UTEAD
Cilt: 9 Sayı: 1-2 Yıl: 2025
Voume: 9 Issue: 1-2 Year: 2025
JITER

ULUSLARARASI TİCARET VE EKONOMİ ARAŞTIRMALARI DERGİSİ

Araştırma Makalesi
Research Paper

JOURNAL OF INTERNATIONAL TRADE AND ECONOMIC RESEARCHES

An Analysis of The Relationship between Greenhouse Gas Emissions and Economic and Social Indicators within The Framework of Environmental Sustainability in Turkey

Türkiye'de Çevresel Sürdürülebilirlik Çerçevesinde Sera Gazı Emisyonları ile Ekonomik ve Sosyal Göstergeler Arasındaki İlişkinin Analizi

Olcay SERVET [a]

[a] Dr., Bağımsız Araştırmacı, olcayservet@hotmail.com

ORCID: 0000-0001-5982-8812

DOI: 10.30711/utead.1760387

MAKALE BİLGİSİ

Makale Geçmişi:
Başvuru Tarihi: 7 Ağustos 2025
Düzeltme Tarihi: 3 Kasım 2025
Kabul Tarihi: 3 Kasım 2025

Anahtar Kelimeler:
Sera Gazı Emisyonu, Kişi Başına GSYİH, Yenilenebilir Enerji, Endüstrileşme

ÖZ

Hızlı ekonomik büyüme ve iş genişlemesinden kaynaklanan gelişen nüfus, sera gazı emisyonlarında artışa yol açmıştır. Artan emisyon seviyeleri, iklim değişikliği ve küresel ısınma gibi birçok çevresel sorunla bağlantılıdır ve bu durum halk sağlığı ve güvenliği için büyük tehditler oluşturmaktadır. Sera gazı emisyonlarını azaltmaya yönelik politikalar geliştirmek, bu emisyonları etkileyen faktörlerin belirlenmesine ve incelenmesine dayanır. Bu amaçla, bu çalışma Türkiye'de 1990-2021 yılları arasında kişi başına düşen GSYH, yenilenebilir enerji kullanımı, nüfus büyüklüğü, sanayileşme ve yabancı yatırımların sera gazı emisyonları üzerindeki etkisini zaman serisi verileri kullanarak incelemektedir. Çalışmada Dinamik En Küçük Kareler (DOLS) yöntemi, Johansen eşbütünleşme testi ve Otoregresif Dağıtılmış Gecikmeli (ARDL) model gibi birden fazla ekonometrik yöntem uygulanmıştır. Ayrıca, sonuçların güvenilirliğini artırmak ve karşılaştırmalı bir değerlendirme sunmak için Tam Değiştirilmiş En Küçük Kareler (FMOLS) ve Kanonik Eşbütünleşme Regresyonu (CCR) yöntemleriyle tahminler yapılmıştır. Bulgulara göre, sera gazı emisyonları kişi başına düşen gelir seviyeleri, demografik büyüme ve sanayi süreçleri gibi faktörler tarafından yönlendirilirken, yenilenebilir enerjiye geçiş emisyonların azalmasında önemli bir rol oynamaktadır. Elde edilen sonuçlar FMOLS ve CCR yöntemleriyle yapılan sağlamlık testleriyle doğrulanmıştır. Bu çalışma, yenilenebilir enerji yatırımlarını teşvik etmek, yeşil dönüşüm projelerini desteklemek ve enerji verimliliği uygulamaları ile karbon yakalama teknolojilerinin kullanımını artırmak suretiyle karbon ayak izinin azaltılmasına yönelik stratejiler sunmaktadır.

JEL Sınıflandırması: C32, O1, Q5.

ARTICLE INFO

Article History:
Received August, 7, 2025
Received in revised form Nov., 3, 2025
Accepted November, 3, 2025

Keywords:
Greenhouse Gas Emissions,
GDP Per Capita, Renewable Energy,
Industrialization

ABSTRACT

Rapid financialboom and a developingpopulace, stemming from business expansion, have induced an uptick in greenhouse fueloline emissions. Increasing stages of emissions are related to numerous environmental problems, inclusive ofweatherextrade and worldwide warming, which pose full-size threats to public fitness and safety. Creating guidelines to lower greenhouse fueloline emissions relies upon on spotting and inspecting the elements that affectthose emissions. To reap this, this studies investigates how in keeping with capita GDP, renewable electricity use, populace size, industrialization, and overseas investments affect greenhouse fueloline emissions in Turkey from 1990 to 2021 the use of time collection data. The examineappliedmore than onestrategies for econometric examination, inclusive of the DOLS method, the Johansen cointegration test, and the Autoregressive Distributed Lag model. Furthermore, to reinforce the reliability and help a comparative overview of the results, estimates the use of the FMOLS and the Canonical Cointegration Regression had beenadditionally determined. According to the findings, greenhouse fueloline emissions are pushedvia way of means ofelementsinclusive ofman or womanprofitsstages, demographic boom, and business processes, while a shift closer to renewable electricityperforms a functionof their reduction. The conclusions reached had beentestedvia robustness examsthe use of FMOLS and CCR strategies. This examineaffordsstrategies for decreasing the carbon footprint via way of means ofselling investments in renewable electricity, backing inexperienced transformation projects, and making use ofelectricityperformancetasksalong side carbon seize technologies.

JEL Classifications: C32, O1, Q5.

1. INTRODUCTION

Global climate change ranks as one of the major environmental issues confronting us at present. The main factor driving this change is the greenhouse effect. In this phenomenon, the Earth's surface takes in solar energy, heats up, and subsequently radiates some of that energy back as infrared heat. Nevertheless, instead of this heat spreading into space, a portion of it gets taken in by greenhouse gases present in the atmosphere. This process leads to an increase in temperature for both the Earth's surface and the atmosphere that surrounds it (Dulkadiroglu, 2018:68).

The period following the Industrial Revolution has seen a notable rise in greenhouse gases in the atmosphere, like (CO_2), (CH_4), (N_2O), (HFCs), (SF_6) and (PFCs). This increase is mainly due to human actions such as burning fossil fuels, alterations in land usage, deforestation, and industrial manufacturing. These gases modify the atmosphere's chemical balance and contribute to global warming over time, resulting in climate change. Climate change adversely affects every aspect of existence, encompassing the physical and natural environment, urban living, economic development, technology, human rights, agriculture and food security, access to clean water, and public health (Tatar and Ozer, 2018:3994).

