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Effects of Ecological Footprint, Carbon Emissions and Trade Liberalization on Green Economic Growth in Turkey: An ARDL Approach

Türkiye'de Ekolojik Ayak İzi, Karbon Emisyonları ve Ticari Serbestleşmenin Yeşil Ekonomik Büyüme Üzerindeki Etkileri: Bir ARDL Yaklaşımı

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ABSTRACT

The aim of this study is to examine green economic growth dynamics in Turkey regarding achieving sustainable development goals. The research specifically aims at examining the causal relationships among ecological footprint, carbon emissions, trade openness, and economic growth. This study employs ARDL cointegration analysis to examine the long-run contribution of these factors on Turkey's economic performance and their compatibility with sustainable development goals. The econometric analysis of this study proves that commercial openness leads to a small short-term effect on economic growth but long-run benefits. But the effects of the ecological footprint index are positive in the short term and negative in the long term on economic growth. The value added of agriculture, forestry, and fishing has no significant effect on economic growth. Our findings show that energy generation from renewable resources had a statistically significant positive effect on economic growth. This is in line with recent studies suggesting that greater use of renewable energy sources leads to higher economic growth. In sum, the evidence shows that Turkey has gone quite a distance towards green economic growth and very much underscores the necessary function of environmental considerations in meeting sustainable development goals. These results lead the researchers to advocate that Turkey take a policy of sustainable and green economic growth. Our advice to policymakers is that they should pursue and implement a coherent set of policies that are green (for protecting the environment) but also supportive for the economy.

MAKALE BİLGİSİ

Anahtar Kelimeler:

Sürdürülebilir Kalkınma, Ekolojik Ayak İzi, Karbon Emisyonları, Yenilenebilir Enerji, ARDL Eşbütünleşme

ÖZET

Bu çalışmanın amacı, sürdürülebilir kalkınma hedeflerine ulaşma konusunda Türkiye'deki yeşil ekonomik büyüme dinamiklerini incelemektir. Araştırma özellikle ekolojik ayak izi, karbon emisyonları ve ticari açıklık ile ekonomik büyüme arasındaki nedensel ilişkileri incelemeyi amaçlamaktadır. Bu çalışmada, söz konusu faktörlerin Türkiye'nin ekonomik performansı üzerindeki uzun dönemli katkısını ve sürdürülebilir kalkınma hedefleriyle uyumluluğunu incelemek için ARDL eşbütünleşme analizi kullanılmıştır. Bu çalışmanın ekonometrik analizi, ticari açıklığın ekonomik büyüme üzerinde kısa vadede küçük bir etkiye yol açtığını, ancak uzun vadede fayda sağladığını

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kanıtlamaktadır. Ekolojik ayak izi endeksinin ekonomik büyüme üzerindeki etkisi ise kısa vadede pozitif, uzun vadede negatiftir. Tarım, ormancılık ve balıkçılık katma değerinin ekonomik büyüme üzerinde önemli bir etkisi yoktur. Bulgularımız, yenilenebilir kaynaklardan enerji üretiminin Ekonomik Büyüme üzerinde istatistiksel olarak anlamlı ve pozitif bir etkisi olduğunu göstermektedir. Bu, yenilenebilir enerji kaynaklarının daha fazla kullanılmasının daha yüksek ekonomik büyümeye yol açtığını öne süren son çalışmalarla uyumludur. Özetle, elde edilen bulgular Türkiye'nin yeşil ekonomik büyüme yolunda oldukça mesafe kat ettiğini göstermekte ve sürdürülebilir kalkınma hedeflerine ulaşmada çevresel hususların gerekli işlevinin altını çizmektedir. Bu sonuçlar araştırmacıları Türkiye'nin sürdürülebilir ve yeşil bir ekonomik büyüme politikası izlemesini savunmaya yöneltmektedir. Politika yapıcılara tavsiyemiz, yeşil (çevrenin korunması için) ve aynı zamanda ekonomiyi destekleyici bir dizi tutarlı politikayı takip etmeleri ve uygulamalarıdır.

1. Introduction

The correlation between economic expansion and environmental deterioration has been examined in recent years. A significant commonality between industrialized and developing nations is economic development. Developing nations augment their economic activity to address issues such as hunger, poverty, and unemployment. They consistently aspire to attain the welfare standards of industrialized nations. Consequently, enhancing living standards and creating jobs to ensure the sustainability of economic growth has emerged as a significant issue in Turkey since the early 2000s. While economic growth is Turkey's primary aim, like other developing nations, it is crucial to achieve development strategies that maintain the principles of sustainable development. From 2002 until 2012, the Turkish economy saw an annual growth rate of roughly 5%, but in 2012, it encountered more subdued development owing to the economic crisis in Eurozone nations and a decline in domestic demand (Orhangazi & Yeldan, 2021; Özer et al., 2021).

Good economic growth Nature is an idea that has been actively discussed by a growing number of places around the world in recent years, with increasingly increased attention to environmental sustainability and sustainable development strategies. The objective of this research is to analyze the relationship between ecological footprint, carbon emissions, and trade liberalization effect on green economic development in Turkey using the ARDL approach. We explore how these factors intersect to play or play a role in the national building of sustainability objectives (Belmonte-Ureña et al., 2021; Mohsin et al., 2022).

Green economy growth refers to a sustainable development approach that seriously endeavors and rallies an economic model towards cutting ecological footprints/carbon emissions and upholding trade liberalization. It is the sustainable way forward, respecting and sustaining our planet's resources while also working towards a healthy balance between economic growth and environmental protection. By adhering to this important concept, we can realize a thriving and resilient economy that flourishes while also sustaining our natural world for generations of enjoyment and use (Ahmed et al., 2022; Fang et al., 2022).

Turkey, which is at the crucial junction of Western Asia and Southeastern Europe, has been actively studying the adverse effects of ecological footmarks, carbon emissions, and the liberalization of trade on a developing green economy. The central objective underpinning the literature research articles has been to explicitly demonstrate the necessity of embracing and sustaining economic development practices that do not compromise the well-being of the environment and its resources (Öcal, Altınöz, & Aslan, 2020; Telatar & Birinci, 2022).

The Turkish economy has undergone major transformation processes over the years, which attract the attention of many researchers to the role sustainable development goals and trade liberalization have to the economy (Alsamara et al., 2019). The analysis that follows seeks to understand the linkages between the green economy and economic growth in Turkey and its sustainable development goals and foreign trade liberalization by paying attention to the role of trade liberalization, ecological footprint, and renewable energy production on economic growth. This analysis makes contributions to the literature on prospects of achieving ecologically sustainable economic growth in the country by relating growth to important economic indicators and trends.

The economic growth course is very much determined by Turkey’s dedication to sustainable development objectives and its receptiveness to trade (Undp, n.d.). Thus, it is necessary to examine the targets and indicators in the sustainable development goals indicated and their appropriateness to Turkey’s economic context. Trade openness and environmental sustainability and the impact of Turkey’s trade policies on green economic growth have been analyzed. This paper will not only provide a broad review of Turkey’s experience but also offer a synthesized view of the opportunities and challenges that Turkey encountered on the road to sustainable green growth.

Turkey has made great progress by aligning its national development strategies with the United Nations Sustainable Development Goals. The nation has recognized several critical domains for prioritized intervention, encompassing poverty alleviation, access to clean energy, sustainable urban development, and climate initiatives. Turkey is enacting policies to augment the proportion of renewable energy sources in its energy portfolio to diminish its carbon footprint and foster environmental sustainability (Erat & Telli, 2020).

