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***Research Article***

# Analysis of The Interaction between Ecological Footprint, Green Technology and Financial Development in Türkiye: Evidence from Fourier ARDL Approach

*Türkiye'de Ekolojik Ayak İzi, Yeşil Teknoloji ve Finansal Kalkınma Arasındaki Etkileşimin Analizi: Fourier ARDL Yaklaşımından Kanıtlar*

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***Abstract***

*Since the 1990s, the importance of concepts such as green technology, financial development and ecological footprint has increased in the economic literature; this situation has revealed the necessity of efforts to ensure environmental sustainability. This study uses the Fourier ARDL approach to investigate the relationships between ecological footprint (EFP), green technologies (GRE) and financial development (FIN) in Turkey in the period 1992-2021. The causality relationship between the variables was examined with traditional and Fourier causality tests. In addition, FMOLS, DOLS and CCR coefficient analyses were applied in order to see the long-term effects of independent variables. In addition to the results showing the existence of a long-term relationship, a one-way causality relationship from financial development to ecological footprint and from ecological footprint to green technologies was reached. The coefficient test results show that green technologies have a positive effect on reducing the ecological footprint; while financial development increases the ecological footprint. In light of the findings of the study, it is concluded that investments in green technologies should be increased in order for Turkey to achieve its sustainable economic growth targets. It is important that the steps to be taken to reduce the ecological footprint are not limited to technological innovations; the financial system should also be structured in a way that encourages environmentally friendly investments.*

***Keywords:*** *Ecological footprint, Green Technologies, Financial development, Türkiye, Fourier ARDL*

***Öz***

*1990'lardan itibaren iktisat literatüründe yeşil teknoloji, finansal gelişim ve ekolojik ayak izi gibi kavramların önemi artmış; bu durum çevresel sürdürülebilirliği sağlama çabalarının gerekliliğini ortaya koymuştur. Bu çalışma, Türkiye'de 1992- 2021 döneminde ekolojik ayak izi (EFP), yeşil teknolojiler (GRE) ve finansal gelişme (FIN) arasındaki ilişkileri araştırmak amacıyla Fourier ARDL yaklaşımını kullanmaktadır. Değişkenler arasındaki nedensellik ilişkisi geleneksel ve Fourier nedensellik testleri ile incelenmiştir. Ayrıca bağımsız değişkenlerin uzun dönemli etkilerini görebilmek adına FMOLS, DOLS ve CCR katsayı analizleri de uygulanmıştır. Uzun dönemli ilişkinin varlığını ortaya koyan sonuçların yanında finansal gelişmeden ekolojik ayak izine, ekolojik ayak izinden ise yeşil teknolojilere doğru tek yönlü nedensellik ilişkisine ulaşılmıştır. Katsayı test sonuçları, yeşil teknolojilerin ekolojik ayak izini azaltma yönünde olumlu bir etki yarattığını göstermekteyken; finansal gelişimin ise ekolojik ayak izini artırdığı yönündedir. Çalışmanın bulguları ışığında Türkiye'nin sürdürülebilir ekonomik büyüme hedeflerine ulaşabilmesi için yeşil teknolojilere yapılan yatırımların artırılması gerektiği sonucuna varılmaktadır. Ekolojik ayak izinin azaltılması adına atılacak adımların yalnızca teknolojik*

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*yeniliklerle sınırlı kalmaması; aynı zamanda finansal sistemin de çevre dostu yatırımları teşvik edecek şekilde yapılandırılması önem arz etmektedir.*

***Anahtar Kelimeler:*** *Ekolojik ayak izi, Yeşil teknolojiler, Finansal gelişme, Türkiye, Fourier ARDL*

## Introduction

It is observed that green technology, ecological footprint, sustainable growth and similar terms have started to appear in the economics literature since the 1990s. This situation brings to mind the question 'What kind of damage has mankind caused to nature throughout history that these concepts have been included in our lives?'. In this context, first of all, it should be stated that the destruction of human beings on nature dates back to ancient times, but the effects of this destruction have begun to be felt clearly and severely in the modern period. When we consider the destruction of human beings on nature from a historical and doctrinal perspective, it is seen that the concept of 'sustainability' (Nachhaltigkeit) first appeared in 1713 in the work of Saxon scientist Hans Carl von Carlowitz in his work 'Sylvicultura Oeconomica'. In this work, Carlowitz made suggestions for minimising the damage to forests for the wood required for the mining sector in the region where he lived and for the sustainable use of forests (Carlowitz, 1713). Until the mid-18th century, the world economy had a production structure based on agriculture and crafts, but with the Industrial Revolution that started in England in 1760, this process evolved into a mass production phase based on mechanisation. Coal, the dominant energy source of this period, led to a significant increase in fossil fuel consumption in the world, while the factoryisation process caused land destruction, water pollution and deforestation (Hobsbawm, 2008; Brown and Başçı, 2008). With the industrial revolution, the human-nature relationship started to be damaged and the foundations of climate change in the world were laid (Yılmaz & Koyuncu, 2020; Çelik & Ünlü, 2024). The main reason for the deterioration of the human-nature relationship to gain a global outlook is that after the Second World War, developing countries took the production structures of developed economies as an example (Tarhan, 2018). Accordingly, the development strategies adopted between 1945 and 1970 put the relationship between socioeconomic policies and the environment on a weak ground, which led to severe damage to nature (Kocaoğlu & Özmen, 2021). While economic development was a priority worldwide from the Industrial Revolution until the 1970s, after this date, the limitation of natural resources and the existence of environmental crises have become more prominent, especially in developed countries (Zeytin & Kırlıoğlu, 2014).

As a result of the damage done to nature throughout history, climate change is currently at the top of the global agenda. Carbon emissions from fossil fuels such as coal, oil and natural gas are the most important factor in the severe occurrence of this problem and the most devastating damage to the environment (Ahmed et al., 2019). In this context, many political, economic, technological and social concepts have emerged that adopt the concept of "green" as a basic guide in order to reduce environmental problems and to provide a sustainable appearance to the human-nature relationship. Among these concepts, "Green Technology" includes many factors that act to promote the transition to sustainable energy by contributing to the reduction of fossil fuel dependency and carbon emissions (Costantini et al., 2017). Green technologies contribute to the reduction of the level of ecological openness in the world and also enable the establishment of sustainability (Adebayo, 2022). Another concept that determines sustainability is "Ecological Footprint". The ecological footprint, which shows the cumulative effects of human activities on nature, was introduced to the literature by Wackernagel and Rees (1997). This indicator is an environmental measure that allows the simultaneous analysis of water, air and soil pollution and covers six basic components such as residential areas, agricultural lands, carbon emissions, meadow areas, fishing areas and forest areas (Kamacı, 2023). Studies on the important function of green technology developments in reducing the ecological footprint in terms of ensuring ecological sustainability have started to increase especially in recent years (Kihombo et al. 2021; Chen et al. 2022; Ahmad et al., 2020). The destructive effects of orthodox economics-based growth policies on the nature-human relationship have brought the concept of green growth to the forefront. This concept focuses on carrying out economic growth and development together with environmental sustainability (Chang et al., 2024). At this point, determining the impact of financial development on environmental problems stands out as a specific topic of discussion. In the literature, two basic approaches stand out in studies examining financial development and environmental problems. According to the first approach, easier access to funding sources in developed financial markets increases the level of investment, which triggers the growth of industries that cause $CO_2$ emissions (Khan et al., 2022; Wang et al., 2020). According to the other approach, easy access to funding sources supports environmental sustainability by increasing investments in innovative and environmentally friendly technologies (Anton and Nucu , 2020; Eren et al., 2019).

When the process of deterioration of the human-nature relationship in Turkey is examined, it is seen that the decisions dated January 24, 1980 led to a structural change and paved the way for foreign trade and financial liberalization. With these decisions, expansion was achieved in the fields of industry and agriculture in line with the goal of economic growth, but at the same time the pressure on natural resources increased. Accelerated industrialisation, urbanisation, and increased trade openness have brought about negative impacts on the environment, and the destruction of natural areas and damage to the ecological balance have created difficulties in terms of sustainability. Figure 1 summarises Turkey's biocapacity and ecological footprint data between 1970 and 2022. It is observed that biocapacity has been continuously decreasing since the 1970s, i.e. the regeneration capacity of natural resources has decreased and they have been consumed faster. The ecological footprint, on the other hand, has increased over time and exceeded the biocapacity, indicating that Turkey's environmental resource use has exceeded the natural regeneration capacity and the pressure on the environment has increased. These two indicators, which approached each other in the 1980s, have reached a risky point in terms of environmental sustainability since the 2000s, with the ecological footprint significantly exceeding the biocapacity.

