



Research Article

An Empirical Investigation into Sustainable Future, Agricultural Production, and Renewable Energy in Türkiye

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ABSTRACT

Identifying the causes of environmental pollution that accompany economic growth has become a crucial issue. This study aims to determine the relationship between environmental pollution, agriculture, energy, and growth in Türkiye from 2000 to 2020. Another aspect of the research is to investigate whether the Environmental Kuznets Curve (EKC) hypothesis is valid for Türkiye. The study is significant due to the limited number of studies examining the environmental impact of agricultural value-added and the lack of consensus in the existing literature. For this purpose, after determining the stationarity of CO₂ emissions, agrarian production, per capita income, and renewable energy series used to represent environmental pollution, the relationship between these variables was examined using the ARDL model. The research concluded that renewable energy and agricultural production can reduce CO₂ emissions in the long term, whereas increases in per capita income can exacerbate them. For the period from 2000 to 2020, which constitutes the limitation of the study, it was concluded that the EKC hypothesis is not valid for Türkiye in the long term. The findings of this paper suggest that policymakers should support environmentally friendly agricultural production and encourage the producers to use renewable energy for reducing environmental pollution.

KEYWORDS

Agricultural Production, Environmental Kuznets Hypothesis, CO₂ Emissions, Renewable Energy.

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1. Introduction

Throughout human history, various activities have caused significant direct or indirect changes in the environment, contributing to social, economic, and cultural development. In particular, the transformations

that followed the Industrial Revolution have led to severe environmental degradation. Industrialisation, urbanisation, and the rising demand for energy have accelerated environmental destruction and intensified greenhouse gas emissions. Among these emissions, carbon dioxide (CO₂) constitutes the largest share (Ayhan et



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al., 2023b; Kartal et al., 2025). Environmental sustainability, often neglected in favor of economic growth, has now become a critical global concern.

The foundation for studies exploring the relationship between economic growth and environmental pollution originates from the work of Kuznets, who examined the relationship between economic growth and income inequality. Kuznets argued that inequality increases during the early stages of economic development but declines once a certain threshold is reached, producing an inverted U-shaped relationship between growth and inequality. In the 1990s, researchers identified a similar inverted U-shaped relationship between environmental degradation and economic growth (Ayhan et al., 2023a; Grossman & Krueger, 1991; Panayotou, 1993; Selden & Song, 1994; Shafik & Bandyopadhyay, 1992). This relationship became known as the “Environmental Kuznets Curve (EKC)”.

According to the EKC hypothesis, countries pursuing economic growth initially prioritize production expansion and GDP per capita increases, often at the expense of the environment. However, once income surpasses a certain threshold, environmental degradation begins to decline. This turning point is associated with structural transformation toward knowledge-intensive industries and services, the enforcement of stricter environmental regulations, and the adoption of environmentally friendly technologies—all of which contribute to reducing ecological damage (Kartal et al., 2024). Due to the growing severity of environmental degradation, studies examining the relationship between economic growth and environmental pollution have gained importance, and the application of the EKC hypothesis in this context has become increasingly common (Acaroğlu et al., 2023; Başar & Tosun, 2021; Kaika & Zervas, 2013; Kartal et al., 2024; Rashid Gill et al., 2018).

While industrialisation is a major driver of environmental pollution, the agricultural sector also plays a significant role in CO₂ emissions. The use of fossil fuels and nitrogen-based fertilizers in agricultural production contributes substantially to environmental degradation. Nevertheless, the Food and Agriculture Organization of the United Nations (FAO) has suggested that agricultural emissions can be mitigated through the use of clean

energy sources.

Although the contribution of agriculture to Türkiye’s economic growth has declined over time, the sector maintains strategic importance due to its role in ensuring food security and supplying raw materials to industry. Sustainable agricultural production—achieved without environmental harm—is therefore essential. Transitioning from fossil fuel-based energy to renewable energy sources in Türkiye’s agricultural sector could effectively reduce CO₂ emissions. Türkiye possesses abundant renewable energy potential, including solar, biomass, wind, geothermal, and hydroelectric resources. Advancing sustainable development is critical for the country, offering substantial social and economic benefits (Bayrakcı & Koçar, 2012).

The continued use of non-renewable energy in agricultural production, deforestation for farmland expansion, and the intensive use of fertilizers and pesticides all contribute to rising CO₂ emissions. However, agricultural activities can also play a mitigating role by enabling plants to absorb and store carbon. Moreover, agriculture offers additional environmental benefits, such as nitrogen fixation, soil water retention, and flood control (Bilgili et al., 2016). Consequently, numerous studies have shown that adopting sustainable agricultural practices can reduce CO₂ emissions (Burney et al., 2010; Lal, 2004). Yet, relatively few studies have directly examined the relationship between agricultural value added and environmental pollution, and the existing literature presents no consensus on this issue. Differences in country structures, income levels, agricultural practices, and data coverage periods contribute to this divergence.

