Üçüncü Sektör Sosyal Ekonomi Dergisi
Third Sector Social Economic Review
60(2) 2025, 1244-1264
doi: 10.63556/tisej.1436

Research Article

Sustainability Of Greenhouse Gas Emissions By Sectors In Turkey: Evidence From Unit Root Tests With Structural Breaks

Türkiye'de Sektörlere Göre Sera Gazı Emisyonlarının Sürdürülebilirliği: Yapısal Kırılmalı Birim Kök Testlerinden Kanıtlar

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08.01.2025	**25.03.2025**

Abstract

Sustainability, which is the process of recovering and redesigning natural resources and protecting natural areas, covers many social, environmental, and economic factors. Sustainability, which has become an important agenda item in recent years, creates many advantages by bringing new trends for all sectors. In this study, the sustainability of greenhouse gas emissions in Turkey in total and for each sector is investigated for the period 1990-2022. Unit root tests were utilized as a method to determine the sustainability. According to the findings, GHG emissions for industrial processes and product use and waste sectors are found to be sustainable. The sectoral sources of unsustainable greenhouse gas emissions in Turkey are the energy and agriculture sectors.

Keywords: *Sustainability, Greenhouse Gas Emission, Sectoral Sustainability, Environment*

JEL Classification: *Q01, Q40, Q56*

Öz

Doğal kaynakların geri kazanılması, yeniden tasarlanması ve doğal alanların korunması süreci olan sürdürülebilirlik; sosyal, çevresel ve ekonomik birçok faktörü kapsamaktadır. Son yıllarda önemli bir gündem maddesi haline gelen sürdürülebilirlik, tüm sektörler için yeni trendleri de beraberinde getirerek pek çok avantaj yaratmaktadır. Bu çalışmada Türkiye'de toplam ve her sektör için sera gazı emisyonlarının sürdürülebilirliği 1990-2022 dönemi için araştırılmıştır. Sürdürülebilirliğin tespit edilebilmesi için yöntem olarak birim kök testlerinden faydalanılmıştır. Elde edilen bulgulara göre, endüstriyel işlemler ve ürün kullanımı ile atık sektörleri için sera gazı emisyonları sürdürülebilir bulunmuştur. Türkiye'de sera gazı emisyonlarının sürdürülebilir olmamasının sektörel kaynakları ise enerji ve tarım sektörleri olarak saptanmıştır.

Anahtar Kelimeler: *Sürdürülebilirlik, Sera Gazı Emisyonu, Sektörel Sürdürülebilirlik, Çevre*

JEL Sınıflandırması: *Q01, Q40, Q56*

1. Introduction

The intensive relationship between economic activities and environmental quality has increased the importance of sustainability today. All ecological risks that may threaten the continuity of development are

Önerilen Atıf /Suggested Citation
Kara, F., 2025, Sustainability Of Greenhouse Gas Emissions By Sectors In Turkey: Evidence From Unit Root Tests With Structural Breaks, *Üçüncü Sektör Sosyal Ekonomi Dergisi*, 60(2), 1244-1264.

also related to sustainability. Along with the development of the ecosystem, to ensure economic and social development, it has become imperative that sectors with high greenhouse gas emissions aim to protect the natural environment. At the same time, increasing the productivity of agricultural areas and encouraging the use of renewable energy resources are important policies that Turkey should follow in the context of sustainable development and the environment. Turkey should design its environmental policies to support growth in this direction.

The research question of this study can be stated as follows: What is the sustainability of greenhouse gas emissions in Turkey in total and for each sector for the period 1990-2022? For which sectors are greenhouse gas emissions sustainable and for which sectors are unsustainable? In particular, the study focuses on sectoral analysis on this issue. Therefore, firstly, current studies in the literature on environmental sustainability are reviewed, then information on the data set and methodology of the study is given and the findings obtained as a result of the analysis are presented. Finally, the findings are evaluated. The results of the analysis identify the sectors that contribute to the sustainability and unsustainability of greenhouse gas emissions in Turkey for the period 1990-2022. This study makes an important contribution to the related literature by looking at environmental sustainability from a sectoral perspective.

2. Literature Review

Since carbon hysteresis and environmental sustainability are closely related, it would be more appropriate to include studies related to this issue in the literature review. Carbon hysteresis refers to the phenomenon where the behavior of carbon-containing systems exhibits a lag or delay in response to external stimuli, such as changes in carbon dioxide (CO_2) levels or environmental conditions. Research indicates the presence of carbon hysteresis in various contexts, including the terrestrial carbon cycle in response to CO_2 forcing (Park and Kug, 2022) gate hysteresis behavior in nano-structure devices like carbon nanotubes and graphene (Lu et al., 2022) and hysteresis effects in organic-inorganic perovskite solar cells impacting power conversion efficiency (Shah et al. 2021). Studies show that carbon hysteresis can have significant implications, such as influencing environmental policies for reducing CO_2 emissions in countries like Turkey (Çağlar and Mert, 2022), highlighting the importance of understanding and mitigating hysteresis effects in different carbon-related systems to improve performance, stability, and environmental impact.

The carbon hysteria hypothesis is closely related to the Environmental Kuznets Curve Hypothesis (EKCH). Therefore, it was deemed appropriate to include studies on the EKCH in the literature. It can be said that there is no common view in the studies where the EKCH is tested. For example; while studies such as (Ahmad et al., 2016; Öztürk and Al-Mulali, 2015; Wang et al., 2016) emphasized that the EKCH is invalid, studies such as (Farhani et al., 2014; Robalino-Lopez et al., 2014; Kohler, 2013; Saboori et al., 2016) found that the EKCH is valid. Most of the studies on Turkey also emphasize the validity of the EKCH (Bölük and Mert, 2015; Gökmenoğlu and Taşpınar 2016; Bilgili et al., 2016; Katırcıoğlu and Taşpınar, 2017). There are also studies that conclude that the hypothesis is invalid (Yurttagüler and Kutlu, 2017; Dar and Asif, 2018). Artan et al. (2015) tested the validity of the EKC hypothesis for Turkey for the period 1981-2012 and analyzed the relationship between economic growth and trade openness and environmental pollution. The findings revealed a long-run relationship between economic growth and trade openness and environmental pollution. Moreover, an inverted-U shaped relationship between economic growth and environmental pollution was found to support the EKC.

