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Determination of the Stability of Ecological Footprint and its Subcomponents in Türkiye: Fourier KPSS Test

Türkiye'de Ekolojik Ayak İzi ve Alt Bileşenlerinin Durağanlığının Analizi: Fourier KPSS Testi

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Abstract

Environmental sustainability plays a critical role in protecting the world's ecosystem. Human activities, significantly increasing greenhouse gas emissions, and the overuse of fossil fuels challenge the planet's capacity to regenerate itself. In this study, which aims to determine whether the ecological footprint and its sub-components are stationary in Türkiye, the data range of the survey includes the years 1961-2022 and consists of annual data. In this study, the Fourier KPSS test is used to determine the stationarity of ecological footprint and its sub-components, which are important indicators of environmental degradation. According to the results of the study conducted using the Fourier KPSS unit root test for the effectiveness of environmental policies implemented in Türkiye, it is concluded that the total ecological footprint, carbon footprint, cropland footprint, and build-up footprint variables are non-stationary. This result indicates that the shocks have a permanent effect on the variables and that the variables do not tend to return to their average after the shocks. Still, instead, the variables tend towards a new equilibrium point. Similarly, it shows that policies that affect the ecological footprint and some of its sub-components will have long-term and permanent effects. It is concluded that the fishing grounds footprint, forest products footprint, and grazing land footprint variables are stationary. This result implies that the impact of shocks on these variables is temporary.

Özet

Çevresel sürdürülebilirlik, dünya ekosisteminin korunmasında kritik bir rol oynamaktadır. İnsan faaliyetleri, özellikle artan sera gazı emisyonları ve fosil yakıtların aşırı kullanımı, gezegenin kendini yenileyebilme kapasitesini zorlamaktadır. Türkiye'de ekolojik ayak izi ve alt bileşenlerinin durağan olup olmadıklarını tespit etmek amacıyla gerçekleştirilen çalışmada, çalışmanın veri aralığı 1961-2022 yıllarını içermekte ve yıllık verilerden oluşmaktadır. Bu çalışmada, çevre tahribatlarında önemli bir gösterge olan ekolojik ayak izi ve alt bileşenlerinin durağanlıklarının tespitinde Fourier KPSS testi kullanılmıştır. Türkiye'de uygulanan çevre politikalarının etkinliğine yönelik olarak Fourier KPSS birim kök testi kullanılarak gerçekleştirilen çalışmanın sonuçlarına göre, toplam ekolojik ayak izi, karbon ayak izi, tarım alanı ayak izi ve inşaat alanları ayak izi değişkenlerinin durağan olmadığı sonucuna ulaşılmıştır. Bu sonuç, değişkenler üzerinde şokların kalıcı bir etkiye sahip olduğu, değişkenlerin yaşanan şoklardan sonra ortalamasına geri dönme eğilimi göstermediği aksine değişkenlerin yeni bir denge noktasına doğru yöneldiği bilgisini vermektedir. Benzer şekilde, ekolojik ayak izi ve alt bileşenlerinden bazılarını etkileyen politikaların uzun vadeli ve kalıcı etkiler yaratacağını göstermektedir. Balıkçılık alanı ayak izi, orman ürünleri ayak izi ve otlak alanı ayak izi değişkenlerinin ise durağan olduğu sonucuna ulaşılmıştır. Bu sonuçta, bu değişkenler üzerindeki şokların etkisinin geçici olduğu sonucunu vermektedir.

Introduction

The global climate crisis is emerging as a challenge that profoundly affects ecosystems, economies, and societies worldwide. Human activities such as increased greenhouse gas emissions, intensive use of fossil fuels, and deforestation lead to irreversible changes in the planet's atmosphere. This is causing average global temperatures, sea levels, and the frequency and severity of extreme weather events to increase. Climate change is reducing agricultural productivity, threatening water resources, and jeopardizing biodiversity. It also deepens social and economic inequalities. (LPP, 2008). There is a consensus that deterioration in environmental quality makes it impossible to sustain economic growth and poses a significant obstacle to poverty eradication (Munasinghe, 1992). It is, therefore, necessary to focus on how much of the planet's regenerative biological capacity should be demanded by specific human activities such as resource consumption and producing goods and services (Kitzes and Wackernagel, 2009).

International cooperation on environmental protection is critical for preserving the global ecosystem. Many international agreements have been signed to ensure ecological sustainability. For example, the United Nations Framework Convention on Climate Change (UNFCCC), signed at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, is recognized as an essential step in the fight against climate change (UNFCCC, 1992). Furthermore, the Montreal Protocol aims to phase out the use of substances that cause ozone depletion and was signed in 1987 (Montreal Protocol, 1987). The Kyoto Protocol was signed in 1997 and aims for developed countries to reduce their greenhouse gas emissions (Kyoto Protocol, 1997). This protocol has been an essential milestone in the fight against climate change. In addition, the Paris Climate Agreement, signed in Paris in 2015, is a comprehensive agreement that aims to keep global warming below two °C and even limit it to 1.5°C (Paris Agreement, 2015). Furthermore, the Convention on Biological Diversity (CBD), signed in 1992 to protect biodiversity, promotes the conservation of ecosystems, species, and genetic resources (CBD, 1992). These agreements demonstrate the international community's determination to collaborate in tackling environmental problems.