Turkey ratified the UNFCCC on May 24, 2004, committing to actions aimed at reducing greenhouse gas emissions, advancing scientific research, facilitating technology transfer, and safeguarding the environment. In 2009, Turkey joined the Kyoto Protocol, the first agreement for executing the UNFCCC. Nonetheless, the protocol does not impose a mandatory requirement on Turkey to quantitatively decrease its greenhouse gas emissions. On April 22, 2016, Turkey became a signatory of the Paris Agreement, which governs the climate framework after 2020. At first, Turkey aimed to limit the anticipated rise in greenhouse gas emissions by as much as 21% by 2030, but subsequently changed this goal to 41%. These objectives are expected to bring about significant transformations not only in the environmental domain but also across energy, health, agriculture, and the economy, playing an essential part in fulfilling nations' sustainable development objectives (Kızılkaya, 2023:41).

In Turkey, the significance of renewable energy sources is rising every day to decrease reliance on foreign resources, cut down on fossil fuel usage, and lessen greenhouse gas emissions. As the worldwide demand for renewable energy escalates, Turkey's appetite for these resources is simultaneously expanding because of various social and economic reasons. As a result, Turkey seeks to increase the proportion of renewable sources within its total energy portfolio (Karamıklı and Sasmaz, 2021:294).

Foreign direct investments (FDI) offer considerable benefits to a nation's economy; however, they also come with certain drawbacks due to their capacity to raise carbon dioxide (CO_2) emissions, leading to environmental harm and health problems. The connection between global investment and ecological issues is explored in scholarly debates via two main theories: The concepts of the Pollution Halo and Pollution Haven theories, which is occasionally referred to as the Pollution Sanctuary Hypothesis. The Pollution Halo Hypothesis posits that international investment can contribute to reducing environmental harm (lowering CO_2 emissions) in less developed nations by promoting advanced technologies and eco-friendly methods. Conversely, the Pollution Haven Hypothesis contends that international investment may lead to greater environmental harm (increased CO_2 emissions) in developing regions, as businesses might move to areas with more relaxed environmental laws. Within this framework, the research also looks into how international investment influences greenhouse gas emissions in Turkey (Kurt et al., 2019:215).

The rise in greenhouse gas emissions is largely driven by industrial development. As the Industrial Revolution began and countries sought to enhance their economic growth, large-scale industries expanded swiftly. This industrial expansion created a greater demand for energy, thereby accelerating emissions. The buildup of these gases has caused harmful effects on the environment and has initiated numerous health issues, jeopardizing the wellbeing of all living organisms (Camkaya, 2024:108).

According to the greenhouse gas emission report from the Turkish Statistical Institute, Turkey's total greenhouse gas emissions experienced a 2. 4% reduction in 2022 when compared to the year before, totaling 558. 3 million tons (Mt) of CO_2 equivalent. In 1990, per capita greenhouse gas emissions were recorded at 4. 1 tons of CO_2 equivalent, while this number rose to 6. 6 tons of CO_2 equivalent by 2022. In that year, energy sources accounted for the highest share of total greenhouse gas emissions at 71.8% in CO_2 equivalent, with agriculture following at 12.8%, industrial activities and product use at 12.5%, and the waste sector making up 2.9%. Emissions from the electricity quarter noticed a upward push of 179. 8% considering that 1990, but they dropped with the aid of using 1.4 % from the preceding year, totaling 400. 6 Mt CO_2 equal in 2022. Emissions linked to business sports and product utilization grew with the aid of using 208. 1% considering that 1990, however, they fell with the aid of using 6.4 % as compared to the preceding year, totaling 69.9 Mt CO_2 equal. The agricultural sector's emissions rose by 37. 9% compared to 1990, but they declined by 5. 1% from the previous year, standing at 71. 5 Mt CO_2 equivalent in 2022. In contrast, emissions from the waste sector increased by 57. 7% since 1990 and by 5. 5% from the previous year, totaling 16. 3 Mt CO_2 equivalent (Turkish Statistical Institute, 2024).

Building on previous discussions, this study aims to investigate how per capita GDP, renewable energy use, population growth, industrial development and foreign investment impact Turkey's greenhouse gas emissions by checking annual statistics from 1990 to 2021. After introduction, the documentation is embedded in four important segments: Section 2 checks relevant literature, describes the research methods used in Section3, Section 4 presents actual results and their analysis, and the final section contains guidelines based on the results.

2. LITERATURE

Important research on greenhouse gas emissions related to climate change and itscauseswerebehind the increase. In Turkey, many research efforts are trying to clarifyfactors which increase greenhouse gas emissions. Kızılkaya et al. (2015) examined how annual data from 1967 to 2010 are coupled to energy consumption in the Turkish transport sector, taking into account factors such as economic development and trade opens analyzed.

They used Johansen's (1990) maximum trace traces to examine joint bloats between these variables. Their results show a favorable long-term link between Turkey's CO2 emissions, energy consumption in transport, economic growth and trade (Kızılkaya et al., 2015:18).

Cetintas et al. (2016) explored the link between CO_2 emissions in Turkey from 1960 to 2011, andex amined how energy consumption, economic development, and urban growth affected CO_2 emission rates both in the short-run and long-run. Their results show a consistent relationship betweenthese factors. As a result, energy consumption, economic progress and urbanization have made positive contributions to CO_2 emissions over time. Nonetheless, they discovered that, in the immediate future, the expansion of the economy and city development had little effect on carbon dioxide emissions (Cetintas et al., 2016:57).

Alper and Alper (2017) explored the connection among carbon dioxide emissions (CO_2), economic development (GDP), and oil usage (OIL) in Turkey spanning from 1985 to 2014 by employing the ARDL bounds testing method and conducting a cointegration analysis. Their estimates for long-term coefficients reveal that both economic progress and energy usage result in environmental damage over the years. Nevertheless, it was found that economic progress adversely affects the environment more significantly than energy consumption does (Alper and Alper, 2017:145).

Utilizing the ARDL bounds cointegration technique, Kızılkaya (2017) investigated the connections between foreign direct investment, carbon dioxide emissions, economic growth, and energy usage in Turkey from 1970 to 2014. The results revealed that, over time, economic growth and energy consumption positively affect CO_2 emissions, while foreign direct investment does not have a notable effect (Kızılkaya, 2017:106).