Coderoni and Esposti (2011) investigated whether the environmental Kuznet Curve is valid for the Italian agricultural sector. The analysis based on data for different periods 1951-2008/1980-2008 did not find any empirical evidence of an inverted-U shaped relationship between agricultural emissions and economic growth of the sector. Bilgili and Bağlıtaş (2014) investigates the relationship between agricultural emission and per capita income. The results show that Environmental Kuznet Curve (EKC) hypothesis is valid for agricultural emission and income. Moreover, there is a co-integration relationship between agricultural emission and both income and agricultural energy consumption. Results again, imply that EKC is true for agriculture sector.

Table 1. Literature On Carbon Hysteria Hypothesis and Environmental Sustainability

Author(s)	Method	Period	Result
Çağlar and Mert (2022)	Panel Unit Root	1965-2020	The results show that the carbon hysteresis hypothesis for China, India, Japan, the Russian Federation and the USA is valid for these countries.

Çağlar and Mert (2024)	Fourier-Based ADF, LM Tests, FFFFF-ADF Unit Root Test	1960-2018	The aim of this study is to investigate whether the carbon hysteresis hypothesis is valid in Turkey. The sample period has been divided into regimes and it has been seen that the positive carbon hysteresis has been valid in all regimes. The direction of the hysteria effect is determined as positive.
Coşkun and Buzdağlı (2024)	RALS-LM Unit Root Test	1960-2021	In the analysis results, it was found that the CO2 emission series is stationary. For this reason, it can be said that there is no carbon hysteresis in Turkey.
Müller-Fürstenberger et al. (2005)	Non–Stationary Panel, Regressions with Integrated Variables	1986-1998	The small CGE model used in the study illustrated that a carbon policy based on income levels may not be suitable, even with an observed inverse U-pattern between income and emissions, emphasizing the complexities of carbon policies.
Yalman (2019)	Pedroni Cointegration Analysis	2000-2016	For 6 countries, cointegration analysis was conducted with the data obtained from the World Bank database and whether the variables were related to growth was analyzed. As a result of the analysis, it was revealed that there is a cointegration relationship between the variables. High technology, electricity consumption and related carbon emissions affect growth. Sustainable growth can be realised if growth is achieved with measures against environmental pollution.
Çoban and Kılınç (2016)	Document Analysis	1990-2013	In this study, data for the period 1990-2013 greenhouse gas emissions in Turkey and especially the causes of emissions from the energy and economic aspects of environmental impact are analyzed. As a result, Turkey in particular has the potential areas hydraulic energy, wind energy, solar energy and geothermal energy. Reducing the environmental damage caused by energy use, renewable energy sources have to be used effectively and efficiently.
Örnek and Türkmen (2019)	Dynamic Panel Data Analysis	1975-2016	The findings show that the EKC approach is valid in developed countries and that sustainability in energy is provided, and that in the emerging market economies the EKC approach is not valid and thus sustainability in energy is not achieved. In emerging market economies, it is necessary to reduce the dependence on fossil fuels by reducing strict environmental policies, taxes and carbon dioxide emissions and to increase the use of renewable energy sources in this context.
Çetintaş and Aydın (2022)	Panel Smooth Transition Regression Model	1995-2018	When the share of renewable energy use in energy consumption occurs below the threshold level, economic growth affects the environment negatively. If it occurs above the threshold level, it is positively affected. Therefore, the widespread use of renewable energy is a solution to reduce environmental pollution. Accordingly, policymakers need to emphasize and encourage energy use.

Ghosh and Paul (2024)	Panel ARDL	1990-2022	Results show that industrialization adversely impacts environmental sustainability in the long run by discharging CO2, while energy consumption has a favourable environmental impact. In the short run, both factors have demonstrated overall as well as country specific adverse effects. Further, Dumitrescu Hurlin Panel causality results reported uni directional causal relationship moving from industrialization and energy consumption to carbon dioxide discharges. These results indicates that efforts of Asian emerging economies towards environmental sustainability are not sufficient.
Sumaira and Siddique (2023)	Augmented Mean Group (AMG), Common Correlated Efects Mean Group (CCEMG) analysis, Westerlund co-integration test, and Dumitrescu-Hurlin causality test	1984-2016	This study has been carried out to analyze the contribution of industrialization and energy consumption by keeping the role of urbanization on environmental pollution for South Asia. The long-run co-integration between industrialization, energy use, urbanization, capital, and environmental pollution is also confrmed by the Westerlund co-integration test. The fndings of the DumitrescuHurlin causality test also confrmed the bidirectional causality between industrialization and pollution. A unidirectional causality is observed from energy consumption to pollution.
Oláh et al. (2020)	Literature Review	2000-2020	The results indicate that there is a negative relationship related to the flow of the production process from the inputs to the final product, including raw materials, energy requirements, information, and waste disposal, and their impacts on the environment. However, the integration of Industry 4.0 and the sustainable development goals enhance environmental sustainability to create ecological support that guarantees high environmental performance with a more positive impact than before.
Jones and Comfort (2019)	Qualitative Analysis, Content Analysis Techniques	-	In this article, an exploratory review of the approaches to sustainability within the European waste management industry is presented, and the authors conclude that the sustainability reports included details of a wide range of environmental, social and economic issues but more generally, the reports had a number of weaknesses that undermined their transparency and credibility.
Demir et al. (2024)	A-ARDL	1970-2021	When carbon emissions from energy consumption are taken into account, it is concluded that the EKC hypothesis is valid in Türkiye. Additionally, it has been observed that the explanatory variables of trade openness and per capita primary energy consumption also contribute to increased carbon emissions.
Singh (2024)	Literature Review	-	This study delves into the complex interplay between socioeconomic development, environmental degradation, and the pursuit of sustainable practices. Importance of adopting sustainable practices across various sectors,