Figure 1 displays the trend of agricultural CO₂ emissions among high-, middle-, and low-income countries from 2000 to 2020. Agricultural CO₂ emissions are highest in middle-income countries, and notably, they have increased since 2010. By 2020, agricultural emissions in middle-income countries reached 108 million tonnes, compared with 36 million tonnes in high-income countries. Low-income countries reported significantly lower levels, rising from 0.837 million tonnes in 2000 to 0.387 million tonnes in 2020. These figures indicate that agricultural CO₂ emissions differ substantially across income groups, reflecting structural variations in agricul-

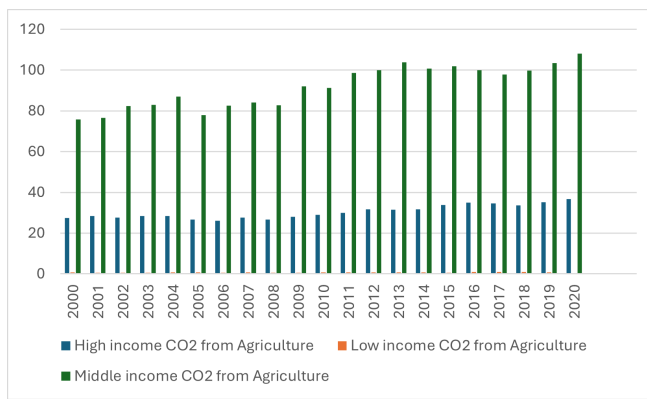


Figure 1: Distribution of Agriculture-Related CO₂ Emissions by Country Income Groups, 2000–2020 (Source: World Development Indicators, 2021)

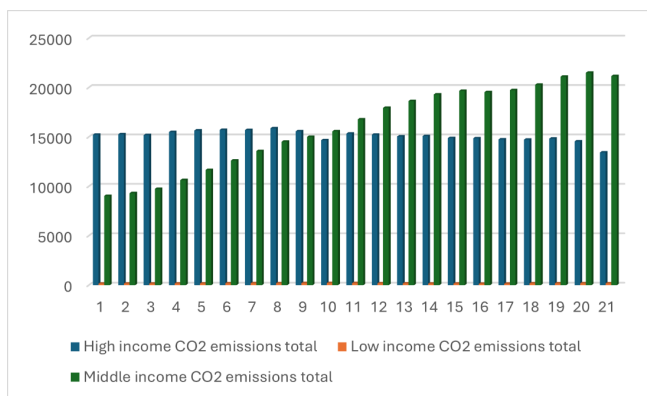


Figure 2: Distribution of Total CO₂ Emissions by Country Income Groups, 2000–2020 (Source: World Development Indicators, 2021)

tural production methods

Figure 2 shows the change in total CO₂ emissions from 2000 to 2020 for different country income groups. High-income countries had the highest emissions in the early 2000s; however, after 2009, emissions from middle-income countries increased sharply, reaching 21 million tonnes by 2020 and surpassing high-income levels. Total emissions in low-income countries remained comparatively low throughout. These results suggest that the center of gravity in global CO₂ emissions has gradually shifted toward developing nations. This shift may be explained by the adoption of greener technologies and sustainable energy policies in developed countries. The

continued upward trend in emissions among middle-income countries, including Türkiye, represents a warning signal for environmental sustainability

Most previous studies examining the EKC hypothesis have focused on industrial and energy sectors to explore the growth–environment nexus (Danish et al., 2017; Hettige et al., 2000; Tan et al., 2015; Wang et al., 2022; Yilanci et al., 2023). However, relatively few have investigated agriculture within this framework, and there remains no clear consensus on its role in environmental pollution. This study addresses that gap by evaluating the impact of agricultural value added on CO₂ emissions within the context of the EKC hypothesis. The analysis focuses on Türkiye, emphasizing the strategic role of agriculture in developing economies in balancing growth and environmental sustainability.

Furthermore, the study examines the influence of renewable energy consumption on environmental pollution, consistent with sustainability objectives. Existing evidence supports the emission-reducing effect of renewable energy use, though the magnitude and direction of this relationship often depend on development levels and other contextual factors (Ayhan et al., 2023b; Sarkodie & Adams, 2018). Given Türkiye's classification as a developing country, it provides a compelling case for analysis.

In the Turkish EKC literature, few studies have treated agricultural value added as a key determinant of environmental outcomes. Considering the sector's dual economic and ecological significance, this represents a notable omission. While insights from research on renewable energy inform this study's approach, the covariate structure adopted here departs from conventional EKC formulations. To the best of our knowledge, the EKC hypothesis has not been tested for Türkiye within a model jointly incorporating agricultural value added and renewable energy. Addressing this research gap forms the central motivation of this study, highlighting Türkiye's distinctive position in the global sustainability landscape. With its strong agricultural capacity, ongoing energy transition, and evolving growth dynamics, Türkiye offers a particularly relevant context for this analysis.