From 1974 to 2014, Pata (2018) explored the relationships among GDP per person, CO_2 emissions per person, financial development, usage of renewable energy per person, the adoption of hydroelectric and alternative energy sources, and urban growth in Turkey. The research applied the ARDL bounds testing method along with Cointegration tests introduced by Gregory-Hansen and Hatemi-J. All three methods revealed a consistent long-term relationship among these factors. The research showed that growth in the economy, improvements in finance, and development of cities negatively impact the environment. In contrast, harnessing renewable energy, hydropower, and other alternative energy sources has a minimal effect on carbon dioxide emissios. Supporting the EKC theory, the outcomes suggest an inverted U-shaped correlation between economic development and carbon output. The research highlighted that Turkey's per capita GDP has not yet achieved a level that would permit significant pollution control and emphasized that renewable energy by itself is insufficient to tackle CO2 emission issues (Pata, 2018:770).

Canbay (2019) explored how economic growth relates to the adoption of renewable energy and environmental pollution in Turkey. This study utilized data from 1990 to 2016 and employed the ARDL bounds testing method. The findings indicated a link between these factors. It was observed that economic progress resulted in increased CO_2 emissions both in the short term and the long term; conversely, the implementation of renewable energy contributed to a reduction in CO_2 emissions during these same times (Canbay, 2019:140).

Yıldız and Gokturk (2019) explored how urban growth, industrial activity, and environmental contamination interact within the Turkish economy from 1986 to 2015 by applying ARDL cointegration analysis. The results reveal a notable and positive connection among the increase in urban population, energy use, and carbon dioxide output. Nonetheless, the research failed to find any significant relationship between the industrial output index and carbon dioxide emissions (Yıldız and Gokturk, 2019:217).

Erkisi and Celik (2020) explored the connections between carbon dioxide emissions, dependence on fossil fuels, and economic growth in Turkey from 1990 to 2015, employing the VAR Granger Causality Analysis technique. Their findings show a one-directional positive relationship where non-renewable energy consumption influences CO_2 emissions in the short term, making it the sole factor affecting CO_2 emissions during this period. These results align with the "Neutrality Hypothesis" which implies that energy use does not have a direct link to economic growth. Thus, it suggests that policies aimed at decreasing energy consumption can help reduce carbon dioxide emissions without harming economic growth (Erkisi and Çelik, 2020:844).

Kılınc and Altıparmak (2020) explored how per capita GDP, population size, primary energy usage, research and development energy funding aligned with socio-economic goals, environmental taxes, and CO2 emissions interrelate in Turkey and 21 EU member states from 2005 to 2014, using dynamic panel data analysis techniques. Their findings reveal that in Turkey and the chosen 21 EU nations, environmental taxes and R&D energy investments targeting socio-economic goals correlate negatively with CO_2 emissions, whereas per capita GDP and primary energy usage correlate positively. They discovered that there was no meaningful connection between the number of people and carbon dioxide emissions (Kılınc and Altıparmak, 2020:217).

Ozdemir and Koc (2020) explored the ongoing stable connection in Turkey by applying the ARDL Bounds Test. They examined a range of factors including per capita CO_2 emissions, individual real GDP, per capita energy usage, renewable energy consumption per individual, and level of trade openness. Their study aimed to analyze EKC theory specifically in relaiton to Turkey. The results revealed a cubic N-shape relationship between income and per capita CO_2 emissions. The assessment of long term coefficients demonstrates that an increase in energy consumption leads to higher per capita CO_2 emissions, while higher usage of renewable energy results in lower emissions. Additionally trade openness has a positive effect on emissions, and all examined factors showed statistical significance (Ozdemir and Koc, 2020:119).

Alnour (2021) investigated the connection between economic development and environmental pollution in Turkey from 1970 to 2017 using the ARDL method with annual time series data. The classical decomposition approach was also employed to assess pollution rates. The findings indicate that while short-term economic growth beneficially impacts environmental pollution, this influence is both positive and constrained when considered over an extended timeframe. An analysis of elasticities across both long and short durations demonstrates that the long-term elasticity exceeds the short-term elasticity, challenging The hypothesis related to the EKC. This data backs the claim that the EKC theory is not applicable in Turkey (Alnour, 2021:290).

From 1965 to 2018, Doganlar (2021) examined yearly data to investigate the impacts of energy use, economic development and financial elements on CO_2 emissions in Turkey. The study employed the bootstrap causality test created by Hacker and Hatemi-J and used the RALS-EG cointegration test to evaluate the relationships among the variables. Results from the RALS cointegration test indicated a consistent long-term relationship among economic expansion, energy consumption, CO_2 emissions, and financial growth. Based on the DOLS evaluation, energy usage and financial development greatly influence CO_2 emissions positively over time, with energy consumption recognized as the primary factor driving environmental pollution in Turkey. Causality analysis showed a one-way causal relationship where financial growth leads to increased CO_2 emissions and where economic expansion drives up energy use (Doganlar et al., 2021:32554).

Konat (2021) investigated how environmental decline relates to economic development in Turkey during the years 1960 to 2016, utilizing EKC hypothesis as a framework. The results indicate a consistent connection between these two factors. Additionally, the examination of long-run coefficients shows an inverted N form (Konat, 2021:105).

Shan et al. (2021) examined how advancements in environmentally friendly technologies, renewable energy options, and CO_2 emissions in Turkey from 1990 to 2018, applying the bootstrap ARDL-bound test method within the STIRPAT framework. The study implemented the Granger causality approach to analyze the connections between the progress of green technologies, energy usage, renewable energy alternatives, population increase, per capita income, and CO_2 emissions. The findings indicate that these factors—such as advances in green technology, renewable energy, energy consumption, population, and income—are linked over an extended period. Even though advancements in eco-friendly technology and renewable energy help decrease carbon dioxide emissions, growing energy needs, population growth, and rising individual income lead to higher CO_2 emissions (Shan et al., 2021:1).

Qoyash and Eren (2022) examined how technological progress and renewable energy utilization affected the environment in Turkey between 1990 and 2019, using the dynamic ARDL simulation method. Their research examined various factors including carbon dioxide output, reliance on renewable and non-renewable energy, advancements in technology, economic growth, tade activities, and foreign investment. Their findings suggest that non-renewable energy use and technological progress contribute positively to CO_2 emissions, whereas renewable energy has a negative –but relatively weak-impact (Qoyash and Eren (2022:110).