			including energy, agriculture, transportation, and waste management, have been explored. It elaborates on the significance of renewable energy sources, regenerative agriculture, efficient public transportation, and circular economy approaches in reducing environmental impacts.
Cariola et al. (2020)	Multilevel Modelling Analysis	2008-2015	This study, based on 12,615 small and medium-sized enterprises (SMEs) operating in the energy sector in 26 European countries. The findings suggest that although countries implementing policies to enhance environmental quality constrain SMEs in improving their production systems, they promote SMEs' financial efficiency through the valuable use of debt.
Le et al. (2022)	Multivariate Quantitative Evaluation Framework	1992-2016	This study thus aims to extend the line of research on environmental sustainability for the case of Asia. They conduct an overall environmental sustainability index based on seven indicators to depict the trend across 31 Asian countries. The results indicate that even for countries belonging to the same income group, the trend of environmental sustainability varies.
Sowah and Kirikkaleli (2022)	NARDL Model, DOLS, FMOLS, CCR Models	1966Q1-2019Q4	This study investigates factors afecting global environmental sustainability DOLS, FMOLS, and CCR models demonstrate that economic growth, energy consumption, and trade openness are positively related to environmental sustainability except for economic growth which shows the negative and insignificant relationship.
Dürrü and Konat (2023)	Stochastic Convergence Method, Fourier Quantile Unit Root Test	1961-2018	The aim of this study is to examine in two directions ecosystem through ecological equilibrium. The results indicate that convergence in ecological balance has been realized for all CIVETS countries. As a result, factors affecting the ecological balance in CIVETS countries such as population growth, rapid industrialization and fossil fuel use have been identified as key policy areas in balancing and equalizing the ecosystem.
Öztürk and Tiftikçigil (2022)	ARDL Boundary Test, Granger Causality	1990-2020	The study shows a dependence between economic growth and greenhouse gas emissions caused by the agricultural sector in the long term.

Environmental sustainability is a critical concept that emphasizes the harmonization of resource allocation, environmental conservation and societal fairness (Yadav et al., 2024). It plays a vital role in the 2030 Agenda for Sustainable Development, highlighting the importance of addressing environmental issues in industrial development policies (United Nations Industrial Development Organization, 2021). Green environmental sustainability involves responsible human interaction with the ecosystem to maintain long-term environmental quality and prevent natural resource depletion (Verma et al. 2023). The global significance of environmental sustainability is increasingly recognized by businesses and governments, aiming to preserve natural resources for future generations through activities like waste reduction, pollution control, and resource conservation using renewable methods (Patel, 2022; Asha et al., 2023). To achieve sustainability, a shift from unlimited growth and consumption to monitored usage and conservation is essential, requiring collaboration between various stakeholders on a global scale (Asha et al., 2023).

Environmental sustainability in the industrial sector is closely linked to effective waste management practices. Studies emphasize the importance of waste management for sustainability, showing that green accounting positively influences waste management, which in turn impacts environmental sustainability (Yulianti et al. 2023). Industrial waste, whether hazardous or non-hazardous, can be recycled to minimize resource scarcity and enhance economic growth through the circular economy's principles of reuse, recycling, and recovery (Srivastava et al., 2023). Utilizing industrial waste like ferrochrome slag for ground improvement not only strengthens soil and controls settlement but also demonstrates a cost-effective and environmentally friendly approach to recycling waste, contributing to a cleaner environment near industrial areas (Ghani and Kumari, 2022). Overall, integrating sustainable waste management practices in industries is crucial for environmental preservation and economic growth, aligning with global sustainable development goals (Srivastava, et al., 2023).

It is possible to find studies investigating the determinants of sectoral greenhouse gas emissions in Turkey in the literature. For example, Özçağ et al. (2017) analysed the change in greenhouse gas emissions in the industrial and agricultural sectors in Turkey for the period 1990-2014 using the LMDI method. It is observed that the main determinant of the change in greenhouse gas emissions in the industry and agriculture sectors is the energy intensity effect. Boğar and Boğar (2017), it is predicted that the proposed Artificial Neural Networks model can model Turkey's CO2 emissions and that CO2 emissions will increase in total and by sectors. A fluctuating stagnation was observed only in the waste sector. According to Ünlüoğlu and Özcan (2023), the effect of the increase in manufacturing industry production on greenhouse gas emissions stems from the rise in the energy demand of the sector. According to the analysis results of Polat (2021) for Turkey, it is understood that the amount of energy consumption per capita and urban population growth included in the model have an increasing effect on carbon emissions.

Wietze (2005) analyzed the factors underlying the changes in carbon dioxide emissions with the decomposition method using 1980-2003 data for Turkey. According to the results of the analyses, the carbon dioxide emission scale effect has the biggest impact on the increase. Carbon intensity and the composition of the economic change are also effective in the rise. Energy intensity is responsible for the decrease in emissions. Ediger and Havuz (2006) analyze sectoral energy use in the Turkish economy for the period 1980-2000 using the decomposition method. They conclude that after 1982, due to the transformation in the Turkish economy, energy intensity has been less improved in some sectors.

Akbostanci et.al. (2011) it analyzed the changes in carbon dioxide emissions in the manufacturing industry in Turkey by applying decomposition analysis (LMDI) for the period 1995-2001. It is concluded that the change in industrial activities and energy intensity are the main factors determining the change in carbon dioxide emissions in the period covered by the study. Dam (2014) analyses the impact of economic growth and energy consumption on carbon emissions in Turkey. The effect of energy consumption on environmental pollution in Turkey was found to be positive and statistically significant, while the effect of imports was found to be negative and significant. Energy consumption is the most important macroeconomic variable causing environmental pollution in Turkey. Aslan and Kum (2011) investigated the stationarity of energy consumption in Turkey for sectoral disaggregated data between 1970 and 2006 using linear and non-linear unit root tests. The findings of the CSR unit root test indicate that there is a stationary structure in agriculture, industry and housing sectors, while there is a non-stationary structure in transportation, non-energy use, final energy consumption and conversion sectors.

In parallel with these studies, the analysis of this study, which makes an important contribution to the sectoral GHG sustainability literature in Turkey, shows that GHG emissions are sustainable for industrial processes, product use, and waste sectors. On the other hand, the sectoral sources of unsustainable GHG emissions in Turkey are the energy and agriculture sectors. According to the latest data published by TurkStat, the energy sector ranked first in the amount of emissions by sector in Turkey. In total GHG emissions (in CO2 equivalents) in 2022, energy-based emissions accounted for the largest share at 71.8%, followed by agriculture at 12.8%, industrial processes and product use at 12.5%, and waste at 2.9%. These data are in line with the findings of the this study and draw attention to the fact that the energy and agriculture sectors are effective in the unsustainability of GHG emissions in Turkey.

Although there is a limited number of studies in the literature on environmental sustainability, which has become important today, there are also studies that examine the sustainability of greenhouse gas emissions on the basis of various sectors. This study is one of them, but unlike other studies, it analyses more sectors. Thus, it allows us to reach more general judgments with more data and sectoral analysis. This study, which analyses the environmental sustainability of key sectors such as energy, industrial processes and product use, agriculture, and waste, will make a significant contribution to the literature. In summary, this is a pioneering study that analyses the sustainability of greenhouse gas emissions in Turkey on a sectoral basis.