Accordingly, this study investigates the relationship between economic growth, renewable energy use, agri-

cultural inputs, and CO₂ emissions within the EKC framework, using annual data for the period 1990–2020. The subsequent sections are structured as follows: the next section reviews the relevant literature, the following section presents the econometric methodology, and the final section discusses the empirical findings and conclusions.

2. Literature Review

Studies examining the relationship between environmental pollution and agriculture—the focus of this study—have produced diverse findings. [Jebli & Youssef \(2017a\)](#) investigated the relationship between per capita renewable energy consumption, agricultural value added, and CO₂ emissions in relation to real GDP, using data from 1980 to 2011 for five North African countries. According to the results of panel Granger causality tests, a bidirectional relationship was observed between CO₂ emissions and agriculture in the short run, while a unidirectional relationship existed from agriculture to real GDP and from renewable energy consumption to agriculture. In the long run, bidirectional causality was found between agriculture and CO₂ emissions, along with a unidirectional relationship between renewable energy and both agriculture and CO₂ emissions. Long-term parameter estimates revealed that increases in GDP and renewable energy consumption raise CO₂ emissions, whereas increases in agricultural value added reduce them.

[Zafeiriou & Azam \(2017\)](#) examined the effect of agriculture and economic growth on CO₂ emissions in France, Portugal, and Spain using the autoregressive distributed lag (ARDL) bounds testing approach. Their results confirmed the validity of the Environmental Kuznets Curve (EKC) hypothesis for all three countries.

[Rafiq et al. \(2016\)](#) analyzed the determinants of CO₂ emissions using the STIRPAT and EKC models for 53 high-, middle-, and low-income countries covering the period 1980–2010. The model included variables such as total population, GDP per capita, industrialization rate, the share of the service sector in GDP, the share of the agricultural sector in GDP, and renewable and non-renewable energy consumption. The findings indicated that economic growth, non-renewable energy consumption, and energy intensity increase CO₂ emissions, while

the service and agricultural sectors help reduce pollution. Industrialization, however, was found to exacerbate environmental degradation.

[Appiah et al. \(2018\)](#) employed fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimators to investigate developing countries over the period 1971–2013. Their analysis examined the relationship between CO₂ emissions, agricultural production, population, GDP, and energy consumption. The findings revealed that economic growth enhances agricultural production, leading to increased CO₂ emissions, while energy consumption and population growth were associated with declines in CO₂ emissions.

[Liu et al. \(2017\)](#) conducted a study covering Indonesia, Malaysia, the Philippines, and Thailand from 1970 to 2013 to test the EKC hypothesis. The study examined the relationships among CO₂ emissions, GDP, renewable energy consumption, agricultural value added, and non-renewable energy consumption. Long-run results provided no support for the EKC hypothesis in these countries. However, renewable energy consumption and agricultural value added were found to reduce CO₂ emissions, whereas non-renewable energy consumption had a positive effect on emissions. In the short run, direct relationships were observed among CO₂ emissions, non-renewable energy, agriculture, GDP, and renewable energy.

[Waheed et al. \(2018\)](#) analyzed the impact of renewable energy consumption, agricultural production, and forest areas on CO₂ emissions in Pakistan for the period 1990–2014 using the ARDL model. Their findings showed that renewable energy consumption and forest conservation have a long-term negative effect on CO₂ emissions, while agricultural production exerts a positive impact.

[Parajuli et al. \(2019\)](#) used dynamic panel data for 86 countries between 1990 and 2014 to explore the impact of agricultural land use and forest cover on CO₂ emissions. Their results revealed that forest areas help reduce carbon emissions, whereas agricultural activities contribute to increased emissions.

[Qiao et al. \(2019\)](#) examined G20 countries within the EKC framework to assess the impact of agriculture,

economic growth, and renewable energy on CO₂ emissions. Using panel FMOLS and vector error correction model (VECM) causality analyses, they found a long-term relationship among the selected variables. The results showed that agriculture increases CO₂ emissions, while renewable energy reduces them, confirming the EKC hypothesis in G20 economies.

Olanipekun et al. (2019) analyzed Central and West African countries from 1996 to 2015 using pooled mean group (PMG), mean group (MG), and augmented mean group (AMG) estimators to assess the effect of agriculture on the environment relative to income levels. Their results indicated that both agriculture and income have detrimental effects on the environment, while renewable energy use mitigates environmental degradation.

Çetin et al. (2020) focused on Türkiye during the period 1968–2016, examining the relationships among agricultural value added, agricultural land, economic growth, renewable energy consumption, and CO₂ emissions using the ARDL model. Their analysis revealed that agricultural value added and agricultural land reduce CO₂ emissions in the long run.