Turkey has prioritized enhancing access to education, healthcare services, and employment opportunities in accordance with the Sustainable Development Goals (SDGs). The acknowledgment of the interconnection between social development and economic growth is evident in Turkey's developmental strategy. This holistic strategy for development illustrates Turkey's dedication to attaining sustainable and inclusive advancement that incorporates economic, social, and environmental dimensions (Aşici, 2015).

Consequently, we shall persist in our analysis within the study to ascertain the answers to the subsequent inquiries:

What is the impact of trade openness on economic growth in Turkey?

What is the effect of the ecological footprint on Turkey's economic development?

What is the correlation between the value added by agriculture, forestry, and fishing in Turkey and economic growth?

What is the correlation between renewable energy production and economic growth in Turkey?

This study aims to analyze the effects of trade openness, sustainable development goals, financial development, and technology on Turkey's economic growth. The subsequent sections of the study encompass the literature review, the research methodology, the analysis results obtained, and the conclusions derived from these results and analyses.

2. Literature Review

The concept of economic growth is a core idea in economics. Economists have extensively studied this topic, resulting in the development of several hypotheses and theories. Research on green growth has progressively highlighted the importance of economic development by focusing on sustainable development, natural resource constraints, and environmental preservation (Belmonte-Ureña et al., 2021; Mentes, 2023).

Economic development research integrates environmental factors into the examination of the growth process. This study encompasses models that focus only on environmental challenges and the detrimental effects of environmental degradation, notwithstanding their enhancement of welfare gains. In contrast, several models see the environmental tax as a welfare advantage and suggest that the tax system may be designed to harmonize with efficiency and equity goals. Numerous economic growth theories emphasize the impact of economic expansion within a framework that considers the interplay between sustainable economic development, CO2 emissions, and ecological imprint. This initiative aims to foster a green economy and provide chances for increased investment and employment in regions with significant environmental advantages (Aslan et al., 2021; Bi et al., 2020; Onofrei et al., 2022).

Research from diverse environmental-economic studies examining the shift of nations from the brown growth paradigm to the green growth paradigm reveals that economic advancement towards a green economy is expedited when there is a focused strategy to attain the requisite level of social satisfaction. The results of studies conducted in various nations validate each other. These results indicate that green economic growth is now vital for both affluent and poor countries. Also, looking at data from both developed and developing countries shows that the cost-benefit relationship does not work when looking at the link between environmental costs and job creation in clean industrial sectors through the lens of the green transition hypothesis about regional structure. Thus, it is recognized that current global issues with 'green' economic growth are apparent. Its clear manifestation in international forums is also predictable (Anser et al., 2021; Belmonte-Ureña et al., 2021; Lenaerts et al., 2022; Magazzino et al., 2022).

Trade liberalization has been widely recognized as a pivotal factor influencing economic growth, environmental sustainability, and green economic transitions. Theoretically, trade liberalization enhances market efficiency and resource allocation, encouraging investments in environmentally friendly technologies (Chhabra, Giri, & Kumar, 2022). However, the environmental impacts of trade liberalization often depend on the regulatory frameworks and the degree of openness to global markets. For instance, Aydin and Turan (2020) highlight that countries with weak environmental regulations may experience adverse ecological effects due to unregulated resource exploitation and increased pollution. In contrast, nations with stringent environmental policies tend to benefit from cleaner production technologies and increased foreign investments in green sectors.

In the Turkish context, trade liberalization has been linked to both opportunities and challenges for achieving green economic growth. Alsamara et al., (2019) emphasize that Turkey's increasing trade openness has facilitated access to advanced green technologies and international markets, fostering economic growth. However, Nathaniel, Murshed, and Bassim (2021) caution that without adequate environmental safeguards, the benefits of trade liberalization may be offset by higher carbon emissions and resource depletion. This dual impact necessitates a balanced approach to policy formulation that integrates environmental sustainability into trade strategies.

Research further indicates that the "pollution haven" hypothesis may partially apply to Turkey, where trade liberalization can attract environmentally intensive industries due to less stringent regulatory frameworks (Usman et al., 2020). Therefore, the impact of trade liberalization on Turkey's green economic growth requires a nuanced analysis that considers sector-specific dynamics and international trade agreements promoting sustainability (Wang & Zhang, 2020).

2.1. Conceptual framework of green economic growth

The literature is advancing a theoretical framework of green economic development by integrating the limitations of welfare economics with environmental and resource constraints. This concept is predicated on establishing a societal framework that safeguards social and environmental systems within defined parameters. Furthermore, the paper addresses the notion of sustainable development, emphasizing the need of fulfilling existing demands without compromising the developmental prospects of future generations.

Furthermore, the relationship among economic growth, natural resources, and the environment is addressed, emphasizing that the sustainability challenge requires a comprehensive response. Consequently, ecological and carbon footprints function as proxies for the large-scale integration of ecological services. In this context, of the thirteen distinct growth models provided, two that exemplify green growth are elucidated below. The first model of green growth might be seen as incorporating green inputs into the conventional neoclassical paradigm. A single-generation growth model is shown via the use of the growth model. By incorporating pollution capital, an individual becomes a holder of green capital, while output is treated as trash. Upon examining statistical efficiency and the benchmark manufacturing process, it becomes evident that natural capital is valued less than other forms of capital. This is due to its inherent benefits compared to other forms of capital. Social wellbeing is contingent upon both consumption and natural resources. The model examines the characteristics contributing to allocation issues via the use of pollution-producing technology and finite natural resources. To maintain an appropriate income level for the functioning of the consumer economy, it adversely affects the saving rate. Increases in taxes proportional to pollution output are considered an ecologically sustainable policy that aligns with the optimal labor tax level; yet polluters do not incur the economic costs associated with pollution (Matuštík & Kočí, 2021; Meraj et al., 2022; Sarkodie, 2021; Yang & Meng, 2020).

2.2. Ecological footprint and its implications

The ecological footprint is defined as “the theoretical land area required for sustainable and equitable bioproduction utilized by individuals, cities, and nations, directly and indirectly linked to their consumption habits and waste generation to fulfill their needs.” The ecological footprint reflects the extent to which a nation overuses or conserves its natural resources. The footprint comprises the primary footprint associated with food, rural living accommodations, transportation, and infrastructure, as well as indirect personal impacts. The path of capital is the portion of the footprint that external trade in goods and services, as well as component materials, enhances. The magnitude of the distortion and the variance in the ecological footprint elucidate the country's natural resources and product imports (Satrovic et al., 2024; Sharma et al., 2022; Zhang et al., 2022).

The ecological footprint may serve as a valuable foundation for the discourse on “weak sustainability.” Otherwise, it cannot be adequately situated within the framework of technological advancements and economic motivations. The ecological footprint was used as a metric in several conversations about the multiple facets of sustainable development. The primary focus in the research is that the ecological footprint may be inadequate in addressing service, supply, and waste management systems, as well as in eliciting concerns from capital investors. The footprint fails to provide price signals for mitigating environmental consequences and does not disperse or negotiate external environmental costs, making further progress and remediation difficult. The findings indicated that the global average human ecological footprint exceeded the biocapacity defined as the biosphere's capacity to generate resources and assimilate waste by 29% during the years 2001-2003. It is projected that by 2030, the depletion of ecosystem services and natural resources will amount to 0.8 planets, in line with current trends. Ecological footprint studies done in different countries showed that low-income countries had very small ecological footprints. On the other hand, countries that depend on the large amounts of money that high-income regions have for consumption especially when it comes to using natural resources and making waste had large ecological footprints

(Bastianoni et al., 2020; Büyüksarıkulak et al., 2023; Kumar et al., 2022; Sarkodie, 2021; Świąder et al., 2020)

2.3. Carbon emissions and climate change

The atmospheric levels of carbon dioxide have risen because of the use of fossil fuels such as petroleum, coal, and natural gas. Carbon dioxide contributes to climate change via its role in the greenhouse effect. Global warming is detrimental since it may modify the climate and impact the living circumstances of humans and other organisms on Earth. The observable effects of climate change under severe circumstances include increased rainfall frequency, altered agricultural seasons, rising sea levels, melting arctic and glacial ice, and intensified hurricanes and storms. The extensive repercussions of such disasters often adversely affect human health. The inability to evaluate swift and severe natural disasters is a significant impediment to economic activities, particularly those heavily reliant on ecological attributes, such as tourism. Direct quantification of the environmental implications of a commercial transaction is not practicable.