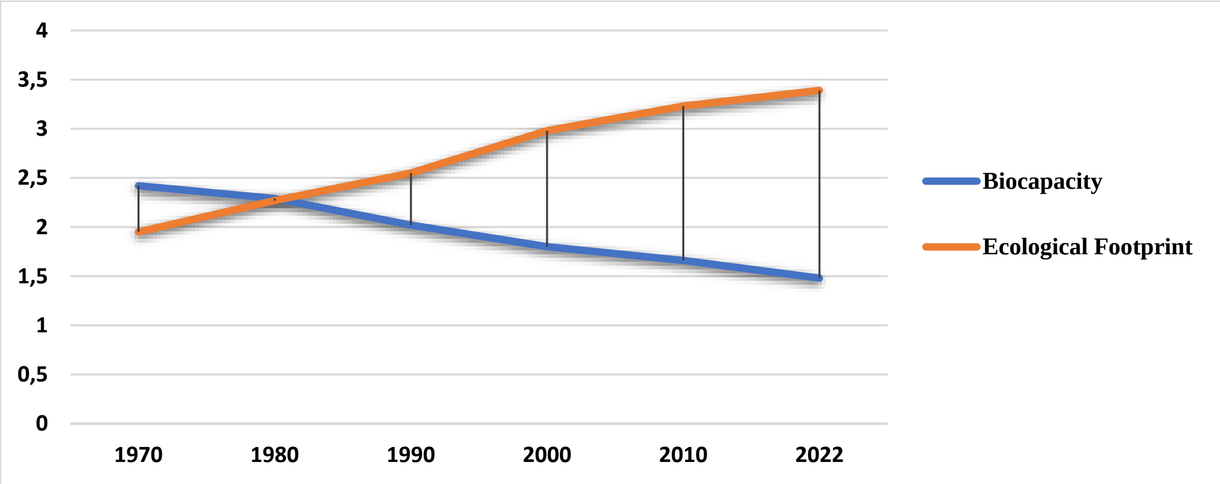



**Figure 1: Per Capita Biocapacity and Ecological Footprint in Türkiye (Footprint Network, 2024)**

Table 1 summarises Türkiye's environmental data for 2023. The analysis reveals that Turkey has a relatively strong performance in the areas of environmentally friendly innovation and energy transition. However, the same success is not achieved in critical areas such as climate policies and carbon emissions.

**Table 1: Türkiye's Green Future Index (2023)**

| Indicators | Ranking | Score |
|---|---|---|
| **Green Innovation,** | 23 | 6.24 |
| **Green Society** | 43 | 5.39 |
| **Climate Policy** | 69 | 2.08 |
| **Energy Transition** | 12 | 4.03 |
| **Carbon Emissions** | 73 | 4.35 |
| **Overall ranking** | 63 | 3.83 |

**Source:** MIT Technology Review,2023

This study aims to examine the effects of green technology (GRE) and financial development (FIN) by focusing on ecological footprint (EFP) in Turkey using the Fourier ARDL approach. The focus is on understanding the complex interaction between these factors in a more comprehensive, detailed and different way. When previous studies in the literature are examined, it is seen that the traditional methods used limit data analysis. In addition, the methods used require certain assumptions about the order of integration of the variables and if violated, they can potentially lead to incorrect results. Another shortcoming of the methods used may be insufficient in terms of the effects of structural breaks or seasonal changes. In the studies, CO2 emission, which is used to represent environmental degradation, is an insufficient variable compared to the ecological footprint. There are limited studies in Turkey (Akgün, & Özmerdivanlı, 2024) where ecological footprint, green technology and financial development are used together. In addition, it is noteworthy that this method is insufficient in the literature where this method is used on the relevant variables (Yilanci et al., 2020; Kirikkaleli et al., 2023; Bergougui, 2024). This method offers several advantages: (i) It removes the necessity of specifying the integration order of variables beforehand, which is particularly beneficial for datasets exhibiting mixed integration properties. (ii) It successfully detects and accounts for multiple structural changes and seasonal variations in the dataset, thereby providing a more comprehensive insight into the relationships among GRE, FIN, and EFP. The organization of this research is divided into four primary sections: The initial section introduces the subject matter and establishes the theoretical framework; the second section surveys existing empirical studies regarding the relationship between ecological footprint, financial development, and green technology; the third section details the methodology used; while the fourth section discusses empirical findings. Finally, the conclusion encapsulates these results and offers suggestions for future actions.

## 1. Literature Review

The literature of the study is summarised in three groups in order to elaborate environmental sustainability. In this context, the first group includes studies focusing on the link between green technologies and ecological footprint; the second group includes studies on the relationship between financial development and ecological footprint; and finally, studies examining the moderating effect of green technologies on the relationship between financial development and ecological footprint will be included.

Nketiah et al. (2024) examined environmental sustainability from the perspective of the impact of green technology on ecological footprint by using NARDL and ARDL bounds test methods in Ghana for the period 1990-2022. In their study, they concluded that green technology makes a positive contribution to the ecological footprint and supports environmental sustainability. Köseoğlu et al., (2022) examined the relationship between green technology and ecological footprint using panel data analysis in 20 countries for the period 1993-2016. In their research, they concluded that the increase in the level of green technology reduces the ecological footprint. Chu (2022) investigated the same relationship using panel data analysis in 20 OECD countries for the period 1990-2015 and found that technologies developed for the environment reduce the ecological footprint level by promoting renewable energy. Zhao et al., (2022) examined the relationship between green technology and ecological footprint in China within the framework of the STIRPAT model for the period 1990-2019. In their research, they concluded that the increase in the level of green technology reduces the ecological footprint. Javed et al.,(2023) examined the relationship between green technology and ecological footprint in Italy for the period 1994-2019 using the ARDL bounds test method. As a result of the research, they concluded that the improvement in the level of green technology reduces the ecological footprint.

Saqip et al., (2024) analyzed the effect of financial development on the ecological footprint for the 10 countries with the highest ecological footprint for the period 1990-2019 using the panel data method. In the study, they found that there is a one-way causality relationship from financial development to ecological footprint and that financial development increases the ecological footprint. Raihan (2024) analysed the impact of financial development on ecological footprint in Brazil for the period 1990-2022 by time series method. As a result of the research, it was found that financial development reduces the ecological footprint. Majeed and Mazhar (2019) examined the impact of financial development on ecological footprint for a sample group of 131 countries for the period between 1971-2017 with panel data analysis. Although different results emerged on a regional or country basis in the analysis, they concluded that financial development generally reduces the ecological footprint. Nathaniel (2024) investigated the effect of financial development on ecological footprint in Bangladesh for the period 1975-2018 by ARDL bounds test method. In the analysis, it was concluded that financial development increases the ecological footprint. Fan et al. (2024) analysed the effect of financial development on ecological footprint for BRICS-T countries for the period 1990-2020 using panel data method. In their study, they concluded that financial development increases the level of ecological footprint.

Bergougui (2024a) analyzed the relationship between green technology, financial development and ecological footprint in Algeria with quarterly data between 1990-2021 using the Fourier ARDL approach. As a result of the analysis, it was concluded that financial development increases the ecological footprint, while green technology reduces it. Aytun et al., (2024) examined the relationship between technological development, financial development and ecological footprint for 19 countries in the period 1980-2016 using the CS-ARDL method. In the study, while no statistically significant relationship was found between technological innovation and ecological footprint, it was determined that financial development played an important role in establishing a sustainable environment. Zhao (2022) analyzed the relationship between green technology, financial development and carbon emissions for 62 countries between 2003-2018 using the System of Moments (SYS-

GMM) method. In the study, it was determined that financial development increases technological development and this contributes to reducing the level of carbon emissions.