Similarly, Oğul (2023) investigated the relationship between agriculture and environmental pollution in Türkiye for the period 1990–2018 using the ARDL approach. The results indicated that in the long run, economic growth, trade liberalization, and agricultural value added increase CO₂ emissions, while renewable energy consumption reduces them. The EKC hypothesis was validated for Türkiye in the long run but not in the short run.

Jebli & Youssef (2017b) also analyzed Tunisia for the period 1980–2011, investigating the relationships among CO₂ emissions, GDP, renewable and non-renewable energy consumption, trade openness, and agricultural value added using VECM and Granger causality tests. The results revealed bidirectional causality between agricultural value added and CO₂ emissions, as well as between agricultural value added and trade openness. Additionally, long-run causality was found among all variables. Parameter estimates showed that non-renewable energy consumption, trade openness, and agricultural value added increase CO₂ emissions, while renewable energy consumption mitigates them. The EKC hypothe-

sis, however, was not supported for Tunisia.

Özbek & Oğul (2023) examined the period 1990–2019 for Türkiye to analyze the impact of agricultural value added, forest area, energy consumption, and GDP on the ecological footprint using ARDL, FMOLS, DOLS, and canonical cointegrating regression (CCR) models. Their findings indicated that agricultural value added, economic growth, and energy consumption increase the short- and long-term ecological footprint, whereas forest expansion reduces it.

Finally, Özbay (2024) investigated the relationship between CO₂ emissions and agricultural value added, crop production index, food production index, and livestock production index in Türkiye during the period 1990–2020 using the ARDL model. The analysis showed a positive long-term relationship between the food production index and CO₂ emissions, while agricultural value added, livestock production index, and crop production index were negatively associated with emissions.

3. Model Specification and Data

3.1. Model Specification

This study examined the relationship between agricultural production, economic growth, renewable energy consumption, and CO₂ emissions in Türkiye, utilizing annual data from 1990 to 2020 within the ARDL (Autoregressive Distributed Lag) model framework. The model was specified in its logarithmic form as follows:

$$\text{LnCO}_{2t} = \alpha_0 + \alpha_1 \ln \text{AP}_t + \alpha_2 \ln \text{GDP}_t + \alpha_3 \ln \text{RE}_t + \varepsilon_t \quad (1)$$

A multiple regression model was employed in the analysis, and various variables that could potentially affect environmental pollution were included in the model. The reason for preferring the multiple regression model is that GDP and RE have been established in the literature as the fundamental variables affecting environmental pollution. The constant term α_0 in the model represents time t and the error term ε_t . Parameters α_1 , α_2 , and α_3 represent the long-run elasticity estimates of agricultural value added, real GDP per capita, and renewable energy consumption. Because there are both positive and negative views in the literature regarding

Table 1: Definition of the Variables Used

Variables	Abbreviation	Period (Annual)	Source
CO ₂ Emissions (metric tons per capita)	CO ₂	2000-2020	World Bank
Agricultural Value Added (constant 2015 US dollars)	AP	2000-2020	World Bank
GDP (per capita, constant 2015 US dollars)	GDP	2000-2020	World Bank
Renewable Energy (total consumption)	RE	2000-2020	International Energy Agency (IEA)

Table 2: Descriptive Statistics for Variables

Variables	LNCO2	LNAP	LNAGDP	LNRE
Mean	1.283369	24.53187	8.951753	10.73976
Median	1.229780	24.47541	8.942239	10.60145
Maximum	1.649789	24.93743	9.407523	11.79253
Minimum	0.940928	24.27793	8.567302	10.03460
Standard Deviation	0.220960	0.203529	0.284479	0.481413
Skewness	0.030586	0.485490	0.291939	0.656971
Kurtosis	1.710113	1.910142	1.704680	2.565360
Jarque-Bera	2.153920	2.752016	2.607574	2.474003

the effects of agricultural production on CO₂ emissions, the α_1 parameter estimates can take either positive or negative values (Qiao et al., 2019). According to the environmental Kuznets curve, an inverted-U-shaped relationship exists between GDP per capita and CO₂ per capita. Therefore, the expected value of parameter α_2 is positive (Grossman & Krueger, 1994). Due to the majority of evidence in the literature indicating a negative relationship between renewable energy and CO₂ emissions, the estimate of parameter α_3 is negative (Jebli et al., 2016).

3.2. Data

The definitions of the variables used in the study, along with the databases from which they were obtained, are presented in Table 1.

Descriptive statistics for the variables are presented in Table 2.

As shown in Table 2, all variables are normally distributed. The graphs of the variables are shown in Figure 3.