Consequently, the value attributed to this cost correlates with the pricing of these items. As the supply diminishes due to climate change, the repercussions will escalate, possibly resulting in increasingly severe effects. Consequently, these environmental aspects must be used in the analysis of economic conditions (Letcher, 2020; Martins et al., 2021; Paraschiv & Paraschiv, 2020).

2.4. Trade liberalization and environmental impact

Before there was a lot of empirical research on the subject, people used cross-sectional models to look at how trade liberalization affected pollution at the international ecological level. Trade uncertainty played a big role in these studies. After that, a lot of academics have investigated trade liberalization through real-world studies, such as endogenous technological change models, specific cases, and clean technologies that have been emphasized in situations where they directly caused pollution. Trade liberalization in other places was shown to adversely impact pollution, while it positively influences pollution in this context. The emphasis was placed on women activists, emerging nations, and ethnic frameworks as they exchanged pollution for trade liberalization, with a discussion on the significance of information. The results were subjected to theoretical scrutiny. Research indicates that trade liberalization has a minimal impact on pollution, or its effects are confined to low- and middle-income nations. Research indicates that it is feasible to address pollution without impeding economic progress. Considering the perspectives and analyses conducted inside the theoretical frameworks, discrepancies between the empirical data are evident. This research seeks to enhance the literature by examining the empirical association between trade liberalization and environmental contaminants in Turkey using ARDL cointegration analysis (Chhabra et al., 2022; Tachie et al., 2020; Usman et al., 2020; Q. Wang & Zhang, 2020).

Trade liberalization is likely to impact the ecological framework of nations. As countries get better at competing in terms of their production capacity, the fast progress brought about by global changes in production is clearly putting pressure on ecosystems around the world and making countries compete for leadership in certain areas. Trade liberalization, globalization, and the principle that each nation should specialize in its most efficient production, including subsistence agriculture, are interrelated concepts. Considering this condition, it is probable that it will generate problems for nations with fragile economic frameworks and incite confrontations about the subject. Commercial competition exists with methods to mitigate challenges arising from international pressures, which include cutting manufacturing costs and reinterpreting trade prohibitions as means to enhance economic advantage while disregarding emission limits (Aydin & Turan, 2020; Nathaniel et al., 2021; W. Wang et al., 2022).

3. Theoretical Framework

Human sustainability has emerged as a crucial component of national development strategies, driven by various international, national, and regional challenges, including global energy demands, rising greenhouse gas emissions, dwindling natural resources, fluctuating commodity prices, and advancements in technology and innovation. The notion of green growth seeks to attain sustainable development by augmenting competitive advantages and mitigating environmental hazards via enhanced resource and energy efficiency. Simultaneously, it rectifies a gap in the literature about economic development, namely its oversight of the growth-enhancing impacts of diminishing carbon dioxide emissions, energy consumption, and other resource-depleting activities. Previous studies have predominantly utilized ecological damage and carbon dioxide emissions as metrics for environmental degradation, concluding that these factors may adversely affect economic performance. We suggest that carbon dioxide emissions can also be interpreted in the context of economic growth and "green growth" as the "cost" associated with polluting technologies (Matuštík & Kočí, 2021; Meraj et al., 2022; Sarkodie, 2021).

Turkey's proactive strategy for green economic growth, alongside its dedication to sustainable development goals and trade liberalization, establishes the nation as a significant case study for examining the interplay between economic prosperity and environmental sustainability.

Thus, our hypotheses to be examined in our research can be expressed as follows:

H_1: The relationship between economic growth and trade openness in Turkey is positive.

H_2: In Turkey, the relationship between economic growth and ecological footprint is positive.

H_3: In Turkey, the relationship between economic growth and carbon emissions is negative.

H_4: In Turkey, the relationship between economic growth and renewable energy production is positive.

3.1. ARDL methodology overview

The autoregressive distributed lag (ARDL) methodology was introduced in 1996. The ARDL approach is widely adopted in recent studies due to its flexibility and lack of prerequisites concerning unit root testing, integration, destructive dependencies of time-series variables, and automation of the lag structure. This method has been employed in recent research without regard to deriving the lag number formula based on variance-covariance stability due to issues related to the variance-covariance stability or testing problems inherent to the normal distribution of the residual term and the inadequacy of the formulas describing F-statistics. Recent advancements in computer software have resolved these issues, and these packages also eliminate the subjectivity associated with the lag number. The ARDL approach offers numerous advantages, including the ability to capture both short-term and long-term relationships by incorporating lags of the dependent variable and causal relationships among time-series variables irrespective of lag order. It is accessible for use by other researchers without requiring advanced values, provides greater desirability compared to estimates derived from the error correction model due to its facilitation of straightforward bounds testing, and extends the benefits of traditional cointegration tests to less complex scenarios (Asiva Noor Rachmayani, 2015; Nkoro & Uko, 2016; Pesaran, 2008; Pesaran, Shin, & Smith, 2001).

3.2. Data and methodology

In this paper, I undertake analysis based on an empirical study of the long-term consequences of ecological footprint, carbon emissions, and trade liberalization on green economic development. For the study data, Turkey is from 1974 to 2022. This was indeed used because the autoregressive distributed lag (ARDL) model can look at short-term as well as long-term relationships and has a rigorous method of proof as well. This section defines what data are used in the empirical framework of this research, the variables studied, and why they are chosen.

3.2.1. Data sources and variable

To study the case, time series data for variables relevant to the Turkish economy for the period 1974-2022 were used. The source of all data pertaining to Turkey, a developing nation, is the World Development Indicators (WDI) and the Global Footprint site. The table 1 in below includes the full details of the data that has been used in the study.

Table 1. Variables

Variables	**Abbreviation**	**Unit**	**Data Source**	
Dependent Variable				
Economic Growth	EG	(2015 constant US dollars)	WDI	
Independent Variables				
The ratio of exports to GDP	EX	(GDP%)	WDI	**COMMERCIAL OPENNESS (CO)**
The ratio of imports to GDP	IM	(GDP%)	WDI	
Co2	Co2	(2015 US Dollars per kg of GDP)	WDI	
The Added Value of Agriculture, Forestry, and Fisheries	VAFF	(2015 constant US dollars)	WDI	
Electricity Generation from Renewable Resources	EGRR	(Percentage of the total)	WDI	
Foreign Direct Investments	FDI	(GDP%)	WDI	
Energy Consumption	EC	(Per capita kg of oil equivalent)	WDI	
Ecological Footprint Index	EFI		Global Footprint Network	

Source: https://databank.worldbank.org/source/world-development-indicators#; https://www.footprintnetwork.org/our-work/ecological-footprint/

This study utilized time series data of variables pertinent to the Turkish economy from 1974 to 2022. All data pertaining to Turkey, classified as a developing nation, has been sourced from the World Development Indicators (WDI) and the Global Footprint website.