The environmental economics literature is making progress in three main areas: First, the environmental Kuznets curve (EKC) hypothesis, which argues that environmental pollution increases at the beginning of economic development and decreases after a certain level of income (Kuznets, 1955; Grossman and Kruger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993). The second is the pollution refuge hypothesis. It has been widely discussed in recent years that foreign direct investment (FDI) contributes positively to the development of developing countries but also leads to environmental degradation in these countries. According to the "pollution refuge hypothesis", developing countries become attractive to multinational companies operating in developed countries because of cheap labor and raw materials and lax environmental policies. Strict environmental regulations in developed countries reduce the competitive advantage of these companies, and therefore, polluting industries are transferred to developing countries, which increases environmental degradation. However, the "pollution halo hypothesis" also argues that FDI reduces environmental pollution by bringing environmentally friendly technologies to developing countries (Cole, 2004). The third area of research is stationarity analysis, which determines whether the effects of policies implemented in the environmental economy are permanent or temporary. These analyses examine the long-term impact of policies by assessing whether time series data are stationary. Stationarity is when a data set does not change its statistical properties (mean, variance, etc.) over time, and this analysis is an essential tool for measuring the sustainable effects of environmental policies. For example, studies by Lee and Strazicich (2003) used stationarity tests to examine the relationship between environmental pollution and economic growth and assessed the long-term effects of policy changes. Similarly, Stern (2004) used stationarity analysis of environmental data to investigate the lasting effects of environmental policies. Such analyses help policymakers understand the effectiveness and sustainability of their environmental strategies.

In the literature, several studies have analyzed stationarity. The most widely used environmental degradation criterion is the level of carbon emissions. There are several important reasons for conducting unit root analysis for carbon emissions in the literature. First, if a unit root is detected in the carbon emission series, it implies that policy shocks to ecological indicators will have a persistent effect. Second, the non-stationary carbon emission series will have important implications for the environmental Kuznets curve (EKC) hypothesis in the long run. Third, examining the stationarity properties of carbon emissions will allow people to learn about the effectiveness of the convergence concept (Solarin and Bello, 2018). Considering the study by Ulucak and Lin (2017), the stationarity analysis of the ecological footprint and its components, which have been accepted as an essential indicator of environmental degradation in recent years, was conducted in Türkiye. The stationarity of a time series provides information about future behavior based on past behavior. More specifically, stationarity properties indicate whether shocks have temporary or permanent effects on a variable (Ulucak and Lin, 2017: 337).

The effectiveness of environmental policies reflects the current state of affairs and guides the formulation of future sustainability strategies. These strategies include increasing resource efficiency, reducing carbon footprint, and transitioning to renewable energy sources. The stability of the ecological footprint indicates the balance between the country's environmental capacity and consumption. The analysis of sub-components reveals in detail how and at what rates basic needs such as food, water, and energy are consumed. Each of these components reflects their impact on different aspects of the ecosystem. For example, water consumption and energy use show direct pressure on water resources and fossil fuel reserves, while food consumption reflects impacts on agricultural land and biodiversity. These analyses are essential in assessing the effectiveness of environmental policies and guiding future sustainability strategies.

In this respect, the study aims to contribute to the sustainable development literature. In this study, a comprehensive analysis of the stability of the ecological footprint and its sub-components in Türkiye has been carried out. The study starts by introducing the historical development of environmental policies and presents hypotheses in environmental economics. In the second part, the conceptual framework of the ecological footprint and its sub-components is presented. The literature summary section details previous studies testing the stationarity of the ecological footprint and its components. The general state of research in this field is given by comparing the findings and methodologies of these studies. The study continues with methods and findings and concludes with a conclusion.

1. Conceptual Framework for Ecological Footprint and its Subcomponents

The concept of Ecological Footprint was first introduced by William E. Rees in 1992. This concept measures how much of a burden people and societies place on nature. Ecological Footprint, which initially emerged as an idea, started attracting more attention with Rees' work. Mathis Wackernagel first systematized the concept of Ecological Footprint and related calculation methods. Wackernagel elaborated on this concept and developed calculation methods within the scope of his doctoral thesis. The unit of measurement resulting from these studies was named “Ecological Footprint”. In a book published in 1996, Wackernagel and Rees discussed the concept of Ecological Footprint in a broader framework. In the book, they explain the relationship between this concept and sustainable development and how to calculate the Ecological Footprint. In this way, the Ecological Footprint concept has become an essential tool in sustainability studies (Wackernagel and Rees, 1998).

The Global Footprint Network (GFN) is an organization that measures the demand for biological capacity worldwide and publishes National Footprint Accounts (NFA) every year. These calculations assess the resource consumption and biological capacity of more than 150 countries worldwide. GFN's data reveals how much natural resources countries consume and the impact of this consumption on the environment. Since the mid-1970s, worldwide demand for natural resources has reached unsustainable levels. This means that demand far exceeds the capacity of the world to replenish its existing resources. This trend is unsustainable, and the depletion of natural ecosystems and resources is inevitable if unsustainable resource consumption is continued. Continuation of the current level of consumption will end with two possibilities: The first is that people consciously choose to switch to more sustainable lifestyles and reduce resource consumption. The second is the depletion of resources and a forced reduction in consumption due to natural constraints. These two possibilities emphasize that natural resources are finite and that the current level of consumption is not sustainable. As a result, resource consumption habits worldwide need to be changed (WWF, 2012: 14).