Figure 3 illustrates that the series comprising CO₂ emissions, agricultural added value, per capita national

income, and renewable energy data exhibit a distinct trend

4. Methodology

To test the unit root level of the series in the model, the ADF (Augmented Dickey-Fuller) and PP (Phillips-Perron) unit root tests developed by Dickey & Fuller (1979) and Phillips & Perron (1988), respectively, are used. Based on the results of the unit root tests, the method is determined, and the analysis is continued. The ARDL (Auto-Regressive Distributed Lag) method, developed by Pesaran et al. (2001), is used to test the cointegration relationship between the variables in the model. The ARDL method tests the cointegration relationship in models with at least two non-stationary variables. The reason for choosing the ARDL method is that it is more flexible than traditional cointegration tests and does not require all variables to be integrated at the same level. Additionally, the ARDL method can be applied to models with small samples. An unrestricted error correction model was created for the ARDL method.

The Dummy variable was added to the model to

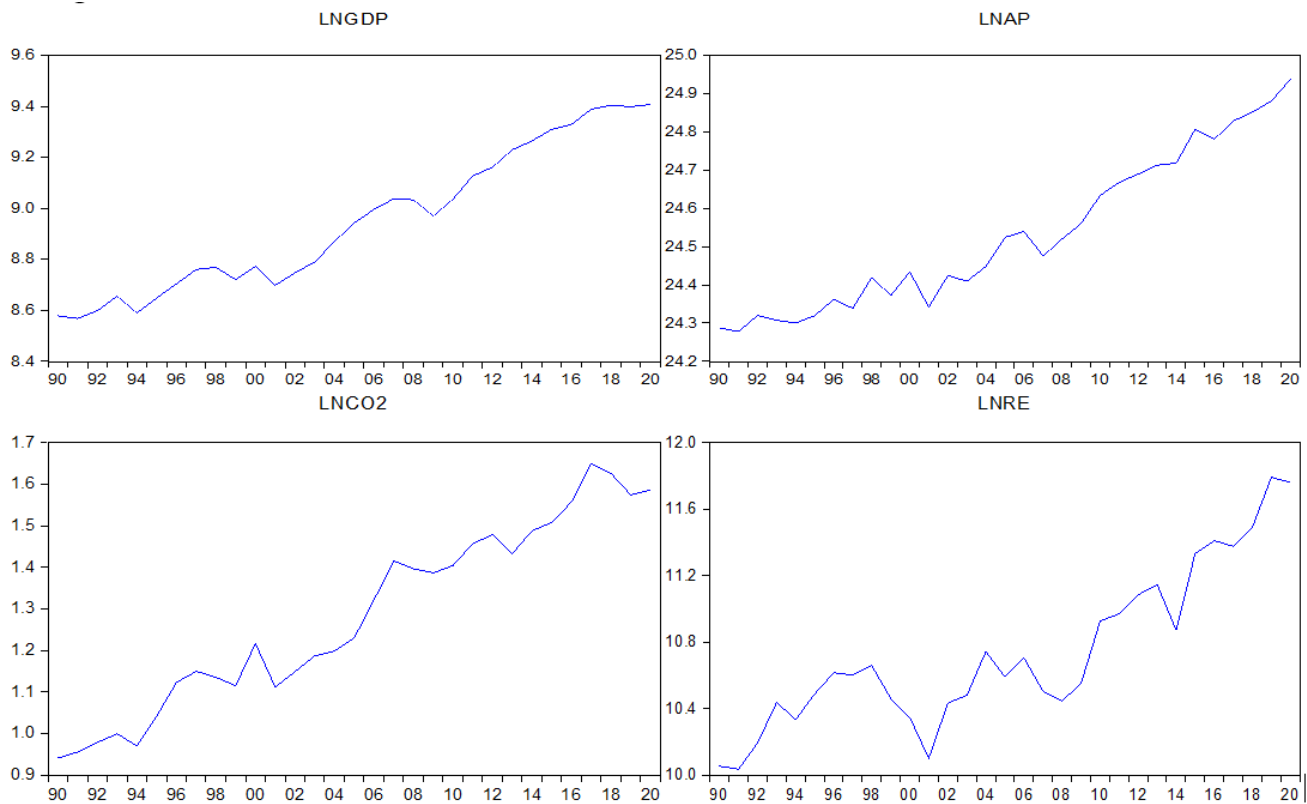


Figure 3: Graphs of Variables

control the effects of the 2001 Turkish crisis. The aim was to prevent structural breaks related to the crisis period and to increase the reliability of the estimation results.

$$\Delta \ln CO$$

$$\begin{aligned} \underline{2}_t = & \beta_0 + \beta_1 + dum1 + \sum_{i=1}^p \beta_{2i} \Delta \ln CO_{2t-i} + \\ & \sum_{j=0}^n \beta_{3j} \Delta \ln GDP_{t-j} + \sum_{k=0}^s \beta_{4k} \Delta \ln RE_{t-k} + \\ & \sum_{l=0}^t \beta_{5l} \Delta \ln AP_{t-l} + \alpha_1 \ln CO_{2t-1} + \alpha_2 \ln GDP_{t-1} + \\ & \alpha_3 \ln RE_{t-1} + \alpha_4 \ln AP_{t-1} + \varepsilon_t \quad (2) \end{aligned}$$