Camkaya (2024) investigated the effects of demographic shifts, economic progress, the adoption of renewable energy, and industrial expansion on CO_2 emissions across both short and extended timeframes. This analysis employed the STIRPAT-Kaya-EKC framework along with the Augmented Autoregressive Distributed Lag (AARDL) model, utilizing yearly data from Turkey collected between 1977 and 2019. The research by Camkaya (2024) indicated that an increase in population over time contributes to higher CO_2 emissions and worsening environmental damage, whereas the shift towards renewable energy has been instrumental in mitigating these negative effects. The findings also suggested that industrial expansion leads to a rise in CO_2 emissions, resulting in greater environmental pollution over both the near and distant future. Furthermore, the research highlighted that the effect of economic development on CO_2 emissions is more significant in the short run compared to the long run (Camkaya, 2024:125).

3. MATERIAL AND METHODS

This section elaborates on the dataset utilized for this research and outlines the econometric techniques applied.

3.1. Data

The impact of population size, industrial expansion, per capita GDP, renewable energy consumption, and foreign direct investment on greenhouse gas emissions (GHG) in Turkey is empirically assessed in this study. The ARDL limits test, the FMOLS technique Phillips & Hansen (1990), the DOLS method Stock & Watson (1993), the CCR method Park (1992), and the FMOLS approach are all used in the analysis. Data on Turkey from 1990 to 2021 was sourced from Global Atmospheric Research Emissions Database (EDGAR) with the World Development Indicators (WDI) database.

Table 1. Logarithmic Forms, Units, and Data Sources for Variables

Variables	Description	Logarithmic Forms	Units	Sources
GHG	GHG emissions	lnGHG	Mt CO2eq/yr	EDGAR
GDP	Gross Domestic Product	lnGDP	Per capita (current $)	WDI
REN	Renewable energy consumption	lnREN	% of total final energy consumption	WDI
	Population		Population (total)	
POP	Industrialization	lnPOP	Industry value added of %GDP	WDI
IND	Foreign direct investment	lnIND	net inflows (% of GDP)	WDI WDI
FDI		lnFDI		

In this study, greenhouse gas emissions are quantified in metric tons of CO_2 equivalent for each year, while GDP per capita is shown in current US dollars. The proportion of renewable energy is calculated relative to total final energy consumption. The population is indicated by the total count of people, and industrial activity is measured by the GDP share linked to industrial value added. Foreign direct investment is described as net inflows shown as a percentage of GDP. To standardize the distribution of data, the variables were transformed into their logarithmic forms. In Table 1, the logarithmic forms of the variables are presented in detail, together with information about their units of measurement as well as data sources. Figure 1 shows the evolution of these variables throughout time.

Figure 1. Annual Trends in the Variables Studied

3.2. Econometric Model

Following the recommendations provided by Raihan & Tuspekova (2022), Raihan (2023), and Xia et al. (2023), this research incorporates the following economic variables to analyze how emissions relate to per capita GDP, renewable energy usage, population size, industrialization, and foreign direct investment:

$$GHG_t = f(GDP_t;\ REN_t;\ POP_t; IND_t;\ FDI_t) \quad (1)$$

where GHG_t represents emissions at time t, GDP_t denotes economic growth at time t, REN_t signifies renewable energy usage at time t, POP_t refers to the population at time t, IND_t is identifies industrialization at time t, and FDI_t indicates foreign direct investment at time t.

The empirical framework is illustrated in the following equation:

$$GHG_t = \beta_0 + \beta_1 GDP_t + \beta_2 REN_t + \beta_3 POP_t + \beta_4 IND_t + \beta_5 FDI_t \quad (2)$$

An alternate representation of equation (2) is the econometric framework shown below:

$$GHG_t = \beta_0 + \beta_1 GDP_t + \beta_2 REN_t + \beta_3 POP_t + \beta_4 IND_t + \beta_5 FDI_t + \varepsilon_t \quad (3)$$

where ε_t stands for the error term and β_0 for the intercept. The coefficients are also denoted by the letters β_1,β_2,β_3,β_4.

Furthermore, the following is a representation of Equation (3) in its logarithmic form:

$$lnGHG_t = \beta_0 + \beta_1 lnGDP_t + \beta_2 lnREN_t + \beta_3 lnPOP_t + \beta_4 lnIND_t + \beta_5 lnFDI_t + \varepsilon_t \quad (4)$$

where $lnGHG_t$ represents the logarithmic value of GHG emissions at time t, $lnGDP_t$ signifies the logarithmic value of economic growth at time t, $lnREN_t$ denotes the logarithmic value of renewable energy usage at time t, $lnPOP_t$ indicates the logarithmic value of population at time t, $lnIND_t$ refers to the logarithmic value of industrialization at time t, and $lnFDI_t$ represents the logarithmic value of foreign direct investment at time t. Analytical methods in this research were executed using EViews software.

3.3. Estimation Strategies

It is crucial to do a stationarity analysis on the selected datasets before applying cointegration techniques in time series analysis. Because the usefulness of unit root tests might vary depending on sample size, different researchers have proposed several unit root tests in the literature to date. Before employing cointegration techniques in time series analysis, the data must undergo a stationarity test. This study employed the Dickey-Fuller augmented test, created by Dickey and Fuller in 1979, along with the DF-GLS stationarity test Elliott et al.(1996), and the P-P test Phillips and Perron (1988) to examine the presence of unit roots.

The Johansen cointegration examination, created by Johansen in 1988, evaluates if time series that are stable at the same degree tend to trend together over an extended period. This test operates under the null hypothesis that indicates the absence of a cointegration connection among the variables involved. It includes two statistics: the two fundamental trace statistics and the maximum eigenvalue.

To calculate the cointegration coefficient between variables that are thought to change simultaneously over time, the techniques used include FMOLS, known as Fully Modified OLS, DOLS, or Dynamic Ordinary Least Squares, along with CCR, which stands for Canonical Cointegrating Regression.

In this study, the ARDL modeling framework was chosen because of its distinct advantages over other approaches. The ARDL modeling framework was used for this investigation due to its clear benefits over alternative methods. One of the primary benefits of the ARDL model is that it does not necessitate all variables to be stationary at the same integration level (I(0)). It also makes it easier to analyze interactions that take place over a longer period of time. Additionally, compared to multivariate approaches, the ARDL method typically yields more reliable findings when working with smaller sample sets. The ARDL model created by Pesaran and colleagues in 2001 was utilized to assess the cointegration connections between the variables since they show integration of order one (I(1)).