3.2.2. Empirical model specification

This study employed the subsequent econometric equation to examine the variables presented in Table 2 for the period 1974-2022:

$lnEG_t = \beta_0 + ln\beta_1 CO_t + ln\beta_2 CO2_t + ln\beta_3 VAFF_t + ln\beta_4 EGRR_t + ln\beta_5 FDI_t + ln\beta_6 EC_t + ln\beta_7 EFI_t + \mu_t$ (1)

The term EG in the equation denotes economic growth, specifically Turkey's GDP. The equation incorporates the following independent variables: commercial openness (CO), carbon emissions (CO2), value added by agriculture, forestry, and fishing (VAFF), electricity generation from renewable energy resources (EGRS), foreign direct investments (FDI), energy consumption (EC), and ecological footprint index (EFI). The commercial openness variable is represented by the ratio of exports to economic growth and the ratio of imports to economic growth. Here represents the constant coefficient, while β_1, β_2,…,and so forth denote the coefficients of each variable and signifie the error term. The transformation of data into natural logarithms is widely endorsed, and some research has been undertaken in this area (Raghutla, 2020).

4. Empirical Results

This chapter is devoted to the empirical examination of cointegration testing among the examined variables. The ARDL model's cointegration results will tell us a lot about how long the variables we looked at, like ecological footprint index, will last, especially in the Turkish economy. We first conducted a unit root test based on the time-series characteristics of the data. The main goal is to look at the long-term connections between energy flow, carbon emissions, trade openness, and economic growth from 1974 to 2022 using the ARDL approach to cointegration. This is a good time frame for finding differences and variations between countries. We determined our trade openness variable by calculating the ratio of international trade to gross domestic product (GDP). The model for this research comprises many variables. The variables are distinctly classified into explanatory, independent, and control variables.

In building our models, we prioritized the incorporation of essential variables together with their assigned predicted indications. It is established that while assessing the long-term links between green growth and numerous parameters, each relationship considerably differs according to the distinctiveness of the components involved.

4.1. Descriptive statistics

This section presents the statistical values of the variables utilized in the study, as detailed in Table 2.

Table 2. Summary Statistics for Variables

	LnEG	LnCO2	LnFDI	LnEFI	LnEC	LnCO	LnVAFF	LnEGRR
Average	26.699	-0.747	-0.742	1.000	7.001	3.643	24.429	-0.585
Medyan	26.689	-0.740	-0.648	0.997	7.016	3.789	24.362	-1.029
Max.	27.808	-0.648	1.287	1.245	7.480	4.396	24.937	2.125
Min.	25.692	-0.876	-3.940	0.708	6.474	2.733	24.054	-4.043
Standard Deviation	0.616	0.049	1.288	0.163	0.310	0.420	0.2559	1.573
Skewness	0.138	-0.660	-0.587	0.025	-0.037	-0.719	0.5617	0.306
Kurtosis	1.85	3.377	2.630	1.588	1.730	2.665	2.1043	2.112
Jarque-Bera	2.848	3.848	3.096	4.075	3.301	4.459	4.215	2.375

Probability	0.240	0.145	0.212	0.130	0.191	0.107	0.121	0.304
Observation	49	49	49	49	49	49	49	49

The Table 2 indicates an equilibrium between stability and variability in Turkey's economic and environmental performance. Economic growth is exhibiting stable performance, oscillating around the average within a narrow range. This indicates that the Turkish economy is primarily demonstrating a stable growth trajectory. Variables such as trade openness and foreign direct investment exhibit wider distributions and greater standard deviations. The case shows that these changes in global trade dynamics and domestic political environments matter a great deal to Turkey's trade and investment paths. The carbon emission data exhibits negative skewness that suggests that the carbon emissions are on a downward trend. This increased standard deviation in electricity generation from renewable sources demonstrates significant variability in production and underscores the need for continued industry support of renewable energy. Indeed, energy consumption and ecological footprint are observed to be significantly stable. That is, energy consumption in Turkey has been stable because of the distribution of energy consumption around average values within a narrow range. An unchanged ecological footprint suggests that the environment is still going to have an effect. The table illustrates Turkey's economic growth in the relationship with environmental variables and some independent variables and their temporal variations. The data is important to measure the efficacy of Turkey's attempts at economic planning and environmental doing to chart the right course of action in the future. In addition, Table 3 below shows the correlation relationships of the variables.

Table 3. Correlation Results

	LnEG	**LnCO2**	**LnFDI**	**LnEFI**	**LnEC**	**LnCO**	**LnVAFF**	**LnEGRR**
LnEG	1							
LnCO2	-0.057	1						
LnFDI	0.629	-0.044	1					
LnEFI	0.785	-0.091	0.568	1				
LnEC	0.954	-0.073	0.600	0.821	1			
LnCO	0.806	-0.037	0.581	0.673	0.784	1		
LnVAFF	0.937	-0.069	0.596	0.770	0.921	0.780	1	
LnEGRR	0.409	-0.328	0.205	0.409	0.428	0.331	0.411	1

The coefficients in the correlation matrix range from -1 to +1. A positive coefficient signifies that an increase in one variable corresponds with an increase in the other, whereas a negative coefficient denotes that an increase in one variable results in a decrease in the other. A coefficient of 0 signifies the absence of a relationship between the variables (Akoglu, 2018). In academic research, to mitigate multicollinearity, the correlation coefficients among independent variables should remain below 0.80. If the independent variables do not have much of a relationship with each other, multicollinearity could happen, which would make the regression analysis results less reliable (Grewal et al., 2004).

There exists a positive correlation (0.806) between trade openness and economic growth, whereas a negative correlation (-0.057) is observed between carbon emissions and economic growth. Foreign direct investments exert a beneficial influence on economic growth (0.629), and the ecological footprint similarly demonstrates a robust positive correlation with economic growth (0.785). Although there is a strong positive correlation (0.954) between energy consumption and economic growth, agriculture, forestry, and fishing also significantly contribute to economic growth (0.937). The generation of electricity from renewable energy sources positively influences economic growth (0.409).

4.2. Unit Root Tests

This section of the study first conducted unit root tests on the variables, and the results of the model based on these tests were presented utilizing the Autoregressive Distributed Lag (ARDL) method.

4.2.1. Traditional unit root test results

The non-stationarity of a series, specifically the existence of a unit root, signifies that the series is affected by its historical values. From this viewpoint, most economic series exhibit a unit root. In an economic analysis, it is essential that the relationships between dependent and independent variables are significant while also ensuring the absence of strong interactions among the variables. In conclusion, the variables are anticipated to oscillate around a stable mean. Nonetheless, if a distinct trend exists in the time series, the correlations among variables may be deceptive. Consequently, discerning whether the relationships between variables are genuine or deceptive hinges on the stationarity of the time series. The lack of unit roots in the variables is crucial for the precision of the analyses. Furthermore, unit root tests assist in identifying the suitable analytical method to employ (Göksu & Balkı, 2023). Table 4 shows the stationarity results of the variables.