In the equation 2, the difference operator ‘ Δ ’ indicates that the natural logarithms ‘ $\ln$ ’ are taken at the beginning of the variables, ‘ ε_t ’ denotes the error term, ‘ $dum1$ ’ denotes the dummy variable, ‘ β_0 ’ denotes the constant term, ‘ $\beta_2, \beta_3, \beta_4$, and β_5 ’ denote the short-term coeffi-

cients, ‘ $\alpha_1, \alpha_2, \alpha_3$, and α_4 ’ denote the long-term coefficients, and ‘ p, r, s , and t ’ denote the lag lengths. The Wald test (F statistic) tests the cointegration relationship between variables in the ARDL model. The existence of the cointegration relationship is determined by comparing the F-statistic value with the critical values calculated by Pesaran et al. (2001) and Narayan (2005).

Hypotheses related to the test;

$H_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = 0$ (no cointegration is found) and

$H_1 = \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq 0$ (cointegration is found)

The null hypothesis (H_0) is rejected when the F-statistic value exceeds the critical value; conversely, the alternative hypothesis (H_1) is rejected when the F-statistic is below the critical value.

Table 3: Unit Root Test Results

ADF	With Constant	P-value	With Constant and Trend	P-value	PP	With Constant	P-value	With Constant and Trend	P-value
lnCO ₂	- 0.826488	0.7969	- 3.284139	0.0882	lnCO ₂	- 0.738860	0.8217	- 3.022387	0.1430
lnAP	1.451331	0.9987	- 1.368709	0.8489	lnAP	2.526235	1.0000	- 2.372165	0.3855
lnRE	1.544947	0.9989	- 2.066920	0.5425	lnRE	0.073989	0.9582	- 2.035419	0.5591
lnGDP	0.104610	0.9608	- 2.527060	0.3137	lnGDP	0.262861	0.9721	- 2.528517	0.3132
1st Dif- ference lnCO ₂	1st Dif- ference - 5.908915***	1st Dif- ference 0.0000	1st Dif- ference - 5.820621***	1st Dif- ference 0.0003	1st Dif- ference lnCO ₂	1st Dif- ference - 7.738657***	1st Dif- ference 0.0000	1st Dif- ference - 7.533311***	1st Dif- ference 0.0000
lnAP	- 9.244992***	0.0000	- 4.346202**	0.0102	lnAP	- 9.371849***	0.0000	- 27.658680***	0.0000
lnRE	- 6.414866***	0.0000	- 3.880144**	0.0286	lnRE	- 6.828824***	0.0000	- 7.199137***	0.0000
lnGDP	- 5.423586***	0.0001	- 5.331976***	0.0009	lnGDP	- 5.612814***	0.0001	- 5.866189***	0.0002

Note: *** and ** display the variables that are stationary at the 1% and 5% significance levels, respectively.

5. Empirical results and discussion

The null hypothesis (H_0) of the ADF and PP unit root tests applied to assess the unit root properties of the series in the model assumes that the series contains a unit root. In contrast, the alternative hypothesis (H_1) assumes stationarity. The unit root test results for the variables are presented in Table 3.

A general evaluation of the unit root test results presented in Table 3 indicates that all variables in the model are stationary at their first differences. Following the unit root tests, it was concluded that testing for cointegration using the ARDL approach is appropriate. The Akaike Information Criterion (AIC) was employed to determine the optimal maximum lag length for the model. Based on this criterion, the most suitable model was ARDL (2,3,0,3). At the same time, since there is no constant or trend in the model, all effects are naturally calculated from the logarithmic levels of the variables.

The calculated F-statistic value for the model (7.295415) exceeds the upper bound critical value of 3.1 at the 1% significance level; therefore, the null hypothe-

sis (H_0) is rejected, and the alternative hypothesis (H_1) indicating the presence of cointegration is accepted.

According to the diagnostic test results presented in Table 5, it was concluded that there was no autocorrelation problem, the model was suitable for a normal distribution, there was no heteroscedasticity problem, no functional form problem existed, and the estimated coefficients were stable. Figure 4 shows the Cusum and Cusum of Squares tests confirming the stability of the coefficients.

According to the CUSUM and CUSUMQ test results, the model appears to have been stable from 1990 to 2020. The test results indicate that the coefficients are stable at a 5% significance level.