Eq. (5) provides the following equation for the ARDL bounds test:

$$\Delta lnGHG_t = \beta_0 + \beta_1 lnGHG_{t-1} + \beta_2 lnGDP_{t-1} + \beta_3 lnREN_{t-1} + \beta_4 lnPOP_{t-1} + \beta_5 lnIND_{t-1} + \beta_6 lnFDI_{t-1} + \sum_{i=1}^{q} \gamma_1 \Delta lnGHG_{t-i} + \sum_{i=1}^{q} \gamma_2 \Delta lnGDP_{t-i} + \sum_{i=1}^{q} \gamma_3 \Delta lnREN_{t-i} + \sum_{i=1}^{q} \gamma_4\, \Delta lnPOP_{t-i} + \sum_{i=1}^{q} \gamma_5 \Delta lnIND_{t-i} + \sum_{i=1}^{q} \gamma_6 \Delta lnFDI_{t-i} + \varepsilon_t \quad (5)$$

where q is the selected lag duration in Equation 5 and Δ is the location of the initial difference operator. By contrasting the calculated F-statistic with the specified minimum and maximum thresholds, the results of the boundaries test are evaluated. The null hypothesis H_0 which asserts that the variables do not exhibit cointegration, is either accepted or dismissed as described below:

* The F-value is ignored if it surpasses the higher threshold.

* The F-value is deemed legitimate if it falls below the lower criterion.

4. EMPIRICAL RESULTS

4. 1. Overview of Statistics

Table 2 presents the overview of statistics for the variables. There are 32 years of data for Turkey, spanning from 1990 to 2021, for each indicator. The positive estimates of skewness suggest that the graphs of the normal distribution lean towards the right. The kurtosis values, which are below 3 for the variables, indicate that the normal distribution graphs are relatively flat. As the p-values obtained from the Jarque-Bera test for every variable exceed the 5% significance threshold, it suggests that the variables are normally distributed. This confirmation permits us to proceed with analyzing the relationships among the variables.

Table 2. The Variables' Statistical Summaries

	lnGHG	lnGDP	lnREN	lnPOP	lnIND	lnFDI
Mean	5.883753	8.699383	2.781597	18.05591	3.330373	-0.052654
Median	5.844006	8.938679	2.690547	18.05952	3.329698	0.190247
Maximum	6.437163	9.439720	3.194583	18.24808	3.468267	1.287408
Minimum	5.384629	7.685381	2.433613	17.84114	3.179047	-1.186175
Stand. Dev.	0.327317	0.598745	0.257827	0.118995	0.088867	0.732436
Skewness	0.099427	-0.268154	0.340702	-0,083383	0.008251	0.018801
Kurtosis	1.769645	1.411754	1.642993	1.950649	1.765069	1.695538
Jarq-Bera	2.071089	3.746866	3.074372	1.505264	2.033792	2.270714
Prob.	0.355033	0.153595	0.214985	0.471125	0.361716	0.321307
Sum	188.2801	278.3802	89.01112	577.7892	106.5719	-1.684939
Sum Sq. Dev.	3.321230	11.11335	2.060720	0.438952	0.244817	16.63035
Obv.	32	32	32	32	32	32

Table 3 displays the examination of the straightforward connections between the variables. The findings indicate that each variable is related to the others, meaning that increases in one variable generally correspond with increases in the others, and vice versa. However, lnREN shows a negative correlation with all variables except lnIND, while lnIND is negatively correlated with all variables except lnREN. This suggests that as renewable energy consumption rises, most other variables—except industrialization—tend to decrease, and the opposite pattern may also ocur.

Table 3. The Findings from the Correlation Analysis

Variables	lnGHG	lnGDP	lnREN	lnPOP	lnIND	lnFDI
lnGHG	1.000000	0.900819	-0.922268	0,989558	-0.288957	0.677294
lnGDP	0.900819	1.000000	-0.948324	0.890088	-0.464556	0.790849
lnREN	-0.922268	-0.948324	1.000000	-0.920104	0.509224	-0.809420
lnPOP	0.989558	0.890088	-0.920104	1.000000	-0.362555	0.674619
lnIND	-0.288957	-0.464556	0.509224	-0.362555	1.000000	-0.439678
lnFDI	0.677294	0.790849	-0.809420	0.674619	-0.439678	1.000000

4.2. Findings of Unit Root Assessments

The results of determining unit roots using the ADF, PP, and DF-GLS tests are presented in Table 4. The data shows that when evaluated at their original levels, the majority of the variables show a unit root; however, after applying the first difference, they stabilize. As a result, every series is categorized as a unified system of first order, or I(1)

Table 4. Results of Unit Root Examination

Logarithmic form of the variables	ADF		DF-GLS		P-P	
	Log levels	Log first difference	Log Levels	Log first difference	Log levels	Log first difference
lnGHG	-3.293412	-5.687902***	-3.165832	-5.522745***	-3.321909	-9.047421***
lnGDP	-1.298974	-5.793996***	-1.489055	-5.880437***	-1.402290	-5.793776***
lnREN	-2.434160	-6.785950***	-2.555203	-6.322301***	-2.290182	-8.079463***
lnPOP	-2.705926	-3.107804*	-1.818293	-3.134651*	-2.759830	-3.107804*
lnIND	-0.844325	-4.710900***	-1.126597	-4.680069***	-0.844325	-4.343250***
lnFDI	-2.744645	-6.210810***	-2.840280	-6.418206***	-2.717715	-11.52153***

***, **, and * relate to the significance thresholds of 1%, 5%, and 10% accordingly.

4.3. Cointegration Test

The results of the Johansen cointegration examination can be found in Table 5. The results shown in Table 5 indicate that the elements of the model demonstrate a persistent relationship. This determination is made by dismissing the null hypothesis, which claims that there is no enduring relationship among the variables. The null hypothesis is dismissed as both the Trace and Maximum Eigenvalue statistics are

greater than the 5% critical threshold, with their respective p-values being under 0. 05. Therefore, at the 5% significance level, there is proof of a long-term connection among the variables in the analyzed model. Following the Johansen cointegration test, a total of 6 cointegration vectors were identified based on the trace and maximum eigenvalue results. This result suggests that the factors in the model are likely to change in sync over an extended period.