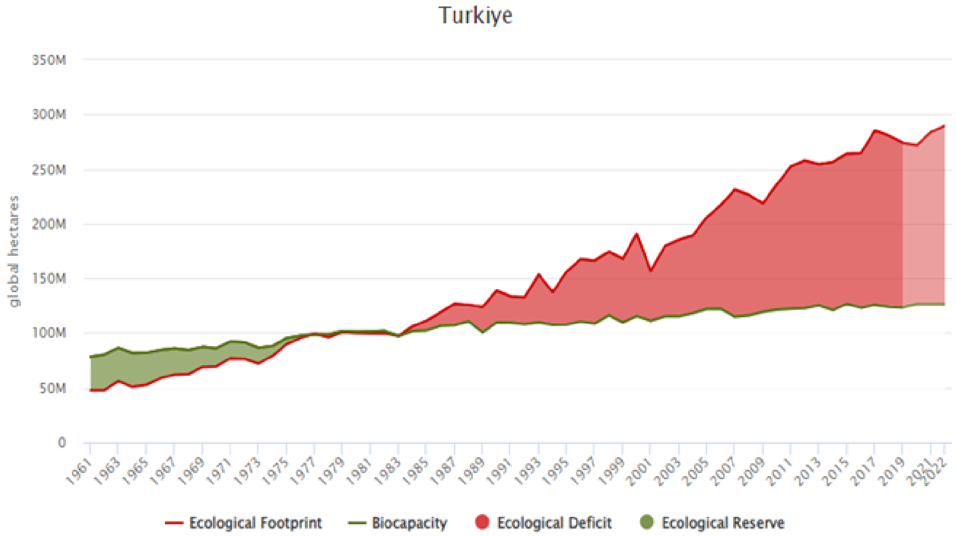


Figure 1. Ecological Footprint, Biocapacity, Ecological Deficit and Ecological Reserve in Türkiye (in Global Hectares) (1961-2022)

Figure 1 presents information on Türkiye's ecological footprint, biocapacity, ecological deficit, and ecological reserves between 1961 and 2022. In 1961, Türkiye's biocapacity was 76.4 million global hectares (kha), and its ecological footprint was 44.4 million kha, indicating an ecological reserve. However, in 1980, the biocapacity increased to 94.1 million kha and the ecological footprint to 93.7 million kha, resulting in an ecological deficit. In 2016, biocapacity reached 114.3 million kha, while the ecological footprint increased to 266.9 million kha, indicating an increasing ecological deficit. 2022 the biocapacity was 126.1 million kha, while the ecological footprint increased to 289.7 million kha. These data show that Türkiye's biocapacity needs to be improved to meet the resources consumed and is on an ecologically unsustainable path.

The sub-components of the ecological footprint are carbon, grassland, forest, fishing ground, agricultural land, and built-up area. Regarding environmental sustainability, various footprints are essential metrics for assessing the impact of human activities on ecosystems. The carbon sequestration footprint refers to the biological capacity required to offset carbon dioxide emissions in the atmosphere and is usually provided by forests (GFN, 2023). The agricultural land footprint indicates the total land area people use for food production, emphasizing the importance of sustainable farming practices (FAO, 2023). The forest footprint is associated with producing forest products and wood consumption necessary to meet human needs (WWF, 2023). Built-up area footprint measures the environmental impacts of urbanization and industrial areas, revealing the pressure of growing population and urbanization on sustainability (UNEP, 2023). The fishing ground footprint refers to the pressure on marine and freshwater resources from fishing activities and highlights the negative impacts of overfishing on ecosystems (FAO, 2023). The grassland footprint refers to the total area of grassland used for livestock activities, and the sustainable management of these areas is critical for the conservation of biodiversity (GFN, 2023).

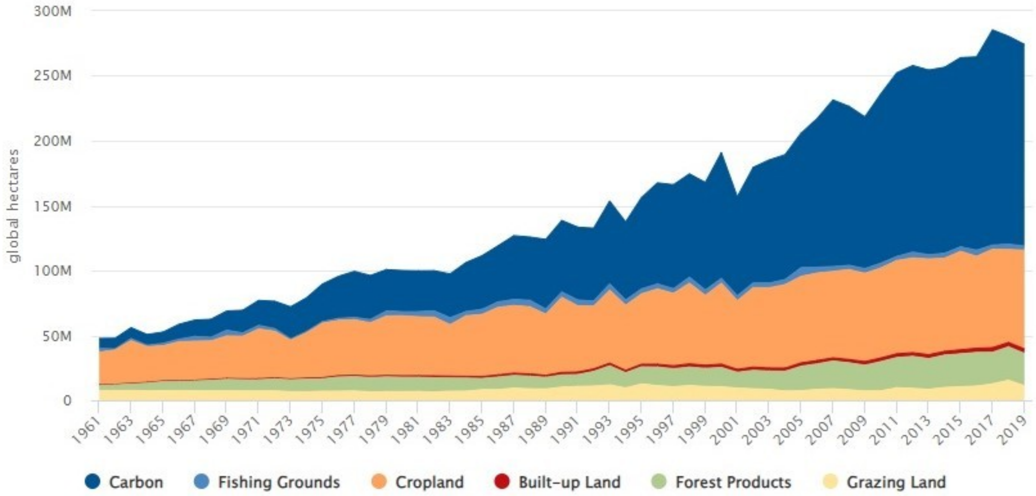


Figure 2. Ecological Footprint of Türkiye by Land Type (in Global Hectares) (1961-2019)
Source: Global Footprint Network (GFN), 2024.