**Table 2: Recent Literature**

| *Green Technologies Effect on Ecological Footprint* | | | |
|---|---|---|---|
| **Author(s)** | **Sample / Period** | **Methodology** | **Direction of effect** |
| (Aytun et al., 2024) | 19 countries / 1980-2016 | CS-ARDL | Negative |
| (Bergougui, 2024) | Algeria / 1990-2021 | Fourier ARDL | Negative |
| (Saqib et al., 2024) | 11 countries/ 1990-2019 | AMG, CCEMG | Negative |
| (Qayyum et al., 2024) | MERCOSUR economies / 1990-2021 | CS-ARDL | Negative |
| (Nketiah et al., 2024) | Ghana/ 1990-2022 | NARDL, ARDL | Negative |
| (Bergougui & Aldawsari, 2024) | Algeria / 1990-2022 | NARDL, FMOLS, CCR, DOLS | Negative |
| (Ntom Udemba et al., 2024) | Russia / 2000-2021 | ARDL, MOLS, DOLS, CCR | Negative |
| (Wang et al., 2024) | BRICS /2002-2016 | PCSE, GMM | Positive |
| (Kirikkaleli et al., 2023) | USA /1970-2018 | Fourier ARDL | Negative |
| (Ozkan et al., 2023) | Türkiye /1990-2018 | ARDL | Negative |
| Javed et al. (2023) | Italy, 1994-2019 | ARDL | Negative |
| (Numan et al., 2023) | 13 countries / 2006-2020 | FGLS, PCSE | Negative |
| (Usman et al., 2022) | Pakistan /1991-2020 | NARDL | Negative |
| *Financial Development Effect on Ecological Footprint* | | | |
| **Author(s)** | **Sample / Period** | **Methodology** | **Direction of effect** |
| (Aytun et al., 2024) | 19 countries / 1980-2016 | CS-ARDL | Negative |
| (Guliyev, 2024) | European countries / 1992–2020 | Bayesian Model | Positive |
| (Saqib et al., 2024) | Top-ten countries with the biggest EF / 1990-2019 | CCEMG, AMG | Positive |
| (Ntom Udemba et al., 2024) | Russia /2000-2021 | ARDL, MOLS, DOLS, CCR | Negative |
| (Balsalobre-Lorente et al., 2023) | APEC countries / 1994-2018 | FMOLS, Panel Fisher Causality | FD ∩ EF |
| (Ngoc & Awan, 2022) | Singapore / 1980-2016 | ARDL | Positive |
| (Aslam et al., 2023) | 43 middle-income countries /1990-2020 | Panel Quantile Regression | Negative |
| (Gill et al., 2023) | Pakistan /1980-2018 | NARDL | FD ∩ EF |
| (Sun et al., 2023) | South Asian /1990-2016 | CS-ARDL | FD ∩ EF |
| (Afshan & Yaqoob, 2022) | China / 1995–2017 | QARDL | Positive |
| (Khan et al., 2022) | APEC / 1990-2016 | CCEMG | FD ∩ EF |
| (Gokmenoglu et al., 2021) | Turkiye / 1960-2014 | FMOLS | Negative |

| | | | |
|---|---|---|---|
| (Baloch et al., 2019) | BRI countries / 1990-2016 | Driscoll-Kraay Panel Regression | Positive |

When a general evaluation of the literature is made, it is seen that the increase in green technology makes significant contributions to environmental sustainability by reducing the ecological footprint in the studies examining the relationship between "green technologies and ecological footprint" , a finding largely supported by recent studies across various regions and methodologies (Nketiah et al., 2024; Bergougui & Aldawsari, 2024; Javed et al., 2023). On the other hand, studies on the relationship between financial development and ecological footprint reveal that their effects on environmental sustainability are still a controversial and complex area , with recent evidence continuing to show mixed results depending on the country context, financial development metrics used, and employed econometric techniques (Saqib et al., 2024; Raihan, 2024; Aytun et al., 2024; Guliyev, 2024). This highlights the need for country-specific analyses like the present study, particularly using advanced methods that account for structural breaks.

## 3. Data and methodology

### 3.1. Data

The study examined the relationship between green technology, financial development and ecological footprint of Turkey for the period 1992-2021. In the study where annual data was used, ecological footprint (EFP) was used as the dependent variable. Ecological footprint refers to the measurement of resources used by people to reproduce what they consume, measured in global hectares and according to the definition made by the global footprint network. The reason for using it as a dependent variable is the concern that global disruptions will put countries in a difficult situation (Guliyev, 2024). Green technologies (GRE) and financial development (FIN) are used as independent variables. Since green technologies are a step towards reducing environmental pollutants, innovation in this area is the main way for businesses to achieve quality improvement, energy efficiency and emission reduction (Manello, 2017; Yin & Zhao, 2024). At the same time, green technologies have a crucial role in treating/cleaning environmental pollution (Du & Li, 2019), reducing ecological impact (Behera et al., 2023) and improving environmental quality (Habiba et al., 2023). There are findings that increasing financial development, which is used as the other independent variable, will significantly improve environmental quality by reducing EFP (Majeed & Mazhar, 2019; Usman & Hammar, 2021), and vice versa, improvements in financial development will increase the ecological footprint (Afshan & Yaqoob, 2022; Ngoc & Awan, 2022). Gauss, Stata and Eviews package programs were used to analyze the data in the study. The variables used, their usage patterns and data sources are presented in Table 3.

**Table 3: Data source and description**

| Data | Code | Unit | Source of data |
|---|---|---|---|
| ***Dependent variables*** | | | |
| *Ecological footprint* | EFP | Total global hectare | Global Footprint Network |
| ***Independent variables*** | | | |
| *Green technologies* | GRE | Patents related to the environment as (% total patents) | OECD |
| *Financial development* | FIN | Index (0–100) | IMF |

The main objective of this study is to address ecological concerns in Turkey and explore the appropriate strategy to achieve climate footprint reduction targets. In this framework, our hypotheses in the study are as follows:

$H_0$: *GRE has a negative effect on EFP in Türkiye.*

$H_1$: *FIN has a positive effect on EFP in Türkiye.*

The findings from this study are expected to make significant contributions to the field of environmental studies by providing insights into the interplay between green technologies, financial development, and ecological footprint in Türkiye. Specifically, the results will illuminate Türkiye's ecological status as it strives for sustainable economic growth. This understanding can guide policymakers in formulating strategies that promote environmentally friendly practices while supporting economic advancements, ultimately working towards a balance between development and ecological sustainability. At the same time, it will also provide a guiding map for countries or country groups with similar economic structures. Descriptive statistics of the variables used in the study are presented in Table 4.

**Table 4. Descriptive Statistics**

| | EFP | FIN | GRE |
|---|---|---|---|
| Mean | 1.747000 | 0.409171 | 0.081638 |
| Median | 1.785000 | 0.430613 | 0.078058 |
| Maximum | 2.200000 | 0.510864 | 0.213728 |
| Minimum | 1.160000 | 0.224670 | 0.038062 |
| Std. Dev. | 0.331248 | 0.084697 | 0.030482 |
| Skewness | -0.175360 | -0.511844 | 2.682694 |
| Kurtosis | 1.617164 | 2.029826 | 12.98899 |
| Observations | 30 | 30 | 30 |

### 3.2. Metodology

In this study, the relationship between green technology, financial development and ecological footprint of Türkiye for the period 1992-2021 is analysed. The methods used in analysing this relationship and the general flow chart of the study are given in Figure 2.