Tablo 5. Test of Johansen Cointegration

Trace test				
Hypothesized No. of CE(s)	**Eigenvalue**	**Trace statistic**	**0.05 Critical value**	**P-value**
None*	0.986696	257.0428	95.75336	0.0000
At most 1*	0.741082	131.7723	69.81889	0.0000
At most 2*	0.674966	92.58619	47.85613	0.0000
At most 3*	0.657703	59.99523	29.79707	0.0000
At most 4	0.490074	28.90504	15.49471	0.0003
At most 5	0.276197	9.373855	3.841466	0.0022
M-Eigen value				
Hypothesized No. of CE(s)	**Eigenvalue**	**M-Eigen Stat**	**0.05 Critical value**	**P-value**
None*	0.986696	125.2705	40.07757	0,0000
At most 1*	0.741082	39.18609	33.87687	0.0106
At most 2*	0.674966	32.59096	27.58434	0.0104
At most 3	0.657703	31.09018	21.13162	0.0014
At most 4	0.490074	19.53119	14.26460	0.0067
At most 5	0.276197	9.373855	3.841466	0.0022

*The p-value at significance level of 5%.

4.4. Findings of DOLS

The DOLS findings obtained through Equation 5, introduced by Stock and Watson in 1993 and extensively utilized by Raihan in 2023, are displayed in Table 6.The findings indicate that an increase of 1% in lnGDP correlates with a 0. 10% growth in projected long-term greenhouse gas emissions. The influence of renewable energy utilization is notably crucial and exhibits a negative association at the 1%.

level, which suggests that a 1% rise in renewable energy use results in a 0. 03% reduction in greenhouse gas emissions. In the same vein, the population variable shows a positive significance at the 1% level, indicating that a 1% increase in population corresponds with a 2. 42% rise in greenhouse gas emissions. Additionally, the long-term coefficient for lnIND reveals a significant positive figure at the 1% level, implying that a 1% enhancement in industrial activities leads to a 0. 49% increase in greenhouse gas emissions. On the other hand, the long-term coefficient for lnFDI does not show any statistical importance.

Furthermore, in this study, following the suggestions of Raihan (2023), we verified the accuracy of the DOLS estimates by applying the FMOLS and CRR methods. The findings from the FMOLS and CRR models are detailed in Tables 7 and 8. With the exception of foreign direct investment, the other factors align with the DOLS model. In particular, there exists a clear connection between greenhouse gas emissions and elements like the gross domestic product per capita, the size of the population, and the level of industrial activity, while the utilization of renewable energy resources generally exhibits a contrary correlation. The suitability of the model for this data is also indicated by the impressive R2 (0. 99) and adjusted R2 (0. 99) values. This suggests that the autonomous elements are responsible for 99% of the differences observed in the dependent element (GHG).

Table 6. DOLS Estimation Results: lnGHG is a Dependent Variable

Variables	Coefficient	Std. Error	t-Statistic	p-value
lnGDP	0.104628*	0.092111	1.135891	0.0928
lnREN	-0.031625***	0.641812	-0.049274	0.0079
lnPOP	2.421611***	0.819715	2.954213	0.0143
lnIND	0.490686***	0.266914	1.838368	0.0001
lnFDI	0.028890	0.069398	0.416303	0.2881
C	-40.39513	16.41381	-2.461045	0.0393
R^2	0.997685			
Adjusted R^2	0.991896			
Standard error of the estimate	0.027042			

***, **, and * relate to the significance thresholds of 1%, 5%, and 10% accordingly.

Table 7. FMOLS Estimation Results: lnGHG is a Dependent Variable

Variables	Coefficient	Std. Error	t-Statistic	p-value
lnGDP	0.051614*	0.026790	1.926600	0.0655
lnREN	-0.242854***	0.083595	-2.905118 18.59617	0.0076
lnPOP	2.245841***	0.120769	6.763503	0.0000
lnIND	0.463393***	0.068514	-1.355892	0.0000
lnFDI	-0.016580	0.012228	-16.02745	0.1873
C	-35.98326	2.245102		0.0000
R^2	0.992855			
Adjusted R^2	0.991426			
Standard error of the estimate	0.029674			

***, **, and * relate to the significance thresholds of 1%, 5%, and 10% accordingly.

Table 8. CCR Estimation Results: lnGHG is a Dependent Variable

Variables	Coefficient	Std. Error	t-Statistic	p-value
lnGDP	0.046001*	0.030944	1.486598	0.0796
lnREN	-0.264526**	0.123577	-2.140577	0.0422
lnPOP	2.240679***	0.152435	14.69926	0.0000
lnIND	0.483880***	0.079978	6.050201	0.0000
lnFDI	-0.017774	0.016840	-1.055467	0.3013
C	-35.84757	2.957450	-12.12111	0.0000
R^2	0.992609			
Adjusted R^2	0.991130			
Standard error of the estimate	0.030181			

***, **, and * relate to the significance thresholds of 1%, 5%, and 10% accordingly.

4.5. The ARDL Bounds Test

The results from the ARDL bounds test, shown in Table 9, reveal an F-statistic of 5.377985. Based on the critical values defined by Pesaran et al., in 2001, the lower threshold at the 5% significance level is 2.81, and the upper threshold is 3.76. Because the computed F-statistic is greater than the upper limit, we dismiss the null hypothesis that posits there is no cointegration. This confirms that a cointegration connection is present among the variables at the 5% significance level.

Table 9. Results of ARDL Bounds Testing and Cointegration

F-bounds test Test statistic	Value	Null hypothesis: No levels of relationship Significance I(0) I(1)
F-statistic	5.377985	At 10%-2.49-3.38
K	5	At 5%-2.81-3.76
		At 2.5%-3.11-4.13
		At 1%-3.5-4.63