Figure 2 shows Türkiye's ecological footprint between 1961 and 2019 regarding global hectares of land types. It shows how different land use types have changed over the years. The blue area represents the carbon footprint and is one of the components that has increased the fastest over time. Starting in 1961 at low levels, the carbon footprint increased dramatically to its highest level in 2019. This increase can be attributed to the rise in industrialization, energy consumption, and fossil fuel use in Türkiye. The orange area shows the agricultural land footprint. Since 1961, agricultural land use has steadily increased, but this increase has been more moderate than the carbon footprint. The expansion of farming activities is directly related to the rise in food production. The light blue area represents the fishing land footprint. This component has been generally stable and has mostly stayed the same. The red area represents the built-up area footprint. This component has increased over time in line with urbanization and infrastructure development, but a minor increase is observed compared to the other components. The green area represents the footprint of the forest products. This component has also increased over time but shows an overall stable trend. Consumption of forest products includes using products such as paper and timber. The yellow area represents the grassland footprint. This component is associated with livestock activities and has shown small fluctuations over time. From 1961 to 2019, there was a general upward trend.

2. Literature

Studies testing the stationarity of ecological footprint and its sub-components are limited. In this section of the study, only the studies that tested stationarity are included (Ulucak and Lin, 2017; Solarin and Bello, 2018; Solarin, Gil-Alana and Lafuente, 2019; Solarin, Gil-Alana and Lafuente, 2021; Alper and Alper, 2021; Yılancı, Pata and Cutcu, 2022). Ulucak and Lin (2017) investigated policy shocks on the ecological footprint of the United States. More specifically, they analyze the stochastic behavior of the ecological footprint and its components (carbon footprint, cultivated area, pasture area, forest products, built-up area, and fishing areas) using Fourier unit root tests, which are more robust under an unknown number of breaks. The stochastic properties of the ecological footprint are essential considerations for implementing global and local policies targeting global warming, climate change, and environmental degradation. Empirical results show that the ecological footprint is non-stationary, which implies that policies affecting the ecological footprint will have long-term and permanent effects. Solarin and Bello (2018) tested the stationarity of the ecological footprint for 128 countries. Using data from 1961 to 2013, the study results show that 81% of the country's sample proves that the ecological footprint is non-stationary. Another study by Solarin et al. (2019) examined the stationarity of the carbon footprint variable for 92 countries. The study's results, which used data covering 1961-2014, indicate that carbon footprint is stationary for 25 countries. Another study by Solarin et al. (2021) aimed to test the stationarity of the fishing grounds footprint for 89 countries. According to the results of the study using data from 1961-2016, it was concluded that the fishing grounds footprint is non-stationary in most countries.

Alper and Alper (2021) analyzed the stationarity of ecological footprint and its subcomponents for Mexico, Indonesia, Nigeria, and Türkiye (MINT) for 1961-2016 using the Fourier unit root test. Looking at the results by country, it is found that the agricultural land footprint in Mexico, the total ecological footprint and the construction land footprint in Indonesia, the agricultural and grazing land footprint in Nigeria, and the fishing land and forest products footprint in Türkiye are stationary. In addition, carbon emission footprint is found to have unit roots in all MINT countries.

Yılancı et al. (2022) tested whether the ecological footprint and its sub-components are stationary for ten developing countries. For this purpose, the Fourier extended Dickey-Fuller unit root test with fractional frequency (FADF) and fractional unit root test with Fourier function (FUR) were used in annual data between 1961 and 2017. The FADF unit root test results suggest the validity of stationarity for about 30% of the series, while the FUR test showed evidence of stationarity for almost all footprint series. These results imply that policy shocks to the ecological footprint are transitory and that policies to reduce pollution in these ten countries have not had the expected effect.

Studies on the stationarity of the environmental footprint and its components generally show that the ecological footprint is non-stationary in most countries. This finding implies that policies affecting the environmental footprint may have long-term and lasting effects and that policies to reduce pollution may not have the expected effect. Studies have focused on various components of the ecological footprint (carbon footprint, cultivated area, pasture area, forest products, built-up area, and fishing grounds) and found that these components exhibit different stationarity characteristics in other countries. In particular, it is emphasized that elements such as carbon footprint and fishing grounds footprint are not static, and therefore, policy interventions in these areas may have temporary effects. In general, research on ecological footprint questions the effectiveness of policies to address problems such as global warming, climate change, and environmental degradation.

3. Dataset, Methodology and Empirical Findings

3.1. Dataset

In the study conducted to determine whether the ecological footprint and its sub-components are stationary in Türkiye, the data range of the study includes the years 1961-2022 and consists of annual data. The data were obtained from the official website of the Global Footprint Network (2024). In the study, the Total Ecological Footprint variable (TotalEcoFP) shows the sum of all other sub-footprint components. The sub-components are Carbon Footprint (CarbonFP), Fishing Grounds Footprint (FishingFP), Cropland Footprint (CroplandFP), Build-up Land Footprint (BuildFP), Forest Products Footprint (ForestFP), Grazing Land Footprint (GrazingFP). In the unit root analysis of the study, the variables were analyzed by taking their logarithms. Analyses were carried out with the Eviews 12 program. Explanations about the variables used in the study are shown in Table 1.