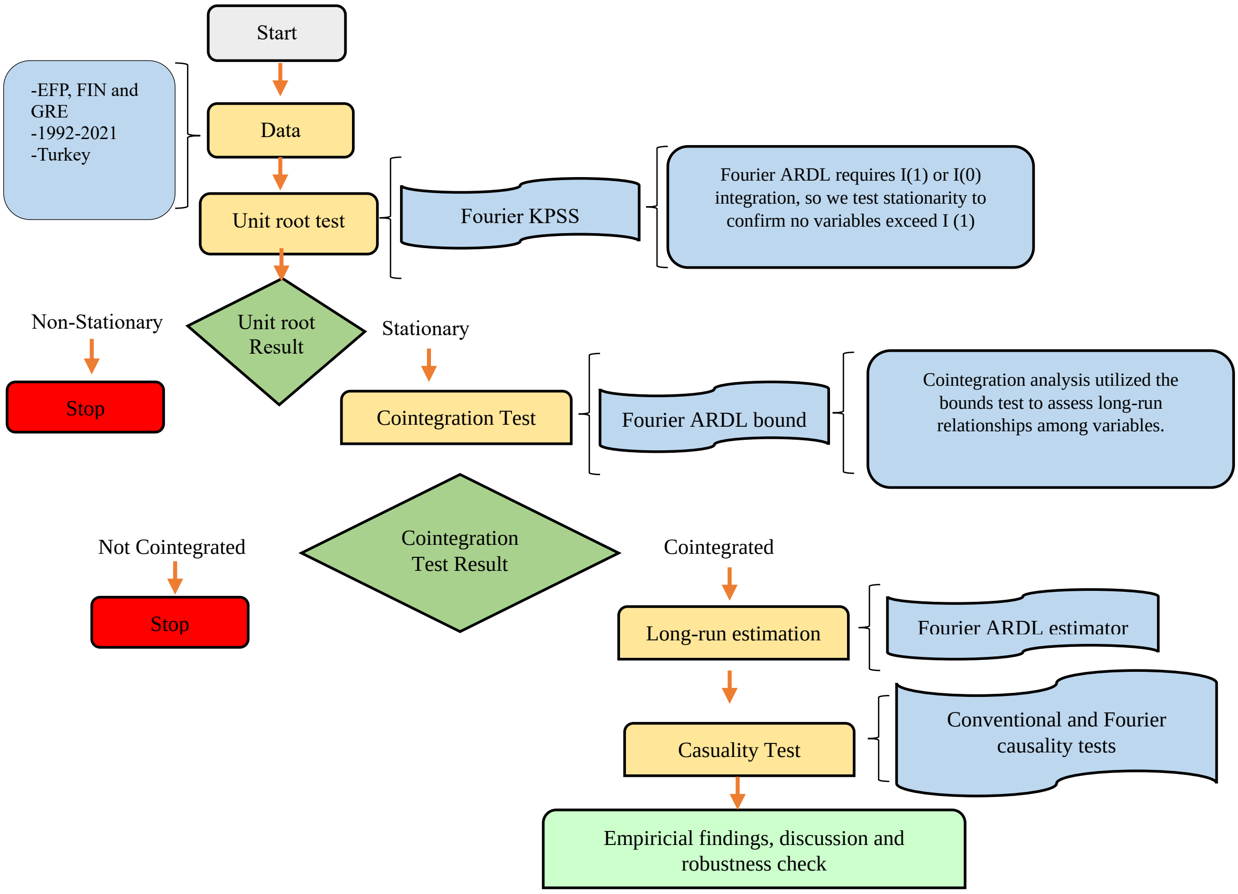



**Figure 2: Analysis flowcharts (Bergougui, 2024a)**

#### 3.2.1. Fourier Unit Root Test

Stationarity is crucial in time series analysis and modeling. A stationary time series indicates that both the mean and variance remain constant over time, which enhances the model's reliability. When forecasting with a non-stationary series, there are increased risks related to uncertainty and potential errors. Analyzing non-stationary data can lead to spurious regression issues, characterized by inflated $R^2$ values and significant t statistics (Sevüktekin & Nargeleçekenler, 2007). To assess unit roots in the data, this study will utilize the Fourier KPSS unit root test as proposed by Becker et al. (2006). This advanced test builds on traditional unit root tests developed by Kwiatkowski et al. (1992) by integrating sine and cosine functions to capture nonlinear disturbances more effectively through its alternative hypothesis.

Deterministic model with $y_t$ as the dependent variable:

$$\Delta y_t = \beta_0 + \beta_1 \sin\left(\frac{2\pi kt}{T}\right) + \beta_2 \cos\left(\frac{2\pi kt}{T}\right) + z_t + \varepsilon_t \tag{3.1}$$

In this expression, $\beta_0$ is the constant term, $\beta_1$ is the sine function parameter, $\beta_2$ is the cosine function parameter, k is the number of frequencies, T is the number of observations. $z_t$ is designed as $z_t = z_{t-1} + v_t$. $v_t$ is the error term belonging to the independent identical distribution (iid, identically independent distribution). Statistic of the test;

$$\tau_\mu(\mathrm{k}) = \frac{1}{T^2}\frac{\sum_{t=1}^{T} \tilde{S}_t(\mathrm{k})^2}{\tilde{\sigma}^2} \tag{3.2}$$

is calculated. This expression is estimated as $\tilde{\sigma}^2 = \delta_0 + 2\sum_{j=1}^{l} w_j \tilde{\delta}_j$. $w_j$ denotes the frequency.

### 3.2.2. Model and Fourier ARDL

In this study, the empirical model of the relationship between EFP, GRE and FIN in Türkiye 1992-2021 using the Fourier ARDL approach is as follows:

$$EFP_t = \beta_0 + \beta_1 GRE_t + \beta_0 FIN_t + \mu_t \tag{3.3}$$

Where EFP: logarithm of ecological footprint, GRE: ratio of green technology patents in total patents, FIN: financial development index.

In cointegration tests that examine the long-run relationship between variables, the level of stationarity is expected to be the same. Banerjee et al., (2017) developed the Autoregressive Distributed Lag Bound Test (ARDL), which is considered an important step in solving this problem. The stationarity level of this model is not 2nd degree and it can examine the long-term relationship between series with different stationarity levels. The FARDL test is built on the ARDL bounds test developed by Pesaran et al., (2001). Fourier ARDL explicitly incorporates structural breaks into the model framework (Enders & Lee, 2012). This feature is particularly advantageous for economic and environmental time series, which are inherently prone to such interruptions. Moreover, Fourier ARDL has the additional advantage of providing a more comprehensive cointegration analysis (Syed et al., 2024). The model of the Fourier lag-distributed autoregressive cointegration test developed by Banerjee et al. (2017) to test the long-run cointegration relationship is as follows:

$$\Delta \mathrm{EFP} = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \cos\left(\frac{2\pi kt}{T}\right) + \delta_3 EFP_{t-1} + \delta_4 GRE_{t-1} + \delta_5 FIN_{t-1} + \sum_{i=1}^{p-1} \varphi_i' \Delta EFP_{t-1} + \sum_{i=1}^{p-1} \varphi_i' \Delta GRE_{t-1} + \sum_{i=1}^{p-1} \varphi_i' \Delta FIN_{t-1} + \varepsilon_t \tag{3.4}$$

In Equation (3.4), $\delta_0$ is the constant term, $\delta_1$ and $\delta_2$ are sine - cosine Fourier functions. $\delta_3$ is the lag parameter of the dependent variable, $\delta_4$ is the parameter of green technology and $\delta_5$ is the parameter of financial development.

### 3.2.3. Conventional and Fourier Casualty Test

In order to determine the existence and direction of the relationship between the variables in the study, both traditional and Fourier causality tests are used. In this context, according to the Granger (1969) causality test, which first allows the effect of a variable on another variable to be estimated and is the first causality test in the literature, a four-way causality relationship can be found between two variables. Toda-Yamamoto test is based on the VAR model. After determining the optimal lag length of the VAR model (k) and the maximum degree of stationarity of the series ($d_{max}$), the VAR model is estimated in (k + $d_{max}$) dimension.

While traditional causality tests are widely used due to their simplicity, Fourier causality tests are more complex but flexible, making them suitable for some special cases. The tests developed by Enders & Jones (2016) and Nazlioglu et al. (2016) are Fourier causality test statistics and both are considered as single frequency and cumulative frequency in this study. However, there is a difference between the two tests in that Enders & Jones (2016) are based on the Granger (1969) causality test procedures, while Nazlioglu et al. (2016) apply the Toda & Yamamoto (1995) test procedure (Bayat & Taş, 2021).

Enders & Jones (2016), following Gallant (1981), apply the Fourier series approach in equation (3.5) to represent the deterministic component of time series.

$$d_{it} = a_{i0} + \sum_{k=1}^{n} a_{ik}\sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} b_{ik}\cos\left(\frac{2\pi kt}{T}\right) \tag{3.5}$$

$d_{it}$ denotes a potentially smooth transition function of time. $k$ is the frequency number of the Fourier function, $t$ is the trend term and $T$ is the sample size. $\pi$ is equal to 3.1416 (Enders & Jones, 2016).

Nazlıoğlu et al. (2016) modify the Toda-Yamamoto test by adapting the Fourier stepwise break approach and extending the assumption that the intercept dates ($\alpha$) are constant over time to take structural breaks into account and modify the VAR model as follows:

$$y_t = \alpha(t) + \beta_1 y_{t-1} + \cdots + \beta_{p+d} + y_{t-(p+d)} + \epsilon_t \tag{3.6}$$

$\alpha(t)$ denotes time and $y_t$ denotes any structural break. Nazlıoğlu, et al. (2016) constructed a Fourier expansion to measure detailed information about structural breaks as in equation 3.7.

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{n} \gamma_{1k}\sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k}\cos\left(\frac{2\pi kt}{T}\right) \tag{3.7}$$

Where n is the number of frequencies, $\gamma\gamma_{1k}$ and $\gamma_{2k}$ measure the width and displacement of the frequency respectively. Equations 3.6 and 3.7 are combined to give equation 3.8.

$$\alpha(t) = \alpha_0 + \gamma_1\sin\left(\frac{2\pi kt}{T}\right) + \gamma_2\cos\left(\frac{2\pi kt}{T}\right) \tag{3.8}$$

### 3.2.4. Co-integration Coefficients

In the co-integration process, which defines the long-run relationship between non-stationary series, if the coefficients are estimated by ordinary least squares method, biased results emerge due to autocorrelation and endogeneity problems. In order to eliminate the endogeneity problem in the estimation process, FMOLS estimators developed by Phillips and Hansen (1990), CCR estimators developed by Park (1992) and DOLS estimators developed by Saikkonen (1992), Stock and Watson (1993) can be used. Phillips and Hansen (1990) showed that the FMOLS estimator is super consistent, asymptotically robust and gives good results even in small samples (Phillips and Hansen, 1990). In order to solve the problems caused by long-run correlations between cointegrated equations and stochastic processes, a semi-parametric correction method is used that takes into account the autocorrelation problem of error terms in addition to the endogeneity relationship between the independent variables and the error term (Berke, 2012).

## 4. Empirical results

In the Fourier KPSS test proposed by Becker et al. (2006) for assessing the stationarity of a series, the null hypothesis posits that the variable is stationary and the hysteresis effect is absent. Conversely, the alternative hypothesis suggests the presence of a unit root, indicating the validity of the hysteresis effect. The outcomes of the unit root test are presented in Table 5.

