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RESEARCH ARTICLE

Determinants of Ecological Footprint in Türkiye: Evidence from the Fourier ARDL Bounds Test Approach

Mustafa TORUN[1], Cüneyt KILIÇ[2], Ahmet Tayfur AKCAN[3], Müşerref ARIK[4]

ABSTRACT

Ecological footprint calculations evaluate sustainability by examining natural resources. The ecological footprint obtained by calculating the number of natural resources per person provides information about the amount of waste produced as well as the natural resources consumed and examines the sustainability of living conditions in the world in this respect. The ecological footprint is one of the frequently encountered topics in the literature in terms of the analysis of environmental impacts. This study examines the factors influencing the Ecological Footprint in Turkey. Using annual data between 1980 and 2018, the relationship of renewable energy consumption, human capital and urbanization variables to the Ecological Footprint is examined. The Fractional Fourier Augmented Dickey Fuller Unit Root Test and the Fourier Autoregressive Distributed Lag Bound Test is used in the study. There is a statistically significant relationship between the renewable energy, human capital and urbanization variables and the Ecological Footprint. When the outputs obtained in the study are examined, it is seen that the variables affect the ecological footprint. The increased value of these variables can be used to explain why the Ecological Footprint increased. Increasing industrial activities due to globalization and technological developments, increasing vehicle traffic in cities due to population growth, unplanned urbanization and destruction of green areas due to the sheltering needs of the increasing population, inability of recycling facilities to adapt to the increasing population and unplanned waste management, etc. factors can increase the ecological footprint. However, as urbanization increases, if a correct plan is drawn by taking these factors into consideration, the negative correlation between the ecological footprint and urbanization can be explained. Within the determined plan; Wastewater management, protection of green areas, prevention of unplanned urbanization and efficient use of resources are explanatory at this point. The empirical findings have important policy implications. According to these policy implications, to offset the effects on the ecological footprint, educational activities to raise environmental awareness and adopt energy-efficient lifestyles should be given due importance, various incentives and supports should be implemented and a green-based lifestyle.

Keywords: Fourier ARDL, Ecological footprint, Renewable energy consumption

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[1]Assoc. Prof., Çanakkale Onsekiz Mart University, Faculty of Economics and Administrative Sciences/Economics, Çanakkale, Türkiye

[2]Prof. Dr., Çanakkale Onsekiz Mart University, Faculty of Economics and Administrative Sciences/Economics, Çanakkale, Türkiye

[3]Assoc. Prof., Necmettin Erbakan University, Faculty of Applied Sciences/International Trade, Konya, Türkiye

[4]Assoc. Prof., KTO Karatay University, Vocational School of Commerce and Industry/Foreign Trade, Konya, Türkiye

ORCID: M.T. 0000-0003-1812-6560;
C.K. 0000-0003-0622-7145;
A.T.A. 0000-0001-8210-7327;
M.A. 0000-0002-5334-8743

Corresponding author:
Müşerref ARIK,
KTO Karatay University, Vocational School of Commerce and Industry/Foreign Trade, Konya, Türkiye
E-mail: muserref.arik@karatay.edu.tr

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1. Introduction

The term ecological footprint (EF) has become the subject of many academic studies on the impact of globalization and the importance of environmental sustainability. The variable of EF investigates the efficient use of natural resources by determining the natural resources with the aim of ensuring environmental sustainability. Because of the research, the natural resource consumption per capita is evaluated. The calculations obtained because of this evaluation also provide statistical data for the studies carried out for the effective use of resources. In determining the EF, not only the resources consumed but also the amount of waste released into the environment per capita is evaluated. From this viewpoint, it can be stated that EF provides output on environmental sustainability by evaluating the relationship between per capita natural resource consumption and waste generation. When the beginnings of EF studies, which are frequently included in the literature, are examined, the research of Rees (1990) and Wackernagel (1994) evaluated the importance of EF, which is one of the most important issues of today.

Although several different variables are used in EF studies in the literature, intensity is observed in the studies on certain variables. Among these variables, renewable energy and fossil fuel consumption have an important place. The impact of renewable energy consumption (REC) on reducing the EF and fossil fuel consumption on increasing the EF is explained. While almost all studies include related variables, this study examines the concepts of trade openness and economic growth as well as urbanization (URB).

Among the studies examining the variables in question, Amin, Song & Shabbir(2022) study, in which G-11 countries were evaluated between 1991 and 2018 and the URB variable was also examined, can be given as an example. The study finds that URB, economic expansion and trade have an impact on environmental problems, while the increase in REC has a mitigating impact on overall environmental degradation. In addition to this study, studies examining the nuclear energy variable are found in the literature. Ahmed, et al. (2022)

examined the countries of the Asia-Pacific region with panel data analysis, Sadiq, et al. (2022) examined 16 OECD countries with both panel data analysis and ARDL, while Jin and Kim (2018) used the nuclear energy variable while examining 30 OECD countries. In fact, research is establishing the link between nuclear energy and pollution and the EF. This study examines the relationship among 4 dependent variables and 1 independent variable.

When the studies within the literature are analyzed, it is seen that there is a high level of similarity between the variables and these variables are repeated in the studies. Although this is the case in terms of variables, it has been determined that traditional analysis methods are widely used in the tests applied. This study was carried out using the Fourier ARDL test, which is the most current version of the ARDL test and takes structural breaks into account.