3. Emprical Framework

3.1.Data

In this study, total greenhouse gas emissions data by sectors published by TurkStat (2024) were used as the data set. The data range of the study is determined as the 1990-2022 period (Turkstat, 2024). In the study, the sustainability of greenhouse gas emissions in total and for each sector is investigated. Unit root tests were utilized to determine sustainability. The stationarity of the analyzed series is taken as an indicator of sustainability. The unit root process, on the other hand, refers to unsustainability.

The first unit root test in the literature was developed by Dickey and Fuller (1979). The Dickey-Fuller unit root test uses a first-order autoregressive model. Within the test framework, the first difference series is taken as the dependent variable and the one-period lagged series is taken as the independent variable. The null hypothesis that the parameter of the independent variable is equal to zero is tested against the alternative hypothesis that the coefficient is less than zero. If the calculated test statistic is greater than the critical values produced by Dickey and Fuller (1979), the null hypothesis cannot be rejected and the series is found to be unit-rooted. These tests are called conventional unit root tests and do not address structural changes in time series. In other words, shocks in time series are assumed to be transitory. Nelson and Plosser (1982) showed that shocks can be permanent.

Moreover, Perron (1989) showed that if the structural break is not included in the unit root test, the results obtained may tend toward the acceptance of the null hypothesis of a unit root. The first unit root test that takes structural break into account was also developed by Perron (1989). In the Perron unit root test, the date of the structural break is exogenously determined and only one structural break can be considered. To overcome these drawbacks, after Perron's unit root test, various unit root tests with structural breaks have been developed such as Zivot and Andrews (1992), Lumsdaine-Papell (1997), Perron (1997), Lee-Strazicich (2003, 2004), Kapetanios (2005), Carrion-i Silvestre et al. (2009), Narayan-Popp (2010).

3.2. Model Specification

In this study, we first apply the Zivot-Andrews (ZA) unit root test, which considers a structural break in the level and slope. The null hypothesis of the ZA test is a unit root process with no structural break. The alternative hypotheses, where a structural break is considered, are defined as follows according to three different model specifications.

$$\Delta Y_t = \mu + \beta t + \delta Y_{t-1} + \theta_1 DU_t(\lambda) + \sum_{1=1}^{k} d_i \Delta Y_{t-i} + \varepsilon_t \quad \text{(Equality 1)}$$

$$\Delta Y_t = \mu + \beta t + \delta Y_{t-1} + \gamma_1 DT_t(\lambda) + \sum_{1=1}^{k} d_i \Delta Y_{t-i} + \varepsilon_t \quad \text{(Equality2)}$$

$$\Delta Y_t = \mu + \beta t + \delta Y_{t-1} + \theta_1 DU_t(\lambda) + \gamma_1 DT_t(\lambda) + \sum_{1=1}^{k} d_i \Delta Y_{t-i} + \varepsilon_t \quad \text{(Equality 3)}$$

The dummy variables in the above equations, which are used to model the structural break, are shown as follows.

$$DU_t(\lambda) = \begin{bmatrix} 1, t > TB\ if \\ 0, t \leq TB\ if \end{bmatrix} \quad \text{(Equality 4)}$$

$$DT_t(\lambda) = \begin{bmatrix} t - TB, t > TB\ if \\ 0, \qquad t \leq TB\ if \end{bmatrix} \quad \text{(Equality 5)}$$

$$\lambda = \frac{TB}{T} \quad \text{(Equality 6)}$$

The main and alternative hypotheses for the ZA test are expressed as follows.

$$H_0: \delta = 0 \quad \text{(Equality 7)}$$

$$H_1: \delta < 0 \quad \text{(Equality 8)}$$

Parameter estimates are made for equations (1), (2) and (3) above, and t statistics are calculated for all possible break dates. The break date (TB) is determined as the point at which the t statistic is the smallest. The calculated t statistic is compared with the critical values developed by Zivot and Andrews (1992) and the testing process is finalized. If the calculated test statistic is greater than the critical value, the null hypothesis cannot be rejected and it is concluded that the series is unit rooted.

In the LM unit root test developed by Lee and Strazicich (2003), unlike the ZA test, structural breaks are also taken into account in the null hypothesis. Moreover, two structural breaks can be considered within the framework of the LM unit root test. The LM unit root test is based on the Lagrange multiplier developed by Schmidt and Phillips (1992). Two different model specifications are applied in the testing process. The regression equation used for Model A, which considers a break in the constant, is expressed as follows.

$$Y_t = \delta' Z_t + \varepsilon_t \qquad \text{(Equality 9)}$$

$$\varepsilon_t = \beta \varepsilon_{t-1} + u_t \qquad \text{(Equality 10)}$$

The above Z_t expression is called the vector of exogenous variables and is defined as follows.

$$Z_t = [1, t, D_{1t}, D_{2t}] \qquad \text{(Equality 11)}$$

The shadow variables included in the exogenous variables vectors are shown below.

$$D_{it} = \begin{bmatrix} 1, t \geq TB_i + 1 \; if \\ 0, \quad otherwise \end{bmatrix} \qquad \text{(Equality 12)}$$

The basic and alternative hypotheses for Model C, which takes into account structural breaks in the fixed term and slope, are expressed as follows.

$$Y_t = \mu_0 + d_1 B_{1t} + d_2 B_{2t} + y_{t-1} + \varepsilon_{1t} \qquad \text{(Equality 13)}$$

$$Y_t = \mu_1 + \gamma t + d_1 D_{1t} + d_2 D_{2t} + \omega_1 DT_{1t} + \omega_2 DT_{2t} + \varepsilon_{2t} \qquad \text{(Equality 14)}$$

The test statistic is calculated using the regression equation below.

$$\Delta Y_t = \delta' \Delta Z_t + \emptyset \tilde{S}_{t-1} + \sum \gamma_i \Delta \tilde{S}_{t-i} + u_t \qquad \text{(Equality 15)}$$

The basic and alternative hypotheses of the LM test are determined as follows.

$$H_0: \emptyset = 0 \qquad \text{(Equality 16)}$$

$$H_1: \emptyset < 0 \qquad \text{(Equality 17)}$$

As in the ZA test, the break dates are determined as the point where the t statistic calculated for all possible break dates is minimum. If the calculated test statistic is smaller than the critical value, the null hypothesis is rejected and it is concluded that the series is trend stationary under two structural breaks.