Table 1. Variables and Their Descriptions

Variables	Symbols	Explanations
Carbon Footprint	CarbonFP	Total Carbon Footprint (Logarithmic)
Fishing Grounds Footprint	FishingFP	Total Fishing Grounds Footprint (Logarithmic)
Cropland Footprint	CroplandFP	Total Cropland Footprint (Logarithmic)
Built-up Land Footprint	BuildFP	Total Built-up Land Footprint (Logarithmic)

Forest Products Footprint	ForestFP	Total Forest Products Footprint (Logarithmic)
Grazing Land Footprint	GrazingFP	Total Grazing Land Footprint (Logarithmic)
Total Ecological Footprint	TotalEcoFP	Total Ecological Footprint (Logarithmic)

3.2. Methodology

The aim of the study is to determine whether the ecological footprint and its sub-components are stationary in Türkiye. Unit root tests are used to determine the stationarity of these variables. For this purpose, the stationarity of the ecological footprint and its subcomponents is analyzed with the FKPSS unit root test developed by Becker, Enders and Lee (2006) using the Fourier function.

Most of the traditional unit root tests in the literature are linear in nature and do not take structural changes into account. This has been a point of criticism in the field, as macroeconomic variables have recently been characterized as fractured and nonlinear. Therefore, unit root tests that are nonlinear and take structural changes into account are seen as more reliable (Lee, 2014).

Prior to the unit root tests conducted by researchers such as Becker et al. (2006), Enders and Lee (2012) and Rodrigues and Taylor (2012) using Fourier functions, the unit root tests in the literature were criticized for the exogenous determination of structural change. This led to the emergence of unit root tests (Lee and Strazicich, 2003; Saikkonen and Lütkepohl, 2002; Lumsdaine and Papell, 1997; Zivot and Andrews, 1992) in which the dates of structural change are determined endogenously. A criticism of these tests is the a priori determination of the number and pattern of structural changes. In recent years, new unit root tests, which have been added to the literature with the use of Fourier functions, offer a solution to this problem (Yılancı, 2017: 55). Since the Fourier approach in unit root tests allows for slower and smoother breaks, it is stated to be more successful in capturing structural changes. In addition, the Fourier function eliminates the need to know in advance the type (sharp or soft), date and number of breaks that are often encountered in unit root analysis (Omay, 2015).

Unlike other conventional unit root tests, the KPSS unit root test developed by Kwiatkowski, Phillips, Schmidt and Shin (1992) tests the stationarity assumption under the null hypothesis. Based on the (KPSS) unit root test developed by Kwiatkowski et al. (1992), the Fourier KPSS (FKPSS) test is one of the first unit root studies conducted by Becker et al. (2006) using the Fourier function. Similar to the KPSS test, the FKPSS test tests the stationarity assumption under the null hypothesis. The Fourier KPSS unit root test detects slow as well as sudden changes and the form, location and number of structural changes do not affect the power of the test. In the FKPSS test, Becker et al. (2006) test the stationarity of the series and the level and trended versions of the equations are given below.

$$y_t = \alpha_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + e_t$$

$$y_t = \alpha_0 + \beta_t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + e_t$$

In the equation, k denotes the number of frequencies, t denotes the trend, and T denotes the sample size.

The FKPSS unit root test tests the stationarity of the series under the null hypothesis (H_0). Rejection of the null hypothesis (H_0) as a result of the FKPSS unit root test indicates that the series has a unit root. After performing the unit root test, the significance of the trigonometric terms of the Fourier functions should be examined with the help of the F test. If the trigonometric terms are significant as a result of the F test, the FKPSS results should be used in the stationarity test, while if they are insignificant, the KPSS test results should be used as the basis for the stationarity test.

The significance of the trigonometric terms is tested with the following hypothesis:

H_0: Trigonometric terms are not significant

H_a: Trigonometric terms are significant

3.3. Empirical Findings

Descriptive statistics of the variables are given in Table 2 below. The descriptive statistics in Table 2 are obtained from the original values of the study data, and unit root tests are performed on the logarithmic data of these variables.

Table 2. Descriptive Statistics for Variables

	CarbonFP	FishingFP	CroplandFP	Build_upFP	ForestFP	GrazingFP	TotalEcoFP
Mean	71607396	3494450.	52884244	1850748.	14148505	8757274.	1.53E+08
Median	56096922	3719304.	52119907	1880462.	11351943	8235473.	1.35E+08
Maximum	1.66E+08	6730723.	79429775	3666479.	25935419	15405096	2.90E+08
Minimum	7710362.	693284.4	24965226	426108.5	4167673.	6358789.	47646922
Std. Dev.	51216448	1182494.	16056838	983227.8	6600348.	1936397.	75967375
Skewness	0.467552	-0.436572	-0.031764	0.170372	0.610330	0.938985	0.367163
Kurtosis	1.832008	3.312200	1.859065	1.865534	2.029931	3.591594	1.826141
Jarque-Bera	5.783115	2.221274	3.373237	3.624722	6.280204	10.01495	4.952710
Probability	0.055490	0.329349	0.185145	0.163268	0.043278	0.006688	0.084049
Observation	62	62	62	62	62	62	62

The data set of the variables analyzed in Table 2 above consists of 62 observations. Considering the analysis period, the mean, maximum, and minimum values of the CarbonFP variable in this period are 71607396, 1.66E+08, 7710362, FishingFP variable in this period are 3494450, 6730723, and 693284, CroplandFP variable in this period are 52884244, 79429775, and 24965226, BuildFP variable in this period are 1850748, 3666479, and 426108.5, respectively. The mean, maximum, and minimum values of the ForestFP variable in this period are 14148505, 25935419, and 4167673, the mean, maximum and minimum values of the GrazingFP variable in this period are 8757274, 15405096, and 6358789, and the mean, maximum and minimum values of the TotalEcoFP variable in this period are 1.53E+08, 2.90E+08, and 47646922, respectively.