Pesaran, Shin & Smith (2001) introduced the ARDL cointegration test. The fact that the analysis method detects the cointegration relationship between variables has enabled the study to form the basis of academic research since 1995. The analysis method developed within the scope of the study investigates the connection between variables by taking long-term lags into account. The research can provide long-term predictions. By analyzing the consistency levels of the coefficients, it can be stated that the ARDL cointegration test has an important place in the literature (Pesaran and Shin, 1995).

While performing the analysis with the ARDL test, it is aimed to minimize the margin of error in the outputs obtained by including F and t statistical values in the analysis. The ARDL test was developed in 2020, and the Fourier version was introduced to the literature and applied as the Fourier ARDL test. The Fourier ARDL test contributes to the analyses in that it is not a prerequisite for stationarity. The use of dummy variables is another difference in methodology (Yılancı, Bozoklu & Gorus 2020).

In this study, the fractional Fourier ADF and Fourier ARDL tests were used to make an analysis for Turkey. This study evaluated the correlation between the EF

(dependent variable) and the independent variables of REC, HC, and URB between 1980 and 2018.

The most up-to-date ARDL analysis in the literature is the Fourier ARDL test applied in the study. This stated situation reveals the importance of this study in the literature as it minimizes the margin of error with the current tests. The Fourier ARDL test to be applied within the scope of the study can be expressed as the most up-to-date ARDL analysis in the literature. The test contributes to the literature by minimizing the margin of error. The fact that the study examines Turkey as a sample can be explained by the rapidly increasing population growth of Turkey, which maintains its status as a developing country and is set to continue to increase with its high migration potential, the expansionary orientation in industrialization and industrial activities, increasing HC accumulation and energy transformation. As a matter of fact, the fact that Turkey is under the influence of all these factors strengthens the threat of EF. The study aims to analyze the relationship between HC, EF, use of REC and URB.

The study is completed in 5 sections. Following the introductory part of the study, the literature review section of the study examines and evaluates the work of people who have worked in the field. In the third part of the study, formulas for the analysis methods used in the study are given and information about the applied methods is provided.

The empirical outputs section expresses the outputs obtained by applying the formulas given in the third part of the study to the relevant variables, and the final evaluation is included in the conclusion section of the study.

2. Literature Review

Several studies in the literature have examined the relationship between the Ecological Footprint (EF), Human Capital (HC), Urbanization (URB), and renewable energy consumption (REC). Although quantitative data analysis is generally used in studies, the studies are designed to statistically evaluate the level of relationship

Table 1: Literature Review of Articles

Research Topic	Author(s) (Date)	Investigation Period	Researched Country/ Country Group	Method	Variables	Results
The aim is to examine the convergence of the Ecological Footprint across the countries studied.	Bayraktar et al., (2023)	1992-2017	BRICS-T	Fractional Frequency Fourier ADF	Ecological Footprint	The convergence results of the ecological footprint vary depending on the tests applied.
The value of biomass use as a renewable energy source in sustainable development is examined.	Asghar et al., (2023)	1990-2017	21 Asian Countries	Panel Data Analysis Cointegration Tests	Biomass Energy Consumption Sustainability Development	The results show that using biomass as a renewable energy source has a positive impact on sustainable development.
The objective of this study is to analyze the impact of green finance on carbon intensity.	Gan and Voda. (2023)	2004-2019	30 Provinces of China	Panel Data Analysis	Carbon Emission Green Finance	It is determined that Green Finance can directly lower the intensity of carbon emissions.
The objective of the study is to analyze the impact of environmental regulations on the GTFP.	Jin, Gao & Pan (2023)	2003-2020	Provinces of China	Endogeneity Tests Robustness Tests	HC	It is considered necessary for the government to invest in creating a favorable ecological environment and adjusting environmental regulations for regional sustainable development.

Table 1: Continue

Research Topic	Author(s) (Date)	Investigation Period	Researched Country/ Country Group	Method	Variables	Results
The aim of this study is to analyze the contribution of renewable and non-renewable energy sources to sustainable development.	Islam, et al. (2022)	1980-2018	ASEAN Countries	PMG FMOLS DOLS CCR	Non-Renewable Energy Renewable Energy Sustainable Development	
This study examines trade openness, energy use, urbanization, economic development and environmental impact.	Amin, et al. (2022)	1991-2018	G11 Countries	Panel Cointegration Test Panel Unit Root Test	Urbanization Economic Growth Trade Openness	Urbanization, economic expansion and trade trigger environmental problems. Increased consumption of renewable energy reduces overall environmental damage.
The aim is to determine the relationship between the variables.	Sun et al. (2022)	1997-2017	China	Panel Data Analysis Durbin Model	REC Carbon Emission	REC and CO2 emissions are negatively correlated.
The aim was to examine the correlation between the variables and to assess the effect.	Ahmed et al., (2022)	2001-2019	Asia Pacific Region	Panel Co-Integration	Nuclear Energy Consumption Carbon Footprint Climate Change	There is a bidirectional causality correlation between the variables.