Another unit root test with structural breaks used in the study is the NP unit root test developed by Narayan and Popp (2010). Two different model specifications are constructed in the NP unit root test process. The M1 model considers two breaks in the constant and the M2 model considers two breaks in the constant and slope. M1 and M2 model specifications are expressed as follows.

$$d_t^{M1} = \propto + \beta t + \varphi^*(L)\left(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t}\right), \qquad \text{(Equality 17)}$$

$$d_t^{M2} = \alpha + \beta t + \varphi^*(L)(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} + \gamma_1 DT'_{1,t} + \gamma_2 DT'_{2,t}) \qquad \text{(Equality 18)}$$

The dummy variables in the model are defined as follows.

$$DU'_{i,t} = \begin{bmatrix} 1, \; t > TB'_{i,} \\ 0 \; , \quad otherwise \end{bmatrix} \qquad \text{(Equality 19)}$$

$$DU'_{i,t} = \begin{bmatrix} 1, (t > TB'_i)(t - TB'_i) \\ 0, \quad otherwise \end{bmatrix} \qquad \text{(Equality 20)}$$

In the NP unit root test, the null hypothesis is a unit root process under two structural breaks. The alternative hypothesis is a trend stationary process with two structural breaks. If the calculated test statistic is smaller than the critical value, it is concluded that the series is trend stationary under two structural breaks.

In unit root tests with structural breaks, it is assumed that the number of breaks is known in advance. Moreover, structural breaks are considered to be caused by sudden changes. Fourier-type unit root tests aim to eliminate these drawbacks. In this context, Fourier-type unit root tests can handle smoother changes instead of sudden changes and the number of breaks is not important.

In this study, we first apply the Fourier ADF test developed by Christopoulos and Leon-Ledesma (2010). Within the framework of the Fourier ADF test, in the first stage, the regression equation extended with the Fourier functions defined below is estimated and the residuals for the model are obtained.

$$y_t = \alpha + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \qquad \text{(Equality 21)}$$

$$y_t = \alpha + \beta t + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad \text{(Equality 22)}$$

In the second stage, the ADF unit root test is applied to the residual series. If the Fourier ADF test statistic is greater than the critical value in absolute terms, the null hypothesis that the series is unit-rooted is rejected and the series is trend stationary under smooth breaks. In this case, it is important to test the significance of the coefficients of the trigonometric terms with the F test. Critical values to compare the obtained F statistic can be obtained from Becker et al. (2006). If the parameters of the trigonometric terms are insignificant, the test turns into a classical ADF test. In the Fourier ADF test, only the model with constant term is considered. However, in this study, the model with constant and trend is applied and the critical values produced by Hepsağ (2021) are used.

Another unit root test used in the study is the Fourier Sollis test developed by Ranjbar et al. (2018). Unlike the Fourier ADF test, the Fourier Sollis unit root test takes nonlinearity into account. Within the framework of the test, test regressions (21) and (22) are estimated and residuals are obtained. In the second stage, the classical Sollis (2009) unit root test is applied to the residuals. If the calculated test statistic is greater than the critical value produced by Ranjbar et al. (2018), the null hypothesis of unit root is rejected and the series is not stationary under soft breaks. However, in case of stationarity, the significance of the parameters of the trigonometric terms is important. If the parameters are statistically insignificant, the test becomes the classical Sollis (2009) test.

The last unit root test applied is the Fourier Kruse unit root test developed by Güriş (2019). In this test, residuals are obtained by estimating test regressions (21) and (22) in the first stage. In the second stage, the classical Kruse (2011) unit root test is applied to the residuals. If the calculated test statistic is greater than the critical value produced by Güriş (2019), the null hypothesis of the unit root is rejected and the series is stationary under soft breaks. If the stationarity result is obtained, the significance of the parameters of the trigonometric terms is tested, and if the parameters are found to be insignificant, the test turns into the classical Kruse (2011) test.

4. Results

Firstly, unit root tests with structural breaks for total greenhouse gas emissions and emissions by sectors are applied and the findings are presented in Table. After the Dickey-Fuller unit root test, many unit root and stationarity tests such as extended Dickey-Fuller (1981), Phillips-Perron (1988), and Kwiatkowski et al. (1992) have been developed.

Table 2. Structural Fracture Unit Root Test Results

Test	Delay Length	Breakout Dates	Test Statistics	Critical Value (%1)	Critical Value (%5)
			Total		
ZA	0	2001	-4,544	-5,57	-5,08
LM (2 Refraction)	1	2004, 2013	-5,632	-7,004	-6,185
NP	7	2003, 2009	-4,913	-5,949	-5,181
			Energy		
ZA	0	2006	-4,639	-5,57	-5,08
LM (2 Refraction)	2	1999, 2005	-5,728	-6,75	-6,11
NP	1	2001, 2006	-1,866	-5,949	-5,181
			Agriculture		
ZA	8	2010	-3,202	-5,57	-5,08
LM (2 Refraction)	8	2010, 2019	-5,640	-7,004	-6,185
NP	0	2004, 2010	-5,048	-5,949	-5,181

Industrial Processes and Product Handling					
ZA	0	2006	-3,778	-5,34	-4,93
LM (2 Refraction)	9	2005, 2009	-7,035	-7,196	-6,312*
NP	0	2004, 2006	-5,990	-5,949*	-5,181*
Waste					
ZA	9	2006	-4,581	-5,57	-5,08
LM (2 Refraction)	8	2016, 2019	-9,531	-6,750*	-6,108*
NP	2	1991, 2000	-5,240	-5,949	-5,181*

**Stationary (It denotes stationarity under soft breaks at the relevant significance level)*

As seen in Table 2, the test statistics calculated for all three tests for the total greenhouse gas emissions series are greater than the critical values. In this framework, the null hypothesis of the unit root cannot be rejected. In other words, total greenhouse gas emissions are not found to be sustainable. In terms of sectors, the test statistics calculated for the energy and agriculture sectors are greater than the critical values for all three tests applied. In other words, greenhouse gas emissions are not found to be sustainable for these two sectors. The results of the analyses conducted for the industrial processes and product utilization sector and the waste sector are different. As seen in Table 1, the time series for the industrial processes and product utilization sector is trend stationary under two structural breaks at 5% significance level according to the LM test and at 1% significance level according to the NP test. The series for the waste sector is trend stationary with two structural breaks at 1% significance level according to the LM test and 5% significance level according to the NP test. In this context, it can be said that evidence of stationarity has been obtained for these two sectors. GHG emissions are found to be sustainable for industrial processes product use and waste sectors. According to the results obtained from unit root tests with structural breaks, the sectoral sources of unsustainable greenhouse gas emissions in Turkey are the energy and agriculture sectors.