The FKPSS unit root test tests the stationarity of the series under the null hypothesis (H_0). Rejection of the null hypothesis (H_0) in the FKPSS unit root test indicates that the series has a unit root. The significance of the trigonometric terms of the Fourier functions should be examined with the help of the F test. If the trigonometric terms are significant as a result of the F test, the FKPSS results should be used in the stationarity test. In contrast, if they are insignificant, the KPSS test results should be used as the basis for the stationarity test.

Table 3. FKPSS Test Results

Variables	k	Min.SSR	FKPSS Test Statistic	F Test Statistic
CarbonFP	1	0.003	0.067 (5)	45.443
FishingFP	1	6.194	0.034 (4)*	9.744
CroplandFP	1	0.273	0.057 (2)	14.945
Build-upFP	1	0.177	0.055 (8)	174.810

ForestFP	2	0.894	0.116 (5)*	18.332
GrazingFP	2	0.549	0.079 (3)*	50.695
TotalEcoFP	1	0.223	0.066 (4)	13.237

Note: The values in parentheses indicate the bandwidth obtained by the Newey-West method. In Becker et al. (2006), the F test table critical values obtained from Table 1 are 6.873 (1%), 4.972 (5%) and 4.162 (10%), while the FKPSS test table critical values are 0.071 (1%), 0.054 (5%) and 0.047 (10%) for k=1 and 0.202 (1%), 0.132 (5%) and 0.103 (10%) for k=2.

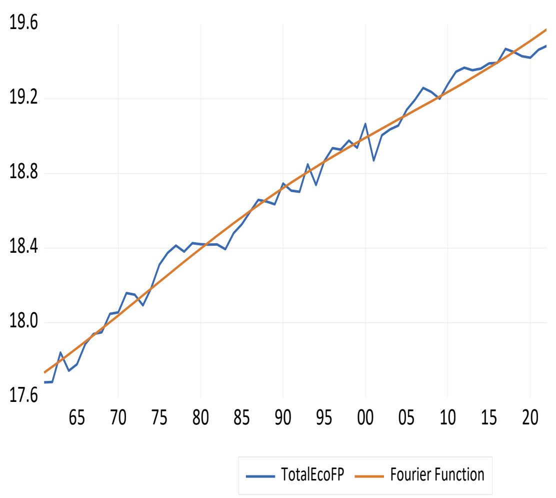
* It indicates that the variable is stationary at its level.

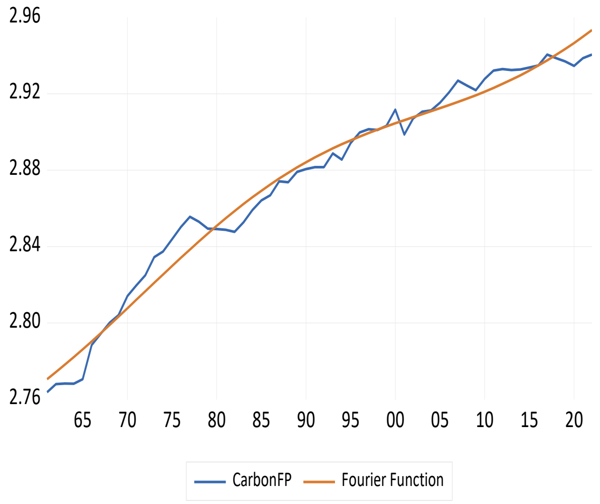
Before analyzing the results of the FKPSS unit root test for ecological footprint and its subcomponents in Table 3, the significance of the trigonometric terms should be examined with the help of the F test. When the F test results for the variables are compared with the table critical value at a 5% significance level, it is seen that the F test statistics are more significant than the table critical value. Therefore, as a result of the F test, it is concluded that the trigonometric terms are essential for all variables, and the FKPSS unit root test can be used in the stationarity test.

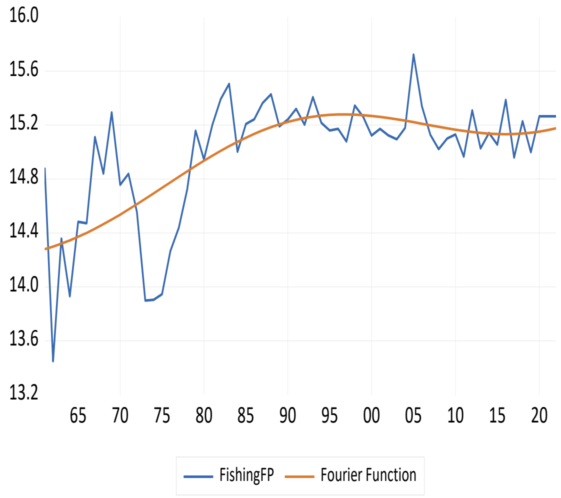
According to the results of the FKPSS unit root test, when the FKPSS test statistic is compared with the table critical values at the 5% significance level, the null hypothesis (H_0) regarding the stationarity of the total ecological footprint, carbon footprint, cropland footprint, and build-up land footprint variables is rejected; therefore, it is determined that these variables are not stationary (unit rooted) at their levels. On the other hand, the null hypothesis (H_0) cannot be rejected when the FKPSS test statistic and the table critical values are compared at the 5% significance level for the variables fishing grounds footprint, forest products footprint, and grazing land footprint. Therefore, it is concluded that these variables are stationary at their level values.