Table 4. ADF and PP Unit Root Test Results

Unit Root Test Result (PP)									
Level									
		LnEG	**LnCO2**	**LnFDI**	**LnEFI**	**LnEC**	**LnCT**	**LnVAFF**	**LnEGRR**
Fixed	t-Statistic	0.69	-2.06	-1.49	-1.41	-0.71	-1.27	1.17	-0.71
	Probability	*0.99*	*0.25*	*0.52*	*0.56*	*0.83*	*0.63*	*0.99*	*0.83*
Stable and Trendy	t-Statistic	-2.583	-2.06	-4.10	-4.76	-3.34	-2.49	-2.00	-2.07
	Probability	*0.28*	*0.55*	*0.01*	*0.00*	*0.07*	*0.32*	*0.58*	*0.54*
				**	***	*			n0
Unstable and Trendless	t-Statistic	8.76	0.70	-1.56	1.46	4.76	2.64	6.35	-0.84
	Probability	*0.99*	*0.86*	*0.10*	*0.96*	*0.99*	*0.99*	*0.99*	*0.34*

First Difference									
		ΔLnEG	**ΔLnCO2**	**ΔLnFDI**	**ΔLnEFI**	**ΔLnEC**	**ΔLnCT**	**ΔLnVAFF**	**ΔLnEGR R**
Fixed	t-Statistic	-6.79	-7.21	-10.58	-11.97	-7.35	-5.99	-12.48	-7.15
	Probabilit y	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
		***	***	***	***	***	***	***	***
Stable and Trendy	t-Statistic	-7.07	-8.70	-10.37	-11.82	-7.25	-5.93	-19.20	-7.68
	Probabilit y	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
		***	***	***	***	***	***	***	***
Unstable and Trendless	t-Statistic	-3.81	-7.24	-10.41	-11.15	-5.72	-5.41	-8.89	-7.194
	Probabilit y	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
		***	***	***	***	***	***	***	***
Note: (*) significant at the 10% level; (**) significant at the 5% level; (***) significant at the 1% level. MacKinnon (1996) one-sided p-values.									
Unit Root Test Result (ADF)									
Level									
		LnEG	**LnCO2**	**LnFDI**	**LnEFI**	**LnEC**	**LnCT**	**LnVAFF**	**LnEGRR**
Fixed	t-Statistic	0.40	-1.87	-1.81	-0.48	-0.73	-1.35	2.34	-0.93
	Probabilit y	*0.98*	*0.33*	*0.36*	*0.88*	*0.82*	*0.59*	*0.99*	*0.76*
Stable and Trendy	t-Statistic								
	Probabilit y	-2.46	-2.05	-4.12	-4.58	-3.34	-2.88	-1.09	-2.28
		0.34	*0.55*	*0.01*	*0.00*	*0.07*	*0.17*	*0.91*	*0.43*
Unstable and Trendless	t-Statistic			**	***	*			
	Probabilit y	7.43	0.34	-1.80	1.58	3.63	2.07	4.82	-1.09
Fixed	t-Statistic	*0.99*	*0.78*	*0.06*	*0.97*	*0.99*	*0.98*	*0.99*	*0.24*

				*					
First Difference									
		ΔLnEG	**ΔLnCO2**	**ΔLnFDI**	**ΔLnEFI**	**ΔLnEC**	**ΔLnCT**	**ΔLnVAFF**	**ΔLnEGRR**
Fixed	t-Statistic	-6.71	-6.60	-9.76	-6.95	-7.08	-5.53	-12.34	-3.41
	Probability	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.01*
		***	***	***	***	***	***	***	**
Stable and Trendy	t-Statistic	-6.73	-5.550	-9.66	-6.85	-7.00	-5.49	-5.12	-3.65
	Probability	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.03*
		***	***	***	***	***	***	***	**
Unstable and Trendless	t-Statistic	0.13	-6.64	-9.81	-10.90	-0.61	-4.84	0.24	-3.40
	Probability	*0.72*	*0.000*	*0.000*	*0.000*	*0.44*	*0.000*	*0.75*	*0.00*
			***	***	***		***		***
Note: (*) significant at the 10% level; (**) significant at the 5% level; (***) significant at the 1% level. MacKinnon (1996) one-sided p-values.									

Table 4 indicates that all variables were determined to be I (1) at both the 1% and 5% significance levels according to the ADF and PP unit root test results.

4.2.2. Results of the structural break unit root test

The mean, trend, or both of a time series may fluctuate due to economic crises, policy alterations, unforeseen disasters, etc. Consequently, it is evident that the ordinary unit root test results of a stationary series are non-stationary. To prevent obtaining such results, it is inadvisable to apply standard unit root tests to series with structural breaks or breakpoints. Structural breaks can be examined in the literature utilizing three models: at the level, at the trend, and at both the level and the trend. Nonetheless, the predominant application is for stationery, encompassing both stationery and trending models. The suitable break time for time series can be determined externally or internally (Mert & Çağlar, 2019). Analysis of the graphs from the study reveals that the series exhibits abrupt discontinuities. The results of the test for structural breaks of the variables are presented in Table 5.

Table 5. Structural Break (Perron, 1989) Unit Root Test Results

Variables	**Fixed Model**				**Fixed and Trendy Model**			
	Level Values		**First Difference**		**Level Values**		**First Difference**	
	t	**p**	**t**	**p**	**t**	**p**	**t**	**p**
LnEG	-1.397	0.999	-7.433	0.0000**	-3.453	0.7213	-7.344	0.0000**
LnCO2	-3.137	0.604	-7.352	0.0000**	-3.280	0.8113	-7.483	0.0000**
LnFDI	-3.917	0.186	-11.30	0.0000**	-5.108	0.0239	-11.33	0.0000**

LnEFI	-2.786	0.793	-11.36	0.0000**	-5.638	0.0000**	-11.31	0.0000**
LnEC	-1.929	0.985	-7.787	0.0000**	-3.842	0.473	-7.700	0.0000**
LnCT	-2.219	0.960	-6.403	0.0000**	-4.117	0.3048	-6.349	0.0000**
LnVAFF	-1.634	0.999	-13.561	0.0000**	-3.490	0.6981	-13.41	0.0000**
LnEGRR	-3.630	0.315	-9.242	0.0000**	-3.594	0.6331	-9.147	0.0000**
Note: * Constant term and constant and trend models were employed in the Structural Level values and first differences. Structural break selection was conducted based on the Dickey-Fuller t statistic. It demonstrates stationarity at the 1% significance threshold. The Schwarz criterion was employed to ascertain the optimal duration of delay. Vogelsang (1993) employed one-sided asymptotic p-values.								

4.3. ARDL estimation results

The method known as "ARDL," which M. Hashem Pesaran, Yongcheol Shin, and Richard J. Smith developed in 2001, stands for "Auto-regressive Distributed Lag." This methodology is extensively employed to ascertain long-term relationships in time series analyses. The ARDL method is employed to investigate the notion of "cointegration," which assesses the existence of a stationary combination of at least two non-stationary variables. The ARDL model provides greater flexibility than conventional cointegration tests like those of Engle and Granger (1987), Johansen and Juselius (1990), and Phillips and Hansen (1990), as it can create a stationary combination despite the variables exhibiting varying degrees of stationarity. This method does not require all variables to be equally integrated, and reliable empirical evidence can be derived from models with limited samples (Narayan & Smyth, 2005).

In the implementation of the autoregressive distributed lag (ARDL) model, ascertaining the optimal lag lengths is crucial for generating robust and reliable analytical outcomes. In this context, multiple statistical information criteria are employed to ascertain the optimal lag length. The Akaike Information Criterion (AIC), the Schwarz Information Criterion (SIC), and the Hannan-Quinn Information Criterion (HQIC) are particularly notable among these criteria. The specified information criteria facilitate the identification of the most appropriate delay structure by offering an optimal equilibrium between model complexity and data fit. The specification of the ARDL model is thus grounded on a more robust foundation, which markedly improves the validity and interpretability of the resulting econometric findings. The duration of the delay was established based on the Hannan-Quinn criterion, with the findings illustrated in Figure 1.