In the second stage of the study, Fourier-type unit root tests allowing soft fractures were applied, and the test results for the fixed and trendy models are presented in Table 3.

Table 3. Fourier Unit Root Test Results

Test	Minimum RSS	k	Test Statistics	Critical Value (%1)	Critical Value (%5)
Total					
Fourier ADF	4191,196	1	-4,616	-5,11	-4,46*
Fourier Sollis	4191,196	1	4,652	11,922	9,218
Fourier Kruse	4191,196	1	8,854	24,24	18,38
Energy					
Fourier ADF	3297,452	4	-3,207	-4,39	-3,70
Fourier Sollis	3297,452	4	3,683	9,597	7,053
Fourier Kruse	3297,452	4	5,918	17,88	13,1
Agriculture					
Fourier ADF	105,330	1	-4,368	-5,11	-4,46
Fourier Sollis	105,330	1	9,200	11,922	9,218
Fourier Kruse	105,330	1	17,854	24,24	18,38
Industrial Processes and Product Handling					
Fourier ADF	182,012	1	-4,912	-5,11	-4,46*

Fourier Sollis	182,012	1	12,654	11,922*	9,218*
Fourier Kruse	182,012	1	21,810	24,24	18,38*
Waste					
Fourier ADF	2,822	1	-4,476	-5,11	-4,46*
Fourier Sollis	2,822	1	13,372	11,922*	9,218*
Fourier Kruse	2,822	1	15,478	24,24	18,38

* *Stable (It denotes stationarity under soft breaks at the relevant significance level)*

As seen in Table 3, the test statistics calculated for the total greenhouse gas emissions series are smaller than the critical values. Only according to the Fourier ADF test, the test statistic is larger in absolute value than the critical value at the 5% significance level. In this context, it can be said that there is strong evidence of a unit root process for the total greenhouse gas emissions series. In other words, total greenhouse gas emissions are not found to be sustainable. In terms of sectors, the time series of the energy and agriculture sectors are found to be unit-rooted under soft breaks according to all three test results. For these two sectors, greenhouse gas emissions do not exhibit a sustainable structure. The series for the industrial processes and product utilization sector is stationary under soft breaks at 5% significance level for all three sectors. The waste series is found to be stationary only according to the Fourier Kruse test, while it is stationary according to the other two tests. In this framework, it can be stated that the evidence of stationarity is stronger for the waste series. However, for the stationarity result to be valid, the parameters of the trigonometric terms of the Fourier functions should be statistically significant. In this context, the statistical significance of the parameters of the trigonometric terms for the tests where stationarity results were obtained were tested and the test results are presented in Table 4.

Table 4. Trigonometric Term Coefficients F Test Results

Test	Test Statistics	Critical Value (%1)	Critical Value (%5)
Fourier ADF (Industry)	45,790	6,873*	4,972*
Fourier Sollis (Industry)	12,645	6,873*	4,972*
Fourier Kruse (Industry)	54,824	6,873*	4,972*
Fourier ADF (Waste)	331,074	6,873*	4,972*
Fourier Sollis (Waste)	331,074	6,873*	4,972*

**Statistically*

As seen in Table 4, all test statistics are greater than the critical values. The null hypothesis that both trigonometric terms are insignificant is rejected for all tests. In this framework, it can be said that the stationarity results obtained in the test processes are valid. The results obtained from Fourier-type unit root tests are similar to the unit root tests with structural breaks that take into account sudden structural changes. According to the Fourier tests, the sectoral sources of the unsustainable structure in greenhouse gas emissions are the energy and agriculture sectors. For industrial processes and product use and agriculture sectors, greenhouse gas emissions are found to be sustainable.

Table 5. Greenhouse Gases Fourier Test Results (Constant Model)

Test	Minimum RSS	K	Test Statistics	Critical Value (%1)	Critical Value (%5)
Total					
Becker Enders Lee	127122,419	1	0,318	0,2699	0,1720
Fourier ADF	127122,419	1	-1,283	-4,43	-3,85
Fourier KSS	127122,419	1	-1,404	-4,14	-3,59
Fourier Sollis	127122,419	1	0,954	9,771	7,348

Fourier Kruse	127122,419	1	2,516	20,32	14,72
			Energy		
Becker Enders Lee	77825,205	1	0,318	0,269	0,172
Fourier ADF	77825,205	1	-1,182	-4,43	-3,85
Fourier KSS	77825,205	1	-1,111	-4,14	-3,59
Fourier Sollis	77825,205	1	0,735	9,771	7,348
Fourier Kruse	77825,205	1	2,924	20,32	14,72
			Agriculture		
Becker Enders Lee	856,087	1	0,305	0,269	0,172
Fourier ADF	856,087	1	-1,065	-4,43	-3,85
Fourier KSS	856,087	1	-0,138	-4,14	-3,59
Fourier Sollis	856,087	1	0,491	9,771	7,348
Fourier Kruse	856,087	1	2,432	20,32	14,72
			Industry		
Becker Enders Lee	2397,694	1	0,329	0,269	0,172
Fourier ADF	2397,694	1	-1,573	-4,43	-3,85
Fourier KSS	2397,694	1	-1,384	-4,14	-3,59
Fourier Sollis	2397,694	1	0,928	9,771	7,348
Fourier Kruse	2397,694	1	2,244	20,32	14,72
			Waste		
Becker Enders Lee	37,534	1	0,314	0,269	0,172
Fourier ADF	37,534	1	-1,363	-4,43	-3,85
Fourier KSS	37,534	1	-2,166	-4,14	-3,59
Fourier Sollis	37,534	1	2,269	9,771	7,348
Fourier Kruse	37,534	1	6,540	20,32	14,72

For critical values see Becker Enders and Lee (2006)

Becker Enders and Lee (2006) state that the nature of structural breaks cannot be known precisely and that there is no specific guide to indicate the location and number of breaks for unit root tests. Based on this situation, Fourier unit root/stationarity tests were developed. Unit root tests based on the Fourier approach can be used when break dates, number of breaks, or break structures are unknown. In addition to the model structures based on a periodic structure, the breaks in the function forms subjected to the Fourier transform also deal with non-periodic structures in the Becker, Enders, and Lee tests. The study provides strong results for sharp and soft breaks and gradual break structures observed in the series. According to Table 5, all series are under soft breaks, and unit root existence is detected.