**Table 5: Becker et al. (2006) Fourier KPSS Unit Root Results**

| | | Frequency (k) | FKPSS |
|---|---|---|---|
| **EFP** | Constant Model | 1 | 0.386[a] |
| | Constant + Trend Model | 2 | 0.163[b] |
| **GRE** | Constant Model | 1 | 0.119 |
| | Constant + Trend Model | 1 | 0.074 [a] |
| **FIN** | Constant Model | 1 | 0.402[a] |
| | Constant + Trend Model | 1 | 0.216[b] |

**Notes:** In the FKPSS test, the critical values for k=1 at 1%, 5% and 10% significance levels are 0.269, 0.172 and 0.131 for the model with constant, 0.071, 0.054 and 0.047 for the model with constant and trend, respectively. The critical values for k=2 at 1%, 5% and 10% significance levels are 0.202, 0.132 and 0.103 for the model with constant and trend, respectively. a, b, c values indicate that the alternative hypothesis is accepted at 1%, 5% and 10% significance levels, respectively.

When making a decision, $H_0$ is accepted if FKPSS > table, $H_1$ is accepted if it is small. Becker et al. table values for k=1 are 10 % 0.131, 5 % 0.172, 1 % 0.269. Table 5 shows that the ecological footprint variable does not have a Fourier unit root at 1% significance level in the model with constant and 5% significance level in the model with constant+trend. Similarly, the $H_0$ hypothesis cannot be rejected at 1% in the fixed model and 5% in the fixed+trend model. The green technology variable has Fourier unit root only in the fixed+trend model.

The graphs below (Figure 3, 4,5,6,7 and 8) show the raw data and Fourier functions of the variables. It shows that the Fourier functions of both ecological footprint and financial development will continue to trend upwards with the effect of deterministic variables in the model with constant term and trend variables. When the Fourier functions in the constant term and constant term-trend variable models are compared, it is seen that the wavelengths of the Fourier functions in the constant term models move in a longer and horizontal band. The shortening of the wavelengths in the model with constant term and trend variable indicates that the effect of exogenous factors determining the Green technology variable is greater.

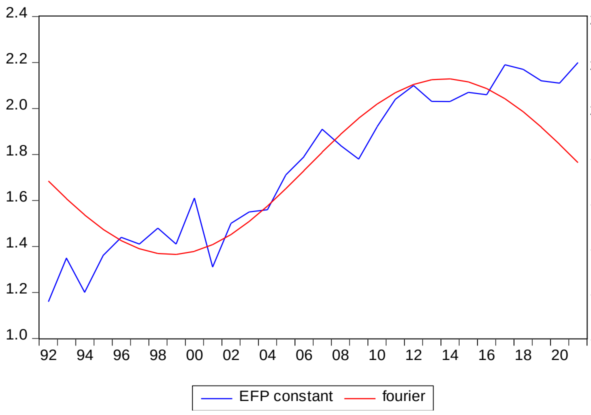



**Figure 3: EFP Constant Model**

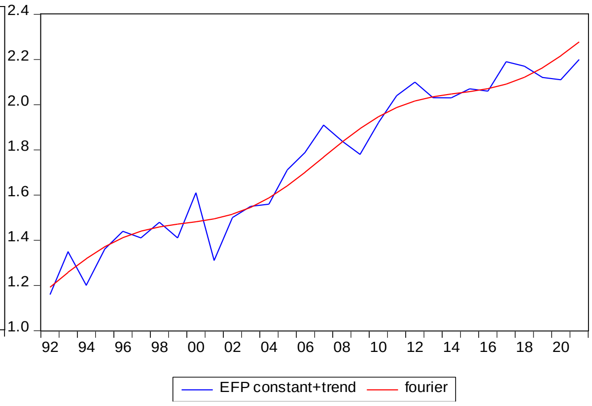
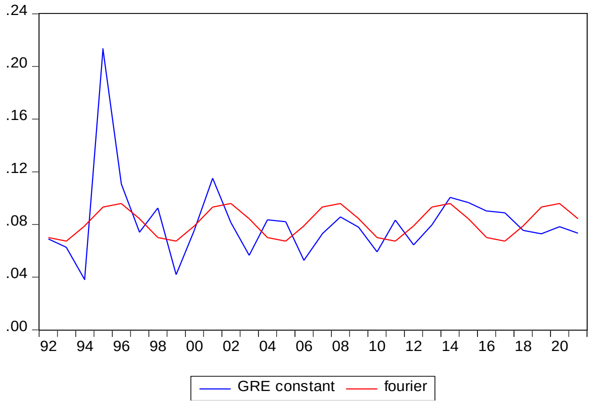



**Figure 4: EFP Constant +Trend Model**



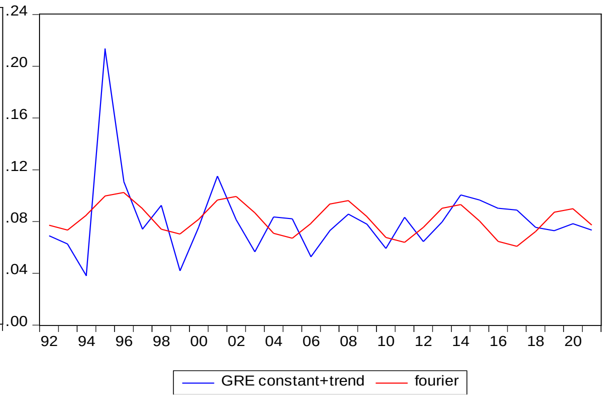
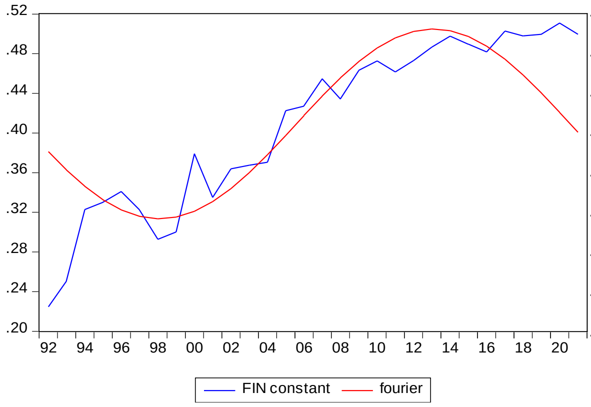




**Figure 5. GRE Constant Model** **Figure 6. GRE Constant +Trend Model**



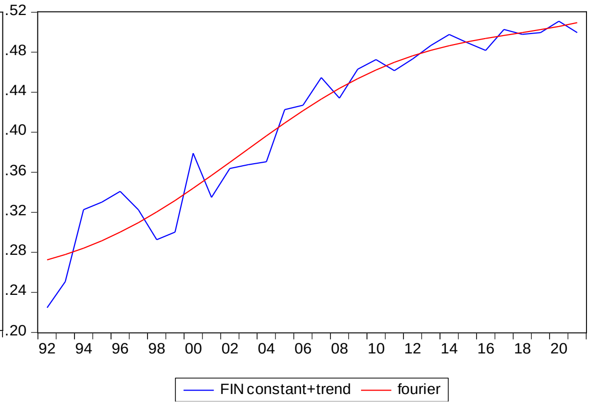




**Figure 7: FIN Constant Model** **Figure 8: FIN Constant +Trend Model**

Table 6 shows the cointegration results between the variables. When examining this table, it is accepted that there is Fourier cointegration if the alternative hypothesis is accepted with FA, FB and t statistics, and there is no Fourier cointegration if the null hypothesis is accepted with FA, FB and t statistics (Yilanci et al., 2020).

**Table 6: Banerjee et al. (2017) FARDL Cointegration Results**

| | t statistic | %90 | %95 | %99 | Optimal frequency |
|---|---|---|---|---|---|
| $F_A$ | 4.844[c] | 3.578 | 5.383 | 3.800 | 1.400 |
| t | -3.032[b] | -1.843 | -2.489 | -3.681 | |
| $F_B$ | 7.202[b] | 4.047 | 5.005 | 11.525 | |

**Notes:** a, b, c values indicate that the alternative hypothesis is accepted at 1%, 5% and 10% significance levels, respectively. Values in parentheses represent probabilities. Bootstrap number is taken as 1000.

If the calculated t-statistic values are greater than 90%, 95% and 99% in absolute terms, there is Fourier cointegration, otherwise there is no Fourier cointegration. According to the cointegration results, t-test statistics exceed the critical values. According to these results, it can be said that there is a long-term Fourier cointegration between the variables. Following the long-term relationship, the causality relationship of the variables is analysed by conventional and Fourier causality tests.