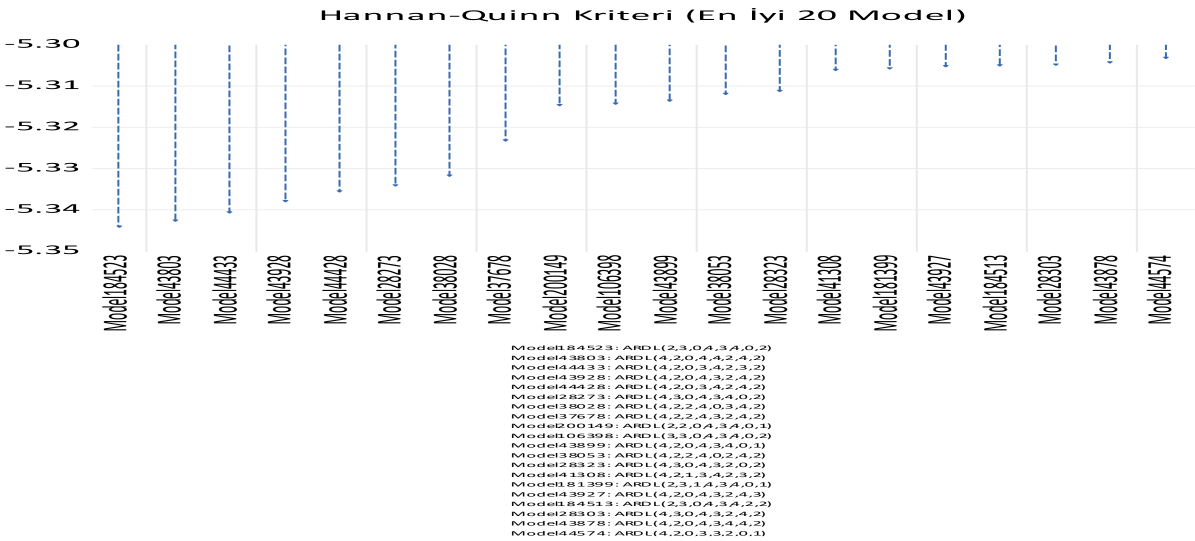

Figure 1. Criteria Selection

Figure 1 illustrates that based on the optimal lag lengths determined using the Hannan-Quinn criterion, the ARDL (2,3,0,4,3,4,0,2) model was chosen for the analysis. The mathematical representation of the model to be estimated is presented first, followed by the hypotheses of the boundary tests below.

The unrestricted error correction model employed in the study is represented by the following equation 2.

$$\Delta lnEG_t = \beta_0 + \sum_{i=0}^{a=2} \beta_{1i} \Delta lnEG_{t-i} + \sum_{j=0}^{b=3} \beta_{2j}\, \Delta lnCT_{t-j} + \sum_{k=0}^{c=0} \beta_{3k}\, \Delta lnCO2_{t-k} + \sum_{l=0}^{d=4} \beta_{4l}\, \Delta lnVAFF_{t-l} + \sum_{m=0}^{e=3} \beta_{5m}\, \Delta lnEGRR_{t-m} + \sum_{n=0}^{f=4} \beta_{6n}\, \Delta lnFDI_{t-n} + \sum_{o=0}^{g=0} \beta_{7o}\, \Delta lnEC_{t-o} + \sum_{p=0}^{h=2} \beta_{8p}\, \Delta lnEFI_{t-p} + a_1 lnEG_{t-1} + a_2 lnCT_{t-1} + a_3 lnCO2_{t-1} + a_4 lnVAF_{t-1} + a_5 lnEGRR_{t-1} + a_6 lnFDI_{t-1} + a_7 lnEC_{t-1} + a_8 lnEFI_{t-1} + \mu_t \quad (2)$$

In the above equation, the Δ difference operation, the “ln” expression at the beginning of the variables indicates that natural logarithms are taken, the μ_t error term, β_0 constant term, $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7, \beta_8$ the short-term coefficients in the equation, $a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8$ long-term coefficients show the delay lengths "a, b, c, d, e, f, g, h". In the classical ARDL method, "F-Bounds" and "t-Bounds" boundary tests are used in the cointegration analysis. The F-Bounds test considers the lagged values of the dependent and independent variables in the model. The hypotheses of the F-Bounds test, $H0$: $a_1 = a_2 = a_3 = a_4 = a_5 = a_6 = a_7 = a_8$ and HA: $a_1 \neq a_2 \neq a_3 \neq a_4 \neq a_5 \neq a_6 \neq a_7 \neq a_8 \neq 0$. The statistical values of this test are compared with the lower and upper bound critical values calculated by Narayan and Smyth (2005). If the computed F-Bounds statistic exceeds the upper critical values designated for I(1), the null hypothesis H0, which posits the absence of cointegration, is rejected, thereby affirming the presence of cointegration. When the F-Bounds statistic falls between the lower and upper critical values, a conclusive determination regarding the null hypothesis of no cointegration cannot be made. The hypothesis is inconclusive, necessitating further evaluation through additional analyses or alternative methods. Kremers et al. (1992), Banerjee et al. (1998), and Tursoy and Faisal (2018) assert that the error correction term will dictate the determination of the co-integration relationship. The negative and statistically significant result of the error correction term (with a p-value below 0.05) signifies a long-term relationship between the variables. If the F-Bounds statistic value is below the lower critical value, it is concluded that there is no cointegration among the variables. Thus, the ARDL test results are shown in Table 6 as follows.

Table 6. ARDL Model Estimation Results Depicting the Impact of Carbon Emissions, Trade Liberalization, and Ecological Footprint on Economic Growth in Turkey

Variables	**Coefficient**	**Std. Dv.**	**t**	**P***
Dependent Variable LnEG				
LnEG(-1)	0.600	0.144	4.150	0.000
LnEG(-2)	-0.324	0.108	-2.983	0.007
LnCO2	-0.109	0.071	-1.540	0.140
LnCO2(-1)	0.209	0.093	2.235	0.038
LnCO2(-2)	-0.316	0.101	-3.127	0.005
LnCO2(-3)	-0.139	0.099	-1.409	0.175
LnFDI	0.030	0.006	4.362	0.000

LnEFI	0.350	0.085	4.103	0.000
LnEFI(-1)	-0.375	0.097	-3.841	0.001
LnEFI(-2)	0.089	0.112	0.789	0.440
LnEFI(-3)	-0.567	0.099	-5.684	2.161
LnEFI(-4)	-0.231	0.069	-3.328	0.003
LnEC	0.106	0.146	0.723	0.478
LnEC(-1)	0.151	0.164	0.924	0.367
LnEC(-2)	-0.163	0.143	-1.139	0.269
LnEC(-3)	0.427	0.150	2.850	0.010
LnCT	0.030	0.031	0.943	0.357
LnCT(-1)	-0.126	0.035	-3.579	0.002
LnCT(-2)	0.157	0.043	3.594	0.002
LnCT(-3)	0.030	0.041	0.742	0.467
LnCT(-4)	-0.068	0.029	-2.304	0.033
LnVAFF	0.141	0.086	1.632	0.119
LnEGRR	-0.005	0.006	-0.827	0.418
LnEGRR(-1)	0.028	0.007	3.771	0.001
LnEGRR(-2)	0.010	0.006	1.474	0.157
C	12.147	2.921	4.157	0.000
@TREND	0.0202	0.004	4.656	0.000
$\widetilde{R}^2 = 0.99, F = 4032.862\ (P = 0.000), DW = 1.98$				
Diagnostic Tests: Serial Correlation (Breush-Godfrey): F=1.65 (P=0.2228), Model Specification (Ramsey-RESET): F=1.51 (P=0.2346) Normality (Jarque_Bera): JB= 1.52 (P=0.466), Heteroscedasticity (Breush-Pagan-Godfrey): F=0.88 (P=0.6177)				

Table 6 demonstrates that the diagnostic tests performed on the ARDL (2,3,0,4,3,4,0,2) model reveal no concerns regarding correlation, heteroscedasticity, specification, or normality. The results of the ARDL cointegration test are shown in Table 7.