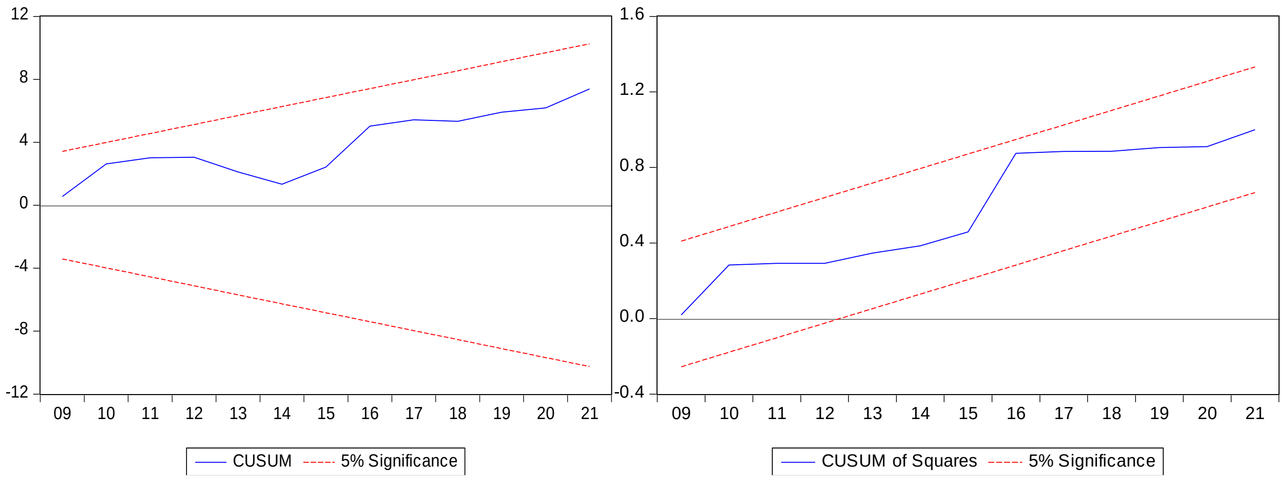
4.6. Diagnostic Inspection

Table 10 shows the findings from the diagnostic assessments related to the model. To check for heteroscedasticity, the Breusch-Pagan-Godfrey test was applied. The results indicated that the p-value was above 5%, implying there are no issues with heteroscedasticity. To evaluate autocorrelation, the Breusch Godfrey LM test was performed. The result demonstrated that the LM probability value also exceeded 5%, leading to the conclusion that autocorrelation is not present in the model. The model's normality was analyzed using the Jarque-Bera test. The results showed a p-value above 5%, which confirmed that the model adheres to a normal distribution. The stability of the model was examined using CUSUM and CUSUMQ, which rely on recursive residuals. Figure 2 displays the CUSUM and CUSUMQ graphs at a 5% significance threshold. The blue lines depict the residuals, while the red lines indicate the confidence intervals. As the residuals remain within these lines, the parameters of the model are deemed stable.

Table 10. Diognostic Test Results

Diagnostic tests	Coefficient	p-value	Decision
Breusch-Pagan-Godfrey test	0.349212	0.9755	Not heteroscedasticity exists
Lagrange multiplier test	4.44E-05	0.9948	Not serial correlation exists
Jarque-Bera test	1.436154	0.4876	Residuals are normallydistributed

Figure 2. The Plots of CUSUM and CUSUMQ (Critical bounds at 5% significance level).



5. CONCLUSIONS

This study looks at the relationships between a number of variables in Turkey, including population size, industrial growth, foreign direct investment, per capita GDP, use of renewable energy, and greenhouse gas emissions. In order to understand how these factors affected outcomes at that time, it looked at data trends from 1990 to 2021. ADF, DF-GLS, and P-P unit root analyses were used to assess the data sequences' order of integration. Additionally, the study investigated the cointegration of these variables using the ARDL limits testing approach and the Johansen cointegration method. The results of the Johansen and ARDL analyses show that the factors under investigation have a long-term cointegration relationship. In particular, it was found that for every 1% growth in GDP per capita, the anticipated long-term greenhouse gas emissions increased by 0. 10%. The results of the Johansen and ARDL analyses show that the factors under investigation have a long-term cointegration relationship. For instance, research showed that a one percent rise in GDP per person results in a 0. 10 percent boost in anticipated long-term greenhouse gas emissions. In contrast, a one percent growth in the use of renewable energy correlates with a 0. 03 percent reduction in greenhouse gas emissions. Furthermore, a 1% increase in industrial activity is linked to a 0. 49% increase in greenhouse gas emissions, whereas a 1% increase in population is linked to a 2. 42% increase in emissions. Conversely, it was found that the lasting impacts of foreign direct investment were statistically insignificant. The study's findings validate that the long-term relationships among industrialization, population growth, renewable energy use, per capita GDP, and environmental pollution are consistent with other research findings.

The findings from this study have significant consequences for policy development. In relation to Turkey, studies usually show a link between greenhouse gas emissions and GDP per person, where economic growth generally increases emissions to a specific extent. Yet, once a certain income threshold is crossed, emissions begin to decline, thanks to the implementation of eco-friendly policies and advancements in technology. Turkey's journey toward industrial expansion and urban progress has led to a rise in energy consumption, causing an uptick in fossil fuel usage. The growth of energy-demanding sectors like iron and steel, cement, transportation, and construction has led to increased greenhouse gas emissions. Turkey depends significantly on coal and natural gas for its energy needs, which adds to the rising emission figures. Lately, Turkey has increased its funding in renewable energy sources, particularly in solar and wind, while also focusing on improving energy efficiency. Turkey has been able to transition to a low-carbon economy more quickly since the Paris Agreement was ratified in 2021, and the Net Zero Goal of 2053 is now in place.In the near future, Turkey's emissions are expected to rise along with economic development. However, over the long haul, if initiatives that support a green economy and technological progress are effective, the connection between economic development and emissions may diminish. Although Turkey's historical economic development has been associated with higher greenhouse gas emissions, the current emphasis on renewable resources and green transformation plans could change this relationship. Accelerated legislative implementation, improved incentives, and industry-wide green transformation are all necessary for a successful transition.

Understanding the correlation between Turkey's greenhouse gas emissions and economic expansion from 1990 to 2022 is vital for assessing the environmental repercussions of economic activities. During this period, Turkey's economy has steadily grown. This growth has been driven by a boost in energy generation and manufacturing activities, resulting in greater emissions of greenhouse gases. Looking at the evolution of Turkey's per capita GDP (in Nominal USD) over the years, it started at around $2,690 in 1990 and grew to $13,105 by 2023. These statistics demonstrate a pronounced rise in per capita GDP since 1990, with a particularly significant surge between 2002 and 2013, although after 2013, some fluctuations were noted. In summary, the increase in per capita GDP from 1990 to 2022 illustrates the overall trend of economic growth in Turkey, yet there have been intermittent fluctuations influenced by global economic circumstances. Throughout this timeframe, the average yearly increase in GDP per person was 3. 09%.