**Table 7: Convensioanl and Fourier Casuality Tests**

| $H_0$: EFP does not cause GRE | | | | | | |
|---|---|---|---|---|---|---|
| | **Wald** | **Asymptotic p value** | **Bootstrap p value** | **k** | **p** | **dmax** |
| Standard GC (Granger, 1969) | 0.665 | 0.41 | 0.44 | - | 1 | - |
| TY & Boostrapt TY (Toda ve Yamamoto, 1995) | 3.989 | 0.04** | 0.06* | - | 1 | 1 |
| Fourier Standard GC-single frequency (Enders & Jones, 2015) | 0.291 | 0.59 | 0.61 | 3 | 1 | - |
| Fourier TY-singe frequency (Nazlioglu etal., 2016) | 5.063 | 0.02** | 0.05** | 1 | 1 | 1 |
| Fourier Standard GC-cumulative frequency (Enders & Jones, 2015) | 0.004 | 0.95 | 0.94 | 3 | 1 | - |
| Fourier TY--cumulative frequency (Nazlioglu etal., 2016) | 3.018 | 0.08* | 0.11 | 3 | 1 | 1 |
| $H_0$: GRE does not cause EFP | | | | | | |
| | **Wald** | **Asymptotic p value** | **Bootstrap p value** | **k** | **p** | **dmax** |
| Standard GC (Granger, 1969) | 0.032 | 0.85 | 0.86 | - | 1 | - |
| TY & Boostrapt TY (Toda ve Yamamoto, 1995) | 0.093 | 0.76 | 0.77 | - | 1 | 1 |
| Fourier Standard GC-single frequency (Enders & Jones, 2015) | 0.05 | 0.82 | 0.82 | 3 | 1 | - |
| Fourier TY-singe frequency (Nazlioglu etal., 2016) | 0.295 | 0.58 | 0.58 | 1 | 1 | 1 |
| Fourier Standard GC-cumulative frequency (Enders & Jones, 2015) | 0.049 | 0.82 | 0.79 | 3 | 1 | - |
| Fourier TY--cumulative frequency (Nazlioglu etal., 2016) | 0.252 | 0.61 | 0.58 | 3 | 1 | 1 |
| $H_0$: EFP does not cause FIN | | | | | | |
| | **Wald** | **Asymptotic p value** | **Bootstrap p value** | **k** | **p** | **dmax** |
| Standard GC (Granger, 1969) | 1.995 | 0.15 | 0.16 | - | 1 | - |
| TY & Boostrapt TY (Toda ve Yamamoto, 1995) | 0.147 | 0.70 | 0.70 | - | 1 | 1 |
| Fourier Standard GC-Single frequency (Enders & Jones, 2015) | 2.198 | 0.13 | 0.15 | 3 | 1 | - |
| Fourier TY-Single frequency (Nazlioglu etal., 2016) | 0.050 | 0.82 | 0.84 | 1 | 1 | 1 |
| Fourier Standard GC-Cumulative frequency (Enders & Jones, 2015) | 0.456 | 0.49 | 0.48 | 3 | 1 | - |
| Fourier TY--cumulative frequency (Nazlioglu etal., 2016) | 0.013 | 0.91 | 0.91 | 3 | 1 | 1 |
| $H_0$: FIN does not cause EFP | | | | | | |

| | Wald | Asymptotic p value | Bootstrap p value | k | p | dmax |
|---|---|---|---|---|---|---|
| Standard GC (Granger, 1969) | 4.279 | 0.03** | 0.06* | - | 1 | - |
| TY & Boostrapt TY (Toda ve Yamamoto, 1995) | 1.033 | 0.30 | 0.31 | - | 1 | 1 |
| Fourier Standard GC-single frequency (Enders & Jones, 2015) | 3.815 | 0.05** | 0.08* | 3 | 1 | - |
| Fourier TY-singe frequency (Nazlioglu etal., 2016) | 0.698 | 0.40 | 0.40 | 1 | 1 | 1 |
| Fourier Standard GC-cumulative frequency (Enders & Jones, 2015) | 3.948 | 0.04** | 0.07* | 3 | 1 | - |
| Fourier TY--cumulative frequency (Nazlioglu etal., 2016) | 0.256 | 0.61 | 0.62 | 3 | 1 | 1 |

**Notes:** ***, ** and * indicate acceptance of the alternative hypothesis at 1%, 5% and 10% significance levels, respectively. Bootstrap number is 1000. k is the optimal frequency, p is the optimal lag length, GC stands for Granger Causality, and TY stands for Toda-Yamamoto Causality. Akaike Information Criterion is used to select the optimal lag length.

According to the findings, there is no evidence that changes in ecological footprint have any causal effect on changes in financial development. Except for the TY & Boostrapt TY and Fourier TY-Cumulative Frequency tests, there is evidence that changes in financial development cause ecological footprint in other causality tests. This supports the results of some previous studies in the literature (Kirikkaleli et al., 2023; Bergougui, 2024; Saqib et al., 2024). The fact that there is a causality relationship from ecological footprint to green technologies may give an idea that there is a tendency that the increases occurring here increase the importance attached to green technologies in Türkiye. However, it is observed that the changes in green technologies do not create any causality effect on ecological footprint. In conclusion, although important steps have been taken in the field of green technology in Türkiye, this process is ongoing and more investment, policy development and social awareness are required. In this regard, the high initial cost of green technologies, the fact that the necessary infrastructure for renewable energy is not yet fully matured, and the lack of continuity in long-term policies affect the confidence of investors.

**Table 8: FARDL Cointegration Coefficients**

| | $EFP_t = \beta_0 + \beta_1 FIN_t + \beta_2 GRE_t + \varepsilon_t$ | | |
|---|---|---|---|
| **Variable** | **FMOLS** | **DOLS** | **CCR** |
| **GRE** | -0.732 (0.08)[c] | -5.087 (0.00)[a] | -0.747 (0.22) |
| **FIN** | 3.927 (0.00)[a] | 3.560 (0.00)[a] | 3.905 (0.00)[a] |
| **C** | 0.195 (0.02)[b] | 0.693 (0.00)[a] | 0.206 (0.01)[b] |
| **SS** | 0.041 (0.02)[b] | 0.594 (0.01)[b] | 0.041 (0.03)[b] |
| **CC** | 0.033 (0.08)[c] | 0.077 (0.01)[b] | 0.035 (0.06)[c] |

**Notes:** a, b, c values indicate that the alternative hypothesis is accepted at 1%, 5% and 10% significance levels, respectively. Values in parentheses represent probabilities. FMOLS stands for fully modified ordinary least squares, DOLS for dynamic ordinary least squares and CCR for canonical correlation regression.

After the causality relationship, tests related to the coefficient analyses of the variables were applied. These tests reveal the effect of independent variables on the dependent variable in the long run and the direction of this effect. When Table 9 is examined, the change in financial development positively affects the ecological footprint at 1% significance level in all three coefficient tests. A 1% change in financial development creates a positive effect of 3.9% according to FMOLS, 3.5% according to DOLS and 3.9% according to CCR, respectively. These findings support the findings of Gokmenoglu et al. (2021) on Türkiye, Ngoc & Awan (2022) on Singapore and Afshan & Yaqoob (2022) on China. In parallel with the results of the studies in the literature, the green technology variable has a negative effect in FMOLS and DOLS tests. A 1% change in green technologies negatively affects the ecological footprint by 0.7% and 5%, respectively. Recent studies in the literature (Aytun et al., 2024; Bergougui, 2024b; Çamkaya, 2024; 2024; Nketiah et al., 2024; Bergougui & Aldawsari, 2024; Wang et al., 2024; Kirikkaleli, Sofuoğlu, et al., 2023; Ozkan et al., 2023; Javed et al., 2023; Sadiq, Wen & Dagestani, 2022; Usman et al., 2022), these findings show parallel results in Türkiye.

There are many studies that obtain similar results using methods such as FMOLS, and CCR. These methods are important econometric techniques generally used in the analysis of long-run relationships. In conclusion, the above-mentioned studies are in line with the trends in the existing literature and reveal that green technologies and financial development have positive effects on environmental sustainability. In this context, the study conducted for Türkiye can be evaluated within the same framework and similar conclusions can be drawn.

## 5. Conclusion

The ecological footprint measurement has prompted individuals and societies to reconsider natural resource consumption, fostering the advancement of innovative green technologies. Financial developments significantly contribute to this transition by enabling the expansion of green technologies through investments from both private and governmental sectors.

The main purpose of this study is to explore the appropriate strategy to address ecological concerns in Turkey and achieve climate footprint reduction targets. The study examined the relationship between green technology, financial development and ecological footprint of Turkey for the period 1992-2021. In the study where annual data was used, ecological footprint (EFP) was used as the dependent variable. Ecological footprint refers to the measurement of resources used by people to reproduce what they consume, measured in global hectares and defined by the global footprint network. The reason for using it as the dependent variable is the concern that global degradation will put countries in a difficult situation (Guliyev, 2024). Green technologies (GRE) and financial development (FIN) were used as independent variables. Since green technologies are a step towards reducing environmental pollutants, innovation in this area is the main way for businesses to achieve quality improvement, energy efficiency and emission reduction (Manello, 2017; Yin & Zhao, 2024). At the same time, green technologies have a very important place in purifying/cleaning environmental pollution (Du & Li, 2019), reducing ecological impact (Behera et al., 2023) and improving environmental quality (Habiba et al., 2023). There are findings that increasing financial development, which is used as another independent variable, will significantly improve environmental quality by reducing EFP (Majeed & Mazhar, 2019; Usman & Hammar, 2021), and conversely, improvements in financial development will increase the ecological footprint (Afshan & Yaqoob, 2022; Ngoc & Awan, 2022).