Table 1: Continue

Research Topic	Author(s) (Date)	Investigation Period	Researched Country/ Country Group	Method	Variables	Results
Assessing the relationship between renewable energy and support schemes is the aim of this study.	Boluk and Kaplan (2022)	2000-2018	EU Countries and Turkiye	Panel Data Analysis	REC Sustainability	According to the variables, the impact on the diffusion of renewable energy varies.
Examining the relationship between variables and human development is the aim of this study.	Sadiq, et al. (2022)	1990-2019	16 OECD Countries	Panel Data Analysis ARDL	Nuclear Energy Consumption Trade Globalization Development	The impact on HC varies according to the variables.
This study examines the relationship between the variables.	Hassan et al., (2022)	1990-2020	16 OECD Countries	Empirical Analysis	Carbon Emission Carbon Footprint Income	Energy efficiency, renewable energy, and technological advantages have a positive relationship with environmental quality.
This study examines the relationship between the variables.	Nathaniel, Yalçıner & Bekun (2021)	1992-2016	BRICS Countries	Empirical Analysis	Natural Resources Renewable Energy Human Capital Ecological Footprint Urbanization	Economic growth and increased use of natural resources increase the EF, while renewable energy reduces it.
The aim of this study is to explore the impact of renewable and non-renewable energy, natural resources, human capital (such as education or skills) and globalisation on the ecological footprint of developing countries.	Sahoo, et al. (2021)	1990-2016	36 Developing Countries	FMOLS DOLS	Renewable Energy Non-Renewable Energy Natural Resources Human Capital Globalization	The results show that non-renewable energy, depletion of natural resources and urbanisation increase the ecological footprint of developing countries and degrade the environmental quality.

Table 1: Continue

Research Topic	Author(s) (Date)	Investigation Period	Researched Country/ Country Group	Method	Variables	Results
It examines the environmental consequences of urbanization, trade, and economic expansion.	Nathaniel (2021)	1971-2014	Indonesia	ARDL	Urbanization Economic Growth Trade Ecological Footprint	Trade reduces environmental quality in the short run, but economic expansion, energy use, and urbanization have consistent long-term effects. In addition, urbanization, economic expansion, and energy use increase environmental degradation.
This study is designed to investigate how economic growth, globalization and energy consumption affect CO2 emissions and their environmental impact.	Pata (2021)	1980-2016	USA	EKC Hypothesis	Globalization Renewable Energy Non-Renewable Energy Carbon Emission Ecological Footprint	Globalization and REC are effective in reducing pollution. In addition, the use of non-renewable energy contributes to environmental pressure.
The aim was to examine the relationship between CO2 emissions and REC.	Hsu (2021)	1990-2018	Taiwan	Empirical Analysis	Energy Consumption Economic Growth CO_2 Emission	No relationship could be found between renewable energy and CO_2 emissions.
This study aimed to evaluate the validity of the EKC hypothesis for the ecological footprint, considering the effects of REC.	Destek,and Sinha (2020)	1980-2014	24 OECD Countries	EKC Hypothesis	Ecological Footprint Trade Openness Renewable Energy Non-Renewable Energy Economic Growth	There is a U-shaped relationship between economic development and the environmental footprint. The increase in the use of renewable energy reduces the ecological footprint.

Table 1: Continue

Research Topic	Author(s) (Date)	Investigation Period	Researched Country/ Country Group	Method	Variables	Results
This study examines the relationship between fossil fuel consumption and CO_2 emissions.	Ayompe, Davis & Egoh(2020)	1990-2017	African Countries	Vector Error Correction Model Johansen Co-integration Test	Carbon Dioxide emission Economic Growth	Population growth and the decline in GDP are found to have a negative impact on CO2 emissions.
The aim is to examine the variables that have an impact on carbon emissions.	Jin and Kim (2018)	1990-2014	30 OECD Countries	Panel Co-Integration Analysis Granger Causality	Nuclear Energy Consumption REC Carbon Emission	There is a relationship between the variables. The use of renewable energy positively affects CO_2 emissions.
It is designed to assess the relationship between the variables.	Apergis and Payne (2014)	1980-2011	25 OECD Countries	Panel Data Analysis	Renewable energy consumption Carbon Dioxide emission	It has been determined that there is a feedback relationship between REC and carbon emissions.
This study examines the variables that impact energy efficiency and the ecological footprint in China.	Chen, and Lin (2008)	1953-2006	China	EMD	Ecological Footprint	The study argues that China should prioritise stabilising economic growth, optimising its industrial structure, regulating domestic oil consumption and improving transport efficiency.

between variables. The literature studies selected a large sample from the 1980s to the 2020s and examined the variable relationship between the relevant years.

The table shows the objectives, authors, sample year range, countries/country groups, empirical tests applied, variables used and results obtained in some of the studies conducted in the literature on the related subject. The studies in the table are compiled by considering the current research published between 2008 and 2023. The high number of publications in the relevant years also provides information about the importance and timeliness of the subject.

When examining the studies that express the relationship between the variables; Jin and Kim (2018) examined 30 OECD countries, Ayompe, Davis & Egoh (2020) African countries, Hsu (2021) Taiwan, Hassan, et al. (2022), Sadiq, et al. (2022) 16 OECD countries, Boluk and Kaplan (2022) EU In the study between countries and Turkiye, Ahmed (2022) Asia, Sun, et al. (2022) China and Amin (2022) determined the correlation between the different variables included in the study in which he studied the G11 countries. Although the positive effect is evaluated in studies conducted in developed countries, the effect can be observed as negative in developing and underdeveloped countries. The fact that integration with REC has not yet been fully achieved explains this situation. Failure to achieve full integration may prevent the effect from being positive.