According to the ARDL coefficient estimation results, all variables in the model are statistically significant in the long term. In the long term, agricultural value added and renewable energy are expected to reduce CO₂ emissions, whereas economic growth is anticipated to increase CO₂ emissions. The EKC hypothesis, which demonstrates an inverse u-shaped relationship between

Table 4: ARDL Bound Test Results

Model	Optimum Lag Length		F-Statistic
CO ₂ =f (AP, RE, GDP)	ARDL (2,3,0,3)		7.295415
Critical Values			
	%1	%5	%10
I (0)	3.42	2.45	2.01
I (1)	3.1	3.63	3.1

Table 5: Diagnostic Tests for the ARDL (2,3,0,3) Model

Diagnostic Tests	F-Statistic	P-Value
Breusch-Godfrey	0.921371	0.4208
Jarque-Bera	0.877571	0.6448
Breusch-Pagan-Godfrey	0.405120	0.9392
Ramsey Reset	0.498286	0.4911
Cusum	Stable	Stable
Cusum of Squares	Stable	Stable

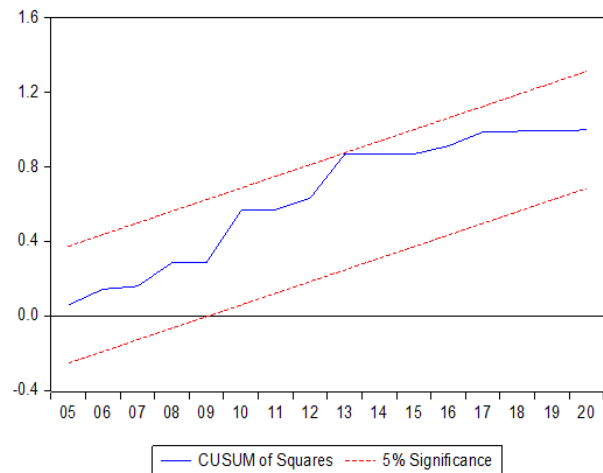
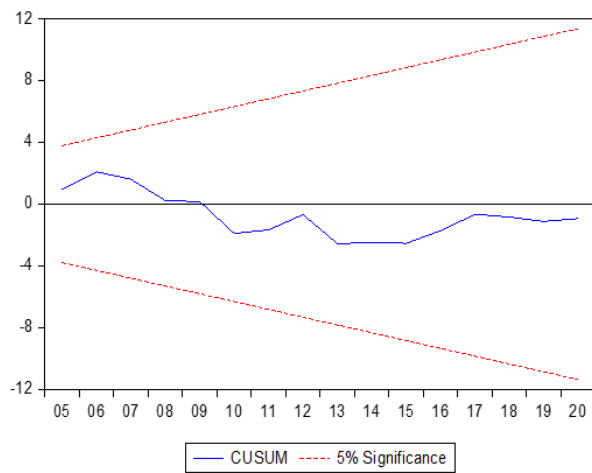


Figure 4: CUSUM and CUSUMQ Test Findings

environmental pollution and economic development, is valid in the short term. In the short term, it is concluded that the one-period lagged effect of agricultural value-added pollutes environmental pollution. The ECT (-1) coefficient in the Table 6 denotes the error correction coefficient. The error correction term coefficient is negative and significant. This provides additional evidence that the model is cointegrated, indicating that any imbalance in the model will be corrected in the long

term.

According to the long-term FMOLS estimation results, the renewable energy variable and the dummy1 variable were not found to be statistically significant. However, according to the ARDL coefficient estimation results, agricultural value added, and renewable energy appear to reduce CO_2 emissions in a consistent manner. An examination of the model's descriptive statistics reveals that the long-term forecast results have high ex-

Table 6: ARDL Coefficient Estimation Results

Variables	Coefficient	P-Value
Short-Run		
ln CO ₂ (-1)	0.297728	0.0653
lnGDP	0.602045	0.0007
lnGDP (-1)	-0.572412	0.0062
lnGDP(-2)	-0.411821	0.0067
lnAP	0.038256	0.7839
lnAP(-1)	0.431388	0.0149
lnAP(-2)	0.466879	0.0103
DUMMY1	-0.091622	0.0096
ECT(-1)	-0.705020	0.0000
Long-Run		
lnAP	-0.305018	0.0000
lnRE	-0.155376	0.0071
lnGDP	1.168719	0.0000
DUMMY1	-0.091622	0.0383

Table 7: FMOLS Long-Run Estimation Results

Variables	Coefficient	P-Value
LNGDP	1.0730	0.0000
LNRE	-0.0774	0.1060
LNAP	-0.3053	0.0000
DUMMY1	-0.0134	0.8261
Model Statistics		Value
R-squared	0.9659	
Adjusted R-squared	0.9620	
S.E. of regression	0.0419	
Long-run variance	0.0023	

planatory power. The R^2 value of 0.9659 indicates that the model explains a large portion of the variance in CO₂ emissions from the independent variables.