Methodologically, the study employs the Fourier KPSS unit root test, Fourier ARDL, conventional and Fourier causality tests, alongside FMOLS, DOLS, and CCR for coefficient analysis. Findings reveal a long-term Fourier cointegration among variables. While changes in EFP do not appear to influence financial development, financial development does impact EFP in several tests. Additionally, EFP is found to influence green technologies. Coefficient analysis demonstrates that financial development contributes positively to EFP, while green technologies exert a mitigating effect on it. These findings align with prior studies (Bergougui, 2024a; Çamkaya, 2024; Nketiah et al., 2024; Köseoğlu et al., 2022; Aytun et al., 2024), offering meaningful insights for environmental research.

Our empirical results indicate that financial development has a statistically significant positive impact on the ecological footprint in Türkiye (coefficients of 3.927, 3.560, and 3.905 in FMOLS, DOLS, and CCR, respectively). This finding aligns with several recent studies suggesting that in certain contexts, financial development may initially exacerbate environmental pressures (Saqib et al., 2024 for high-EF countries; Fan et al., 2024 for BRICS-T; Nathaniel, 2024 for Bangladesh; Guliyev, 2024 for some European countries; Ngoc & Awan, 2022 for Singapore). This could imply that financial resources in Türkiye might still be channeling towards carbon-intensive sectors rather than predominantly supporting green investments. However, this contrasts with other studies that found a mitigating effect of financial development on environmental degradation (Raihan, 2024 for Brazil; Aytun et al., 2024 for middle-income countries; Majeed & Mazhar, 2019 globally; Gokmenoglu et al., 2021 for Türkiye using older data). These discrepancies underscore the complexity of the finance-environment nexus and may stem from differences in time periods, measurement proxies for financial development, control variables, and estimation techniques. Conversely, the finding that green technologies (GRE) exert a mitigating effect on the ecological footprint (negative coefficients in FMOLS and DOLS) is consistent with a broad consensus in the literature (Nketiah et al., 2024; Javed et al., 2023; Bergougui, 2024a; Kirikkaleli et al., 2023; Köseoğlu et al., 2022), confirming the critical role of green innovation for Türkiye's sustainability goals. The unidirectional causality from EFP to GRE suggests that rising environmental concerns might be stimulating green technology adoption, while the lack of significant causality from GRE to EFP in the causality tests (despite the significant coefficient in the long-run model) might indicate that the impact of these technologies, while present, is perhaps not yet pervasive enough or occurs with lags not fully captured by the causality test framework.

From a policy perspective, these results emphasize the need for Türkiye to enhance investments in green technologies and restructure its financial systems to prioritize environmentally friendly initiatives. Policymakers should:

- **Increase Investments in Green Technologies:** Allocate resources to research, development, and deployment of green technologies to reduce environmental pressures.
- **Restructure Financial Systems:** Design financial incentives that reward sustainable practices and discourage investments in high-carbon industries.
- **Strengthen Public-Private Partnerships:** Encourage collaboration between governments and the private sector to scale up environmentally sustainable initiatives.
- **Enhance Public Awareness:** Conduct campaigns to educate the public on the importance of sustainable consumption and environmental stewardship.
- **Establish Robust Regulatory Frameworks:** Implement policies that enforce stricter environmental standards and promote accountability among industries.

In conclusion, the study contributes significantly to the literature on environmental sustainability by offering actionable insights tailored to Türkiye's unique economic and environmental context. The findings not only aid in understanding the dynamics of ecological sustainability but also provide a roadmap for aligning financial and technological strategies to support long-term environmental goals. Future research could further explore sector-specific policies to refine these strategies and enhance their effectiveness.

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***Araştırma Makalesi***

**Analysis of The Interaction between Ecological Footprint, Green Technology and Financial Development in Türkiye: Evidence from Fourier ARDL Approach**

*Türkiye'de Ekolojik Ayak İzi, Yeşil Teknoloji ve Finansal Kalkınma Arasındaki Etkileşimin Analizi: Fourier ARDL Yaklaşımından Kanıtlar*

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**Genişletilmiş Özet**

**Çalışmanın Amacı:** Bu çalışmanın temel amacı, Türkiye'deki ekolojik kaygıları ele almak ve iklim ayak izi azaltma hedeflerine ulaşmak için uygun stratejiyi keşfetmektir.

**Araştırma Soruları:** Türkiye'de yeşil teknolojiler ekolojik ayak izini düşürmede yardımcı oluyor mu? Diğer taraftan finansal gelişmeler ekolojik ayak izini arttıran bir faktör müdür?

**Literatür Araştırması:** Çalışmanın literatürü, çevresel sürdürülebilirliğin detaylandırmak amacıyla üç grupta özetlenmiştir. Bu kapsamda birinci grupta yeşil teknolojiler ve ekolojik ayak izi arasındaki bağlantıya odaklanan araştırmalar; ikinci grupta finansal gelişme ile ekolojik ayak izi arasındaki ilişkiyi ele alan çalışmalar ve son olarak yeşil teknolojilerin finansal gelişme ve ekolojik ayak izi ilişkisi üzerindeki düzenleyici etkisini inceleyen araştırmalara yer verilecektir.

Nketiah vd., (2024) 1990-2022 dönemi için Gana örneğinde NARDL ve ARDL sınır testi yöntemlerini kullanarak çevresel sürdürülebilirliği, yeşil teknolojinin ekolojik ayak izi üzerindeki etkisi perspektifinden incelemişlerdir. Araştırmalarında, yeşil teknolojinin ekolojik ayak izi üzerinde olumlu bir katkı sağladığı ve çevresel sürdürülebilirliği desteklediği sonucuna ulaşmışlardır. Köseoğlu vd., (2022) 1993-2016 dönemi için 20 ülkede panel veri analizini kullanarak yeşil teknoloji ve ekolojik ayak izi arasındaki ilişkiyi incelemişlerdir. Araştırmalarında, yeşil teknoloji seviyesindeki artışın ekolojik ayak izini azalttığı sonucunu varmışlardır. Chu (2022), 1990-2015 dönemi için 20 OECD ülkesinde panel veri analizini kullanarak aynı ilişkiyi araştırmış ve çevreye yönelik geliştirilen teknolojilerin yenilenebilir enerjiyi teşvik ederek ekolojik ayak izi seviyesini azalttığını tespit etmiştir. Zhao vd., (2022) 1990-2019 dönemi için Çin'de yeşil teknoloji ve ekolojik ayak izi arasındaki ilişkiyi STIRPAT modeli çerçevesinde incelemişlerdir. Araştırmalarında, yeşil teknoloji seviyesindeki artışın ekolojik ayak izini azalttığı sonucunu varmışlardır. Javed vd.,(2023) 1994-2019 dönemi için İtalya'da yeşil teknoloji ve ekolojik ayak izi arasındaki ilişkiyi ARDL sınır testi yöntemiyle kullanarak incelemişlerdir. Araştırma sonuncunda yeşil teknoloji düzeyindeki iyileşmenin ekolojik ayak izini azalttığı sonucunu varmışlardır

Saqip vd., (2024), 1990-2019 dönemi için en yüksek ekolojik ayak izine sahip 10 ülke için finansal gelişmenin ekolojik ayak izi üzerindeki etkisini panel veri yöntemiyle analiz etmişlerdir. Araştırmada, finansal gelişmeden ekolojik ayak izine yönelik tek yönlü bir nedensellik ilişkisi olduğunu ve finansal gelişmenin ekolojik ayak izini artırdığını tespit etmişlerdir. Raihan (2024), 1990-2022 dönemi için Brezilya'da finansal gelişmenin ekolojik ayak izi üzerindeki etkisini zaman serisi yöntemiyle analiz etmiştir. Araştırma sonucunda, finansal gelişmenin ekolojik ayak izini azalttığını tespit etmiştir. Majeed ve Mazhar (2019), 1971-2017 yılları arası dönem için 131 ülkeden oluşan bir örneklem grubu için finansal gelişmenin ekolojik ayak izi üzerindeki etkisini panel veri analiziyle incelemişlerdir. Analizde bölgesel veya ülke bazında farklı sonuçlar ortaya çıksa da genel ekseriyetle finansal gelişme ekolojik ayak izini azalttığı sonucuna varmışlardır. Nathaniel (2024), 1975-2018 dönemi için Bangladeş'te finansal gelişmenin ekolojik ayak izi üzerindeki etkisini ARDL sınır testi

yöntemiyle araştırmışlardır. Analizde finansal gelişmenin ekolojik ayak izini artırdığı sonucuna varılmıştır. Fan vd., (2024), 1990-2020 dönemi için BRICS-T ülkeleri için finansal gelişmenin ekolojik ayak izi üzerindeki etkisini panel veri yöntemiyle analiz etmişlerdir. Çalışmalarında finansal gelişmenin ekolojik ayak izi seviyesini yükselttiği sonucunu saptamışlardır.