Although the positive effect is evaluated in studies conducted in developed countries, the effect can be observed as negative in developing and underdeveloped countries. This situation can be explained by the fact that integration with REC has not been fully achieved yet, and failure to ensure full integration may prevent the effect from being positive. From this point of view, the variables analyzed in this study and those in the literature are similar. Although the variables are similar, the tests used in the study differ from the tests applied by other studies in the literature.

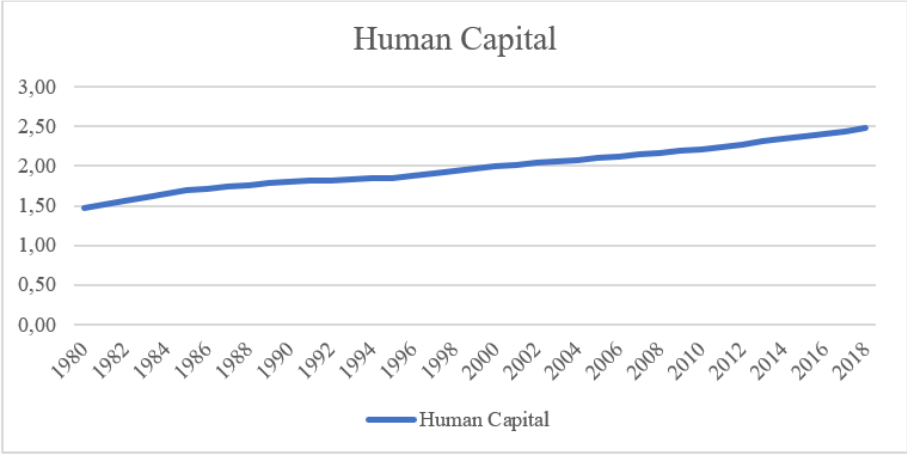
Panel Co-integration Test (Jin and Kim, 2018; Ahmed et al., 2022; Amin et al., 2022), Panel Data Analysis (Apergis and Payne, 2014; Sadiq et al., 2022; Boluk and

Kaplan, 2022; Sun, et al., 2022; Amin, 2022; Asghar, 2023; Gan, 2023), Granger Causality Test (Jin and Kim, 2018), Johansen Co-integration Test (Ayompe,Davis & Egoh 2020), Fractional Frequency Fourier ADF (Bayraktar et al., 2023) and ARDL bounds test (Nathaniel et al., 2021; Sadiq et al., 2022) have been applied in the studies on the subject. However, the Fourier ARDL test was not found in the tests applied in the studies. Fourier analysis is the most up-to-date test in the field and gives the most accurate results in applications with its structure that minimizes the margin of error. In this direction, it is thought that this study will contribute to the literature by applying the Fractional Frequency Fourier ADF and Fourier ARDL.

3. Data and Methodology

Although scholars started discussing the concept of EF in the 1980s, Wackernagel and Rees, (1996) measured the concept. For this reason, the year range of the study starts from 1980, when the subject was first started to be analyzed. Therefore, in this study, we evaluate the data of Turkey between 1980 and 2018. In this section of the study, we express the data of the variables to be analyzed graphically.

Figure 1: Human Capital Ratio by Years (1980-2018)



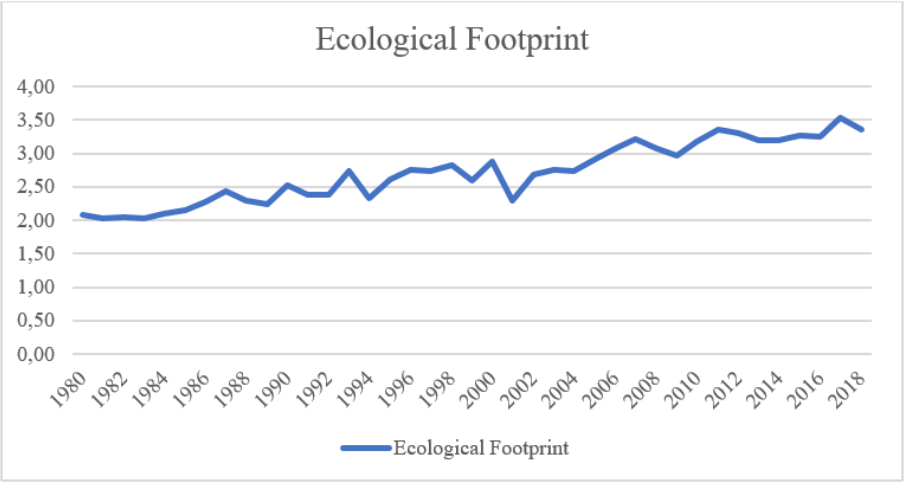
Source: (PennWorld Table, version 10.0. Economic)

The figure shows the values of the HC variable from 1980 to 2018. This variable, which is addressed in many studies in the field, is becoming increasingly important due to the increasing impact of globalization. When the idea of HC is evaluated descriptively, it can be defined as capital that supports knowledge-based development while fulfilling production tasks. The concept, which is a type of knowledge capital, shows an important activity at the point of intellectual development.

Figure 1 shows that HC started to increase with globalization in 1980. When looked at proportionally, the HC ratio, which was 1.46 in 1980, was calculated as 2.47 in 2018. When examined by years, there is no break in the increase. This shows that there is a stable increase.