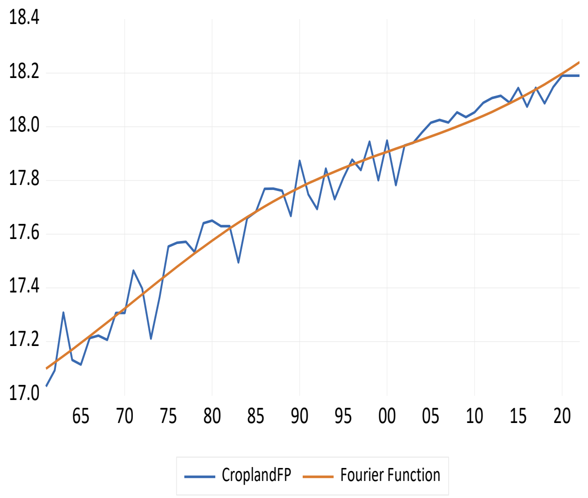
As a result, it is concluded that shocks permanently affect the total ecological footprint, carbon footprint, cropland footprint, and build-up land footprint variables and that the variables do not tend to revert to the mean after the shocks. Instead, the variables tend to move towards a new equilibrium point. These results suggest that policies affecting the ecological footprint and some subcomponents will have long-term and permanent effects. On the other hand, the effect of shocks on the variables of fishing grounds footprint, forest products footprint, and grazing land footprint is transitory. In other words, it is concluded that the variables tend to return to their average after the shocks.

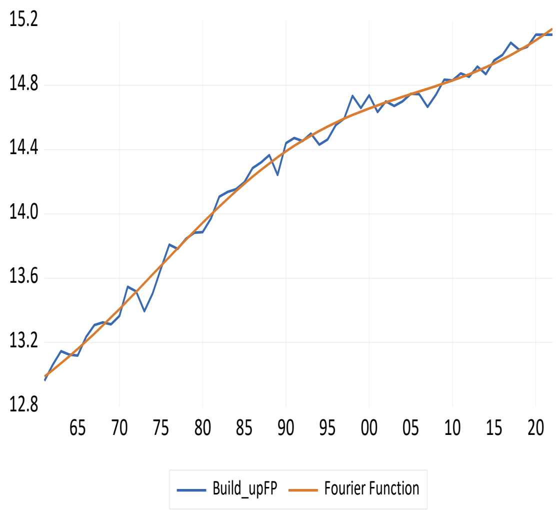
The graphs of the variables' level values (logarithmic) are presented in Figure 3 below. As can be seen in the figure, it can be said that the Fourier functions are quite successful in capturing the structural changes in the Ecological footprint and its sub-components.

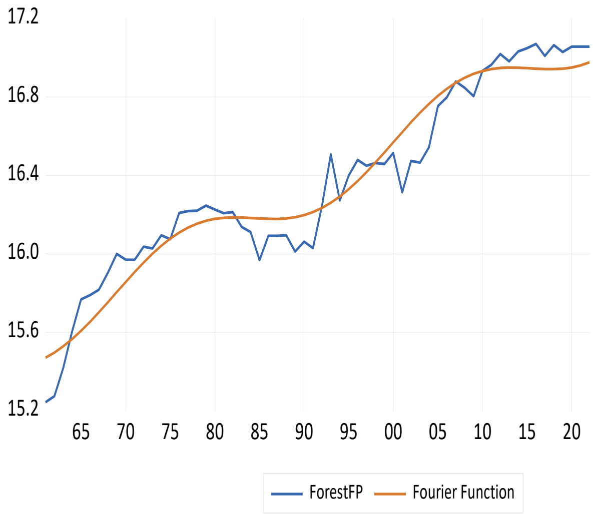

19.6
19.2
18.8
18.4
18.0
17.6
65 70 75 80 85 90 95 00 05 10 15 20
TotalEcoFP
Fourier Function


2.96
2.92
2.88
2.84
2.80
2.76
65 70 75 80 85 90 95 00 05 10 15 20
CarbonFP
Fourier Function


16.0
15.6
15.2
14.8
14.4
14.0
13.6
13.2
65 70 75 80 85 90 95 00 05 10 15 20
FishingFP
Fourier Function


18.4
18.2
18.0
17.8
17.6
17.4
17.2
17.0
65 70 75 80 85 90 95 00 05 10 15 20
CroplandFP
Fourier Function


15.2
14.8
14.4
14.0
13.6
13.2
12.8
65 70 75 80 85 90 95 00 05 10 15 20
Build_upFP
Fourier Function


17.2
16.8
16.4
16.0
15.6
15.2
65 70 75 80 85 90 95 00 05 10 15 20
ForestFP
Fourier Function

