we aimed to obtain findings about the convergence behavior of the ecological footprint and its components. The results show that there is no convergence or divergence over a long period, and that environmental policies applied in different years divide the convergence or divergence behavior into windows. As a matter of fact, environmental policies implemented in different periods in EU countries have had different effects.

Stationary time-varying coincides with the environmental policies that have been shaped in EU countries since the 1970s. The EU launched the first action plan between 1973 and 1977, and then the second action plan was launched between 1977 and 1984. The results show that the shock policies are not permanent. As a matter of fact, it is thought that the need for EU countries to constantly revise their environmental policies and to implement new programs, plans and strategies is due to the ineffectiveness of the policies. Although these policies seem to be effective to a great extent, it is seen that they are not enough to reduce the footprint of the EU as it is expected. It is clearly stated in the reports of WWF and EEA that the EU is insufficient in achieving its policy targets. For this reason, we believe that national policies should be supported by national policies, taking into account country and footprint specific features.

Studies in the literature provide different results about the existence of convergence. There are no results to support the findings obtained in our study on a time-varying basis, since the stationarity is not tested by considering the sub-periods in the current studies. In this respect, the study will guide future studies. On the other side, the fact that the stationary is not in general in the sub-periods as similar as Ulucak and Lin [15] and Harvey et al.'s [19] studies. Solarin and Bello [18] examined the non-stationary state of the ecological footprint series to the fact that the variable reflects an upward trend on a trending path and sees it as usual. At this point, the fact that the EU countries are countries with a high consumption tendency confirms this result. Since the ecological footprint and its sub-components are a very comprehensive indicator, they are also evaluated separately in the study. Considering the properties of the sub-components, generally the presence of divergence draws attention. Therefore, common environmental policies implemented by countries create permanent and long-term effects on the series. On the other hand, series have a long-term memory process and it is possible that convergence may occur in the long term. As a result, although international policies at the EU level are generally successful in reducing ecological footprint, they are not sufficient. Accordingly, they should be supported by national policies.

As a result, the effects of environmental policies implemented in different years on EF and its components also change. In determining convergence, it is more useful to test convergence as windows rather than as a process. On the other hand, even if environmental policies are effective, their effects may be limited. For this reason, it is recommended that policymakers determine the level of impact as well as the effectiveness of policies in reducing EF and its components.

The limitations of this study, first of all, our analysis covers 16 EU member states for the period 1961–2016. The limitations of this study in general arise from the data

set. First of all, the number of countries whose data can be accessed in a healthy way is quite low. One possible reason for this is because some EU countries have joined the EU very recently. Another important point is that the data set is short because the data are annual and it is not possible to make a country-based analysis. In our study, we considered country-specific characteristics using heterogeneous methods (fixed effect) within the panel data methodology. As a result, country-based information cannot be obtained in our study. However, the availability of long or high-frequency data to allow country-based analysis will enable more detailed results for future studies. Another limitation is that we only deal with EU countries in our study. The panel analysis results that can be obtained for countries that implement a state system (USA, China, etc.) and maintain similar environmental policies, can contribute significantly to this field.

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