EF is another issue to be examined in the study. EF data per capita is considered for analysis in the study. Although the increase in the amount of EF can be the result of the inefficient use of natural resources and the high amount of waste, reducing the value can be achieved with a planned environmentalism approach. Figure 2 shows the change in EF (per person) from 1980 to 2018.

Figure 2: Ecological Footprint Ratio per Person by Years (1980-2018)



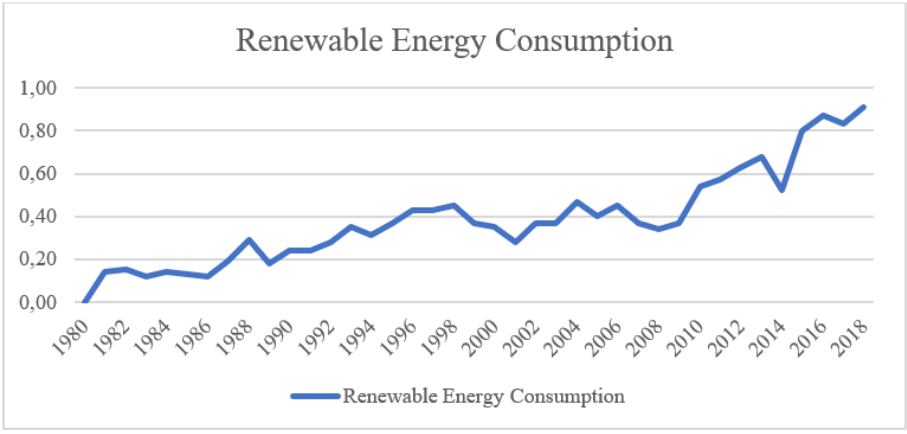
Source: (Global Footprint Network)

The course of the per capita EF value, which is another variable frequently examined in the literature and considered within the scope of the study, between 1980 and 2018 is shown in Figure 2. Although the figure shows that the EF value is between 2.00 and 3.50 on average, it can be interpreted that the value increases from year to year. The reason for this situation is the acceleration of globalization, increasing population, infrastructure problems, deficiencies in environmental planning, etc. multiple factors can be shown.

When the studies in the literature are examined, it is seen that there is more than one study examining the EF. In the study by Mattila (2012) examining sustainability in the relationship between EF and economic growth, the development of eco-efficiency between 2002 and 2005 is mentioned. In addition, the impact of consumption activities on the environment is also included in the scope of the study. In contrast, Chen, Lee & Chen (2022) examined HC and URB as components of the EF in their study.

Another variable to be analyzed is the REC. Besides the fact that energy consumption is at a high rate for countries, energy consumption in Turkey is provided from more than one source. These sources include wind energy, solar energy, geothermal energy, biomass energy, etc. is located. Turkey, a country that not only produces but also consumes energy, is still dependent on foreign sources for energy. Although there are fossil-based types among the energy types that increase the EF, countries tend to reduce their EF rates by not adopting the understanding of environmental sustainability. At this point, it can be stated that the increase in REC has a reducing impact on the EF. In the evaluation made for Turkey, it is determined that REC constituted 11.9% of the total energy consumption in 2018 (World Bank, 2022).

Figure 3: Per Capita Energy Consumption from Renewables (1980-2018)



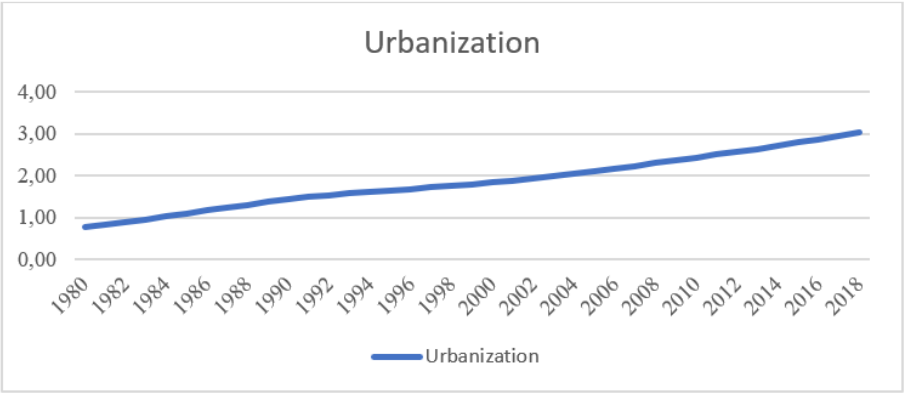
Source: (Our World in Data, 2022)

When Figure 3 is analyzed, it is seen that the data on per capita REC are given for the years 1980-2018. Since high fossil energy has a negative impact on the EF, it is deemed appropriate to evaluate the amount of renewable energy consumed per capita in this study. With this assessment, the impact of increases and decreases in per capita REC on CO_2 emissions should be analyzed.
When the figure is examined, it is seen that the series constantly experiences sudden increases and decreases. The lack of full compliance with the new energy consumption explains this situation

The last variable whose values are expressed in Figure 4 is URB. Because of the increase in unplanned URB, environmental pollution, infrastructure problems, water scarcity, etc. factors can negatively affect the EF.

Based on this idea, URB statistics between 1980 and 2018 are examined within the scope of the study. These variables were obtained from the World Bank database. The values are expressed under the heading of world development indicators and defined as "urban population growth" variable.