Bergougui (2024), 1990-2021 yılları arasında çeyreklik verilerle Cezayir'de yeşil teknoloji, finansal gelişme ve ekolojik ayak izi ilişkisini Fourier ARDL yaklaşımıyla analiz etmiştir. Analiz sonucunda, finansal gelişmenin ekolojik ayak izini artırdığı, yeşil teknolojinin ise ekolojik ayak izini azalttığı sonucuna ulaşılmıştır. Aytun vd., (2024) ise 1980-2016 döneminde 19 ülke özelinde teknolojik gelişme, finansal gelişme ve ekolojik ayak izi ilişkisini CS-ARDL yöntemiyle incelemişlerdir. Araştırmada, teknolojik yenilik ile ekolojik ayak izi arasında istatistiksel olarak anlamlı bir ilişki bulunmazken, finansal gelişmenin sürdürülebilir çevrenin tesis edilmesinde önemli bir rol oynadığı tespit edilmiştir. Zhao (2022) ise 2003-2018 yılları arasında 62 ülke için yeşil teknoloji, finansal gelişme ve karbon emisyonları arasındaki ilişkiyi Momentler Sistemi (SYS-GMM) yöntemiyle analiz etmiştir. Araştırmada, finansal gelişmenin teknolojik gelişmeyi artırdığı ve bu durumun karbon emisyon düzeyini azaltmaya katkı sağladığı belirlenmiştir.

## Güncel Literatür

| *Green Technologies Effect on Ecological Footprint* | | | |
|---|---|---|---|
| **Author(s)** | **Sample / Period** | **Methodology** | **Direction of effect** |
| (Aytun et al., 2024) | Middle-income countries / 1980-2016 | CS-ARDL | Negative |
| (Bergougui, 2024b) | Algeria / 1990-2021 | Fourier ARDL | Negative |
| (Saqib et al., 2024) | Top-ten countries with the biggest EF / 1990-2019 | CCEMG, AMG | Negative |
| (Qayyum et al., 2024) | Southern Common Market (MERCOSUR) economies / 1990-2021 | CS-ARDL | Negative |
| (Nketiah et al., 2024) | Ghana/ 1990-2022 | NARDL, ARDL | Negative |
| (Bergougui & Aldawsari, 2024) | Algeria / 1990-2022 | NARDL, FMOLS, DOLS, CCR | Negative |
| (Ntom Udemba et al., 2024) | Russia / 2000-2021 | ARDL, MOLS, DOLS, CCR | Negative |
| (Wang et al., 2024) | BRICS /2002-2016 | PCSE, GMM | Positive |
| (Kirikkaleli, Sofuoğlu, et al., 2023) | USA /1970-2018 | Fourier ARDL | Negative |
| (Ozkan et al., 2023) | Türkiye /1990-2018 | ARDL | Negative |
| Javed et al. (2023) | Italy, 1994-2019 | ARDL | Negative |
| Sadiq et al. (2022) | Top-ten countries with the biggest EF / 1990-2017 | FGLS, PCSE | Negative |
| (Usman et al., 2022) | Pakistan /1991-2020 | NARDL | Negative |
| *Financial Development Effect on Ecological Footprint* | | | |
| **Author(s)** | **Sample / Period** | **Methodology** | **Direction of effect** |
| (Aytun et al., 2024) | Middle-income countries / 1980-2016 | CS-ARDL | Negative |
| (Guliyev, 2024) | European countries / 1992–2020 | Bayesian Model | Positive |
| (Saqib et al., 2024) | Top-ten countries with the biggest EF / 1990-2019 | CCEMG, AMG | Positive |
| (Ntom Udemba et al., 2024) | Russia /2000-2021 | ARDL, MOLS, DOLS, CCR | Negative |

| | | | |
|---|---|---|---|
| (Balsalobre-Lorente et al., 2023) | APEC countries / 1994-2018 | FMOLS, Panel Fisher Causality | FD ∩ EF |
| (Ngoc & Awan, 2022) | Singapore / 1980-2016 | ARDL | Positive |
| (Aslam et al., 2023) | 43 middle-income countries /1990-2020 | Panel Quantile Regression | Negative |
| (Gill et al., 2023) | Pakistan /1980-2018 | NARDL | FD ∩ EF |
| (Sun et al., 2023) | South Asian /1990-2016 | CS-ARDL | FD ∩ EF |
| (Afshan & Yaqoob, 2022) | China / 1995–2017 | QARDL | Positive |
| (Khan et al., 2022) | APEC / 1990-2016 | CCEMG | FD ∩ EF |
| (Gokmenoglu et al., 2021) | Turkiye / 1960-2014 | FMOLS | Negative |
| (Baloch et al., 2019) | BRI countries / 1990-2016 | Driscoll-Kraay Panel Regression | Positive |

Literatüre yönelik genel bir değerlendirme yapıldığında, "yeşil teknolojiler ve ekolojik ayak izi" ilişkisini inceleyen araştırmalarda yeşil teknolojideki artışın ekolojik ayak izini azaltarak çevresel sürdürülebilirliğe önemli katkılar sağladığı görülmektedir. Buna karşın, finansal gelişme ile ekolojik ayak izi arasındaki ilişkiye dair çalışmalar, çevresel sürdürülebilirlik üzerindeki etkilerinin hâlâ tartışmalı ve karmaşık bir alan olduğunu ortaya koymaktadır.

**Yöntem:** Metodolojik olarak çalışmada sırasıyla Fourier KPSS birim kök testi, Fourier ARDL, geleneksel ve Fourier nedensellik testleri ve uzun dönem katsayı testleri olan FMOLS, DOLS ve CCR kullanılmıştır.

**Sonuç ve Değerlendirme:** Değişkenler arasında uzun vadeli Fourier eşbütünleşmenin olduğu bulgusuna ulaşılmıştır. Nedensellik test sonuçlarına göre, ekolojik ayak izindeki değişmelerin finansal gelişmedeki değişimler üzerinde herhangi bir nedensellik etkisi olduğuna dair kanıt bulunamamıştır. Finansal gelişmede meydana gelen değişimlerin TY & Boostrapt TY ve Fourier TY-Cumulative Frequency testleri dışında diğer nedensellik testlerinde ekolojik ayak izini nedenseli olduğuna dair bulgular mevcuttur. Ayrıca ekolojik ayak izinden yeşil teknolojilere doğru bir nedensellik ilişkisi bulunmuştur. Katsayı sonuçları ise finansal gelişmenin ekolojik ayak izini pozitif, yeşil teknolojilerin ize ekolojik ayak izini negatif etkilediği yönündedir. Özetle, elde edilen bulgular hipotezlerimizi destekler ve literatürdeki çalışmalarla (Bergougui, B. 2024a; Çamkaya, 2024; Nketiah et al., 2024; Köseoğlu et al., 2022; Aytun et al., 2024) aynı yöndedir. Bu hipotezlerdeki beklentilere verilecek cevaplar çevre çalışmaları alanına anlamlı katkılar sağlayacaktır. Özellikle, çalışmanın sonuçları Türkiye'nin sürdürülebilir ekonomik büyüme yolunda ekolojik durumunu ortaya koyacaktır. Aynı zamanda benzer ekonomik yapıya sahip ülkelerde veya ülke grupları açısından da yol gösterici bir harita çıkaracaktır. Sonuç olarak, literatürdeki bu benzer bulgular Türkiye'deki araştırmanın önemini artırmakta; mevcut iklim politikalarının gözden geçirilmesi ve yeşil teknoloji uygulamalarının teşvik edilmesi gerekliliğini vurgulamaktadır. Bu da hem çevresel sürdürülebilirliği sağlamak hem de ekonomik büyümeyi desteklemek açısından kritik bir rol oynamaktadır.

Çalışmanın bulguları ışığında Türkiye'nin sürdürülebilir ekonomik büyüme hedeflerine ulaşabilmesi için yeşil teknolojilere yapılan yatırımların artırılması gerektiği sonucuna varılmaktadır. Ekolojik ayak izinin azaltılması adına atılacak adımların yalnızca teknolojik yeniliklerle sınırlı kalmaması; aynı zamanda finansal sistemin de çevre dostu yatırımları teşvik edecek şekilde yapılandırılması önem arz etmektedir. Ayrıca çalışmada önerilen stratejiler arasında kamu politikalarının güçlendirilmesi ve özel sektörün yeşil inovasyonlara yönlendirilmesi yer almaktadır. Böylece insan-doğa ilişkisindeki bozulmaların en aza indirilmesi sağlanabilirken, Türkiye'nin doğal kaynaklarının daha verimli bir şekilde kullanılması mümkün hale gelecektir. Sonuç olarak, bu çalışma hem akademik alanda hem de politika geliştirme süreçlerinde dikkate alınması gereken önemli bulgular sunmaktadır.