Table 6. Greenhouse Gases Fourier Test Results (Model with Fixed Trend)

Test	Minimum RSS	k	Test Statistics	Critical Value (%1)	Critical Value (%5)
Total					
Becker Enders Lee	4191,196	1	0,2052	0,071	0,054
Fourier ADF	4191,196	1	-4,616	-5,11	-4,46*
Fourier KSS	4191,196	1	-3,024	-4,69	-4,08
Fourier Sollis	4191,196	1	4,652	11,922	9,218
Fourier Kruse	4191,196	1	8,854	24,24	18,38
Energy					
Becker Enders Lee	3297,452	4	0,109	0,217	0,1478*
Fourier ADF	3297,452	4	-3,207	-4,39	-3,70
Fourier KSS	3297,452	4	-2,152	-4,16	-3,58
Fourier Sollis	3297,452	4	3,683	9,597	7,053
Fourier Kruse	3297,452	4	5,918	17,88	13,1
Agriculture					
Becker Enders Lee	105,330	1	0,305	0,071	0,054
Fourier ADF	105,330	1	-4,368	-5,11	-4,46
Fourier KSS	105,330	1	-4,256	-4,69	-4,08*
Fourier Sollis	105,330	1	9,200	11,922	9,218
Fourier Kruse	105,330	1	17,854	24,24	18,38
Industry					
Becker Enders Lee	182,012	1	0,107	0,071	0,054
Fourier ADF	182,012	1	-4,912	-5,11	-4,46*
Fourier KSS	182,012	1	-3,676	-4,69	-4,08
Fourier Sollis	182,012	1	12,654	11,922*	9,218*
Fourier Kruse	182,012	1	21,810	24,24	18,38*
Waste					
Becker Enders Lee	2,822	1	0,108	0,071	0,054
Fourier ADF	2,822	1	-4,476	-5,11	-4,46*
Fourier KSS	2,822	1	-2,102	-4,69	-4,08
Fourier Sollis	2,822	1	13,372	11,922*	9,218*
Fourier Kruse	2,822	1	15,478	24,24	18,38

For critical values see Becker Enders and Lee (2006). **It denotes stationarity under soft breaks at the relevant significance level.*

As seen in Table 6, among the tests conducted for the total emission series, only the Fourier ADF test yielded a stationarity result under soft breaks. In other words, it can be said that there is strong evidence in favor of the unit root result under soft breaks. In this context, total emissions are not found to be sustainable. Similar results were obtained for the energy and agriculture sectors. According to Becker et al., the series is stationary in the energy sector and Fourier CSR tests in the agriculture sector. However, all other tests indicate a unit root under soft breaks. It is seen that emissions in these two sectors are not sustainable. For the industrial and waste sectors, evidence of stationarity is obtained under soft breaks. In addition, tests that take into account nonlinearity also yield stationarity results. It can be said that emissions from industry and waste sectors are sustainable when structural changes are taken into account.

5. Conclusion

The continuity of development is possible by ensuring environmental sustainability and the environmental dimension of sustainability is related to the use of limited natural resources without harming ecosystems. The number of studies on environmental sustainability, which is an issue for which all individuals and organizations should take joint responsibility, has increased considerably in recent years. This study tries to reveal the sectoral sources of sustainability of greenhouse gas emissions in Turkey. In parallel with this study, which tries to reveal the sectoral sources of sustainability of greenhouse gas emissions in Turkey, it can be analysed for different periods by including the data of other countries. Thus, environmental sustainability can be evaluated in a multidimensional way by comparing countries.

In the literature, studies investigating the determinants of sectoral greenhouse gas emissions and their relationship with macroeconomic variables using various methods are frequently encountered. In addition, some studies have developed strategies to reduce greenhouse gas emissions in certain sectors. However, this study is a pioneering study that evaluates the greenhouse gas emissions of sectors in terms of sustainability in Turkey. In other words, it contributes to filling the gap in the literature as an important study that addresses the current issue within the framework of environmental sustainability, which has become extremely important today.

Based on this, in this study, the sustainability of greenhouse gas emissions in Turkey in total and for each sector is investigated for the period 1990-2022. To determine the sustainability, unit root tests that deal with both sudden structural breaks and soft breaks were applied as econometric methods. According to the findings obtained from both methods, greenhouse gas emissions were not found to be sustainable. In other words, greenhouse gas emissions are not found to be sustainable. When the break dates are analyzed, 2001, which was the crisis year for the Turkish economy, and 2009, when the global crisis was felt in Turkey, stand out. In terms of sectors, GHG emissions are not found to be sustainable for energy and agriculture sectors. Despite the rapid growth in the energy sector, it can be said that environmental investments are insufficient. In the agricultural sector, it can be said that an environmental policy could not be implemented in parallel with the increasing mechanization. In the intermediate dates, 2006, when the law on climate change and sustainable energy was enacted, stands out. Among the other sectors analyzed greenhouse gas emissions were found to be sustainable for industrial processes and product use and waste sectors. For these sectors, 2006 was determined as the common break date. In this context, it is revealed that the unsustainability in total greenhouse gas emissions originates from the energy and agriculture sectors. Developing and implementing environmental policies in these sectors is essential. Identifying the factors that cause greenhouse gas emissions and taking the necessary measures will be effective in shaping the environmental policies of all sectors, especially the sustainability of agricultural production and the efficient use of energy.

Agriculture suffers the most from climate change since it is the sector that will be affected, it is necessary to adapt to climate change. Agriculture is the second sector that causes climate change with greenhouse gas emissions after the energy sector. Consideration of food security with the planning to be made specifically for the agricultural sector will be able to reduce greenhouse gas emissions.

Energy utilization trends of all sectors in Turkey show a general upward trend over the years. The most important factor contributing to the increase in greenhouse gas emissions in Turkey between 1990 and 2014 is the energy intensity effect. On the other hand, the magnitude of the positive contribution of this effect to greenhouse gas emissions, especially in the industrial sector, is gradually decreasing. With the continuation of this positive development in energy intensity in the industrial sector, emissions can be reduced in absolute terms. This change in the energy intensity effect in the industrial sector is significant. This positive development implies that the level of energy used in the production of unit output in Turkey's industrial sector has started to decline, which means that energy is used more efficiently. This is an indication that the increasing energy demand in Turkey has started to be met from renewable energy sources such as solar and wind, which do not emit carbon emissions. The acceleration of legal regulations and investments in renewable energy plays an important role in this effect. Although the share of the waste sector in total GHG emissions is small, it is important to consider it as a whole with its environmental and social impacts. Being able to identify the largest emitters by dividing global greenhouse gas emissions by sectors is important in implementing emission reduction policies and combating climate change. Turkey's development of a balanced energy policy by getting rid of its dependence on external energy sources will also make a significant contribution to environmental sustainability.