Figure 4: Urbanization Ratio by Years (1980-2018)



Source: (World Bank, 2022)

When the URB variable is examined, it can be stated that this variable has shown a more stable increase over the years and has experienced less decline than the EF and REC variables. This situation shows that the URB continues to increase. The ratio, which was between 0.77 and 0.82 in 1980, accelerated with the influence of globalization and experienced periods of decline, but was determined to be 3.02 in 2018.

It is aimed to examine the relationship between HC, EF, REC and URB by considering the data from 1980 to 2018 between the values in the figures and the variables to which the values belong. Fourier ARDL and Fractional Frequency Fourier ADF unit root tests were used to analyze the variables under study. In this study, the Fourier ARDL cointegration test, which is the most advanced version of the ARDL cointegration test, is applied. This test aims to minimize the margin of error.

In addition to applying the Fourier ARDL test in the study, the Fractional Frequency Fourier ADF, which is an improved version of the Fourier ADF, was also among the tests applied. The critical values in the tests included in the study were evaluated considering the data obtained from the Bozoklu, Yılancı and Gorus (2020) study.

Fourier ADF analysis is discussed for the first time in the literature by Enders-Lee (2012). The analysis differs from other studies in the literature in that it adds sine and cosine values to the calculations. Taking the relevant values into consideration is important in minimizing the margin of error in the analysis.

The formulation of the Fourier ADF analysis.

$$\Delta yt = c_0 + c_1 \sin\left(\frac{2\pi kt}{T}\right) + c_2 \cos\left(\frac{2\pi kt}{T}\right) + c_3 y_{t-1} + \sum_{i=1}^{p} a_i \Delta y_{t-i} + e_t \quad (1)$$

The "Fractional Frequency Fourier Augmented Dickey Fuller Unit Root Test" by developing frequency values in the FADF (Bozoklu, Yılancı and Gorus, 2020), which takes into account the sine and cosine values and minimizes the margin of error. The test formulation is shown in equation (2).

$$y_t^* = \alpha_0 1_t^* + \beta_0 t_t^* + \lambda_1 \sin_{1,t}^* + \lambda_2 \cos_{1,t}^* + u_t, \quad t = 1,2,3,\dots,T \quad (2)$$

Within the scope of the research, researchers first apply the Fourier ADF test, followed by the Fourier ARDL cointegration test. Pesaran et al. (2001) report the ARDL method in the literature. Although Pesaran, Shin and Smith (2001) introduced the ARDL test, Yılancı, Bozoklu and Gorus (2020) use its Fourier version. To use the test with the smallest margin of error, the series must first be stationary at first order and then the best lag length must be calculated.

The ARDL bounds test developed by Pesaran, Shin and Smith (2001) can be written in error correction notation as in Equation 3.

$$\Delta \mathrm{FP}_t = \beta_0 + \beta_1 FP_{t-1} + \beta_2 EC_{t-1} + \beta_3 FDI_{t-1} + \sum_{i=1}^{p-1} \varphi_i' \Delta \mathrm{FP}_{t-i} + \sum_{i=1}^{p-1} \delta_i' \Delta \mathrm{EC}_{t-i} + \sum_{i=1}^{p-1} \emptyset_i' \Delta \mathrm{FDI}_{t-i} + e_t \quad (3)$$

The Fourier ARDL test is defined as follows. First, instead of using dummy variables, the following Fourier function was used.

$$d(t) = \sum_{k=1}^{n} a_k sin\left(\frac{2\pi kt}{T}\right) + \sum_{K=1}^{N} b_k \cos\left(\frac{2\pi kt}{T}\right) \quad (4)$$

The study followed Becker, Enders and Lee (2006) and Ludlow and Enders (2000) and allowed a single frequency as follows.

$$d(t) = y_1 sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) \quad (5)$$

Yılancı, Bozoklu and Gorus (2020) obtained the following equation (Equation 6) by including the Fourier expansion in Equation 3.

$$\Delta \mathrm{FP}_t = \beta_0 + y_1 sin\left(\frac{2\pi kt}{T}\right) + y_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 FP_{t-1} + \beta_2 EC_{t-1} + \beta_3 FDI_{t-1} + \sum_{i=1}^{p-1} \varphi_i' \Delta \mathrm{FP}_{t-i} + \sum_{i=1}^{p-1} \delta_i' \Delta \mathrm{EC}_{t-i} + \sum_{i=1}^{p-1} \emptyset_i' \Delta \mathrm{FDI}_{t-i} + e_t \quad (6)$$

There are 4 different constraints that need to be examined in the formula. These are expressed in stages (i), (ii), (iii), and (iv), respectively.

(i) If F_A, F_B, and t are substantial, HC, EF, REC, and URB have a co-integration connection.
(ii) There is no co-integration connection between HC, EF, REC and URB if FA, FB and t are meaningless.
(iii) If F_A and F_B are substantial but t is not, the first degenerate condition is observed.
(iv) A second degenerate scenario is encountered if F_A and t are large but F_B is not.

It is considered necessary to arrange the formulas according to the variables to be examined in the tests to be applied.

The empirical findings of the research are stated in the following section of the study using the above formula.

4. Empricial Findings

This part of the study presents the outputs obtained after the application of the analysis methods stated in the third part to the variables within the study. In this section, the outputs are expressed and interpreted in tables.