Table 7. ARDL Cointegration Test Results

f (LnEG │LNCO2, LnFDI, LnEFI, LnEC, LnCT, LnVAFF, LnEGRR,) **ARDL (2,3,0,4,3,4,0,2) k:7 m:4 n=45**		**Test Statistics** **FOVERALL** 8.413*** **tDV** -6.542***		**Result**
				Co-integrated
Table of Critical	1%	5%	10%	

Values							
Tests	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	
F OVERALL	4.109	5.785	3.091	4.413	2.635	3.838	n=45
t DV	-3.96	-5.49	-3.41	-4.85	-3.13	-4.53	-
Estimates have been derived based on Case #V. ***, the %1 significance level, k; the count of independent variables, m; the maximum lag length, and n; the total number of observations.							

The F-Bounds Test (FOVERALL) and the t-Bounds Test (tDV) indicate that the model exhibits symmetric/linear cointegration at the 1% significance level. This is attributable to the test statistic values exceeding the upper limit values established for I(1). This scenario illustrates that the linear combinations of the variables converge towards equilibrium and coalesce over the long term. The results of the ARDL Long-Term Estimation results are shown in Table 8.

Table 8. ARDL Long-Term Estimation Results

Long-Term Forecast Results, Dependent Variable: LnEG				
Variables *	**Coefficient**	**Std. Dv.**	**t**	**P**
LnCO2(-1)	-0.493*	0.139	-3.537	0.001
LnFDI	0.042*	0.011	3.551	0.001
LnEFI(-1)	-1.016	0.187	-5.417	3.578
LnEC(-1)	0.721**	0.314	2.295	0.027
LnCT(-1)	0.032	0.069	0.471	0.640
LnVAFF	0.195	0.117	1.657	0.105
LnEGRR(-1)	0.046*	0.015	3.059	0.004
Note: * The coefficients are obtained from the CEC regression. *: Significant at 1%, **: Significant at 5%				

The model revealed that the one-period lagged value of carbon emissions (LnCO2(-1)) is negative and statistically significant (coefficient = -0.493, p = 0.001), suggesting that environmental pollution adversely affects economic growth. The substantial and noteworthy impact of foreign direct investments (FDI) (coefficient = 0.042, p = 0.001) demonstrates that foreign investment fosters economic growth. The detrimental and substantial impact of the ecological footprint (LnEFI (-1)) (coefficient = -1.016) underscores the necessity of sustainable development. The notable and statistically significant result of energy usage (LnEC (-1)) (coefficient = 0.721, p = 0.027) suggests that energy consumption acts as a catalyst for economic growth. Nonetheless, the insignificance of trade openness (LnCT (-1)) and the value added in agriculture, forestry, and fishing (LnVAFF) suggests that these variables exert a minimal influence on economic growth. The positive and significant impact of renewable energy production (EGRR (-1)) (coefficient = 0.046, p = 0.004) unequivocally illustrates the role of renewable energy sources in the economy. These findings underscore the significance of environmental sustainability policies for economic growth and the essential role of energy consumption. The results of the ARDL Short-Term Estimation Results are shown in Table 9.

Table 9. ARDL Short-Term Estimation Results

Short-Term Forecast Results, Dependent Variable: LNEKBY				
Variables *	**Coefficient**	**Std. Dv.**	**t**	**P**
EC_{t-1}	-0.723*	0.075	-9.669	0.000
D(LnEG(-1))	0.324*	0.082	3.943	0.001
D(LnCO2)	-0.110**	0.052	-2.130	0.043
D(LnCO2(-1))	0.456*	0.064	7.184	0.000
D(LnCO2(-2))	0.140***	0.069	2.014	0.055
D(LnEFI)	0.350*	0.056	6.298	0.000
D(LnEFI(-1))	0.710*	0.124	5.717	0.000
D(LnEFI(-2))	0.799*	0.103	7.729	0.000
D(LnEFI(-3))	0.232*	0.050	4.599	0.000
D(LnEC)	0.106	0.088	1.212	0.237
D(LnEC(-1))	-0.264**	0.098	-2.695	0.012
D(LnEC(-2))	-0.428*	0.094	-4.551	0.000
D(LnCT)	0.030	0.019	1.581	0.126
D(LnCT(-1))	-0.120*	0.021	-5.718	0.000
D(LnCT(-2))	0.038***	0.022	1.757	0.091
D(LnCT(-3))	0.069*	0.020	3.512	0.002
D(LnEGRR)	-0.005	0.004	-1.163	0.256
D(LnEGRR(-1))	-0.010**	0.005	-2.167	0.040
C	12.147*	1.255	9.681	0.000
@TREND	0.020*	0.002	9.740	0.000
$\widetilde{R}^2 = 0.94, F = 38.0744\ (P = 0.000), DW = 1.98$ *: Significant at %1, **: Significant at %5, ***: Significant at %10				

The error correction term (ECt-1) in the model was negative and statistically significant at the 1% significance level (coefficient = -0.723, p = 0.000), suggesting that the return to long-term equilibrium will occur after 1/0.723 = 1.38 years. The immediate detrimental impact of carbon emissions (D(LnCO2)) on economic growth (coefficient = -0.110, p = 0.043) signifies that environmental pollution negatively influences economic growth. The positive and significant coefficients of one-period and two-period lagged carbon emissions (D(LnCO2(-1)) and D(LnCO2(-2))) at 0.456 and 0.140, respectively, indicate the delayed positive effects of carbon emissions. The immediate positive and substantial impact of the ecological footprint (D(LnEFI)) (coefficient = 0.350, p = 0.000) underscores the role of sustainable development in fostering economic growth. The adverse lagged effects of energy consumption (D(LnEC)), with coefficients of -0.264 and -0.428, underscore the significance of enhancing energy efficiency for economic growth. The short-term effects of trade openness (D(LnCT)) and renewable energy production (D(LnEGRR)) are generally insignificant, suggesting that their short-term influence on economic growth is constrained.

The CUSUM and CUSUM2 illustrating the stability and reliability of the estimated coefficients are displayed Figure 2.