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Araştırma Makalesi

Sustainability Of Greenhouse Gas Emissions By Sectors In Turkey: Evidence From Unit Root Tests With Structural Breaks

Türkiye'de Sektörlere Göre Sera Gazı Emisyonlarının Sürdürülebilirliği: Yapısal Kırılmalı Birim Kök Testlerinden Kanıtlar

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Genişletilmiş Özet

Amaç: Ekonomik faaliyetler ile çevresel kalite arasındaki yoğun ilişki günümüzde sürdürülebilirliğin önemini artırmıştır. Bu çalışmanın amacı, 1990-2022 dönemi için Türkiye'de sera gazı emisyonlarının toplamda ve her bir sektör için sürdürülebilirliğini araştırmaktır.

Yöntem: Çalışmada, toplamda ve her bir sektör için sera gazı emisyonlarının sürdürülebilirliği araştırılmıştır. Sürdürülebilirliği belirlemek için birim kök testlerinden yararlanılmıştır. Çalışmada ilk olarak seviye ve eğimde yapısal kırılmayı dikkate alan Zivot-Andrews (ZA) Birim Kök Testi uygulanmıştır. Christopoulos ve Leon-Ledesma (2010) tarafından geliştirilen Fourier ADF testi uygulanmıştır.

İkinci aşamada ise artık serilere ADF birim kök testi uygulanmıştır. Çalışmada kullanılan bir diğer birim kök testi ise Ranjbar ve diğerleri (2018) tarafından geliştirilen Fourier Sollis testidir. Fourier ADF testinden farklı olarak Fourier Sollis Birim Kök Testi doğrusal olmamayı dikkate almaktadır. Uygulanan son birim kök testi ise Güriş (2019) tarafından geliştirilen Fourier Kruse birim kök testidir.

Bulgular: Toplam sera gazı emisyonları serisi için her üç test için hesaplanan test istatistikleri kritik değerlerden büyüktür. Bu çerçevede, birim kök sıfır hipotezi reddedilememektedir. Diğer bir deyişle, toplam sera gazı emisyonları sürdürülebilir bulunmamıştır. Sektörler açısından bakıldığında, enerji ve tarım sektörleri için hesaplanan test istatistikleri, uygulanan her üç test için de kritik değerlerden büyüktür. Diğer bir deyişle, bu iki sektör için sera gazı emisyonları sürdürülebilir bulunmamıştır. Endüstriyel işlemler ve ürün kullanımı sektörü ile atık sektörü için yapılan analizlerin sonuçları farklıdır. Endüstriyel işlemler ve ürün kullanımı sektörü için zaman serisi LM testine göre %5 anlamlılık düzeyinde ve NP testine göre %1 anlamlılık düzeyinde iki yapısal kırılma altında trend durağandır. Atık sektörüne ait seri ise LM testine göre %1 ve NP testine göre %5 anlamlılık düzeyinde iki yapısal kırılma ile trend durağandır. Bu bağlamda, bu iki sektör için durağanlığa dair kanıt elde edildiği söylenebilir. Sera gazı emisyonlarının endüstriyel işlemler ürün kullanımı ve atık sektörleri için sürdürülebilir olduğu tespit edilmiştir. Yapısal kırılmalı birim kök testlerinden elde edilen sonuçlara göre, Türkiye'de sürdürülemez sera gazı emisyonlarının sektörel kaynakları enerji ve tarım sektörleridir.

Toplam sera gazı emisyonları serisi için hesaplanan test istatistikleri kritik değerlerden küçüktür. Sadece Fourier ADF testine göre, test istatistiği %5 anlamlılık düzeyinde kritik değerden mutlak değer olarak daha büyüktür. Bu bağlamda, toplam sera gazı emisyonları serisi için birim kök sürecine ilişkin güçlü kanıtlar olduğu söylenebilir. Her iki trigonometrik terimin de anlamsız olduğu boş hipotezi tüm testler için reddedilmiştir. Bu çerçevede, test süreçlerinde elde edilen durağanlık sonuçlarının geçerli olduğu söylenebilir. Fourier tipi birim kök testlerinden elde edilen sonuçlar, ani yapısal değişimleri dikkate alan yapısal kırılmalı birim kök testleri ile benzerlik göstermektedir. Fourier testlerine göre sera gazı

emisyonlarındaki sürdürülemez yapının sektörel kaynakları enerji ve tarım sektörleridir. Endüstriyel süreçler ve ürün kullanımı ile tarım sektörleri için sera gazı emisyonları sürdürülebilir bulunmuştur.

Sonuç: Kalkınmanın sürekliliği çevresel sürdürülebilirliğin sağlanması ile mümkündür ve sürdürülebilirliğin çevresel boyutu sınırlı doğal kaynakların ekosistemlere zarar vermeden kullanılması ile ilgilidir. Tüm birey ve kuruluşların ortak sorumluluk alması gereken bir konu olan çevresel sürdürülebilirlik konusunda yapılan çalışmaların sayısı son yıllarda oldukça artmıştır. Bu çalışma, Türkiye'de sera gazı emisyonlarının sürdürülebilirliğinin sektörel kaynaklarını ortaya koymaya çalışmaktadır.

TÜİK tarafından yayınlanan son verilere göre, Türkiye'de sektörlere göre emisyon miktarında enerji sektörü ilk sırada yer almaktadır. Toplam sera gazı emisyonlarında (CO2 eşdeğeri olarak) 2022 yılında enerji kaynaklı emisyonlar %71,8 ile en büyük paya sahipken, bunu %12,8 ile tarım, %12,5 ile endüstriyel işlemler ve ürün kullanımı ve %2,9 ile atık takip etmiştir. Bu veriler, çalışmanın bulgularıyla uyumludur ve Türkiye'de sera gazı emisyonlarının sürdürülemez olmasında enerji ve tarım sektörlerinin etkili olduğuna dikkat çekmektedir.

Sera gazı emisyonlarına neden olan faktörlerin belirlenmesi ve gerekli önlemlerin alınması, tarımsal üretimin sürdürülebilirliği ve enerjinin verimli kullanımı başta olmak üzere tüm sektörlerin çevre politikalarını etkin bir şekilde şekillendirecektir.