Table 2: Descriptive Values of the Variables

	Ecological Footprint	Human Capital	Renewable Energy Consumption	Urbanization
	EF	HC	REC	URB
Mean	2.711282	1.979639	0.390825	1.852174
Median	2.730000	1.967192	0.372533	1.795092
Maximum	3.530000	2.479055	0.91456	3.023012
Minimum	2.020000	1.469023	0.121835	0.778726
Std. Dev	0.444357	0.270363	0.213304	0.631002
Skewness	0.028978	0.063024	0.853878	0.117164
Kurtosis	1.786051	2.109632	3.133269	2.056058
Jargue-Bera	2.400177	1.314045	4.768059	1.537147
Proability	0.301168	0.518393	0.092178	0.463674
Sum	1.057400	7.720590	1.524217	7.223480
Sum Sq. Dev	7.503236	2.777655	1.728951	1.513021
Observations	39	39	39	39

The above information includes multiple information such as the minimum and maximum values of variables, probability values, mode and median values. The expressed values are important in terms of being descriptive. Table 3 is important for determining the ADF test results and the degree to which the series is stationary.

Table 3: Fractional Frequency Fourier ADF Test Results

Variables	k	Min KKT	FFADF Test Statistic	Optimal Lag Length	F Test Statistics	FFADF %1 Critical Value	FFADF %5 Critical Value	FFADF %10 Critical Value
EF	0.1	0.726591	3.682082	1	6.440704	-4.87987	-4.26469	-3.95616
ΔEF	3.8	0.954480	7.211575	1	2.026829	-4.32422	-3.65693	-3.31667
HC	0.2	0.001475	-2.663442	6	4.348617	-4.87804	-4.2659	-3.96258
ΔHC	2.4	0.000950	-2.623264	9	4.842245	-4.57925	-3.91711	-3.5715
ΔΔHC	2.4	0.001128	-5.488755	9	1.352868	-4.57925	-3.91711	-3.5715

REC	0.1	0.177583	-1.964921	1	3.103442	-4.87987	-4.26469	-3.95616
ΔREC	5	0.181258	-8.504023	0	2.366425	-4.21133	-3.5507	-3.22669
URB	1.3	0.002067	3.026177	9	3.091448	-4.96172	-4.35584	-4.04304
ΔURB	1.1	0.000927	-6.293324	9	53.93319	-4.98567	-4.36093	-4.05824

Note: Based on the values obtained from the study of Bozoklu, Yılancı and Gorus. (2020), the constraint values of the frequencies at 1%, 5% and 10% significance levels respectively; -4.87987, -4.26469, -3.95616 for 0.1; -4.87804, -4.2659, -3.96258 for 0,2; -4.98567, -4.36093, -4.05824 for 1,1; -4.96172, -4.35584, -4.04304 for 1,3; -4.57925, -3.91711, -3.57015 for 2,4; -4.32422, -3.65693, -3.31667 for 3,8 and -4.21133, -3.5507, -3.22669 for 5.

In the table, the stationarity levels of the variables used in the study are examined and the FFADF test is used for the analysis. In the table, Fractional Frequency Fourier ADF (FFADF) test statistical values and F Test statistical values of EF, HC, REC and URB variables are evaluated and the extent to which they are stationary is determined. In the table, frequency values of 4 variables (k), min. KKT, FFADF test statistic value, optimal lag length, 1%, 5%, and 10% significance levels.

First, when the EF is examined, it is seen that the FFADF test statistic value of the series, 3.682082, is smaller than the values at 1%, 5% and 10% significance levels. Accordingly, the series is non-stationary and contains a unit root. In this case, the series should be different until stationarity is achieved. When the series is differenced at first order, the FFADF test statistic value of 7.211575 is greater than the significance levels of 1%, 5%, and 10%. This indicates that the series has no unit root and is stationary at the first difference.

The HC series with the FFADF test statistic value of -2.663442 is smaller than the reference values. Accordingly, while the series is non-stationary, the FFADF test statistic value is lower than the 1%, 5%, and 10% significance levels when the series is taken at the first difference, indicating that the series is non-stationary at the first degree. When the second difference of the HC series is taken, the FFADF test statistic value is greater than the constraint values, indicating that the series has become stationary.

The other variable to be analyzed is the REC variable. The fact that the FFADF test statistic value of -1,964921 at the level value of the variable is smaller than the

indicates levels of significance that the series is not stationary at the level value, while it can be said that the series reaches stationarity when the first degree difference of the series is taken.

The last of the variables is tested as the URB. When the URB variable was analyzed at the level value, the FFADF test statistic value was calculated as 3.026177. When the value is compared considering the significance levels, the value calculated at all three significance levels is found to be smaller than the constraint value. This indicates a unit root in the series and the series is not stationary. When the first difference in the series is taken, the FADF test statistic value of -6.293324 is greater than the 1% significance level. This indicates that the series is stationary at the first difference.

Table 4: Fourier ARDL Test Results

AIC	*FA*	*Bootstrap Critical Values*			*t*	*Bootstrap Critical Values*			*FB*	*Bootstrap Critical Values*		
		%10	*%5*	*%1*		*%10*	*%5*	*%1*		*%10*	*%5*	*%1*
-1.201523	7.198145**	5.517701	6.470723	9.317924	-5.329036***	-4.028064	-4.361360	-5.245762	9.352838**	5.936553	7.184694	10.25311

Note: It is analyzed by considering the constraint values obtained from the study of Yılancı, et al. (2020).