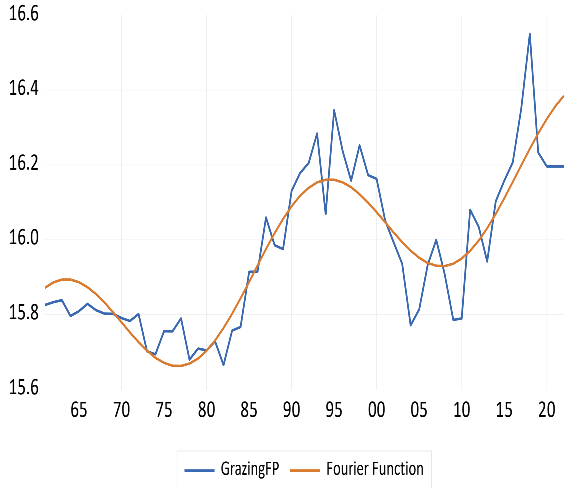


Figure 3. Structural Changes Regarding the Ecological Footprint and Its Sub-Components

Conclusion and Recommendations

Environmental sustainability is critical to protecting the global ecosystem and meeting the needs of future generations. Today, anthropogenic activities such as increasing greenhouse gas emissions, intensive use of fossil fuels, and deforestation are severely straining the planet's natural regenerative biological capacity. This situation creates negative impacts such as climate change, reduction in biodiversity, and depletion of natural resources. In this context, determining Türkiye's ecological footprint and the stability of its sub-components is of great importance for environmental sustainability. In this study, which aims to determine whether Türkiye's ecological footprint and its sub-components are stationary or not, the data range of the study includes the years 1961-2022 and consists of annual data. The data were obtained from the official website of the Global Footprint Network (2024). In the study, the Total Ecological Footprint variable (TotalEcoFP) shows the sum of all other sub-footprint components. The sub-components are Carbon Footprint (CarbonFP), Fishing Grounds Footprint (FishingFP), Cropland Footprint (CroplandFP), Build-up Land Footprint (BuildFP), Forest Products Footprint (ForestFP), Grazing Land Footprint (GrazingFP).

This study examines the stationarity of the total ecological footprint and its subcomponents with the FKPSS unit root test developed by Becker et al. (2006) using the Fourier function. Compared to conventional unit root tests, unit root tests with the Fourier approach are more successful in capturing structural changes as they allow for slower and smoother breaks. Moreover, the Fourier function eliminates the need for a priori knowledge of the type (sharp or soft), date, and number of breaks often encountered in unit root analysis. Moreover, this analysis with the unit root test is an essential tool to measure the sustainable effects of environmental policies.

In the analysis of the study, the significance of the trigonometric terms is examined with the help of the F test before analyzing the results of the FKPSS unit root test for the ecological footprint and its sub-components. When the F Test results for the variables were compared with the table critical value at a 5% significance level, it was found that the F-test statistics were greater than the table critical value. It was concluded that the trigonometric terms of all variables were significant, and the FKPSS unit root test could be used in the stationarity test.

According to the results of the FKPSS unit root test, when the FKPSS test statistic is compared with the table critical values at the 5% significance level, the null hypothesis (H_0) that the total ecological footprint, carbon footprint, cropland footprint, and build-up land footprint variables are stationary is rejected, and therefore, these variables are found to be non-stationary (unit rooted) at their levels. This result indicates that shocks permanently affect the total ecological footprint, carbon footprint, cropland footprint, and build-up land footprint variables and that the variables do not tend to return to their average aftershocks; on the contrary, the variables tend towards a new equilibrium point. These results suggest that policies that affect the ecological footprint and some of its sub-components will have long-term and permanent effects. On the other hand, the null hypothesis (H_0) cannot be rejected when the FKPSS test statistic and the table critical values are compared at the 5% significance level for the variables fishing grounds footprint, forest products footprint, and grazing land footprint. Therefore, it is concluded that these variables are stationary at their level values. Hence, it is concluded that the effect of shocks on fishing grounds footprint, forest products footprint, and grazing land footprint variables is transitory. In other words, it is concluded that the variables tend to return to their average after the shocks. The findings of the study support the results of studies in the literature (Ulucak and Lin, 2017; Solarin and Bello, 2018; Alper and Alper, 2021).

It is possible to make various suggestions for reducing the total ecological footprint and increasing resource efficiency in Türkiye. Both policymakers and individuals have various duties to minimize the total ecological footprint. Policymakers should encourage the use of renewable energy sources and the financing of new investments in this field. Individuals' preference for products and services that use renewable energy sources in their daily lives will support efforts to reduce the ecological footprint. Similarly, since fossil fuel-based energy production results in high carbon emissions and environmental pollution, promoting energy efficiency, preferring energy-efficient household appliances, insulation practices in homes, and turning off unused electronics will contribute to reducing the ecological footprint. Improving individuals' eating habits and preferring foods with low environmental impact will contribute to reducing the ecological footprint. Preferring reliable products with shorter life cycles and transparently documented environmental effects can ease the burden on nature. Encouraging and preferring public transportation and direct flights, reducing the use of single-use plastics, and expanding recycling in all institutions will reduce the ecological footprint.

Finally, future studies can focus on the sub-components of the ecological footprint and conduct research specific to these sub-components. Examining different ecological footprint sub-components and analyzing these components' behavior over time will provide important information. Such research will help countries to develop and improve their environmental sustainability strategies.

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