When examining the shifts in Greenhouse Gas Emissions in Turkey, the total emissions were noted as 220. 5 million tons of CO_2 equivalent in 1990. By 2021, emissions rose to 564. 4 million tons of CO_2 equivalent, marking an approximate rise of 156% from 1990 levels. When compared to 2021, emissions decreased by 2.4% to 558.3 million tons of CO_2 equivalent. According to an analysis of per capita emissions, the amount of CO_2 equivalent emissions per person was 4.1% in 1990 and 6.6% in 2022. According to these statistics, Turkey's expanding economy has resulted in a notable rise in greenhouse gas emissions. Nevertheless, the 2. 4% reduction in emissions noted in 2022 might suggest that investments in renewable energy and policies aimed at energy efficiency are beginning to show positive outcomes. This suggests that gradually, the connection between economic growth and emissions might decrease, allowing for the possibility of achieving environmental sustainability.

Turkey has achieved substantial advancements in renewable energy from 1990 to 2022. Throughout these years, the amount and diversity of renewable energy types used in producing electricity have increased. In the 1990s, the country's renewable energy output heavily relied on hydroelectric stations. As the 2000s began, production of geothermal energy was launched, particularly with the establishment of geothermal facilities in Western Anatolia. The 2010s saw a surge in investments into wind energy, leading to a total wind energy capacity of 10,592 MW by 2022. Investments in solar energy also grew during this time, with solar capacity reaching 9 GW by 2021. As outlined in the Turkey National Energy Plan released in 2023, the objective is to boost solar capacity to 52. 9 GW and wind energy to 29. 6 GW by the year 2035. In 2020, renewable sources contributed 42% to the overall electricity generation, but this figure dropped to 36% in 2021. The decrease was primarily attributed to a fall in hydroelectric output. Between 1990 and 2022, Turkey's capacity and variety in renewable energy expanded greatly. Importantly, the advancements in wind and solar energy have enhanced Turkey's energy security and supported its sustainable development objectives.

Turkey's population was around 56 million in 1990 and grew to 85 million by 2022. Over these years, the population of Turkey expanded by roughly 52%. This growth has resulted in an increased need for energy, leading to a boost in greenhouse gas emissions.

The industrialization journey in Turkey picked up speed, especially after moving to a growth model focused on exports post-1980. From 1990 to 2022, there was notable growth in industrial output; however, this increase was accompanied by a significant uptick in greenhouse gas emissions. In the Early Industrial Expansion Phase (1990-2000), Turkey's manufacturing sector flourished as small and medium businesses emerged and organized industrial areas expanded. During this time, there was an increasing reliance on fossil fuels like coal, oil, and natural gas, along with the rise of industries that consume a lot of energy. From 2000 to 2010, industrial production escalated rapidly, fueled by innovations in key sectors including cement, iron and steel, automotive, and chemicals. During this time, there was a significant uptick in energy needs within the industrial field, which further fueled greenhouse gas emissions. The years from 2010 to 2022 were defined by the digital transformation of industries, marked by the launch of Industry 4. 0 initiatives and investments into renewable energy sources. Although the shift to low-carbon production was slow, some industrial areas began adopting renewable energy into their processes, indicating a move towards more environmentally friendly industrial practices.

Emissions associated with industrial activities originate from two primary sources: those tied to energy consumption in the industrial sector and those generated by manufacturing processes. Carbon dioxide emissions increase considerably when natural gas, coal and oil gas are used in manufacturing. The industrial field is responsible for roughly 30% of Turkey's overall greenhouse gas emissions, with cement manufacturing being a significant factor. Primary approaches to lowering emissions in the industrial sector involve using renewable energy sources, enhancing energy efficiency, and applying carbon capture methods. Moreover, the European Union's Carbon Border Adjustment Mechanism (CBAM), which is going to be implemented in 2026, mandates that Turkish industries shift to production methods that emit less carbon. Speeding up this transition could strengthen Turkey’s industrial sector in the worldwide marketplace. In conclusion, while the expansion of industries has resulted in higher emissions, adopting renewable energy sources and more sustainable practices can significantly reduce the carbon impact of the industrial field.

Foreign direct investment (FDI) in Turkey started to grow with the economic reforms introduced in the 1980s and gained notable traction after the year 2000. These investments have largely been centered in sectors such as industry, energy, and infrastructure, and they are tied to emissions of greenhouse gases either directly or indirectly. In the year 1990, the inflows of FDI reached $0. 8 billion, whereas greenhouse gas emissions were at 219. 5 million tons of CO_2-equivalent. By 2022, FDI had climbed to $10. 6 billion, with emissions hitting 558. 3 million tons of CO_2-equivalent. When analyzing the Sectoral Distribution and Emission Impact of Foreign Direct Investment: Industry (25-30% share): An increase in funding for the automotive, cement, metal, and chemical industries has resulted in elevated energy use and carbon emissions. Energy (15-20% share): Investment in particular, with an emphasis on renewable sources, has aided in decreasing emissions. Services and Infrastructure (more than 50% share): Funding in areas like banking, telecommunications, and logistics has focused on low-emission opportunities. These patterns illustrate the dual impact of FDI on Turkey's environment, where industrial investments elevate emissions, while energy sector funding, especially in renewables, contributes to reduction efforts. Energy-efficient initiatives and modern manufacturing technologies brought in by foreign investors have helped create factories that consume less energy. The shift toward low-carbon production methods, along with Turkey's green transformation policies and the need to adhere to EU market standards, has prompted foreign investors to adopt greener practices. Thus, FDI reflects a complicated connection to environmental sustainability, where its contribution to industrial growth increases emissions, while its role in promoting renewable energy and enhancing efficiency leads to emission reductions. The European Union's Carbon Border Adjustment Mechanism (CBAM) requires foreign businesses doing business in Turkey to lower their carbon footprint. The 2053 Net Zero Emissions goal may guide foreign investors toward green energy and low-carbon industry initiatives. From 1990 to 2022, as foreign direct investment (FDI) rose, so did emissions as a result of industrial activities and energy usage. Nevertheless, in more recent years, investments in renewable energy and energy efficiency initiatives have started to lessen the carbon footprint associated with FDI. In Turkey, the complex connection between foreign direct investment and greenhouse gas emissions shows that financial support in the industrial and energy sectors has resulted in increased emissions. Conversely, investments focused on renewable energy and environmentally friendly transformations have contributed to lowering emissions.

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