Table 4 shows that the test findings are expressed using the Bootstrap Estimator and the F and t statistical values are evaluated considering the Akaike Information Criterion. When the statistical significance of FA is examined, it is seen that the significance level of 7.198145 is higher than the 5% and 10% significance levels. Additionally, the value is greater than 9.317924 at the 1% significance level. When the t-statistic value of -5.329036 is examined, it can be stated that the value is greater than the significance level.

When the F_B statistical value (9.352838), which is another statistical value, is examined, it is observed that the series is greater than 5.936553 at the 10% significance level and 7.184694% at the 5% significance level, and the same value is less than 10.25311 at the 1% significance level.

Table 5 emerges when the long-term forecast findings are evaluated.

Table 5: Long-Term Forecast Results

Variable	Coefficient	Stnd. Error	t-statistic	Probability
HC	5.823631***	1.802481	3.230898	0.0029
REN	0.746312***	0.258238	2.890019	0.0069
URB	-2.024339**	0.820680	-2.466661	0.0192
C	-5.349208**	2.120874	-3.963105	0.0168

Note: While performing the evaluation, the probability value is compared with the constraint value of 0.05.

When the long-term estimation results are examined, it can be said that the probability value for HC (0.0029), REC (0.0069) and URB (0.0168) is significant on the EF nt. This shows that REC, HC and URB affect the EF. Looking at the long-term coefficients, a 1% increase in human capital leads to a 5.82% increase in EF. In addition, a 1% deviation in REC changes 0.74%. The last variable, a 1% change in URB, has an effect of -2.02% on the EF.

5. Conclusion and Discussion

There has been a significant increase in EF due to increasing globalisation, population growth and inadequate regulation for the growing population. Although the inadequacy of policies towards population is effective in more than one field, it can be expressed within the scope of environmental planning. Regulations that do not progress in integration with the population in terms of adapting to the increasing population have caused population growth to lead to unplanned URB. The increase in migration from rural areas to cities with population growth can also be a reason for this situation.

In addition to the unplanned URB, the failure to plan the resource consumption of the increasing population constitutes another pillar of environmental problems. The increase in the use of vehicles in cities due to population growth leads to infrastructure problems on the basis of traffic problems. Although the aforementioned problems are some factors that cause the EF to increase, more than one variable affecting the EF is examined in the literature. In this study,

renewable energy, human HC, and URB variables, which are among the variables affecting the EF, are examined.

Among these, many variables such as URB, openness to trade, economic growth, renewable energy and HC play a crucial role. This study identifies renewable energy, HC, and URB as some variables that influence the EF. Using annual data between 1980 and 2018, the relationship between REC, HC and URB variables and the EF is examined. FFADF tests and FARDL tests are used in this study. When the long-term estimation results of the study are examined, it has been revealed that the probability value of the EF for HC (0.0029), REC (0.0069), and URB (0.0168) is significant. There is also a positive relationship between HC and EF. Looking at the long-term coefficients, a 1% increase in HC causes a 5.82% increase in the EF. These results are very important for policy makers. There is a need to follow various policies to increase the environmental awareness of HC. In this regard, adding issues related to the environment and climate change to the curriculum can support the sustainability of resources at the individual level. HC development should be supported for adopting energy-saving lifestyles such as green technology innovation and environmentally friendly transportation habits. Further efforts should be made to balance the impact of population size on the EF through various incentives and subsidies.

On the other hand, statistically significant relationships were found between REC and EF. A 1% change in REC reduces the EF by 0.74%. The reason for this situation may be that renewable energy does not pollute the environment and has a reducing effect on fossil fuel consumption. In terms of environmental protection, REC can reduce the EF in addition to conventional energy consumption.

Therefore, innovations in renewable energy technologies are effective in reducing the negative impact of energy consumption on the environment. More budget should be allocated to R&D expenditures in renewable energy projects. Turkey is rich in renewable energy resources. For this reason, R&D support should be provided to enterprises in the country that prioritise research in this field. Investments in the field of renewable energy should be increased by giving due

importance to resource transfer in order to investigate the potential of renewable energy resources in detail. Private sector and government cooperation should set enforceable mandatory renewable energy targets.

Another result of the study is the existence of a negative relationship between URB and EF. It has been determined that a 1% change in URB has an effect of -2.02% on the EF. It has been determined that the increase in URB has positive effects on the environmental quality. Factors such as the increase in the educated population brought about by URB, the increase in environmental awareness, and the increase in the importance given to green technologies have caused URB to reduce its EF. Therefore, it can be stated that activities such as increasing investments in environmentally friendly technologies, implementing various tax policies and giving due importance to educational activities to raise environmental awareness increase the positive impact of URB on environmental quality. To increase the positive effects of URB, practises that adopt a sustainable lifestyle in many areas such as recycling, smart cities, environmentally friendly food consumption, and the use of renewable energy vehicles should be implemented. Efforts to increase the environmental quality of URB should be continued and even increased.

As a result, when the relationship between EF and REC, HC and URB is considered in general, it is determined that in order to balance the effects of these variables on EF, environmental awareness should be increased, educational activities should be given importance, various incentives and subsidies should be applied and a green-based economy should be targeted with selective taxation procedures. In addition, it is thought that increasing the number of studies examining the impact of EF on the economy will increase awareness in this field.

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