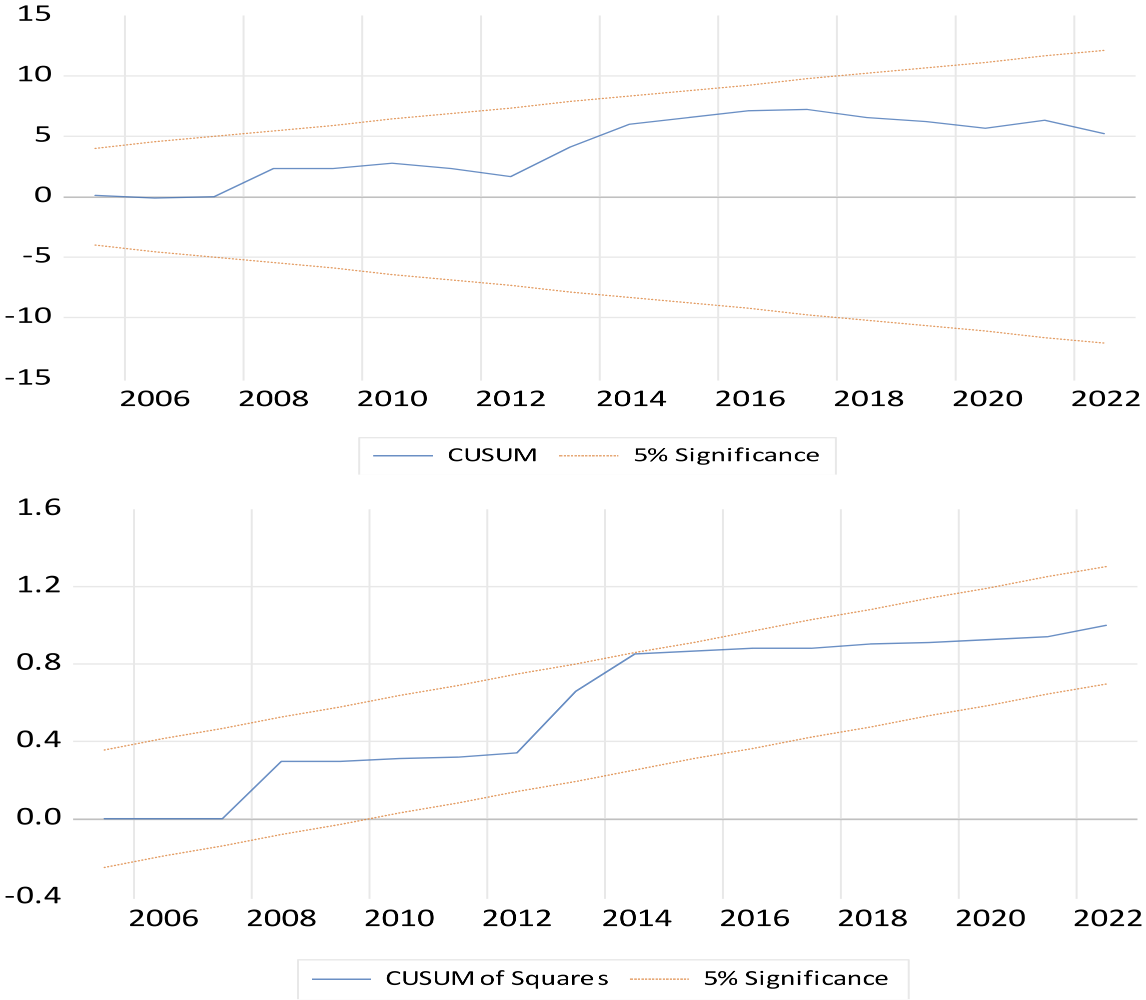

Figure 2. CUSUM and CUSUM2 Graphs

Upon examination of the CUSUM and CUSUM2 graphs, the estimated coefficients consistently fall within the boundaries denoting the 5% significance level. Consequently, the established model demonstrates stability within a 95% confidence interval.

5. Discussion and Conclusion

This research illustrates the fine and meaningful relationship between economic growth, ecological impact, carbon emissions, and trade liberalization in Turkey. It is the findings of the considerable difficulty of reconciling economic progress with environmental sustainability. There is a strong correlation between trade openness and economic growth, but trade can indeed bolster Turkey's economy, provided it is carefully regulated to avoid ecological damage and carbon emissions. The urgent necessity for cleaner, more effective forms of energy is evident by the detrimental effect of carbon emissions on economic development.

The findings of this study underscore the complex relationship between trade liberalization and green economic growth in Turkey. While the positive effects of trade openness on economic development are evident, its environmental implications are more ambiguous. Consistent with prior studies (Alsamara et al., 2019; Aydin & Turan, 2020), this research demonstrates that trade liberalization has facilitated economic growth in Turkey by enhancing access to foreign markets and green technologies. However, as Nathaniel et al. (2021) highlight, the lack of robust environmental regulations has limited the potential of trade liberalization to contribute meaningfully to green economic growth.

Policy recommendations emerging from this analysis emphasize the need for regulatory reforms that align trade policies with environmental objectives. Strategies such as green tariffs, incentives for cleaner production technologies, and participation in international agreements like the Paris Accord can mitigate the adverse ecological impacts of trade liberalization while maximizing its economic benefits. Moreover, encouraging foreign direct investments in renewable energy and eco-friendly industries could further strengthen the nexus between trade openness and sustainable development goals (Chhabra et al., 2022; Wang & Zhang, 2020).

To achieve a sustainable and resilient green economy, Turkey must integrate environmental criteria into trade liberalization policies. By prioritizing green trade strategies, Turkey can reconcile the competing pressures of economic development and environmental sustainability, ensuring that trade openness becomes a driving force for sustainable economic growth.

Results of the study suggest that renewable energy has an important role in promoting economic development. It also matches international initiatives for sustainable development proposing a diversification of energy sources, including more renewables. While ecological footprint enhances the short-term development, the long-term consequences require enhanced environmental management strategies. Policymakers should emphasize policies that are both development-friendly and minimize ecological harm in favor of policies based on renewable energy yet also sustain industrial practices.

More studies in the future may investigate how technological progress and financial growth would help achieve an economy at balance and equilibrium. It would be a holistic strategy by which Turkey can achieve Sustainable Development Goals, economic growth, and environmental sustainability in parallel.

The main contribution of this research lies in its comprehensive knowledge of the relationships among economic development, carbon emissions, ecological impact, and trade liberalization running, respectively, through Turkey. They show trade openness can help promote more economic development, but it can also exacerbate environmental dilemmas and require carefully engineered governmental actions to balance competing pressures. The results of the research suggest that the detrimental impact of carbon emissions on economic development requires their integration into economic planning as sustainable energy solutions and emission reduction methods.

The ability of renewable energy investments to support sustainable growth is underscored by the positive effect renewable energy has on economic growth. The considerable association of the ecological footprint and growth suggests that contemporaneous economic activity corresponds to elevated resource use, which could push the sustainability boundaries should such activity continue. The research confirms that economic development should be achieved through comprehensive policies, which will control environmental deterioration.

The results of this study highlight the need to reconsider policy to promote sustainable economic development through decreased environmental harm in Turkey. First, policy must drive trade liberalization involving environmental criteria to prevent worsening trade that does not incorporate environmental safeguards, which can lead to unregulated resource exploitation or pollution from increasingly free trade. To reconcile trade development with environmental preservation, regulatory frameworks that stimulate cleaner industrial technology and energy-efficient practices are needed.

Rigorous emission control strategies such as carbon taxes or cap and trade systems are needed to address the detrimental effect of carbon emissions on economic development. The helpful impact of renewable energy on economic growth proves its need to advocate for renewable energy. For investment in green energy infrastructure to increase, policies must advance green financing accessibility, assure regulatory consistency, and support investments in renewable energy infrastructure.

Regulating the ecological footprint is critical for long-term sustainability, as the research finds. Stabilizing the ecological footprint is possible if actions are taken to implement comprehensive resource management strategies that include sustainable agriculture, waste reduction, and efficient energy use. Equitable economic growth with alignment to Turkey's sustainable development objectives requires a thorough integration of trade, energy, and environmental policy.

This research reveals the big impact that ecological footprint, carbon emissions, and trade liberalization have on green economic development in Turkey. While trade openness does spur economic progress, trade openness also brings environmental problems, therefore necessitating the practice of sustainable trading. Better energy plans and stricter environmental laws are urgently needed because the destructive effects of carbon emissions on development must be addressed. Any increase in investments in renewable energy is necessary to achieve the sustainable development targets, as the contributions of renewable energy to economic growth are beneficial. To fully replicate the results, it requires systemic policies that can harmonize economic development with environmental protection, leading to a transition towards a green and sustainable, resilient economy.

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