The model also has high explanatory power according to the DOLS long-term estimation results. According to the DOLS long-term estimation results, GDP growth leads to an increase in CO₂ emissions, while agricultural value added reduces CO₂ emissions. Overall, the DOLS results support the FMOLS findings.

6. Conclusion

This study investigated the relationship between environmental pollution, agricultural production, per capita income, and renewable energy consumption in Türkiye between 2000 and 2020. Initially, the stationarity of the variables was examined using the ADF and PP unit root

tests, which revealed that all variables were stationary at the I(1) level. After conducting diagnostic tests, the relationship between the dependent and independent variables was analyzed using the ARDL model. Within this framework, the relationship between per capita GDP and CO₂ emissions was tested in accordance with the EKC hypothesis.

In the case of Türkiye, the EKC hypothesis suggests that environmental pollution initially increases with rising per capita income but eventually declines after a certain income threshold is reached. The findings of this study indicate that this hypothesis holds true in the short term but not in the long term. Although per capita income has continued to rise, environmental pollution has not declined accordingly. This suggests that Türkiye has not yet reached the income level at which pollu-

Table 8: DOLS Long-Run Estimation Results

Variables	Coefficient	P-Value
LNGDP	1.1085	0.0000
LNRE	-0.0898	0.3658
LNAP	-0.3130	0.0000
DUMMY1	-0.1237	0.4744
Model Statistics	Value	
R-squared	0.9739	
Adjusted R-squared	0.9413	
S.E. of regression	0.0498	
Long-run variance	0.0036	

tion begins to decrease. Our results indicate that the expected “turning point” has not materialized; instead, CO₂ emissions have continued to increase over the long run. This outcome is plausibly linked to Türkiye’s energy mix, which remains dominated by fossil fuels, as well as to the persistence of carbon-intensive production in the industrial and transportation sectors and the limited implementation of effective carbon-pricing mechanisms. Similar to other developing economies such as China, India, and Indonesia, Türkiye exhibits the characteristics of a transition economy in which the EKC does not hold over the long term.

The analysis further revealed that agricultural production and renewable energy—two key variables in this study—have a long-term mitigating effect on environmental pollution, consistent with prior findings in the literature (Çetin et al., 2020; Liu et al., 2017; Özbay, 2024; Rafiq et al., 2016). While no significant short-term relationship was found between agricultural production and CO₂ emissions, the one- and two-period lags in agricultural production showed an increasing impact on emissions. The dummy variable representing the 2001 structural break was found to be statistically significant in both the short and long term.

Another important finding of this research is that increasing the use of renewable energy can effectively reduce CO₂ emissions—a key policy objective for countries seeking to combat climate change. Renewable energy not only mitigates environmental pollution but also decreases dependence on imported energy sources. Given Türkiye’s heavy reliance on foreign energy supplies, it is essential to increase investments in renewable

energy and provide incentives to encourage private-sector participation. Policies promoting renewable energy investments—such as low-interest loans, expanded credit facilities, and reduced bureaucratic barriers—would contribute to both emissions reduction and sustainable economic growth.

In the agricultural sector, expanding environmentally friendly policies and low-emission production techniques is crucial. Reducing fossil fuel consumption and encouraging the use of alternative, eco-friendly fuels should be prioritized. Likewise, financial support programs for farmers should be broadened to promote sustainable agricultural practices. Limiting the use of chemical fertilizers and encouraging the adoption of low-carbon production methods will help protect soil health and reduce CO₂ emissions. Ensuring the continuity of such practices will assist policymakers in achieving their environmental and sustainability targets.

Overall, the evidence suggests that Türkiye diverges from the classical inverted-U pattern described by the EKC literature, instead following a long-run path characterized by carbon-intensive growth. Therefore, effective policy design should emphasize scaling up renewable energy investments, disseminating clean technologies in agriculture, and strengthening energy efficiency measures. Given Türkiye’s high energy import dependence, integrating carbon-reduction targets into the national growth strategy is essential for achieving sustainable development and contributing credibly to global climate mitigation efforts.

Finally, while this study focuses on CO₂ emissions as the primary indicator of environmental degradation,

it is important to recognize that environmental quality encompasses multiple dimensions—including air pollutants, soil contamination, water scarcity, and biodiversity loss. Future research should broaden the analytical framework to include these additional indicators and examine related factors such as resource diversity in agriculture, the diffusion of environmentally friendly technologies, soil pollution, and climate impacts. Expanding the dataset and employing diversified analytical techniques will enable a more comprehensive understanding of the complex relationship between economic growth, agriculture, and environmental sustainability in Türkiye.

Supplementary Material

Supplementary material is available online at: [10.51300/JSE-2025-156](https://doi.org/10.51300/JSE-2025-156)

Conflict of Interests

The authors declare that they have no competing interests.

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LUMINOUS
INSIGHTS



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